STRATEGIES FOR IMPROVING SOIL HEALTH IN THE SOUTHEASTERN UNITED STATES' COASTAL PLAIN

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Abstract

Rather than being viewed as an inert matrix to hold nutrients and water that promotes plant growth, the soil should be understood as a living and life-giving natural resource. Soil health, a term often used interchangeably with soil quality or soil fertility, is defined as the soil's capacity to sustain plant growth and fitness, ecological biodiversity, and environmental quality. A series of biological, chemical, and physical characteristics are measured to establish baseline levels, with subsequent measurements allowing land managers to monitor short- and long-term changes in soils health. These changes can be used to assess the ability of select soil management to positively impact soil health, whether it be for restoring lands damaged by industry, improving weathered soils impacted by over-use, erosion, and time, or enhancing a soil's ability to withstand extreme climatic events such as excessive heat and/or drought. This review will explain the factors commonly measured to determine a soil health, and present ongoing research examples of how conventional management practices are being used to positively impact soil health and improve soils in the Southeastern Coastal Plain of the United States.

Keywords

Soil Health, Southern Coastal Plain, Soil Organic Carbon, Caron Mineralization, Aggregate Stability

Introduction

The Natural Resources Conservation Service (NRCS) defines soil as:"(i) unconsolidated mineral or organic material on the immediate surface of the Earth that serves as a natural medium for the growth of land plants. (ii) The unconsolidated mineral or organic matter on the surface of the Earth that had been subjected to and shows effects of genetic and environmental factors of: climate (including water and temperature effects), and macro- and microorganisms, conditioned by relief, acting on partial material over a period of time. A product – soil differs from the material from which it is derived in many physical, chemical, biological, and morphological properties and characteristics. [1]. Even though the soil is considered a renewable resource, its formation occurs on time scales that are often incomprehensible to the general public. While soil formation is generally a continual process, the soil is also lost through the natural erosion processes by wind and rain. The losses that occur through these natural processes can be exacerbated by climate change which can result in increased rates of flooding and intense droughts, which make soils more susceptible to wind erosion. Additionally, direct loss of productive soils by human activities, such as construction and over-farming, occur as the human population grows and drives increased demands for housing and food. Taking them together, natural, climate change-

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influenced, and direct human-related losses of soil result in further stress being placed on the world's remaining soil resources. Considerable efforts to conserve soils have been adopted to ensure that these soils remain productive worldwide. These conservation efforts focus on reducing soil disturbance and improving soil health while concomitantly increasing productivity in a sustainable manner. While soil disturbance and productivity are easily measurable traits, soil health is a much more nebulous but widely researched area.

Importance of Soil Health

Soil health is often defined as the capacity of a soil to sustain plant growth and fitness, ecological biodiversity, and environmental quality [2]. Therefore, soil health is a measure of the current function and an estimate of long-term sustainability. Improvements in soil health are associated with improvements in soil water and nutrient retention, improvements in water and air quality and reduction in greenhouse gases, improvements in plant health and increases in crop yields, improvements in the biological diversity of macro- and micro-fauna, expansion and improvement of wildlife habitat, and reductions in soil erosion.

How is Soil Health Assessed

Several laboratory tests are often utilized to assess soil health. Two of the most comprehensive and most oft-adopted frameworks for assessing soil health are: i. the Soil Management Assessment Framework (SMAF; [3]); and ii. the Comprehensive Assessment of Soil Health (CASH; [4]). Rather than rely on a single laboratory analysis, these frameworks utilize a suite of laboratory tests to measure a series of physical, chemical, and biological properties referred to as "indicators" (Table 1). The Natural Resources Conservation Service's Technical Note on Soil Health (No. 450-03) provides a more in-depth look into the individual soil health indicators and their associated laboratory methods [5]. To describe the assessments briefly, within each framework, measured values for each indicator are provided a rating based on scoring functions as determined by each framework. These ratings are then aggregated, resulting in an overall quality score (CASH), or soil quality index (SMAF). While they can be used for comparisons between geographic locations, it should be noted that these measurements are most helpful in tracking the progression of newly implemented soil management practices designed to improve soil conditions over time.

Table 1. Comparison between SMAF and CASH laboratory measurements

Indicators	**SMAF**	**CASH†**
Physical		
	Macroaggregate stability (AGS)	Aggregate stability
	Bulk density (BD)	Surface hardness

	Plant-available Water	Subsurface hardness
	Water-filled pore space (WFPS)	Available water capacity
Chemical		
	Extractable P	Extractable P
	Extractable K	Extractable K
	pH	pH
	Electrical Conductivity (EC)	Minor Elements (Na, Mg, S)
	Na adsorption ratio	Micronutrients (Fe, Mn, Zn, Cu, B, and others)
Biological		
	Soil Organic Carbon (SOC)	Organic Matter (OM)
	Microbial Biomass C (MBC)	Soil Protein
	B-glucosidase enzyme activity	Soil Respiration
	Potentially mineralizable N (PMN)	Active Carbon

†CASH also provides additional (add-on) indicators recommended for particular land-use applications: biological – root pathogen pressure rating, potentially mineralizable N (PMN); chemical – salinity and sodicity, and heavy metals.

