Soil Structure Examined

by Thomas E. Schumacher and Walter E. Riedell

SCIENCE

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Introduction

'Dirt,' which is a non-technical term for the solid part of soil, is considered by many to be something that needs to be cleaned up and discarded. It is the *loss of structure* (the removal of the pore space between the soil solids, or the detachment of solid particles from their matrix) that turns a valuable substance (soil) into an annoyance (dirt). With this article, we discuss soil structure and its importance in the value and utility of soil. We have chosen a format based on common questions associated with soil structure.

Soil Structure Defined

Soil is considered by many to be simply a mixture of solids, liquids, and gases. This is analogous to speaking of a building as a mixture of wood, steel, glass, brick, and air without regard to the relationship of the components and the functional nature of the assembled building. So it is with this in mind that we highlight the difference between 'dirt' and 'soil.' The term 'soil' implies structure whereas 'dirt' does not. When we talk about a building's attributes or uses, we not only speak of the material from which the building is constructed, but also (implicitly) of the structure of the building (see Figure 1). We might be referring to the number of rooms, the dimension of the rooms, and how the rooms are connected to each other. But the organization of the materials and the existence of spaces within the building are absolutely essential to a building's function and categorization as a building.

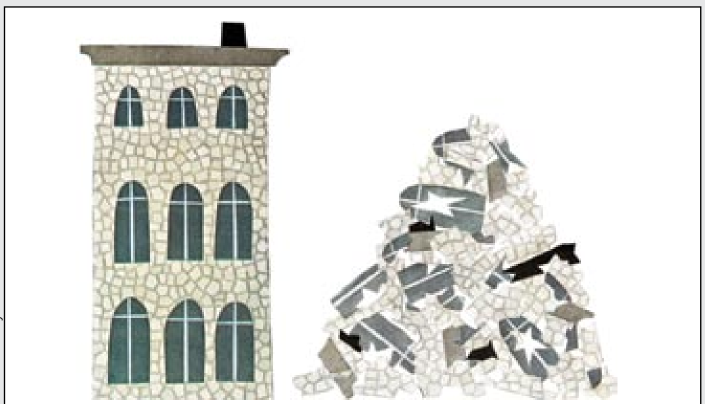

Illustration by Karin Anderson & Jaime Zebill.

Figure 1. These buildings are a simple analogy for soil structure. The building on the left has a structure that allows utilization for different functions: perhaps there is a restaurant on the bottom floor, apartments on the second floor, and an art studio on the top floor. In contrast, the pile of rubble on the right has no utility because it lacks structure. Note that chemical analysis of the components of both buildings would find no differences. Thus, structure adds complexity and utility not measured by chemistry alone.

Similarly, 'soil' must have some organization to its components, and spaces among them, to be functional as a soil. Roots and other living soil organisms do not live in the 'dirt' any more than we live in the brick, wood, stone, or steel girders of a building. Rather, soil-dwelling organisms exist in the 'rooms' created by the structure of the soil just as we live in the rooms of a building. Furthermore, if a room is not connected to another room, it has little to no value for our activities—the same is true for the spaces in the soil, which must be connected to other spaces to be usable (inhabitable) by roots and other organisms within the soil.

Macropores are not inherently stable.

Questions about Soil Structure: How does soil structure come to exist?

Soil structure is the product of the interplay of many physical, electro-chemical, and biological forces acting on and within the soil. For crop productivity, the most critical component of soil structure is the configuration of the pore space. Biological organisms play a major role in the development of soil structure and the resulting stabilization and maintenance of pore space. Indeed, soil structure is generally very poor to nonexistent if biological activity is missing (if the strata or material is largely devoid of biological activity and organic matter, it is excluded from the category of soil).

Physical and chemical forces also play a significant role in the localized development of fractures or cracks within the soil that correspond to lines of weakness. Soil structure is a result of the continual flow and transformation of energy (mechanical and chemical) within the soil system. The agents of energy transformation are primarily biological organisms, but also include physical phenomena such as wetting-drying and freeze-thaw cycles.

What role do biological organisms have in creating soil structure?

