Soil Compaction Solutions: Prevention, Management, and Recovery

Jodi DeJong-Hughes (UMN Extension) and Aaron Daigh (UNL)

Soil compaction in agricultural fields continues to be a significant challenge in modern production agriculture. Several factors contribute to this issue, including the increased size and axle load of equipment, mechanization advancements such as four-wheel drive and tracks that allow operation on wet soils, the expansion of farm sizes with limited time for fieldwork, and the shift from diverse crop rotations—including deep-rooted forages—to continuous grain cropping. Compaction is particularly concerning because its negative impacts are often not immediately visible, making it difficult to recognize until crop performance declines.

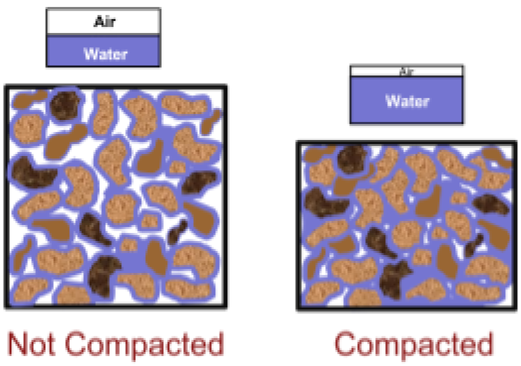

Figure 1. Illustration of pore space and mineral arrangement in non-compacted soil versus compacted soil.

Compaction occurs when soil particles are pressed together, reducing pore space and increasing bulk density (Figure 1). This limits water infiltration, drainage, and aeration, making it harder for plant roots to access water and nutrients. Aggregates are pushed closer together as force is applied to the soil surface, and if the pressure is high enough, they break apart, further restricting pore space. Large pores, essential for water movement and root penetration, are lost, while an excess of smaller pores holds moisture tightly, reducing drainage. Wet soils are especially vulnerable since moisture acts as a lubricant, allowing aggregates to collapse more easily under pressure.

Figure 2: Corn plants grow through a heavily surface crusted soil.

Soil compaction takes different forms, including surface crusting, tillage pans, and wheel-traffic compaction:

- **Surface crusting** forms when raindrops dislodge soil particles, creating a tightly packed layer that reduces infiltration and increases runoff and erosion (Figure 2). This can trap seedlings, preventing emergence and leading to poor stand establishment.
- **Wheel-traffic compaction** is the most significant cause of soil compaction in the Upper Midwest (Figure 3). As equipment sizes have grown, modern tractors now weigh nearly 20 tons, with

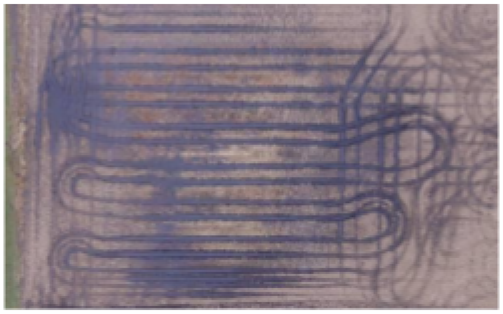

Figure 3. Aerial view of wheel traffic created during harvest.

combines and grain carts reaching up to 60 tons per axle. High axle loads, especially when operating on wet soils, can drive compaction three to four feet deep, beyond the reach of common tillage implements. Deep compaction limits root exploration and makes crops more vulnerable to drought stress.

- **Tillage pans** develop from repeated tillage at the same depth, particularly with moldboard plowing and disking (Figure 4). These compacted layers, typically 0.5 to 2 inches thick, can restrict root penetration and water movement. They can be mitigated by varying tillage depths or using specialized tillage techniques. No-till systems, while sometimes associated with higher bulk density, often improve soil aggregation, aiding water and oxygen infiltration.

Figure 4: Tillage layer, also known as a plow pan, is created from multiple years of tilling at the same depth.

