# Physical Indicators of Soil Health in Row-Crop Agriculture

**Grant Bennett**
Program Associate - Crop Soil & Environmental Sciences

**Shelby Lebeau**
Environmental Science Lab Coordinator/Instructor

**Dr. Mike Daniels**
Distinguished Professor, Extension Soil and Water Conservation

**Dr. Kristofor R. Brye**
Professor – Applied Soil Physics and Pedology

**Bronc Finch**
Assistant Professor - Soil Fertility

**James M. Burke**
Program Associate – Crop Soil & Environmental Sciences

**Eric Simon**
Program Associate - Crop, Soil & Environmental Science



## Introduction

Sustainable agricultural practices emphasizing soil health are receiving more attention from producers amidst rising input costs and thin profit margins. The concept of soil health views soil as a living ecosystem composed of air, water, minerals, organic matter and organisms, all of which contribute to the health of soil and subsequent plant health.

Historically, low fertilizer and pesticide costs have led to soil being viewed as a mere medium for plant growth that must be supplemented with large quantities of fertilizer and heavy irrigation to produce profitable yields. After decades of intense tillage, fertilization and irrigation, however, crops and subsequent yields have become increasingly reliant on external inputs. Over time, these practices have had a detrimental effect on soil structure and the soil's ability to retain moisture, nutrients and organic matter, and to harbor beneficial organisms that cycle plant-available nutrients.

With rising input costs now leading to lower returns on investments, producers are more willing to adopt sustainable management practices aimed at improving soil health and increasing profitability. Many known practices can improve the physical, chemical and biological properties of soil that contribute to maintaining or improving soil health. This fact sheet will focus on physical indicators of soil health.

## Bulk Density

Bulk density is a physical property indicator of soil health. Bulk density is the ratio of dry soil mass to the volume that soil mass occupies. A typical mean

| Soil Texture | Bulk Density (g cm$^{-3}$) |
|---|---|
| Sand | 1.65 |
| Loamy Sand | 1.60 |
| Sandy Loam | 1.55 |
| Loam | 1.50 |
| Sandy Clay Loam | 1.50 |
| Silty Clay Loam | 1.50 |
| Silty Loam | 1.50 |
| Clay Loam | 1.45 |
| Silty Clay | 1.45 |
| Sandy Clay | 1.40 |
| Clay | 1.35 |

**Table 1: Average bulk density values for soil texture classes (Zeri et al., 2018).**

soil bulk density value is 1.50 g/cm$^3$ but varies somewhat by soil texture (Table 1).

Bulk density is related to the fraction of pore space in soil or total porosity. Soil naturally has pores, or void spaces, throughout the profile that store and/or transport air and water. However, as soil is tilled and compacted, soil bulk density can increase, meaning a greater dry soil mass per unit volume, effectively causing large pores (i.e., macropores) to become smaller pores (i.e., micropores).

Compaction not only limits the flow of air and water into and out of the soil profile, it also limits the ability of plant roots to penetrate deeper into the soil to reach moisture and nutrients. As compaction worsens, soil root growth can decrease and, in some cases, can only penetrate a few inches into the ground before having to grow horizontally in search of water and nutrients (Figure 1).

Compaction can occur at any soil depth and is often the result of non-sustainable management practices.

Early season tillage can remedy the effects of compaction, although this is only a temporary solution. Over time, the soil will often re-compact without alteration of management practices or the addition of organic matter.