Biological organisms cycle and recycle energy from the sun through food webs. Roots and plant debris are the primary source of energy captured from photosynthesis. This material is utilized by a myriad of organisms that feed off of each other, thus imparting mechanical and chemical forces that create tensions between soil particles. These tensions can cause soil particles to move, forming pores with various shapes, sizes, and connectivity. Some biological entities, such as plant roots, create differential forces within the soil via localized drying of the soil. This creates tension between the wetter and drier portions of the soil, resulting in localized cracks. Larger biological entities, such as plant roots and earthworms that grow or move in the soil, also directly displace soil to create connected pore arrangements.

Macropores (larger pores that allow water drainage and air movement) are not inherently stable (much as large rooms in a building) and require stabilization in order to persist. Biological organisms produce many soil-stabilizing substances. These substances are primarily various forms of soil organic matter, including substances like glomalin (produced by mycorrhizae), and also many other kinds of compounds that interact and form bridges between the inorganic (mineral) components of the soil (clay, silt, and sand particles). These adhesive or glue-like organic substances will resist the intrinsic tendency of the pores to collapse over time in response to external forces. However, these compounds eventually degrade, or are used as a food source by other biological organisms, and continually need replacement to maintain soil structure.

Tillage destroys the continuity of existing pores in the soil.

How does human activity affect soil structure?

Humans have a profound effect on soil structure, both directly and indirectly. A loss of soil structure can have catastrophic consequences (see photo on this page). Since soil structure is heavily dependent on biological activity within the soil, and is related at least in part to the complexity of soil food webs, anything that humans consciously or unconsciously do to manipulate the biological community in the soil will affect the pore characteristics within the soil.

An obvious impact on soil structure is the imposition of external forces such as tillage. Tillage, if done at the correct soil moisture content, can create large pore spaces—however, these larger pore spaces tend to be less stable, and are more convoluted (less connected), than pores produced by biological activity. Large pores created by tillage tend to collapse relatively quickly, sometimes not lasting for even one growing season.

In addition, tillage disrupts some of the biological entities that stabilize soil structure, such as fungal hyphae (long threads that wrap around soil particles), remnants of roots, and earthworms. During tillage, stabilizing compounds are exposed as a food source for microorganisms and are consumed, resulting in a loss of structural stability.

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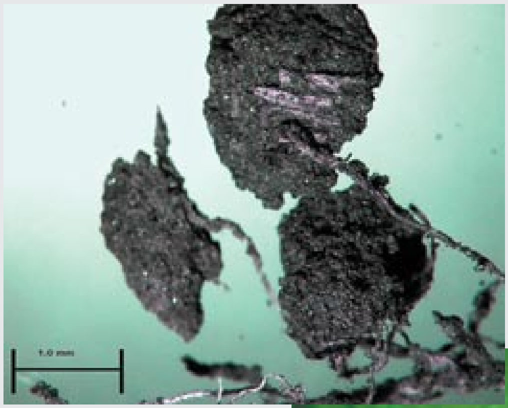
Removal of vegetation and residue is another human activity that impacts soil structure. Exposure of the soil surface makes it vulnerable to damaging external physical forces such as rain and wind, which further degrade structure and often result in loss of soil by erosion. Vegetation removal eliminates a primary source of energy needed by soil biological organisms, thus reducing soil structural development and stabilization.

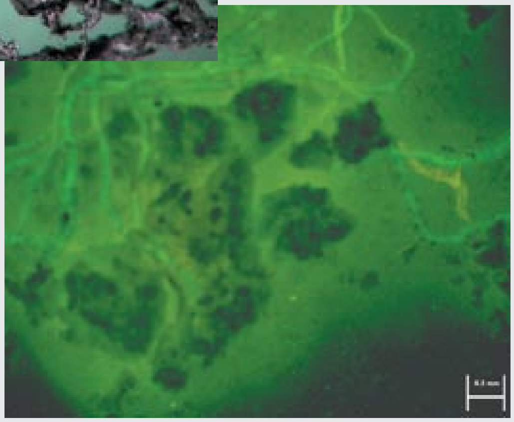
What effect does soil structure have on the viability and productivity of crop plants?

Pore size distribution, pore connectivity, as well as total amount of pore space are determined by soil structure. Pore characteristics in turn dictate the critical factors of the belowground environment including water storage,

Photo by Edgar R. Musser, via Clay Robinson, Tx.A&M.

'Black Sunday' dust storm of 1935 at Pampa, TX. Wind erosion is a result of a lack of vegetative cover and a loss of soil structure.





