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Soil Compaction:
Detection, Prevention, and Alleviation

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This is the seventeenth in a series of technical notes about the effects of land management on soil quality.

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Overview

Soil that is excessively compacted is limited in its ability to function. Soil compaction occurs when moist or wet soil particles are pressed together and the pore spaces between them are reduced. Adequate pore space is essential for the movement of water, air, and soil fauna through the soil. The mechanical strength and poor oxygen supply of compacted soil restrict root penetration. Soil moisture is unavailable if layers of compacted soil restrict root growth. Compaction restricts infiltration, resulting in excessive runoff, erosion (Pierce et al., 1983), nutrient loss, and potential water-quality problems. Soil compaction can restrict nutrient cycling, resulting in reduced yields.

Soils in all regions of the country are susceptible to compaction with extreme cases in the upper Midwest, the Pacific Northwest, and the Southeast. Eroded soils are inherently low in content of organic matter and are especially susceptible to compaction.

Compaction is caused primarily by wheel traffic, but it also can be caused by animal traffic or natural processes. Soil is especially susceptible to compaction when it is at field capacity or wetter, has a low content of organic matter, or has poor aggregate stability. Saturated soils lack adequate strength to resist the deformation caused by traffic. Moldboard plowing and excessive tillage break down soil aggregates. After the aggregates are broken down and the soil surface is bare, the soil is more likely compacted by the excessive vehicle passes common in conventional tillage systems. Excessive traffic in forests during thinning and harvesting activities can cause compaction that will be detrimental to the next crop of trees. Grazing on wet soils in a confined area can create compacted layers.

Types of compaction

Surface crusting restricts seedling emergence and water infiltration. It is caused by the impact of raindrops on weak soil aggregates. Soils with cover crops or high-residue cover are less likely to form crusts.

Surface compaction occurs anywhere from the surface down to the normal tillage depth. The compacted layer can be loosened by normal tillage, root growth, and biological activity.

A *tillage pan* is a compacted layer, a few inches thick, beneath the normal tillage depth. It develops when the depth of tillage is the same year to year.

Deep compaction occurs beneath the level of tillage. Ground contact pressure and the total weight on the tire from the axle load significantly affect the amount of subsoil compaction. Deep compaction is difficult to eliminate and may permanently change soil structure. Prevention is important.

Inherent hardpans can form on some soil types because of variations in soil particle sizes, consolidation of particles by rainfall, and certain organo-chemical factors. These pans are aggravated by tillage and traffic.

Detecting Soil Compaction

Generally, compaction is a problem within the top 24 inches of the soil. Signs of compaction are:

- Discolored or poor plant growth.
- Excessive runoff.
- Difficulty penetrating the soil with a firm wire (survey flag) or welding rod (18” long).
- Lateral root growth with little, if any, penetration of roots into compacted layers.
- Platy, blocky, dense, or massive layers.

Quantitative methods of detecting compaction are (Jones, 1983):

- Measuring soil bulk density.
- Measuring penetration resistance with a commercially available cone penetrometer.

Bulk density measurement

Bulk density is defined as the weight of dry soil per volume. The Soil Quality Kit Guide (NRCS Soil Quality Institute, 2001) includes full directions for using the core method to measure bulk density. Table 1 provides interpretations based on soil texture. Samples can be taken from the surface 3 inches or from 3-inch increments beginning at the top of the compacted layer.

Table 1.—General relationship of soil bulk density to root growth based on soil texture (Pierce et al., 1983; R.B. Grossman, personal communication, 1996).

