PENNSTATE
College of Agricultural Sciences
Cooperative Extension

CONSERVATION TILLAGE SERIES
Number Three

Soil Compaction and Conservation Tillage

INTRODUCTION

Soil is a complex medium, but for simplicity we can think of it as a combination of solid mineral and organic particles and pore space. Pore space allows for air and water storage and movement in soils. Compaction squeezes the soil and, since solids do not compress, pore space is reduced. A footprint or wheel track rut in a field, for example, signals compaction.

The ideal silt-loam soil is composed of mineral particles, organic matter, and pore space. One-half the pore space should be filled with water and the other half with air (see chart below). This physical characteristic of soil can be measured and is expressed as bulk density, void ratio, or porosity. The degree of compaction in a soil can be estimated by measuring these factors; compaction increases bulk density and reduces void ratio and porosity.

When pore space shrinks, there is less air and moisture in the soil, a condition that negatively influences seed germination, seedling emergence, root growth, nutrient uptake, and in reality all phases of crop growth and production.

SOIL CHARACTERISTICS AND COMPACTION

Field operation management, especially selecting and using tillage equipment, should be directed toward developing and maintaining an optimal proportion of soil components (water, air, organic matter, and mineral components) for productive and sustainable agriculture.

Soil Texture

Soil's mineral components are classified by particle size as sand, silt, or clay. Soil "texture" refers to the relative proportions of these particles in a given soil type. Finely textured soils (with a higher percentage of silt and clay) inherently hold more water than soils with a coarse texture. Also, finer-textured soils often are more compact, and movement of water and air is slower. These soils may therefore be more difficult to work and to manage in order to avoid compaction.

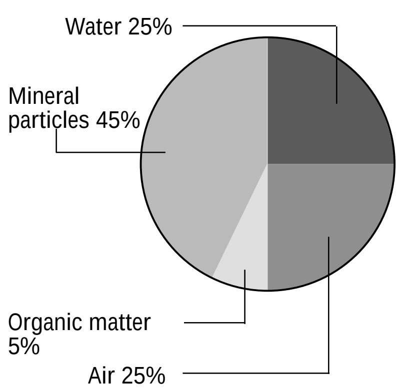
Soil Structure: Role of Pore Space

Except for sand, the mineral proportion of soil occurs in groups of particles bonded together by organic compounds to form soil aggregates. These give soil its "structure." Soil with a good structure is loose and friable. Pore space between the aggregates allows for most of the storage and movement of air and water in soil.

The air and water occupying these "empty" spaces are both vital. Seeds require oxygen and water to germinate. For healthy plant and root development, roots must have oxygen in order to take up nutrients. Water is an essential component of photosynthesis, the process responsible for building plant structures, and soil nutrients must be in solution before roots can absorb them.

Soil with good structure, or "tilth," is physically looser than compacted soil. To penetrate the soil, seedlings require a loose soil structure. Roots develop stronger and more extensive systems in porous soil; they meet less resistance and can follow the spaces between aggregates where water and nutrients in solution can be found and used.

Composition of ideal silt loam soil.



As pore space is reduced by compaction, water flow through the soil is blocked. If water is applied to soil faster than it percolates into the soil, the excess runs off, often causing erosion, loss of plant nutrients and pesticides, and pollution of streams and other water. Runoff water is lost from the field and thus is not available to plants when needed later in the season.

In compacted wet soils, water fills the few pore spaces left at the expense of air. The lack of air (oxygen) may produce changes in soil chemistry that are unfavorable for nutrient availability or uptake. For example, wet compacted soils favor denitrification, a bacterial process by which nitrate in the soil is converted to gaseous nitrogen compounds and is therefore lost to the crop. Such soils may show a reduction in pH, creating an acid condition and making other nutrients less available. (See other publications in this series for details on nutrient dynamics under conservation tillage.)

Soil Structure: Role of Organic Matter

Organic matter usually makes up less than 10 percent of soil's solid component, yet because it provides the bonding agents for soil aggregates, organic matter is more important than its low proportion might indicate. Soils with a high organic matter content tend to have larger, stronger, and more stable aggregates that resist compaction. Soils low in organic matter tend to be more susceptible to compaction. Soil organic matter levels usually decrease where low-residue crops, such as potatoes and soybeans, are grown. The continual removal of corn for silage and of straw from small grains also cause a depletion of organic matter.

Growing crops that leave substantial amounts of residue can increase soil organic matter, depending upon tillage. Crops requiring annual tillage that incorporates any residue will briefly boost organic matter content, but ultimately such tillage hastens organic matter decomposition and disappearance. A study in Delaware reported no increase in humus over time in reduced tillage (chisel-plowed) fields while showing an almost 50 percent increase in humus for fields in no-tillage for 7 or 8 years. Residue left in no-till situations year after year allows for a long-term increase in soil organic matter.