Stable soil aggregates were formed in 54 days on millet planted as part of a cover-crop cocktail following forage pea in a fine sandy loam soil near Bismarck, ND. In the upper photo, three micro-aggregates are held together by fine roots and fungal hyphae enmeshing soil particles. In the higher magnification photo to the right, glomalin and hyphae are easily distinguished in one of the micro-aggregates following a laboratory procedure that gives them a green color. These micro-aggregates can be further linked by roots, hyphae, and organic compounds to form aggregates. Microscopic biological entities such as these are the true source of soil structure.

Photos by Kristine Nichols, USDA-ARS.

water drainage, air movement, and ease of root growth. Consider a building that does not have proper air circulation, plumbing, or room sizes (and connectivity) for its function (e.g., an office building with only closets for rooms, or rooms without doors or windows) and you have a good idea of how soil structure can affect the productivity and viability of plants.

How is soil structure related to soil quality?

Soil quality describes the suitability of a soil for a current or proposed land use in terms of agricultural or horticultural productivity, environmental impacts, and contributions to human or animal health. The belowground environment largely determines how the soil functions for plant growth, removal of pollutants, nutrient cycling, hydrology, and carbon storage. Since the belowground environment strongly influences plant growth and is dependent on soil structure, this structure and other soil quality factors are tightly linked together. Indeed, many of the measures of soil quality evaluate pore arrangement or processes dependent on soil structure, either directly or indirectly.

What management practices can help create and maintain a useful soil structure?

In order to answer this question one needs to know the soil texture, the land use, and how the management practice affects soil structure. If the land use is grain crop production, we would like a soil structure that has a range of soil pore sizes such that we get good drainage, good water storage, good aeration, and a high degree of permeation by roots. Soil pores are often classified into macropores, mesopores, and micropores. *Macro*pores, the largest pores, are greater than 1 mm in diameter (1 mm is the thickness of a dime). *Micro*pores are less than 0.01 mm (a human hair is about 0.05 mm in diameter). *Meso*pores are the size range between micro- and macropores. Crumb structure (granular in shape with many pores within and between the granular units) best approximates the optimum pore size distribution for crop production.

To maintain optimal soil structure for crop growth, management practices must promote high levels of biological activity and root growth. If the soil is dense (a high percentage of pores are micropores), management practices may be needed to encourage more macropores and mesopores. Management practices that increase soil organic matter, reduce traffic by heavy equipment, and promote biological activity such as earthworms and roots, are generally needed to increase the amount of stable macropores. Conversely, soil compaction is a process that reduces total porosity and converts larger pores into smaller pores. Generally, this creates a poorer environment for plant growth. (Sometimes there is a need for moderate compaction, such as during planting when good seed-to-soil contact is required, although this beneficial compaction is in a tiny localized area below and to the side of the seed.) Soil management guides dealing with the problem of soil compaction can provide more specific advice than we can in this article. (*Editors' Note: See 'Pressure Relief' in the Sept. '05 issue for a discussion of compaction caused by machinery, ground contact pressures from tires and tracks, etc. See also 'Controlled Traffic, Anyone?' in the March '05 issue. Rick Waldren's 'Roots: The Foundation,' March '06, describes root ability to overcome compaction, as well as the problems with measuring the small-scale restrictions and opportunities that the root tips and root hairs encounter.*)

Soil structure determines pore characteristics, which in turn dictate water storage, water drainage, air movement, and ease of root growth.

What is the role of soil structure in water storage and water availability?

Soil pores between 0.05 and 0.1 mm will store water that is potentially available to plant roots. Soil pores within this size range are influenced by both soil texture and structure. Soil *texture* (the percentages of sand, silt, and clay) is a static property of the soil that is not easily changed through management practices, while soil *structure* is a more transient property that can be managed within the constraints of soil texture.

Soil stability develops through 'active' organic compounds such as glomalin creating a 'glue,' as well as biological structures such as roots and hyphae that bind particles into porous arrangements.

One of the principal goals of soil management programs is to influence soil structure (and therefore pore characteristics) to improve water storage and water availability. Macropores (pores >1 mm) drain easily under the influence of gravity unless underlying strata are already saturated. Water in pores that are less than 0.05 mm in size is not available for use by crops (it is bound too tightly to the soil particles by physical and chemical forces). Only in pores between these sizes does plant-available water typically occur.

What is the difference between soil porosity and pore size distribution?

Soil porosity describes the percentage of air space available in a given volume of soil. Soil pore size distribution divides the total porosity into different classes based on the pore sizes, which range from pores smaller than a bacterium to large pores easily visible to the human eye.

