Critical Soil Health Parameters to Improve Crop Production

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Summary

Soil health is a critical determinant of plant performance. This manuscript describes how the physical, chemical, and biological components within the soil interact to create good soil health. Soil structure is important to provide support for plants, nutrient and water cycling, decreased compaction, and more efficient carbon storage. Measurements of soil properties are presented that can be done in the field on any soil.

Introduction

Soil health is an important topic these days. But what is soil health and why is it important? More importantly, how can we reliably measure soil health?

Soil health can be thought of as the ability of the soil to function in the way it is supposed to function—to do what it is supposed to do. The functioning of the soil for crop production can be defined as the productive capacity, or, from a crop production standpoint, the bu/acre or $/acre the soil is able to produce. The primary functions of soils are to serve as support for plants, sequester carbon, and to cycle nutrients and water which are critical for crop production. We often think of these functions as a one-way street, but they are actually cycling within the soil. They are described as "cycles" because the soil captures nutrients and water, stores it, and then makes it available to plants when they need it. The plant material is then broken down by soil microbes (bacteria and fungi) after harvest, and the nutrients are recaptured within the soil and stored for later use. The health of the soil determines the ability of the soil to support and continue these cycles.

Soil health is difficult to measure directly, so it is determined as the measured physical, chemical, and biological characteristics (Figure 1). The "inherent" properties of soils are based on the materials that were deposited to form the soil. How we manage the soil greatly influences the other properties of the soil, and determines the soil health.

The physical characteristics of the soil are dependent on the amount of sand, silt, or clay that the soil is composed of. The chemical components of soil include pH, nutrients, and water. The biological components include everything from large animals (e.g. armadillos, moles, voles, etc.), earthworms, arthropods (insects, spiders, etc.), bacteria, fungi, nematodes, and plants. The physical, chemical, and biological factors work together to

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create the soil ecosystem. All of the individual components are intimately integrated to build the functionality of the soil ecosystem. How we manage the soil determines the components that make up the soil and how well they function. While moderation of the physical soil characteristics can take centuries to modify, or be as rapid as a flood bringing in sand, the chemical and biological components respond rapidly to management practices. Optimal soil conditions decrease soil compaction, reduce limitations to root growth, improve water infiltration and storage capacity, increase aeration, and improve nutrient uptake, storage, and delivery to plants.

Soil aggregates are soil particles that cohere or bind to each other to form a defined soil structure. The formation and characteristics of soil aggregates are dependent on the physical, chemical, and biological components of the soil. The soil aggregates are also a key indicator of soil health. A soil that has stable aggregates indicates a better soil structure, while soil aggregates that quickly disperse indicate poor soil structure. Because of their central role in soil health, this report includes a review of soil aggregates in soils from six representative management systems.

Experimental Procedures

Soil Health Buckets were obtained from the Kansas Soil Health Alliance (*https://kssoilhealth.org/*). Soil samples were collected from fallow fields and fields planted to wheat, under both tilled and no-till management. Soil was also collected from a long-term hay meadow field. All soils were Parsons silt loam. Soil sampling was performed using a sharp-shooter shovel. A 6-in. deep slice of soil from each location was collected and transferred to a gallon zip-lock plastic bag and brought to the lab for analysis and demonstration.

The soil structure was first determined based on the Visual Evaluator of Soil Structure (VESS; *https://www.farmingforabetterclimate.org/improving-farm-profitability/soils-fertilisers-and-manures/assess-your-soil-structure/*). The VESS provides a simple framework that uses a qualitative approach to evaluate the physical characteristics of soil structure, including the size, shape, orientation, and distribution of soil aggregates. The VESS evaluation can be used in a variety of settings, including agricultural fields, gardens, and other areas to provide an assessment of soil physical structure and indicate potential concerns.

To measure the health of soil aggregates, small soil aggregates were collected from the samples and put into coffee filters. Tap water was slowly dripped onto the soil samples from water bottles with small holes in the lids. This simulates rainfall and shows how quickly soil will be lost from the soil surface during a rain event.