CAUSES OF SOIL COMPACTION

Traffic Over the Field

Soil compacts when pore space is reduced and bulk density is increased. Therefore, any process that reduces pore space causes soil compaction. Its major cause is traffic over the fields. Tractors, implements, livestock, and even humans can compact soil when traveling across a field.

How much compaction occurs depends on many factors: soil physical conditions, soil type (texture) as well as weight and design of the load on soil, distribution of the load over the number of axles and tires, and to a lesser degree, number of trips made over the same area. It is generally accepted that a pressure of 4 psi or more on most soils can produce compaction with economic implications. For reference, a pickup truck will impose about 50 psi pressure on the soil, a liquid manure spreader 70 to 90 psi, a 1,200-pound cow approximately 40 psi, and an all-terrain vehicle only 4 to 5 psi.

There are two types of soil compaction—shallow and deep. Shallow compaction occurs near the soil surface (within normal plow depth) and is influenced primarily by pressure applied to the soil surface. Freezing-thawing and wetting-drying cycles and even tillage can help break up shallow compaction. At the University of Tennessee, in a 3-year no-till study on silt-loam soils, the force required to push a soil penetrometer to a 6-inch depth dropped from 220 pounds the first year to 140 pounds the third year.

Deep compaction, which has been measured as far as 28 inches below the surface, is caused mainly by axle load. Deep compaction is extremely difficult to correct since it is below the normal tillage zone. Wetting-drying and/or freezing-thawing cycles have little effect on compaction at such depth. Deep compaction is detrimental for all crops because it reduces water and air storage in the deeper part of the soil profile. With a lower storage volume, droughts have a greater potential to induce moisture stress. Deep-rooted crops such as corn and alfalfa are hampered in developing a full root system and therefore may not reach potential yield or quality.

Number of Passes

Even one pass over a field under poor conditions can cause significant damage. In any given situation, the first pass of a wheel causes 80 percent of the potential compaction. Subsequent passes cause additional, but progressively less, compaction. After four passes, the additional compaction becomes very small and probably can be ignored. One option is to establish drive rows and take the compaction losses there, while protecting the rest of the field. This is one form of controlled traffic.

Tillage Operations and Equipment

Tillage can either create or help to alleviate soil compaction. By their nature, tillage operations break up soil into smaller particles. Excessive tillage may pulverize soil aggregates, destroying the structure that provides desirable pore space. Some tillage equipment, such as moldboard plows, may aerate the soil and increase percolation at the surface while creating a compacted layer just below tillage depth. Such a layer is called a “plowpan” or “hard pan.” Discs can also produce a hard pan just below tillage depth while overtilling the soil near the surface, especially where multiple passes are made the same year.

To alleviate compaction, subsoiling with heavy duty shanks to depths of 15-24 inches or even deeper and usually spaced about 30 inches apart has been tried with mixed results. Subsoiling is an expensive operation requiring about 30 horsepower per shank. Its greatest benefits appear to occur in the southeastern United States, where soil is subject to little or no freezing. Short-term benefits have been measured, but some scientists think that subsoiling may, in the long run, make compaction worse. Subsoiled fields may recompact to a greater degree from normal operations than without any such subsoiling treatment. Apparently, subsoiling reduces the soil’s capacity to support loads of equipment without compacting.

Equipment Weight and Tire Inflation

As farm tractors, combines, and other equipment have become larger, they have also gotten heavier. Tractors weigh up to 40,000 pounds, and liquid manure spreaders can weigh as much as 28,000 pounds when fully loaded. Some pieces of equipment have axle loads that exceed the legal weight limit on public highways. Often, higher tire inflation pressures are used to support such heavy weights, and this places higher pressures on the soil surface. With radial tires, soil pressure is approximately equal to inflation pressure, while with bias-ply tires there is increased soil pressure at the tire’s edge because the sidewall carries part of the load. Both radial and bias-ply tires are used on tractors, combines, and implements.

Tire and Axle Number

Dual tractor tires, compared to single tires, decrease pressure on soil, but the affected area is at least twice as large. Since as little as 4 psi can cause compaction, duals or even high-flotation tires do not prevent compaction; they merely change the distribution. Testing at USDA’s National Tillage Laboratory indicate there is no crop yield increase for dual tires over single tires. Tandem axles on heavy trailers, such as grain wagons, liquid manure spreaders, and large sprayers, are a better way to spread the load over more tires.