An optimum pore size distribution includes macropores for drainage and air exchange as well as smaller mesopores that are suitable for storing water that is available for crops to use. Figures 2 and 3 are examples of how management affects soil porosity and pore characteristics.

What is the difference between soil texture and soil structure?

Soil texture describes the percentages of clay, silt, and sand particles in the soil. These particles are inorganic (mineral). Clay particles have a size below 0.002 mm (a cubic inch of loam soil, 20% clay, has approximately 1 *trillion* clay particles), silts are from 0.002 to 0.05 mm (a cubic inch of loam soil, 40% silt, has approximately 800 million silt particles), while sand is from 0.05 mm up to 2 millimeters (a cubic inch of loam soil, 40% sand, has approximately 1000 sand particles).

These size distributions only apply to unconnected soil particles, often called primary particles. Primary particles in the soil cannot be easily broken down or dispersed except over geologic timeframes. The secondary particles

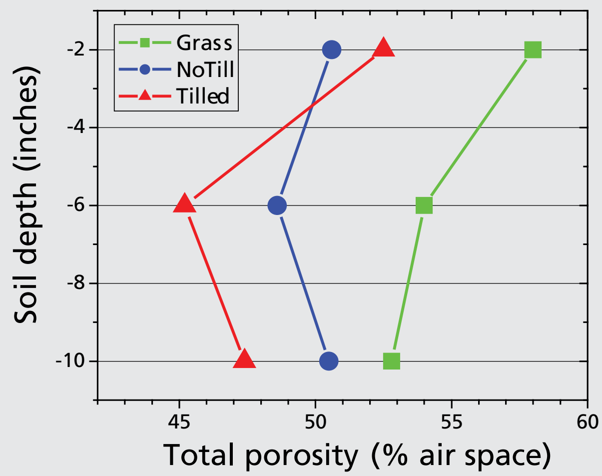


Figure 2. Total soil porosity in the top 12 inches of typical soils from central South Dakota as affected by soil management. Grasslands typically have higher total porosity than cropland. This is related to their extensive root systems, which create and stabilize soil pores, especially macropores. Source: A. Eynard, T.E. Schumacher, M.J. Lindstrom & D.D. Malo, 2004, Porosity and Pore-size Distribution in Cultivated Ustolls and Usterts, *Soil Sci. Soc. Am. J.* 68: 1927–1934

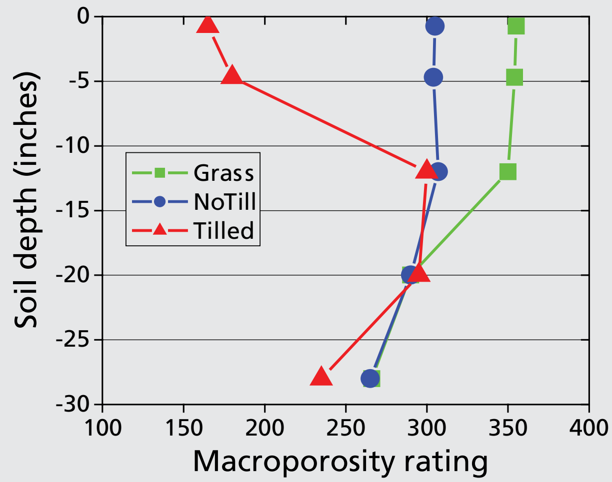


Figure 3. The same sites as Figure 2. The macropore rating was derived from observations of pores greater than 1 mm in size and of a cylindrical and connected nature. A higher rating represents a greater number of observations of these types of pores. The grass and the no-till cropland had a greater amount of macropores than the tilled system within the upper 12 inches. This translates into improved movement of water into the soil as long as the macropores are open to the surface. Vegetation and residue cover on the surface protect the functionality of macropores.

(micro-aggregates) that contribute to soil structure are formed from primary particles being bound together into a larger, relatively stable soil unit. Micro-aggregates form macro-aggregates, which near the surface have sizes from 1 to 50 mm; deeper ones will be 20 to 500 mm.

