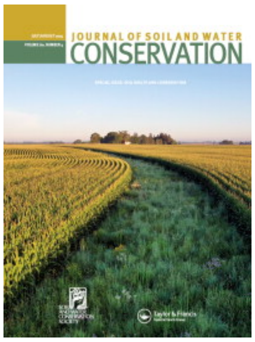

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Soil health and conservation

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A SECTION: INTRODUCTION

Check for updates

Soil health and conservation

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The topic of soil health sparks an array of opinions about what soil health is, the best metric with which to measure soil health, how to explain it to non–soil scientists, and how to demonstrate its value to everyone. As organizers of this special issue on soil health and conservation for the *Journal of Soil and Water Conservation*, we had many of those same conversations and shared our opinions. We are grateful to the authors who wanted to share their experiences and ideas with us in this issue. Because soil health is an emerging topic, we have prepared this overview article highlighting each of our own perspectives. Our goal is that each of you will be enriched by the articles in this issue and the impact of soil health on conservation and the future of our ecosystem.

THE EVOLUTION FROM SOIL TILTH TO SOIL HEALTH

Jerry L. Hatfield, retired, USDA Agriculture Research Service National Laboratory for Agriculture and the Environment

One of my favorite but sobering quotes is from George Washington Carver in 1938 when he discussed the impact of soil degradation. He said, "Wherever the soil is wasted the people are wasted. A poor soil produces only a poor people—poor economically, poor spiritually and intellectually, poor physically." Soil is one of our most precious resources, and over my career I have realized that we can enhance our soils and restore them; however, to achieve that goal, we have to begin to think and act differently in how we manage our agroecosystems.

Soil health has become the current word of choice to describe the state of soils. If we look back, Karlen et al. (1990) wrote a paper on *soil tilth*, describing the history of the concept and perceptions about it. Soil tilth was about the physical condition of the soil for tillage, seedbed preparation, and plant emergence. They proposed that a better understanding of soil tilth could lead to better management of soil and water resources. Tilth was rapidly replaced by *soil quality*, defined as the capacity of a specific type of soil to function within natural or managed ecosystems, supporting plant and animal productivity, maintaining or enhancing water and air quality, and promoting human health and habitation. The concept of soil quality naturally led to the process of creating tools for the quantitative assessment of quality. These tools recognized the fact that soil is a complex system of physical, chemical, and biological processes and their interactions.

There are many examples of types of measurements that have been suggested to quantify soil quality; however, these were developed to determine the state of the soil resource. For example, Karlen, Gardner, and Rosek (1998) used different soil quality measurements to evaluate the impact of the Conservation Reserve Program (CRP) on changes in the soil during a period in which the land was not cultivated. They found that biological indicators changed most quickly, and all of the benefits from being in CRP could be quickly reversed with tillage if the land was placed back into crop production. Soil quality has attracted an international audience, and in a recent review of soil quality indicators, Sharma et al. (2023) concluded that the interacting factors of biology,

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chemistry, and soil physical properties determine how crops and inherent soil properties affect soil quality.

Soil health has replaced *soil quality* as the current term describing the state of soils; however, this terminology has focused more on the ability to maintain or enhance soil functionality as part of the ecosystem. Soil functions critical to agriculture are supplying water, providing nutrients, promoting gas exchange between the soil and the atmosphere, and providing support for growing plants. The USDA Natural Resources Conservation Service (2025) defines soil health as an assessment of how well soil performs all of its functions now and how those functions are being preserved for future use. The Soil Health Institute was formed with the mission to safeguard and enhance the vitality and productivity of soils through scientific research and advancement. Through its efforts, summaries have continued to be presented on the agronomic and economic impact of soil health in different regions, as demonstrated by the article from Looker et al. in this special issue.

The concept of soil health has reinforced the need to understand and quantify the interactions among biological, chemical, and physical processes occurring within the soil. One of the studies that called attention to the role of soil biology in changing soil was from Wiesmeier et al. (2019), who found, after summarizing the worldwide literature, that soil biology was the major factor causing soil organic matter changes. Soil organic matter changes and the processes affecting these changes have led to the regenerative agriculture movement, which promotes practices that increase soil organic matter across all agricultural systems. These practices include reduced tillage intensity, maintaining continuous soil cover, maintaining a continual living root in the soil, increasing crop diversity, and integrating livestock. Lal (this issue) demonstrated how soil health is a direct function of soil organic matter and the linkage between practices that affect soil organic matter is related to soil health. Aspects of each of these practices are part of the articles in this special issue.

Soil health has to become the norm in our discussions about the future of soil management to meet our societal goals for food, clean water, clean air, and healthy habitats. As organizers of this special issue, we are grateful to do our part in fostering more discussion about how we achieve soil health.