Causes and Effects of Soil Compaction

Soil compaction is primarily caused by wheel traffic from agricultural equipment, with its severity depending on axle load, tire pressure, and soil moisture at the time of field operations. As modern equipment becomes larger and heavier, the risk of deeper and more severe compaction increases. High axle loads can compact soil three to four feet deep, beyond the reach of normal tillage, making it difficult to correct.

Agricultural Equipment and Soil Compaction

Any field traffic has the potential to cause compaction, and while some level is unavoidable, farmers can take steps to limit its extent and severity. Key factors under a producer's control include:

- **Axle Load** – Determines how deep **compaction** occurs. Heavy equipment, such as combines and grain carts, can exceed 60 tons per axle when fully loaded, compacting the subsoil, especially when operated on wet fields.
- **Tire Inflation Pressure** – Higher tire **pressure** increases compaction severity and depth. Radial tires, which operate at lower pressures than bias-ply tires, can reduce compaction when properly inflated. Regularly checking tire pressure before fieldwork helps minimize damage.
- **Tracks vs. Tires** – While tracks distribute weight over a larger area, they still exert pressure through multiple rollers, which can add to

compaction effects (Figure 5). Studies show that properly inflated radial tires can sometimes result in less compaction than tracks.

Figure 5: Tractor tracks.

Effects of Soil Compaction on Crop Growth and Yield

Soil compaction has long-term negative effects on plant emergence and growth, reducing root penetration, nutrient uptake, and water availability. The main consequences include:

- **Restricted Root Growth** – As soil density increases, roots struggle to penetrate compacted layers, reducing the plant's ability to access water and nutrients. This is especially problematic during drought conditions.
- **Poor Water Infiltration and Drainage** – Compacted soils retain water longer, leading to waterlogging and oxygen deprivation, which stresses plants and increases susceptibility to disease.
- **Reduced Crop Yields** – Studies have **shown** that compaction can cause yield losses of 10–50 percent, depending on soil type, severity, and crop species. Corn and soybeans, for example, often experience reduced root mass and lower grain production in compacted soils.
- **Increased Runoff and Erosion** – Reduced infiltration leads to higher surface runoff, which not only increases soil erosion but also results in nutrient loss, further degrading soil fertility over time.

Diagnosing Soil Compaction

A penetrometer or tile probe is an effective tool for identifying compacted zones. By comparing areas of stunted, nutrient-deficient crops to healthy growth zones, farmers can detect potential compaction issues. Testing should be conducted one or two days after a rainfall when the soil is uniformly moist, ensuring accurate penetration resistance readings. A penetrometer reading above 300 psi (pounds per square inch) suggests compaction, though it does not necessarily indicate restricted root growth. It is important to document the depth at which resistance increases significantly.

Beyond penetrometer readings, plant symptoms can provide clear indicators of compaction. Uneven emergence is often one of the first visible signs. In compacted soils, seedlings struggle to break through the surface, leading to patchy stands with

Figure 6. Aerial view of wheel tracks from multiple passes across a field.

delayed or stunted growth. As the season progresses, plant height variability may become more pronounced, particularly in crops like corn, where uniformity is critical for maximizing yields (Figure 6). Plants growing in compacted areas may exhibit reduced vigor, slower canopy closure, and increased susceptibility to drought stress due to limited root access to moisture.

A shovel can be used to excavate a hole deeper than the compacted zone identified with the penetrometer. Examining root distribution provides further evidence of compaction. Key questions to assess include:

- Are the roots concentrated in surface layers or extending throughout the soil profile?
- Do the roots appear flattened or lack fine lateral roots?
- Are roots growing laterally in an "L" shape upon hitting a dense layer?

If any of these signs are observed, compaction is likely present, and remediation strategies should be considered. Identifying the depth and severity of compaction enables the selection of appropriate management techniques, whether through natural alleviation, cover crops, or mechanical remediation.