Compaction from periodic wheel traffic contributed to greater bulk density in a silt-loam

**Figure 1: Corn roots in compacted (left) and non-compacted (right) in heavy clay soil (Drury et al., 2004).**

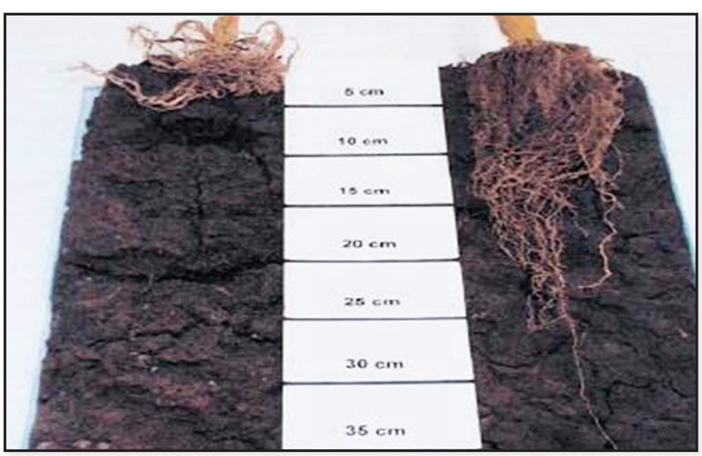


**Figure 2: Field with cover crop (left) and no cover crop (right) (Weise, 2022).**

soil under cotton production in eastern Arkansas (Lebeau et al., 2024). Bulk density in the wheel track row was 1.1 times greater than in the bed and no-wheel track row (Lebeau et al., 2024). The bed and no-wheel track row have greater total porosity due to less compaction, allowing those areas of the field to hold 0.33 cm more water in the top 10 cm of the soil compared to the wheel track row (Lebeau et al., 2024).

Management practices such as limiting the intensity and frequency of tillage and increasing soil organic matter are effective methods of reducing soil bulk density. Growers can increase the amount of plant or crop residues retained on site and/or with the use of cover crops (Figure 2).

Crop rotation and using crops with different root types and depths are also beneficial. It is important to include direct bulk density quantification in annual soil sampling procedures.

## Water-holding Capacity

Closely related to soil bulk density and total porosity is soil water-holding capacity. Water-holding capacity is the amount of plant-available water that can be stored in soil. Water-holding capacity is the difference between the soil water contents at field moisture capacity and permanent wilting point. Field moisture capacity is the amount of water in the soil after the soil has been saturated and drained under the force of gravity. Permanent wilting point is the amount of water in the soil or soil water content when the soil becomes so dry that plants wilt and cannot recover, dying even when supplied with adequate water afterward.

Water-holding capacity is an important physical property of soil for several reasons. Not only do plants need water to survive, but many other forms of biological activity depend on adequate soil moisture as well.

When soil can effectively hold larger amounts of water, it extends the time crops are able to survive between rainfall and irrigation events. By extending that time frame, producers can potentially reduce costly irrigation.

In a recent study surveying the effects of cover crops in the Lower Mississippi River region of eastern Arkansas, Lebeau et al. (2023) reported that groundwater-irrigated silt-loam soils under various crop-cover crop species, along with varied tillage management, have greater water storage when dry compared to similar silt-loam soils and tillage management under crop (soybean or cotton)-no-cover crop treatments.

Cover crop duration across study sites ranged from less than one year to as long as 19 years, with most cover crop sites under less than three years of crop-cover crop management (Lebeau et al., 2023).

Knowing a soil's water-holding capacity can also help producers plan for irrigation by taking some of the subjectivity out of whether a field needs water when the surface is dry. Soils with low water-holding capacity are often indicative of a large bulk density, perhaps even compaction, and poor aggregate stability. Increasing soil organic matter is an effective way to improve a soil's water-holding capacity. Using more sustainable management practices that leave crop residue on the soil surface or with light incorporation, keeping living roots in the soil year-round and reducing the amount of soil disturbance can improve soil water-holding capacity and soil health.

## Aggregate Stability

Aggregate stability refers to the soil's ability to resist being broken apart when disruptive forces like wind, rain or tillage occur. All mineral soils consist of a combination of sand, silt, and clay particles, which are defined by differences in particle diameters. Over time, together with soil organic matter, sand, silt, and clay particles bind into groups called peds or aggregates. Soil aggregates aid in the movement of air and water into and out of the soil profile and are critical for erosion protection and root growth.