While soil texture describes the percentages of different-sized primary particles, soil structure describes the geometric or spatial character of the soil matrix: i.e., structure is the way the parts (primary and secondary particles) are bound together to create various spaces amongst the parts. Aggregates are formed from connections between primary particles and smaller micro-aggregates. Soil structure can be described in terms of pore characteristics, including their shape, continuity, size distribution, total amount, and functioning (e.g., ease of water or air flow in the soil), or by geometry of the solids since one is the inverse of the other (total soil volume is either solids or pore space).

How does soil texture influence structure?

Soils that are high in sand have very low percentages of pores that store plant-available water. Management practices that maintain or build soil organic matter in these soils can improve the structure, but have a limited capability of doing so. Soils high in clay tend to have high percentages of pores that store water, but much of this water is not available to plants. Even under optimum management, soils of these extreme textures cannot be changed into a soil with wonderful structure, although many soils in these categories can still be significantly improved. A loam-textured soil is more likely to develop optimal soil structure, although even the structure of a loam soil can be degraded through poor soil management. A loam soil is composed of 7 – 27% clay, 28 – 50% silt, and less than 52% sand, as well as plentiful organic matter. Because clay has so much more surface area than silts and sands, its properties largely define a loam's characteristics.

What determines the stability of soil structure?

Structural stability requires 'connections' between particles and reinforcement of those connections. Structural stability is the ability of the soil to withstand an external force without a collapse of large pores into smaller pores and/or without dispersing into individual particles of sand, silt, and clay. It is the same as a building being able to withstand a strong wind or other force.

Soil stability is developed through 'active' organic compounds such as glomalin acting as 'glue,' as well as biological structures such as roots and hyphae that bind particles into porous arrangements. Inert and recalcitrant (not easily broken down) organic compounds contained in soil also act as passive 'insulators' which physically separate soil aggregates.

Photo by Paul Jasa.

Soil profile in the Nebraska panhandle (near Alliance) in a wheat >>summerfallow system with several tillage operations per year with disks and sweeps. There is no structure in the upper 6 inches of tilled soil (technically, "massive structure"), below that is ~ 2 inches of severe tillage pan, and then fair soil structure below the tillage pan. The platy structure in the tillage pan was induced by tillage operations. The tillage pan apparently had cracks that allowed the passage of roots. Accordingly, Schumacher surmises that in this case the roots are not being seriously restricted by the tillage pan and it therefore wouldn't respond to deep ripping.

How does structure affect rooting, water infiltration, and air movement?

A well-structured soil has naturally occurring pores and spaces ranging in size from the diameter of earthworms (macropores) to microscopic sizes. Like water flowing downhill, roots tend to grow along the path of least resistance. Because pores provide a convenient and easy path to follow, the pore arrangement helps determine where roots grow. Sometimes roots will penetrate soil to make their own pores, but this takes more energy. Additionally, if the soil particles are held together strongly (such as in a severe plow pan) the roots cannot penetrate and must grow laterally. Water and gas (carbon dioxide, oxygen, etc.) also move through soil pores. Plant roots and many other underground organisms have metabolisms that require oxygen, which must be continually replenished from the atmosphere at a relatively steady rate. Obviously this requires soil pore continuity. The best situation is when roots, water, and oxygen are all present in a matrix of interconnected soil pores.

Photo by Tom Schumacher.

Soil structure can be modified by management. This field had been chisel plowed, and the portion of the soil that was loosened was carefully removed, revealing this dense soil layer that remained after the chisel plow operation. The dense layer could impede root growth, water infiltration, and gas exchange. Tillage is a major source of compaction.

Is soil organic matter in any way related to structure?

Soil organic matter stabilizes pores and helps to keep them open. In addition, soils with higher organic matter levels will support larger earthworm populations, which do an excellent job of making stable pores that are large enough to allow water to infiltrate rapidly as well as efficient gas flow in and out of the soil. Keep in mind that soil organic matter is a relatively crude measurement and not tightly correlated to structure. However, if soil organic matter is truly increasing, most likely structure is also improving.

Tillage is to soil structure as a wrecking ball is to a building.

What creates structure? How long of a time period does it take?

Soil structure is created when soil solids are physically moved in such a way as to cause the formation of pores. Some of the agents that physically move soil are earthworms, roots, soil freeze-thaw cycles, and soil wetting and drying cycles. In addition, as roots grow in soil, they remove water from the soil directly adjacent to the root. This localized soil drying by the root system will result in the formation of cracks and pores near the root. Because of the annual nature of soil freeze-thaw cycles, and because earthworms and roots are relatively slow in interacting with the soil, the length of time it takes to create a stable soil structure is generally measured in years. It is important to note that natural processes that move soil are generally concurrent with biological 'glue' secretion that binds the new arrangement, unlike tillage operations. As described earlier, pores created by tillage are unstable and collapse during the growing season.