Results and Discussion

Soil structure impacts how well roots will be able to grow into the soil, the aeration of the soil, and the water available to the plant. Examination of soil using the VESS rating indicates the soil structure and relative compaction. For both no-tilled soils, the soil aggregates readily crumbled into smaller fragments with no clods, giving the soil a rating of Sq1, indicating the soil was very friable (Figure 2A, C). Friable is a term to describe how easily the soil crumbles between the fingers. Friable, or mellow, soil is very good for plant establishment, as the plants have good aeration and readily-available water for growth. There is minimal compaction, so roots are able to grow easily. The tilled wheat soil broke apart more readily on the surface soil due to the wheat roots. The deeper soil was difficult to break apart and had large clods, rating this soil as firm or compact (Sq3; Figure 2B). The tilled fallow soil was very difficult to break apart, requiring two hands and some force to separate the soil at all depths (Figure 2D). Large clods were evident, demonstrating how compact this soil was (Sq4). The soils were all moist; when dry, the tilled fallow soil would have been very difficult to break apart. The soil from the hay meadow showed abundant roots and was fairly easy to break apart (Figure 2E). The soil was primarily held together by the dense roots (Sq2). The higher ratings (Sq3 and Sq4) indicate that the soil is compacted, and steps should be taken to improve how friable the soil is.

Carbohydrates (sugars) are the currency of life on earth. They are a key factor in all aspects of our food systems, field to table. Carbohydrates are formed by plants through the conversion of sunlight and CO_2 during photosynthesis into stable energy sources used by most life on earth (in one form or another). These sugars are exchanged by organisms in the soil as they “barter” for needed items. Plants make sugars and excrete them into the soil; fungi and bacteria take up these carbohydrates in exchange for nutrients needed by the plant. Fungi and bacteria also excrete carbohydrates into the soil. The abundance of carbohydrates in the soil is related to the functionality of the biological components of the soil. Glomalin is a sugar-protein formed in the soil and roots by arbuscular mycorrhizal fungi. Glomalin, together with fungal hyphae and plant roots, create soil aggregates that bind together the soil particles into a structure. These aggregates stabilize the soil, reducing erosion, protecting carbon, and enhancing water and nutrient cycling within the soil.

Soil structure is critical to support plants, provide water and nutrient cycling, and reduce the loss of soil particles through erosion. To estimate the soil aggregate stability, we used a small rainfall simulator. The tilled fallow lost significantly more soil than the no-till fallow (Figure 3). This greater loss of soil particles is because of poor soil structure in the tilled soil. While it was originally thought that tillage was needed to improve soil structure and create a good seed bed, research has shown that tilling actually destroys the soil structure by breaking up aggregates. Tillage also breaks up the fungal hyphae and plant roots. Additionally, the excessive aeration of the soil with tillage causes the organic matter to be broken down more rapidly, further releasing carbohydrates that stabilize the soil aggregates and carbon dioxide to the atmosphere (CO_2).

Conclusions

Agronomists have long thought that tillage is required to “open” the soil and provide a good seed bed for plant establishment. New research has demonstrated that, while originally tillage may have been needed to convert historical grasslands into soils suitable for crop production, continued tillage creates more problems than solutions. Tillage destroys the soil structure, collapsing the pores formed by fungal hyphae and plant roots. Tillage creates conditions of poor aeration, lower organic matter, and surface crusting. Reducing tillage builds the soil microbial community that is responsible for the soil and water cycling that is critical for crop production.

The Soil Health Buckets used in this study are available from the Kansas Soil Health Alliance. In addition to the visual assessment of soil health and the measurement of aggregate stability, additional tests on infiltration and water uptake by soils in the field and the slake test help landowners measure soil health in their fields.

Acknowledgments

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Table 1. Assessment of soil structure

Structure quality	Size and appearance of aggregates	Visible porosity and roots
Sq1 Friable	Aggregates readily crumble with fingers; aggregates are mostly less than 0.25 inches	Highly porous Roots are present throughout the soil
Sq2 Intact	Aggregates easy to break with one hand Mix of porous, rounded aggregates from 0.1 to 0.25 inches. No clods present	Most aggregates are porous Roots are present throughout the soil
Sq3 Firm	Most aggregates break with one hand Mix of porous aggregates from 0.1 to 0.4 inches. Some non-porous aggregates (clods) may be present	Macropores and cracks present Porosity and roots both within aggregates
Sq4 Compact	Requires considerable force to break aggregates with one hand Mostly large aggregates greater than 0.4 inches Blocky and non-porous aggregates Horizontal or platy structures may be seen	Few macropores and cracks All roots are clustered in macropores and around aggregates
Sq5 Very compact	Difficult to break up soil Most aggregates are more than 0.5 inch; very few less than 0.25 inches Angular and non-porous aggregates	Very low porosity Macropores may be present. May contain anaerobic zones (grey-blue color). Few roots if any, and roots are restricted to cracks

Based on the Visual Evaluator of Soil Structure (VESS): *https://www.farmingforabetterclimate.org/improving-farm-profitability/soils-fertilisers-and-manures/assess-your-soil-structure/*.