Aggregate stability is indicative of proper nutrient cycling, organic matter content, and biological activity. As organic matter is built up in soil, it promotes the coalescence of micro-aggregates into macro-aggregates (Fanning, 2024), which may be susceptible to breakdown by outside forces such as wind, rain and tillage. During rainfall, soils with poor aggregate stability may develop clogged pores with loose soil particles and/or sediments that detached from the force of raindrops impacting an unprotected, bare soil surface. Clogged surface pores may prevent or limit infiltration, thus potentially limiting soil moisture for roots. In this scenario, not only will a field not benefit from rainwater, but the resulting surface runoff may remove soil particles and sediment (i.e., erosion) and soluble and/or suspended, sediment-bound nutrients.

An effective way to improve aggregate stability is to avoid management practices that disturb the soil too much, such as excessive tillage, and/or leave the soil bare for extended periods of time. Soils without adequate surface protection are also susceptible to wind erosion, where loose soil particles may be carried away by the wind, some of which may impact and detach more particles that could also be subject to off-site transport and/or may damage plants.

Sustainable management practices that use cover crops and areas of reduced wheel traffic contributed to improved soil aggregation on a silt-loam soil under cotton production in the southeastern portion of the Lower Mississippi River Valley. In the split-field study of wheel-track effects on soil properties under cotton production conducted by Lebeau et al. (2024), the entire field had been under furrow-irrigated cotton production on raised beds for at least 15 years prior to the study, with one area of the field utilizing no-till for at least four years and planted to cotton-cereal rye cover crop for at least six years. Immediately adjacent to the cover crop area, within the same field, conventional-till was used for at least six years and cotton-no-cover crop planted for at least four years prior to the study (Lebeau et al., 2024). The study reported 2.3 times and 1.6 times greater water-stable aggregates in cereal rye cover crop-no-wheel track and -wheel track combinations, respectively, compared to no-cover crop-no-wheel track and -wheel track combinations (Lebeau et al., 2024).

Additionally, the cover crop-wheel track combination had 1.8 times greater total water-stable aggregates compared to in the no-cover crop-wheel track combination (Lebeau et al., 2024).

Adopting sustainable practices that add organic matter and keep the soil at least covered with plant material year-round with minimal disturbance from tillage, or that keep live roots present with a cover crop, may improve aggregate stability. Implementation of sustainable practices can strengthen soil aggregates, shielding the soil surface from potential water and wind erosion and protecting biological processes that aid in plant growth and development.

## Infiltration

The soil's ability to allow water to infiltrate greatly influences plant health of upland crops, such as corn, cotton, wheat, soybean and soil organisms, as well as reducing potential erosion. Infiltration is the process of water entering the soil into pores and is typically quantified as a rate, or the amount of water that infiltrated per unit time (i.e., cm or inches per minute or hour), or the cumulative amount of water infiltrated (i.e., mm, cm, or inches; Table 2).

| Soil Texture | Soil Infiltration Rate (Inches per hour) |
|---|---|
| Clay | 0.04 to 0.2 |
| Clay Loam | 0.2 to 0.4 |
| Loam | 0.4 to 0.8 |
| Sandy Loam | 0.8 to 1.2 |
| Sand | Less than 1.2 |

**Table 2: Soil infiltration rate among select soil textural classes (Buchen, 2022).**

Water travels into and through the soil profile through soil pores. Soils with poor structure can limit or even prevent infiltration. When it cannot penetrate the soil, water can run off a field, transporting loose soil particles as soil erosions. A lack of  vegetative cover can exacerbate this.

Depending on a field's topography, water that cannot infiltrate the soil may pool on the surface, causing poorly aerated conditions and, potentially, negatively impacting plant health.