Soil texture	Ideal bulk densities	Bulk densities that may affect root growth	Bulk densities that restrict root growth
	--------------------------	g/cm^3	--------------------------
Sands, loamy sands	<1.60	1.69	>1.80
Sandy loams, loams	<1.40	1.63	>1.80
Sandy clay loams, loams, clay loams	<1.40	1.60	>1.75
Silts, silt loams	<1.30	1.60	>1.75
Silt loams, silty clay loams	<1.40	1.55	>1.65
Sandy clays, silty clays, some clay loams (35-45% clay)	<1.10	1.49	>1.58
Clays (>45% clay)	<1.10	1.39	>1.47

Soil cone penetrometer

A cone penetrometer allows faster and easier readings than bulk density measurements. The soil penetrometer consists of a cone attached to a rod that is pushed through the soil. The force required to push the cone through the soil divided by the area of the base of the cone is the *cone index*. The cone index is the standard measurement used for soil compaction and is read on the dial indicator of the penetrometer. Cone index is reported in units of pounds/square inch, or psi. Sometimes cone index is reported in bars. A bar is one atmospheric pressure, or about 15 psi. Roots usually cannot penetrate soil compacted to 300 psi or more. This critical value varies with soil type and moisture content of the soil when tested (Schuler et al., 2000). There are potential penetration problems at 145 psi.

The following instructions for using a penetrometer will ensure good results:

- Soil moisture will impact readings and should be near field capacity. If the user is sure there is compaction and is only trying to determine the depth of the compacted layer, then moisture content is not critical.
- Insert the soil penetrometer smoothly without jerking motions. An uneven force will result in a reading that is not representative.
- The penetrometer should be inserted at a constant rate of 1.2 inches/sec (3 cm/sec). Small variations will not affect the reading. Starting and stopping also will not affect the reading.
- Insert the penetrometer until the cone index reads 145 psi, which is an indication of potential penetration resistance. Stop and record the depth.
- Continue insertion. When the cone index is again less than 145 psi, record the depth. This is the bottom of the hardpan or compacted layer.
- If 145 psi or greater is never reached down to 18 inches, stop, record the maximum reading, and remove the penetrometer.
- Repeat the procedure at all sample locations.
- If soil sticks to the penetrometer, clean off the rod and cone with water after use.

Interpreting compaction indicators

The impact of compaction on crop productivity is determined not only by the amount of compaction, but also by the timing and duration of drought, crop type, planting date, crop variety, and other cropping system factors. Thus, indicators of soil compaction, such as bulk density and cone index readings, are not perfect indicators of the *effect* of compaction. For example, crops might show the effects of compaction only during years of high or low rainfall. No-tilled soils can have high compaction, as indicated by bulk density and cone index, but plants may grow well if biopores allow for root growth and water infiltration.

Preventing Soil Compaction

Prevention is important because all compaction is expensive to treat and deep compaction may have permanent, untreatable effects on productivity (Voorhees et al., 1989).

Controlled traffic

A controlled traffic system separates traffic zones from cropping zones within a field. Yields normally improve when traffic is restricted to controlled zones between the rows because the soil directly beneath the rows can retain a loosened structure. A controlled traffic system works well with row crops. If drilled crops are grown, a skip row is required (Reeder and Smith, 2000).

One component of controlled traffic systems is ensuring that all equipment covers the same width or multiples of the same width. A second component is minimizing the number of traffic lanes. Table 2 provides examples of traffic patterns. In the first scenario in table 2, the tractor tire width is 60” and the combine tire width is 120”. Thus, each set of six rows will have four tire paths and 44 percent of the ground will be trafficked. By increasing the tractor tire width to match the combine tire width (as in the second scenario), the number of paths and area trafficked are cut in half.

Permanent high-residue cropping systems, otherwise known as conservation tillage systems, generally work well with controlled traffic systems because previous crop rows are not tilled and thus traffic rows remain visible. Controlled traffic can be an integral part of ridge-till systems and no-till systems with permanent beds.

Mulch tillage systems (systems with tillage across the entire field) require auto-steer technology (Sandusky, 2003) using guidance from a Global Positioning System (GPS) to locate traffic lanes year after year. Auto-steer technology keeps all field operations in the same traffic lanes. Some systems are even capable of 1-inch accuracy. This technology allows controlled traffic with standard agricultural equipment and full-width tillage. Automatic steering and controlled traffic reduce compaction beneath the row, thereby increasing infiltration and reducing the hazard of erosion and the need for subsoiling. Other advantages of auto-steer technology and controlled traffic include the potential to (Sandusky, 2003):

- Extend work time into night hours.
- Plant in spring over fall subsoiling or fall fertilization strips.
- Protect drip-irrigation lines.
- Get improved yields where harvest machines must be kept on rows.