For a tractor of a given weight, four-wheel drive is better than two-wheel drive because the weight can be evenly distributed to all tires. Better yet is to use tracks that create an ever longer footprint, thus spreading the weight over a larger surface area. All these approaches reduce the pressure on the soil and therefore reduce the depth of shallow compaction. By spreading the weight over more axles, deep compaction is reduced or eliminated.

Note that a 200-plus horsepower tractor equipped with rubber tracks applies only an average of 6 psi to soil. This approaches the "no-economic impact" level of 4 psi. With a soil pressure of 4 psi on typical soils, very little compaction would occur on the first pass, so that additional passes would contribute practically no compaction.

Working Wet or Poorly Drained Soils

Often soils are worked or driven on when too wet. When soil is wet, the bonds holding aggregates together are weak and pliable, so they can be more easily destroyed. Compaction is the result. Most farmers recognize that driving on a wet field leaves ruts, a visible sign of compaction. The wetter the soil, the deeper the rut will be, and the more the soil compacts.

Sometimes fields are worked too wet in the spring to gain early planting dates for that year, but this may also create compaction layers that negatively affect crop production for years in the future. Indications that soil is too wet to work or drive on include mud sticking to tires and ruts deeper than 1 inch. Also, if the soil is too wet to plow, it is too wet to no-till plant.

Typically poorly drained soils are difficult to work without causing compaction since they are often too wet for long periods. Do not work on wet soils; this makes the problem worse by compacting soil even more. If feasible, drain wet spots in fields either by surface or by subsurface drainage. Compacted soils drain poorly, but this should be treated as a temporary situation.

Several approaches can be followed to improve drainage in a compacted field, including changing tillage tools (i.e., using a chisel plow instead of a moldboard plow), reducing tillage and traffic over the field, converting to a no-till program, and rotating the field to a deep-rooted forage crop for several years.

COMPACTION'S SYMPTOMS AND EFFECTS

Certain characteristic symptoms may indicate a compaction problem.

Plant Growth Indicators

Soil compaction affects plant growth in many ways. Air and water movement and storage in the soil are restricted, causing shortages to the plants. Roots do not develop well or penetrate well in compacted soil, so shallow root systems and malformed roots are symptoms of compacted soil. Plants are generally stunted, and moisture and nutrient stresses may occur. Nitrogen and/or potassium deficiency symptoms in plants are common. Crop growth and yield probably will be reduced.

In corn experiments at Purdue University, compacted plots resulted in stand reductions of 20 to 30 percent, plant height decreases of one-third to one-half, and yield reductions of about 19 percent compared to noncompacted plots. Corn yields were 160 bushels per acre for noncompacted soil compared to only 130 bushels for compacted plots**.**

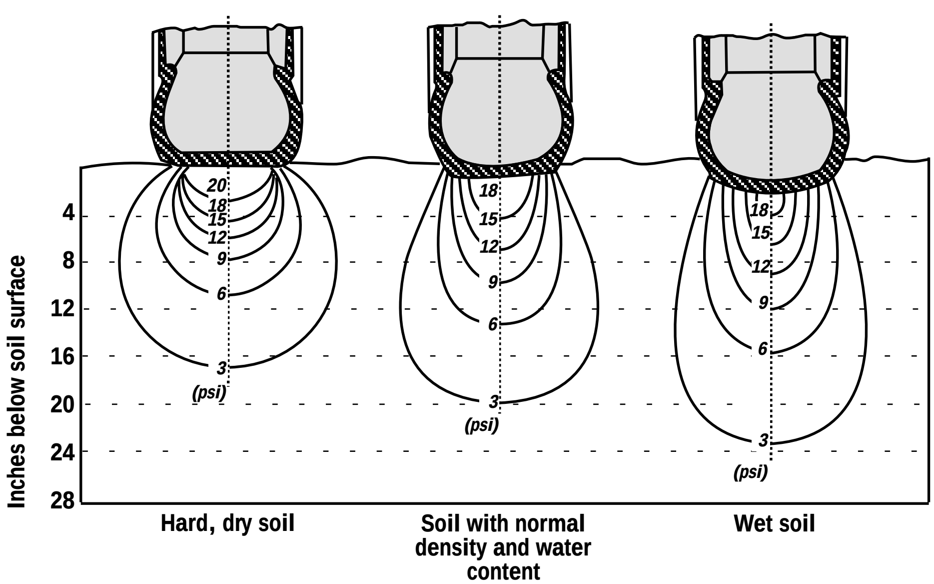
Poor Soil Structure

Formation of large soil clods after tillage may indicate compacted soil. Compacted soil is more resistant to tillage forces and after tillage tends to be more cloddy. Also, shallowly compacted soil may form a crust after rainfall or irrigation owing to poor soil structure and reduced infiltration. Besides increasing runoff and erosion, crusting may impede plant emergence and lead to uneven stands. Overworking (tilling) soil at the surface, typically with a disc, can destroy soil structure and increase crusting. This phenomenon can occur in most soils but is more likely in soils with a high clay content.