Given the renewed focus on conservation practices, and efforts to improve soil health to counter the impacts of climate change, soil health assessments must provide accurate, clear-to-understand results and provide regional relevancy for the producers who incorporate them into their management routine. Therefore, it should be noted that the two major soil health assessments, SMAF and CASH, were developed using soils from portions of the country that have soils with much higher C content. The SMAF was developed using midwestern soils as a baseline, while CASH was developed using soils from the northeast [6]. Neither CASH nor SMAF considered soils from the southeast during the development of their metrics. However, the exclusion of the southeastern US during the development and testing of these assessments does not preclude them from being used in this region. Instead, indicator ratings and overall quality scores in the case of CASH, and soil quality index in the case of SMAF, need to be taken with a grain of salt. The groups working on both assessments understand these shortcomings, and efforts are underway to provide adjustments to scoring functions to account for regional differences in soil traits [5]. Users of these assessments should also understand that improvements to a soil indicators rating, even if considered low by another region's standards, are still improvements to that soil's overall health.

Since these assessment frameworks are best used to monitor soil health over time, frequent utilization of their entire suite of laboratory tests is not required nor recommended. These analyses will provide insight into the success of an implemented practice but do not replace annual, standard soil testing to determine lime and fertilizer requirements. Additionally, a series of evaluations by the Soil Health Institute, located in North Carolina, of the most commonly measured soil indicators condensed laboratory analysis down to three critical measurements they recommend be performed: i. soil organic carbon; ii. carbon mineralization; and iii. aggregate stability [7-9].

While whole books can and have been written on each of these three soil characteristics, we will touch on each briefly. Soil organic carbon (SOC) is one of the most routinely measured soil quality indicators [10]. This is unsurprising given the integral role of organic matter in soil formation. A soil's organic carbon content is often measured via dry combustion or loss-on-ignition analyses, which involves "burning off" the soils organic carbon at high temperatures. From these tests, a SOC value can be reported as a percentage of the total soil volume. Carbon mineralization is the process by which SOC is oxidized, resulting in CO_2 emissions. This process is microbially driven and is often measured via soil respiration, with increased carbon dioxide levels indicative of a more active soil microbial community. Protocols exist for the measurement of soil respiration both in the field and in the laboratory [11]. Soil aggregates give soil its structure and allow for air circulation and water infiltration. Tests designed to measure aggregate stability when erosional forces (e.g., tillage, water, and wind, water) are applied are varied [12], however these methods are in overall agreement that poor aggregate stability can be used to predict a soil's susceptibility to erosion [13], as well as predict compaction-related issues [14]; compaction reduces water infiltration resulting in drainage issues, and hampers root penetration thereby lowering crop productivity.

Soil Health Improvement Strategies for the Southeastern Coastal Plain

The soils of the Coastal Plain (MLRA 133A) extend from Virginia through Georgia and the Florida panhandle, and over to Louisiana. According to the NRCS, these soils are characterized as having poor organic matter content (i.e., low SOC) and being susceptible to water erosion and soil compaction [15]. A study by Ye et al. [16] revealed that conventionally managed farmland in South Carolina traditionally rated as low/poor for many tests typically used for soil health assessments. Likewise, a study by Roper et al. [17] revealed similar findings for sites in North Carolina in both Coastal Plain and Piedmont soils using the CASH assessment.