However, soils with high infiltration rates can also cause issues. When water flows too freely and rapidly passes through the root zone, the drainage water can potentially transport soluble nutrients beyond the root zone and into groundwater. This process is called leaching. Leaching can be worse in sandy soils or soils with low soil organic matter concentrations compared to finer-textured soils or soils with larger soil organic matter concentrations. Nitrogen compounds, specifically nitrate (NO3-), are also prone to leaching in many soils. The implementation of sustainable practices can improve infiltration to retain moisture and nutrients in the root zone. Combined with regular soil testing, producers can monitor nutrient levels to prevent over-application and loss of nutrients.

## Summary

Taking steps to improve the physical properties of soil may, in turn, facilitate improvements in soil biological and chemical functions. Many negative impacts on soil health can be remedied by implementing sustainable management practices. One key to improvement is to ensure that soil is not left bare for long periods of time. Using crop residue, planting cover crops, building organic matter, rotating crops and reducing tillage will have positive effects on many soil physical properties and functions.

Regular soil sampling helps guide management practices and is an effective way to monitor soil health improvement over time with changes in management. For more information on when and how to collect soil samples, contact the local county extension office.

## References


Buchen, L. (2022). *It rained yesterday: why aren't my sensors responding?*. Trellis. Retrieved from https://mytrellis.com/blog/infiltrationrate.

Drury, C.F., Tan, C.S., Reynolds, W.D., Fox, C.A., McLaughlin, N.B., Bittman, S. (2004). *Tillage practices for corn production. Advanced silage corn management* 2004. https://farmwest.com/resources/books/advanced-silage-corn-management-2004/chapter-4/.

Fanning, C. (2024). *Cover-crop effects on near-surface soil properties over time in the Lower Mississippi River Valley*. Graduate Theses and Dissertations Retrieved from https://scholarworks.uark.edu/etd/5476.

Lebeau, S., Brye, K.R., Daniels, M.B., & Wood, L.S. (2023). *Cover crop effects on infiltration, aggregate stability, and water retention in the Lower Mississippi River Valley*. Agrosystems, Geosciences, & Environment, 6(1), e20341. https://doi.org/10.1002/agg2.20341.

Lebeau, S., Brye, K.R., Daniels, M.B., & Wood, L.S. (2024). *Cover crop and wheel-track effects on soil properties under cotton production in eastern Arkansas*. Agrosystems, Geosciences, & Environment, 7(3), e20549. https://doi.org/10.1002/agg2.20549.

Weise, E. (2023). *Ancient farming practice makes a comeback as climate change puts pressure on crops*. USA Today. https://www.usatoday.com/story/news/2022/12/28/cover-crops-can-help-fight-climate-change-effects-us-farms/10798179002/?gnt-cfr=1&gca-cat=p.

Zeri, M., Alvala, R.C.S., Carneiro, R., Cunha-Zeri, G., Costa, J.M., Spatafora, L.R., Urbano, D., Vall-Llossera, M., Marengo, J. (2018). *Tools for communicating agricultural drought over the Brazilian semiarid using the soil moisture index*. MDPI. https://www.researchgate.net/publication/328238567_Tools_for_Communicating_Agricultural_Drought_over_the_Brazilian_Semiarid_Using_the_Soil_Moisture_Index.

Printed by University of Arkansas Cooperative Extension Service Printing Services.

**GRANT BENNETT** is a program associate in the department of Crop, Soil & Environmental Sciences. **SHELBY LEBEAU** is an environmental science lab coordinator/instructor. **DR. MIKE DANIELS** is a distinguished professor with Extension Soil and Water Conservation. **DR. KRISTOFOR R. BRYE** is a professor in applied soil physics and pedology. All are located at the University of Arkansas in Fayettville. **BRONC FINCH** is an assistant professor of soil fertility. **JAMES BURKE** is a program associate - Crop, Soil & Environmental Sciences. **ERIC SIMON** is a program associate - Crop, Soil & Environmental Sciences. All are with the University of Arkansas System Division of Agriculture Cooperative Extension, Little Rock. FSA2215-PD-12-2024