New Wet Spots

New wet spots in fields may indicate that a plow pan is forming and the compaction is inhibiting drainage. Standing water on the surface can indicate that the soil profile has inadequate pore space and therefore less water storage capacity. With reduced pore space, most of the

Effect of soil moisture on load penetration under a tractor tire. (Tire size 11-28 inches; load 1,650 lb; inflation pressure 12 psi.)



Source: USDA, adapted from Soehne 1958.

pores may be filled with water and the soil becomes "waterlogged." This causes a loss of nitrogen through denitrification and an air shortage in soil. Since wet soils compact easily, working the wet spots simply compacts the soil even more; the result is a vicious cycle and the situation goes from bad to worse in a hurry. The problem is also evident in "drive rows" in a row crop field. Tracks drain poorly after a rain, so compaction increases even more during the next trip over the field.

Greater Power Required for Tillage

If soils are compacted, an increase in power to accomplish tillage operations may be required. In an experiment in Illinois, compacted soil caused a 10- to 16-fold increase at low speeds and a 4- to 8-fold increase at high speeds in energy needed to prepare a seedbed to a given fineness. The draft of a narrow pointed chisel increased from 70 pounds in noncompacted soil to 350 pounds in compacted soil.

Positive Effects of Slight Compaction

Most effects of soil compaction are detrimental to crop growth. In some cases, however, slight compaction can aid germination and plant growth when soil moisture is low, such as during periods of low rainfall or in soils with a low water-holding capacity. Soil compaction increases traction, but the tradeoffs are unfavorable. In Pennsylvania, soil compaction usually has net negative effects, often quite severe.

STRATEGIES FOR MANAGING SOIL COMPACTION PROBLEMS

The best way to manage soil compaction is to control or minimize it before it happens. Treat the causes, not the symptoms. Once compaction occurs, correction is difficult and costly, and can require years. A review of compaction's main causes will provide clues about what to do.

The best ways to minimize soil compaction can be summarized as follows:

- Reduce traffic over the field, as traffic is the main cause of soil compaction. Are all those trips necessary? Try combining two implements in the same pass or use wider equipment if power is adequate.
- Control traffic so you are driving on the same areas repeatedly and thus protecting the rest of the field from compaction.
- Reduce tillage. Try various minimum tillage or no-till practices. Keep in mind that preserving soil structure, increasing organic matter, and reducing trips over the field reduce compaction.
- Use lighter equipment and/or remove ballast. Use smaller tractors for light work and remove ballast when not needed.
- Use flotation tires or tracks, or reduce tire inflation pressure. This lessens the pressure per unit of the soil surface and thus reduces compaction.
- Use tandem tires rather than duals. This spreads the load over more axles and reduces soil pressure without increasing the compacted area. On a four-wheel drive tractor, traction will improve because the rear tires are running in a compacted track.
- Don't work soil or drive on fields unless soil is dry enough. Time gained this year may cost you in the future because of compaction.
- Maintain as much organic matter in soil as feasible. Increased organic matter generally makes aggregates stronger so they can better support traffic with less compaction. Reduced tillage, use of cover crops, choice of crop, and crop rotations can all add residues and thus organic matter.
- Drain soils that tend to be wet. Since wet soil is more susceptible to compaction than dry soil, it makes sense to eliminate wet spots if possible. An added bonus is that dry soils tend to warm faster in spring.
- Practice crop rotation to include forages with deep roots. Deep-rooted forages such as alfalfa can penetrate compacted soil layers and leave pore space and organic matter when they decay. Hay crops also provide a break in the annual tillage routine and help build soil structure and create pore space.

Productive soil is a valuable resource and must be protected. Prevention is the best method for controlling compaction. Once a soil has become compacted, correcting it is difficult and costly, and may take years. Following these guidelines may require changing your cropping programs, soil management practices, and production techniques. However, reducing soil compaction will bring important benefits, including reduced erosion and pollution, less energy required for tillage operations, more efficient use of fertilizer, and improved crop yields.

FURTHER READING

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Penn State College of Agricultural Sciences research, extension, and resident education programs are funded in part by Pennsylvania counties, the Commonwealth of Pennsylvania, and the U.S. Department of Agriculture.

Issued in furtherance of Cooperative Extension Work, Acts of Congress May 8 and June 30, 1914, in cooperation with the U.S. Department of Agriculture and the Pennsylvania Legislature. J. L. Starling, Acting Director of Cooperative Extension, The Pennsylvania State University.

This publication is available in alternative media on request.

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