SOIL HEALTH AS THE KEY TO A VIBRANT ECOSYSTEM

Adam Reimer, National Wildlife Federation

Farming is an inherently risky endeavor: temperature, precipitation, and soil conditions all affect crop and livestock production, while farm incomes are impacted by market and policy conditions. Global changes, especially climate change, are also increasing these risks in agricultural systems. The existence of risks in agricultural production does not mean that farmers are without options. Farmers have long excelled at adapting to and managing production risks. Key among these strategies is building soil health, especially in crop production systems. Agriculture fundamentally relies on a stable and productive natural resource base, especially soil, water, and air. By focusing on building healthy soils, farmers and land managers can increase system resilience, decrease vulnerability to disturbances, and support sustainable agricultural production.

Soil health recognizes that soils are complex ecosystems with physical, chemical, and biological components that interact to determine overall productivity and vitality. A healthy soil is one with the "continued capacity of soil to function as a vital living ecosystem that sustains plants, animals, and humans" (USDA Natural Resources Conservation Service 2025). Physical components such as *available water capacity* (the ability to store water) and *aggregate stability* (how well soil crumbs hold together under rainfall) impact a soil's ability to tolerate drought and heavy water events. Chemical components, including *overall nutrient balance* (the appropriate level of nutrients like nitrogen, phosphorus, and potassium the crop needs) and *extractable phosphorus* (phosphorus availability to a crop), are important for healthy crop growth, long-term soil functioning, and healthy waterways. Biological components such as *organic matter* (plant-derived carbon [C]) and *soil respiration* (measurement of microorganism activity) reduce reliance on inputs and are essential for the function of physical and chemical soil health components.

Soil health is a key aspect of conservation agriculture, a concept grounded in four primary principles: (1) increasing production diversity, (2) maintaining living roots throughout the year, (3) minimizing soil disturbance, and (4) maintaining soil cover during as much of the year as possible (Lal 2020). These principles are key guides for land managers in determining how to build healthy soils. Farmers often achieve these soil health principles through a variety of practices and management approaches integrated into conservation cropping systems. Most commonly, farmers will implement reduced or no-till systems to minimize soil disturbance and maintain living roots, use extended crop rotations to increase plant diversity over time, and use cover crops between cash crops to increase diversity, maintain living roots throughout the year, and increase soil cover. Over time, building soil health through these practices can also allow farmers to reduce synthetic inputs through more targeted nutrient management practices and integrated pest management, leading to increased economic resilience for farm operations.

These conservation management practices support healthy soil ecosystems, help reduce negative environmental impacts from farming operations, and confer greater operational resilience. These overlapping and complementary benefits emphasize the need for integrated, systems-based approaches to agricultural production to achieve high levels of soil health and operational resilience. Despite the substantial benefits that soil health approaches can provide, adoption of key practices by farmers in the United States has remained low. Currently, cover crops are used on less than 10% of crop acres annually, while no-till systems are used on roughly 25% of cropland (Wallander et al. 2021). A variety of barriers can prevent a farmer from incorporating these important practices into their operation, ranging from technical challenges at the field scale to economic barriers to a lack of adequate markets or social support. These barriers are context-specific and can vary widely depending on the producer, the practice in question, and the producer's situation.

Government conservation programs are a powerful tool for supporting farmer adoption of soil health practices, but in the United States they are insufficient in their current form and scope to meet the societal need for building healthy soils in US agriculture. New policies and programs may be needed to encourage this transition through voluntary practice adoption by farmers and land managers. Soil health programs and policies must be grounded in the perspectives and needs of producers, especially given the integrated systems approach needed to build and maintain healthy soils. Previous research has demonstrated the importance of systems thinking in cover crop adoption decisions (Church et al. 2020), implying that programs should address mindset and management barriers in addition to economic and technical barriers.

SOIL HEALTH AS A CRITICAL PART OF SEMIARID AGRICULTURE

Humberto Blanco, University of Nebraska–Lincoln

Soil conservation and soil health are intrinsically interconnected. Traditionally, soil conservation might have been viewed as a branch of soil science that deals primarily with protecting soil from erosion, particularly during and right after the Dust Bowl era (Bennett 1939). Yet, conserving soils is not simply about managing soil erosion, but also, more holistically, about maintaining the overall health of the soil. The principles that apply to soil conservation also apply to soil health management, including keeping the soil covered, maintaining permanent vegetative cover and living roots, reducing soil disturbance, growing diverse plant species with different canopy heights and rooting depths, and pursuing synergistic effects between crops and farm animals. Now, it is stimulating to see that soil is being emphasized more as a living and complex system that deserves to be valued and conserved.