Aerial imagery from drones can highlight problem areas by revealing differences in plant height, canopy density, and overall crop uniformity. Comparing these visual signs with in-field assessments can help pinpoint compaction issues and inform management decisions to mitigate their effects.

Managing Soil Compaction

The best strategy for managing soil compaction is prevention. Once compaction occurs, it can be difficult and costly to correct. Several management practices can help minimize the risk of soil compaction, particularly when working with heavy machinery and variable soil moisture conditions.

Avoid Field Operations on Wet Soils

Wet soils are highly susceptible to compaction because water reduces the strength of soil aggregates, making them more prone to collapse under pressure. A simple field test can help determine if the soil is too wet for fieldwork—if a handful of soil ribbons easily between the fingers, it is too wet (Figure 7). Waiting even a day or two can significantly improve soil strength and reduce compaction risk.

Figure 7. When soil can be shaped into a ribbon by squeezing it between your thumb and forefinger, it suggests that it is too moist for planting.

Limit Load Weight and Tire Pressure

Heavier loads increase axle weight, driving compaction deeper into the soil. To keep compaction within the top 10-12 inches—where tillage can help alleviate the problem—axle loads should not exceed 10 tons per axle. While reducing equipment size may not always be feasible, limiting the load carried—such as partially filling grain carts or manure spreaders—can help reduce the depth and severity of compaction.

Tire selection and inflation pressure also play a key role; lower inflation pressures increase the tire's footprint, distributing weight over a larger area and reducing soil pressure. To minimize compaction, tire pressure should be around 10 psi. Radial tires, which operate at lower inflation pressures than bias-ply tires, are recommended for reducing soil impact.

Controlled Traffic and Strategic Field Operations

Repeated passes over a field can result in up to 80 percent of the surface being tracked during a growing season. Since most compaction occurs on the first pass, concentrating traffic in designated lanes, known as controlled traffic farming (CTF), helps limit compaction to specific zones while preserving the rest of the field. CTF works best in systems like no-till, strip-till, or ridge-till, and GPS-guided auto-steer technology can help align operations. Avoiding unnecessary field passes and minimizing activities like "unloading on the go" can also help reduce compaction. When possible, grain carts should be parked in designated areas, such as headlands, rather than driven across the field.

Improving Soil Health to Resist Compaction

Soil with good structure and high organic matter content is more resistant to compaction. Practices that improve soil aggregation—such as minimizing tillage, planting cover crops, and incorporating organic matter—can strengthen soil structure and enhance its ability to recover from compaction. Crop residues should be evenly distributed across the field rather than removed, and manure can be added to build organic matter. Cover crops offer additional benefits, such as increasing soil strength, reducing erosion, and enhancing nutrient cycling.

Deep Tillage: A Temporary Fix

Some farmers use deep tillage, or subsoiling, to break up compacted layers. However, research across the Corn Belt has shown inconsistent benefits from this practice. If the soil is too wet, subsoiling may not effectively fracture compacted layers and can actually worsen the problem. Additionally, once loosened, the soil is more vulnerable to recompaction from subsequent field operations. If subsoiling is necessary, it should be done only when the soil is dry enough to fracture properly and only 1–2 inches below the compacted layer. Leaving untreated check strips can help assess whether subsoiling has improved soil conditions and crop yield.
Straight-shanked subsoilers are preferred over parabolic models (Figure 8), which disrupt the soil more intensively and can loosen soil throughout the entire tillage depth, increasing the risk of recompaction.

Figures 8a and 8b. Photo of a) straight-legged shank and a b) parabolic shank

Summary

By adopting these management practices, farmers can effectively reduce the risk of compaction, enhance soil health, and ensure long-term productivity. Soil compaction remains a challenge, but with a clear understanding of its causes and consequences, producers can take proactive steps to minimize its impact and preserve soil vitality. By staying informed and making thoughtful decisions, farmers can foster a resilient, thriving soil environment that supports sustainable farming for years to come. The effort invested today will lead to healthier soil, more robust crops, and a brighter future for agriculture.