Despite these low soil health assessment ratings, the soils of the Coastal Plain are productive and can be improved and preserved when utilizing proper management practices. In the analysis by Ye et al. [16] of farm plots managed under long-term (i.e., 40+ years) conservation tillage by the Agricultural Research Service (USDA), they demonstrated that farmland under this management practice saw modest but significant improvements to both soil carbon (as measured by the CASH active carbon test) and N (as measured by potentially mineralizable nitrogen). These results reflect the Novak et al. [18] report on over the first twenty-four years of the study, where they found that SOC more than doubled (from 5.3 g kg^{-1} to 11.1 g kg^{-1}) within the first 12 years of implementation of conservation tillage and continued to increase before plateauing (at 15.9 g kg $^{-1}$) roughly twenty-three years after conservation tillage began. Indeed, reductions in tillage – to reduced till, conservation tillage, or no-tillage practices – have often been linked to increased carbon pools within the soils receiving these tillage managements [19]. As soils are tilled and mixed, bacteria are exposed to air, return to an active state, and consume the soil's readily accessible carbon pools. This activity results in increased bacterial respiration and a concomitant reduction in soil organic carbon [20]. On the other hand, reduced tillage practices result in less soil disturbance [21], lower soil respiration rates [22], and increased organic residue left on the soil's surface. This increased residue coverage provides organic carbon to the soil upon decomposing and helps reduce erosion [23]. Additionally, a meta-study looking at the impacts of conservation tillage practices from a global perspective demonstrated significant increases in aggregate size, and water stable aggregates [24]. Unfortunately, long-term tillage is detrimental to aggregate stability, primarily through the loss of soil carbon. This process can potentially be reversed by switching to conservation tillage practices; however the study by Ye et al. [16] demonstrated that increases in water stable aggregates are not guaranteed even after decades of careful conservation practices. Formation of aggregates is a complex process influenced by various environmental factors; however, it has been demonstrated that fungi, particularly arbuscular mycorrhizal fungi (AMF), may play a significant role [25]. Therefore, the introduction of microbial inoculants focused on introducing AMF to the soil may provide a boost to a soil's aggregate formation capabilities.

Another recommended approach to improving soil health is the introduction of cover crops. In addition to providing ground cover to assist in erosion control, cover crops can positively influence several biological, chemical, and physical soil characteristics. Frequently, leguminous cover crops, such as crimson clover (*Trifolium incarnatum* L.), are used to build soil nitrogen reserves, but their tap root systems also help improve soil infiltration and reduce compaction. In a study by Ducey and Bauer [26] looking at cotton yields (Figure 1), they were able to demonstrate that combining conservation tillage with cover cropping practices over a three-year period resulted in positively impacting cotton yields in soils with low electrical conductivity (EC) values (0.2 to 0.75 mS/m). These results indicate that adding cover cropping practices to complement conservation tillage can help reduce the negative impacts of extremely low soil EC on cotton yields in Coastal Plain soils.

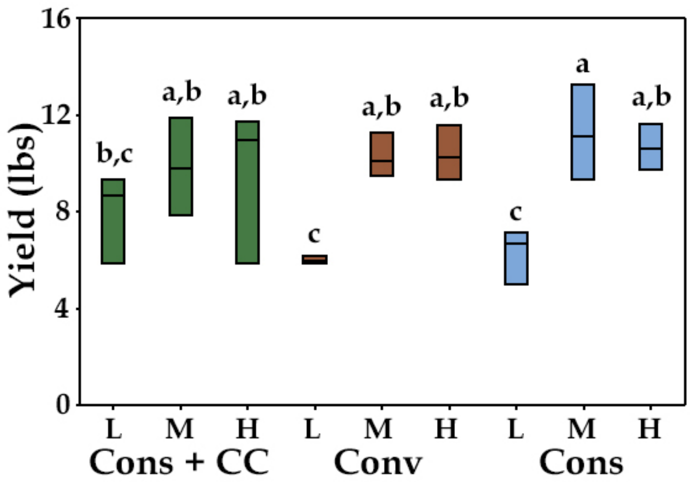

Figure 1. Cotton yield (lbs per 80-foot row length) averages over three years (2016 to 2019) from plots mapped to low (L), medium (M), and high (H) soil electrical conductivity. Plots were managed under conventional tillage (Conv), conservation tillage (Cons), or conservation tillage with cover cropping (Cons + CC). Treatments that do not share a letter differ significantly ($p < 0.05$). These findings are reported from results of Ducey, TF, and Bauer, PJ of ARS-USDA [26].

Selection of certain cover crops has been demonstrated to increase AMF soil levels [27]; as previously mentioned, these AMF may assist in the formation of stable aggregates if the practice of cover cropping is adopted long-term.

Conclusion

Farmers implementing practices for improving soil health contribute to ensuring a sustainable, and – in the long run – profitable future for agriculture in the southeastern Coastal Plain. When possible, particular focus should be placed on increasing the soils organic carbon pool and decreasing carbon mineralization rates, which can be achieved through reductions in tillage frequency, through various conservation tillage practices. Efforts to increase soil aggregate stability should be a long-term goal when improving soil health, with the understanding that seeing significant improvements may take decades. This process can potentially be sped up by promoting particular microbial species, such as AMF, by cover cropping or microbial inoculation, but further research is required. Research efforts by the Agricultural Research Service (USDA) focused on soil health have demonstrated that conservation tillage and cover cropping practices can improve soil health indicators and positively influence crop yields when replacing conventional tillage systems.

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