Other strategies to prevent compaction

Other strategies that minimize compaction are (Schuler et al., 2000; Reeves, 1994):

- Avoid working wet soils. Improve drainage if necessary.
- Decrease tire pressure to increase surface area, thus reducing soil compaction.
- Use radial tires in lieu of bias-ply tires to create a larger footprint and more surface area.
- Use duals or triples to replace singles. However, this measure increases the area affected by compaction.
- Maximize the number of axles under grain cars or slurry wagons to decrease the axle load per tire.
- Minimize the use of tractor-trailers or other vehicles with high inflation pressure and small footprints in agricultural fields.

Table 2.—Examples of traffic patterns for controlled traffic systems (Reeder and Smith, 2000).

Number of rows	Tractor (in)	Combine (in)	Number of paths	% Trafficked
		30” row spacing		
6	60	120	4	44
6	120	120	2	22
8	120	120	2	17
8	60 & 120	120 & 180	6	50
12	60 & 120	120 (6-row)	4	22
16	60 & 120	120 & 180 (8-row)	8	33
24	60 & 120	120& 180 (12-row)	12	33
		36” row spacing		
6	72	144	4	37
8	72	144	4	28
12	72	144	4	18

- Frequently empty combines and grain carts to minimize field traffic while also minimizing high axle loads that can permanently compact the subsoil.
- Select a tractor with four-wheel drive, front-wheel drive, or a rubber track system, which spreads the load over a larger surface area. However, the extra traction makes it possible to drive on wetter soils, giving the operator the potential to create significant deep compaction.
- Adjust ballast weights for each field operation.
- Reduce the number of trips by using high-residue management systems (conservation tillage).
- Increase the content of organic matter by reducing tillage and using high biomass crop rotations with cover crops. The organic matter improves aggregate stability, which reduces soil compaction.
- Avoid tillage, such as moldboard plowing and disking, which breaks down aggregates and destroys structure.
- Use cover crops and crop residue to conserve moisture. Wetter soils have lower soil strength and thus are less restrictive to root growth.

Alleviating Soil Compaction

Shallow soil compaction caused by natural processes or field operations can usually be alleviated with chisel plowing at shallow depths. However, repeated trafficking by heavy vehicle loads causes deep compaction, which requires more drastic alleviation measures, such as subsoiling. In some regions, combinations of traffic, tillage pans, a low content of organic matter, and natural conditions or processes can lead to deep compacted zones. Subsoiling is recommended if yields are limited by compaction. Subsoiling usually refers to tillage at a depth of at least 35 cm (14 in). Inserting any narrow tool to a depth of less than 35 cm is considered chisel plowing (Raper, 2003).

Although subsoiling or chiseling can alleviate compaction immediately, research shows that a second pass by a single vehicle may nullify the benefits of subsoiling or chiseling (Raper, 2003; Schuler et al., 2000). Before subsoiling is performed, it is important to prevent the recurrence of compaction and prolong the benefits of subsoiling through a controlled traffic system, conservation tillage, crop rotations, cover crops, and in-row tilling (subsoiling or chiseling under the row). Strip tillage is one method of preserving the benefits of subsoiling. It is essentially in-row subsoiling with a no-till planter equipped with row cleaners. The operation consists of pulling a shank directly beneath each row and planting directly behind the in-row subsoiler, thus preventing any traffic compaction. Alternatively, subsoiling and planting can be performed as separate operations.