How does tillage affect soil structure?

Any kind of tillage destroys the continuity of existing soil pores. Disruption of pore continuity impedes water infiltration, reduces gas exchange to and from the soil, and inhibits prolific root and hyphae growth. Tillage operations loosen the soil and create new soil pores, but these pores tend to be unstable and consolidate quickly over time. Pores formed by tillage are also more convoluted, which makes them less efficient in promoting root growth, water infiltration, and gas exchange. A second effect of tillage on soil structure is the formation of a tillage pan just below the portion of the soil profile that is lifted or mixed by the tillage implement. Tillage pans are areas of soil compaction that can further impede root growth, water infiltration, and gas exchange (see photo on this page and Figure 4). Figuratively speaking, tillage is to soil structure as a wrecking ball is to a building.

If more-porous soils are better for root growth, is a tilled soil better yet?

As discussed, tillage destroys the continuity of the existing pores in the soil profile. Setting this negative aspect of tillage aside, let's concentrate on the idea that tilled

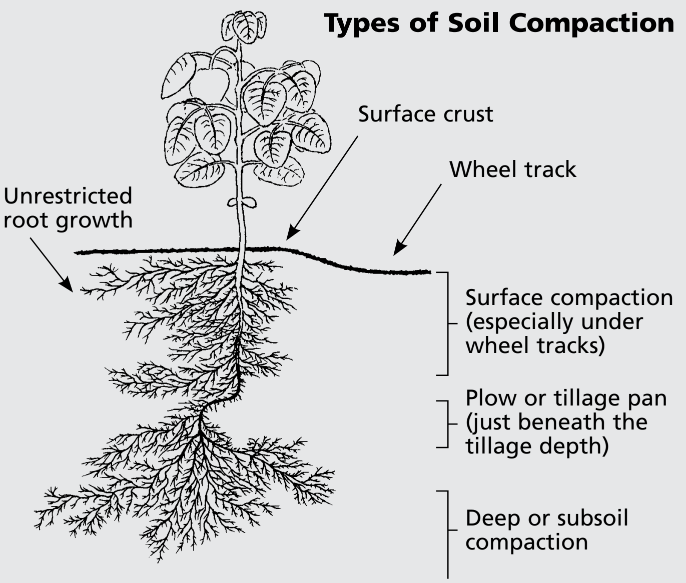


Illustration by Matt Hagny.

Figure 4. Typical root growth responses to soil compaction. Three main forms of soil compaction are illustrated: patterned surface compaction (wheel traffic), plow or tillage pan compaction, and uniform subsoil compaction. Compaction changes the physical structure of soil, creating a poor rooting environment and reducing root growth in those portions of the soil profile. Digging a sizable hole to examine rooting patterns and soil structure with depth is the best way to identify the three main forms of soil compaction.

Photo by Paul Jasa.

Wheat field near Alliance, NE in a tillage wheat >>summerfallow system. The powdery loose dust on the surface looks something like a lunar landscape, but in this case is technically soil because it still harbors biology, contains organic matter, and has remnants of structure in the small aggregates. However, the similarity to the dust on the moon is enlightening, since tillage is beating the life out of the soil. Without biology, the other particles soon lose their structure, becoming merely a pile of dust.

soils are soft under foot. It is true that tillage makes new soil pores. Most of the pores in tilled soil are initially quite large. Over time, tilled soils consolidate from external forces (such as rainfall) and the pore system collapses. Since the pores do not have much vertical continuity in a collapsed tilled system, the roots have a more difficult time growing.

Also, the softness of tilled soil makes it vulnerable. When it rains, the physical forces associated with raindrops hitting the soil surface cause a layer of surface compaction that reduces water infiltration (i.e., the pores get clogged with soil particles dislodged from their matrix). At this point, water begins to run off the field, creating rills and ephemeral gullies that are evidence of soil losses by erosion. In climates that are continuously short of rainfall, the loss of water through runoff can be particularly devastating to yield productivity. It is much better to have a soil with a stable structure and durable pores that permit rain to infiltrate into the soil profile.

Doesn't tillage enhance rooting by preparing a place for roots to grow?