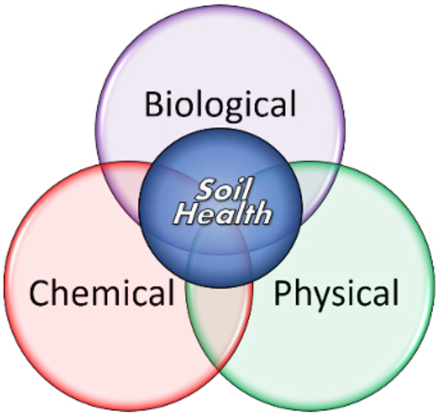

Figure 1. Soil interactions determining soil health.

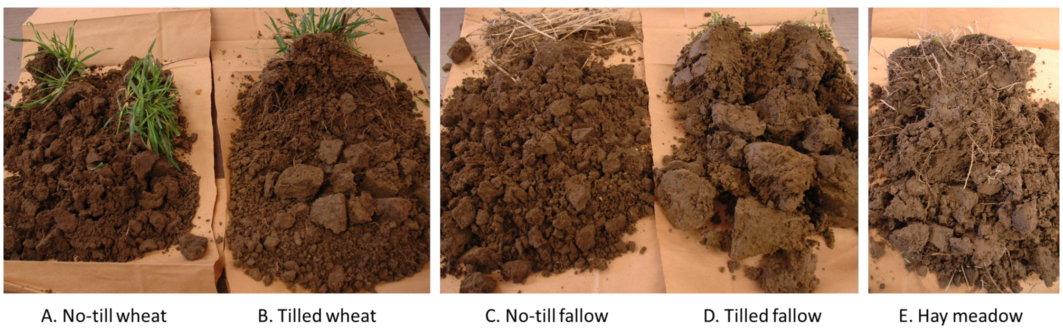

Figure 2. Comparison of six soils A) no-till wheat, B) tilled wheat, C) no-till fallow, D) tilled fallow, and E) hay meadow, rated using the Visual Evaluator of Soil Structure (VESS; *https://www.farmingforabetterclimate.org/improving-farm-profitability/soils-fertilisers-and-manures/assess-your-soil-structure/*).

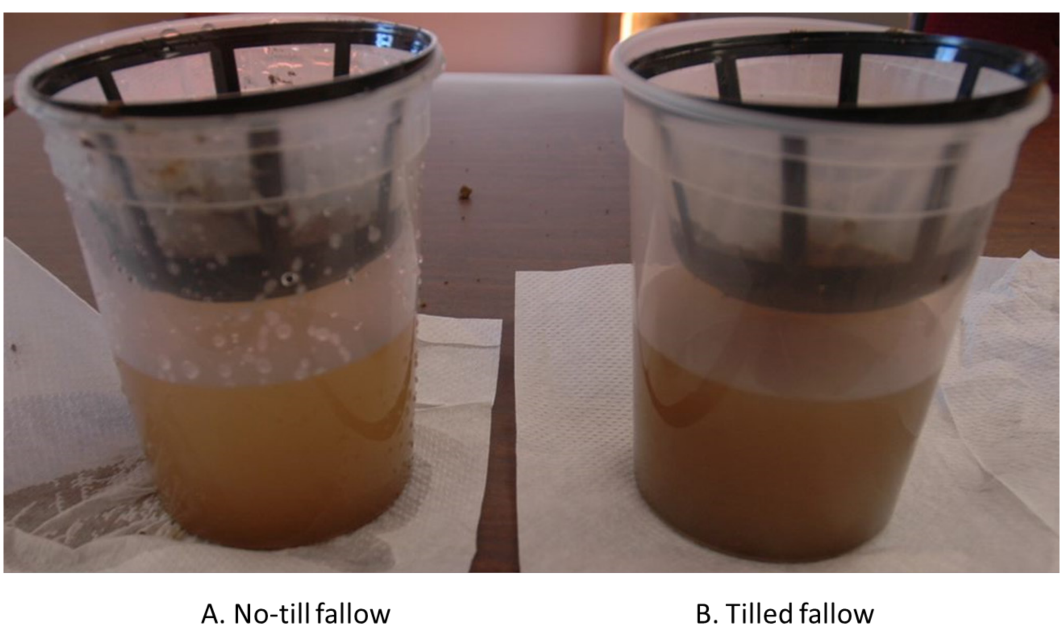

Figure 3. Rainfall simulation runoff comparison of A) no-till fallow and B) tilled fallow.