Subsoiler shank design is an important part of a tillage system. In the 1950s, subsoiler shanks tended to be straight and projected slightly forward. Parabolic shanks soon became popular because they required less draft force. However, when curved shanks are used at deeper or shallower depths than designed, draft forces can increase. Curved subsoiler shanks tend to disrupt the soil in a symmetric manner, leaving soil on either side of the subsoiler shank as it moves forward and causing surface soil disturbance and burial of crop residue (Raper, 2003). The bentleg subsoiler was developed to disrupt the soil in an asymmetric manner, shattering the pan but leaving the surface almost undisturbed. This shank is bent to one side at 45° with the leading edge turned by 25°. For this reason, many farmers interested in high-residue management use this form of tillage as a method of alleviating compaction while maintaining high amounts of residue on the soil surface (Raper, 2003).

Subsoiling and chiseling cost time and energy. They should be performed only when needed. The benefits of chiseling and subsoiling are generally not long lasting. To avoid wasting an expensive trip across the field, consider the following points (Schuler et al., 2000; Raper, 2003):

- Determine the depth and extent of the compaction problem across the field by taking penetrometer readings correctly. Taking readings in dry soil may give the false impression of a compaction problem.
- Use the appropriate equipment (select a proper subsoiler shank for the desired amount of soil mixing and residue cover) and subsoil when the soil is dry enough for the equipment to properly fracture the pan but moist enough for the equipment to pull the shank. Subsoiling when the soil is too dry will disturb more surface soil, and subsoiling when it is too wet will not fracture the compacted layer, thus wasting the trip. A good compromise is near the permanent wilting point.
- Subsoil or chisel to the depth of the compacted layer. Examine the soil profile to determine the depth of the compacted layer and plan to subsoil or chisel 1 inch below the zone. If several observations are made with a penetrometer or by measurement of bulk density, site-specific tillage can focus on certain portions of the field, e.g., eroded areas or a specific soil type.
- Select the proper spacing, such as in-row versus complete field disruption. Complete field disruption spacing should be 60 to 80 percent greater than the operation depth.
- Timing is important. Subsoiling after fall harvest often works well because more time is available and the compaction caused by harvesting operations can be eliminated. Fall subsoiling also allows better infiltration in winter, when rainfall is more plentiful in many climatic regions. In some regions, such as the Southeast Coastal Plain, however, spring subsoiling is preferable because compacted layers will normally reconsolidate over the winter. Many strip-till planters subsoil and plant in one operation.
- Most importantly, have a controlled traffic plan in place to prevent the recurrence of compaction after subsoiling. Again, in some regions, such as the Southeast Coastal Plain, compaction will naturally recur and may require annual subsoiling.
- In permanent stands, such as grazing lands, orchards, and forests, subsoiling may be needed during planting. As a last resort, pastures can be renovated with bentleg subsoilers. Damage to actively growing roots can be reduced by subsoiling during winter or dormancy. Care should also be taken in forests to subsoil only where needed and to the depth of compaction. Rotational grazing and proper planning of watering facilities and permanent lanes may reduce compaction on grazing lands.

Summary

Soil compaction reduces the ability of the soil to function (to regulate infiltration, provide a deep rooting environment, store available water, etc.) and thus reduces crop yields. To locate the depth and position of the compacted layer in a field, such tools as a penetrometer must be used properly. In particular, penetrability should be measured when soil moisture is at field capacity. Preventing compaction avoids the cost of yield losses and the cost of alleviating compaction. Avoid performing field operations when the soil is wet. High-residue management systems, crop rotations, cover crops, and other conservation practices that increase the content of organic matter lessen the effects of compaction. Controlled traffic systems using row spacing or permanent rows lessen compaction in crop-growing areas. Automatic steering helps to reduce traffic, and site-specific tillage helps to economize subsoiling and chiseling. Subsoiling can alleviate soil compaction in some situations. Important issues to be considered before subsoiling include selection of shanks on the basis of the desired amount of soil disruption and surface residue, timing of tillage, depth of tillage, soil moisture, how to keep soil compaction from recurring, and how subsoiling fits within the entire management system.

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