Under some circumstances tillage prepares for roots to grow in a limited 'container' (see Fig. 4). For example, roots of corn or soybean can grow to a depth of 3 – 5 feet or more. Most agricultural soils are tilled to a depth of about 8 inches, or perhaps 12 inches or more with deep ripping (i.e., subsoiling; engaging the soil deeply with a shank). Because crop roots have the genetic capacity to grow much deeper into the soil profile, well beyond the tilled zone, a tillage operation that disrupts soil pores and creates a tillage hardpan will impede root growth below the tilled zone and may prevent crops from reaching their genetic potential, which in turn may reduce yield potential. Growing crops with impeded roots is analogous to growing plants in a pot with limited capacity.

Crops appear to grow faster and have better color if tillage is done. Doesn't this indicate that tillage is beneficial for crop growth?

There are two aspects of tillage that may help crops to initially grow faster and have better color when compared with crops grown under no-till. The first is related to soil temperature. Tillage buries surface residues, exposing the darker soil which absorbs more of the energy in sunlight. Dark-colored soils with little residue will dry out and warm up more quickly in the spring, which in turn facilitates planting operations and increases early crop growth, especially in high-latitude climates. Because water warms about five times more slowly than dry soil, the drying effect resulting from tillage can also be a major contributor to springtime warming.

The second aspect is mineralization of soil organic matter. When soils are tilled, more of the previously stable soil organic matter is exposed to microbial activity. Microbes break down the soil organic matter and release nitrogen, phosphorus, sulfur, zinc, and other nutrients that are used by the crop. It is important to note here that the relatively slow early growth of crops under no-till soil management can be alleviated by the use of cover crops (to help manage previous crop residues and facilitate drying as discussed in the previous paragraph) and starter or 'pop-up' fertilizers (to enhance plant nutrient availability early in the season). Furthermore, slower early growth does not necessarily result in lower yields.

No-tillers often talk about needing more down-pressure on their planters and drills—shouldn't the soil be softer if it has more structure and porosity under no-till?

No, softness does not equate with structure. The appearance of softness is a function of unstable large pores that are easily deformed and compressed. It is like having a house made of straw instead of brick. Oftentimes no-till soils are denser that tilled soils and require more down-pressure for the cutting elements of a planter or drill to achieve a certain depth. However, the pore configuration tends to be more stable and connected in no-

Photo by NASA.

The dusty lunar surface. Soil scientists would not classify this material as soil because it has no biological activity, and it does not have organic matter.

Photo by F.D. Haas, via Dirceu Gassen.

Tillage of soils while wet, especially high-clay soils, can severely damage the structure. Below the tilled portion, the structure is decent.

till soils, so air and water movement is better, thus providing a good seedbed.

If I have a hardpan (tillage pan), will freeze-thaw take care of that? Will shrink-swell? Or do I need a ripper?

Freeze-thaw and shrink-swell will have only a limited impact on tillage pan disruption. The impacts of these physical forces are dependent on the number of cycles. In northern climates there may be only one or two freeze-thaw cycles per year (especially at depth), so changes in structure occur slowly. A ripper will 'remove' a tillage pan if the ripper is used when the soil is dry, but if a ripper is used in wet subsoil then the tillage pan quickly reforms and will be even more dense. During ripping, the tillage pan is broken up into soil clods that are internally dense but are separated from each other by pores which may alleviate the effects of the tillage pan on water and air movement and root penetration through this portion of the soil profile. Yet the clods are still very dense, and continued tillage is likely to result in the re-forming of a tillage pan. Overall the soil density increases again as the large unstable pores collapse under rainfall and field traffic.

Favorable economic responses to deep ripping are rare. In general, successful results from ripping are obtained if a naturally occurring dense layer exists, such as in the old forest soils of Michigan, or in certain sandy soils of the southeastern U.S. coastal plains. These soils are more favorable to root growth above *and below* the dense layer. 'Removal' (shattering) of the dense layer allows the roots to take advantage of the lower part of the soil profile.

Tillage implements can themselves create dense layers. Generally, tillage pans are limited in thickness and occur just below the deepest depth attained by the tillage implement. In soils with tillage pans, a subsoiling pass can be advantageous to break up the dense layer if done under appropriate conditions (i.e., dry subsoil). The tillage pan does not easily re-form unless tillage is repeated. There isn't a need to repeatedly rip soils where a dense layer does not exist. This is different from soils where the root zone has a continuous dense layer, i.e., the subsoil is dense throughout the potential root zone due to geologic makeup. In soils with continuously dense subsoil, the beneficial effects of ripping are likely to be temporary even if done under ideal conditions, and can be detrimental under wet conditions.

Soils that are dense without a definite layer are unpredictable when it comes to favorable responses to ripping. For instance, glaciated soils such as those found in the eastern Dakotas have dense subsoil. Ripping these soils doesn't have much benefit, is very costly, and may make things worse if the ripping is done when the subsoil is wet. It is quite rare that ripping provides any long-term benefit in soils with uniformly dense subsoil.

Tillage-induced reductions of soil density are never very long-lasting. Tillage moves big blocks of soil. This is quite different from, for instance, an earthworm moving soil on a much smaller scale and secreting glue-like organic compounds to cement the new arrangement in place. Tillage equipment doesn't secrete any such organic 'glue,' and is generally detrimental to the soil's existing glue and glue-making organisms.

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In order to truly get rid of the tillage pan, one needs to change practices that created the tillage pan in the first place—i.e., stop doing tillage (especially disk, moldboard plow, and v-blade tillage). One needs to find the reason for the tillage pan formation and eliminate it from your practices. Additional causes of soil compaction are excessive traffic, heavy loads on small footprints, and traffic on wet soil. Crops with deep rooting patterns such as sunflower and alfalfa are more likely to penetrate a moderately dense soil layer, but even these will not penetrate a severe tillage pan.

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Because the causes and characteristics of tillage pans are so diverse and because soil traits are highly variable from region to region, it is difficult to prescribe a 'one-size-fits-all' recommendation for ripping prior to implementing no-till. This needs to be decided on a case-by-case basis, preferably in consultation with soil management specialists. The presence of a dense layer should always be directly determined by digging a hole and looking for signs of a distinctly dense layer with less dense soil above *and below* this layer within the potential root zone. If roots are already growing through the dense layer, then ripping is unlikely to be beneficial.

Additionally, keep in mind that the evaluation of the need for subsoiling may often be skewed by our mentality. Our culture, especially in the agricultural community, has the general notion that "doing something is better than doing nothing." However, in reality, any given work action *may or may not* be productive. It is deeply engrained in agriculture's mindset that tillage is productive, that it is beneficial. Tillage is far more destructive than is commonly understood. So, beware of the mental bias towards 'doing something.'

Summary

Soil structure is crucial to the value and utility of soil for crop and forage production. Soil structure can be improved or degraded by human impacts and management. Biological activity in the soil is the main contributor to good soil structure, and this soil biology is highly dependent on plants and their remnants for sustenance. This biological activity is thwarted by soil disturbance (tillage). In terms of maintaining or enhancing soil structure and soil productivity, the best management practices will include minimizing compacting activities (by machines or livestock), maximizing crop or forage growth, retaining a mulch to protect the soil and feed the soil biology, and eliminating tillage as a method of temporarily creating favorable soil structure.

Tread Lightly

by Matt Hagny

TECHNIQUE

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Out of necessity, spraying activities often are conducted under adverse conditions, such as when soils are damp. Sprayers keep getting bigger, which isn't a bad thing so long as the heavier loads are carried properly. The table on p. 407 shows the weight of the most compacting axle of common sprayers (both front and rear are shown for Apaches) with selected tire options (usually the widest and narrowest offered by the manufacturer) as well as a few larger aftermarket tires that producers have chosen in attempting to minimize field rutting and deep compaction.

For comparison, 'proper' inflation pressures have been calculated (see table notes). The force exerted on the soil ("ground contact pressure") is always within 5 – 10% of the *proper* tire inflation pressure. (Decreasing inflation pressure below recommended won't reduce the tire's ground pressure further, but over-inflating certainly can cause higher ground pressures because the footprint shrinks. However, extreme *over*-inflation pressures will not be a good estimate of contact pressure because the footprint can only shrink so much.) The values reported are 'worst case' scenarios: fully loaded with liquid nitrogen, fuel, etc. (water instead of UAN drops the inflation needed slightly). Limiting top-end transport speeds while loaded allows reduced inflation.

The majority of these pressures are well into the danger zone for causing severe soil damage and rutting even in modestly damp conditions, as well as inducing erosion when water runs down the wheel tracks on slopes. For comparison, humans walking have contact pressures of