I hear this question sometimes: does improving soil properties or indicators of soil health (e.g., aggregate stability, microbial properties, organic matter fractions) lead to increased bushels per acre? Maintaining and improving soil health goes beyond an increase in crop yields (Lehmann et al.

2020). Soil conservation and health are holistic missions with broad societal implications. They are about managing agroecosystems to support civilizations or generations of people. One may not understand the value of soil conservation and health unless a person thinks about what we consume, where we live, and what we wear, among other considerations. Almost all of what we consume (plant and animal products) relies on soil, our dwellings rest on the soil, and the clothes we wear are made from plant or animal fibers. The concept of *one health* cannot thus be overemphasized (Montgomery et al. 2024). Healthy soil supports healthy plants, which in turn support healthy animals, and ultimately human health and our overall well-being and existence. The connection of our existence to a living entity, known as soil, cannot be more obvious. Yet, soil is often dubbed as *dirt* or something that is of limited or no value.

I also hear this question: how do we measure soil health? The best metric or indicator of soil health is the delivery of all soil ecosystem services, including provisioning, supporting, and regulating services (Comerford et al. 2013). Healthy soil should be capable of producing food, feed, fiber, and fuel for generations to come in a sustainable manner. It should be able to hold available water during droughts, release excess water during floods, and moderate soil temperature during excessive heat. It should be able to filter nonpoint source pollutants and improve or maintain water and air quality. It should be able to protect soil C, minimize nutrient (e.g., nitrogen and phosphorus) losses, and recapture lost soil C. The latter soil services not only reduce crop production costs but also maintain the health of soils. If the soil cannot deliver all the essential services mentioned or has a diminished ability to deliver such services, then the soil is not healthy. Also, if soil is eroding at rates greater than soil formation rates (about 2 cm per 1,000 years), then the soil is not healthy.

Nowhere is soil conservation and soil health maintenance more critical than in water-limited or semiarid regions such as the US Great Plains. Crop-fallow systems with about 14 months of chemical fallow, limited or variable biomass input, and rapid organic matter decomposition in these regions often lead to C losses and overall deterioration of soils. Indeed, most soils in semiarid regions have lost about 40% to 50% of the original C. Restoring the lost soil C is key to improving soil physical, chemical, and biological properties. Soils are like humans. Some soils, such as those in arid and semiarid regions, need more remedies than soils in high-precipitation or high-biomass input systems. Some soils are left without much residue in winter or spring before crop establishment or are disturbed right before the season when soil is most susceptible to erosion and degradation. Low-C, eroded, and coarse-textured soils, which abound in semiarid environments, need targeted conservation practices.

Cover crops are considered one of the reemerging practices to manage the health of soils. Planting cover crops during fallow in crop-fallow systems can be an opportunity to improve soil properties, reduce nitrate leaching, and restore lost soil C. Yet, adoption of cover crops in water-limited regions can be a challenge due to limited precipitation. The soil benefits of cover crops are a function of the quantity of biomass that they produce. Cover crops may provide limited soil benefits even in the long term if the annual biomass input is below the threshold levels (<1 Mg ha^{-1}). Boosting cover crop biomass production, especially in semiarid regions, calls for opportunistic practices. For instance, early cover crop termination or planting forage crops in years with precipitation amounts above or near normal may be strategic to reduce any negative effects of cover crops on subsequent crop yields.

Thinking not only about soil health but also about resilience is vital. We often focus on applying more irrigation water and more inorganic fertilizers to produce crops rather than equally focusing on improving the capacity of the soil to retain water and nutrients, resist abrupt changes, and return to predisturbance levels after stresses, known as resilience. Soils should have a spring-like behavior and rebound rapidly after extreme weather events, such as droughts, floods, and rainstorms.

Boosting the adoption of soil conservation practices should be our goal to safeguard soils. Current modern agriculture with increased use of irrigation water, fertilizers, and pesticides may not be a sustainable practice. Incorporating biological soil conservation practices such as cover crops, biochar, animal manure, and conservation strips paired with continuous no-till practices could contribute to balancing our farming practices. Continued research funding support from state and federal agencies is also indispensable for evaluating the extent to which some of the emerging practices conserve and improve the health of soils. Some practices such as no-till have proven records to conserve soil and improve soil health, but other practices such as cover crops and biochar application deserve additional research under on-farm conditions. The interconnectedness between soil conservation and health calls for increased efforts in soil conservation for restoring and improving the declining health of our soils.

Further, conservation practices such as cover crops and organic amendments may deliver more benefits when targeted to environmentally sensitive soils than when used in relatively fertile, nearly level, and fine-textured soils. Yet, most data on conservation practices are from prime agricultural lands and not specifically from degradation-prone soils. Precision agriculture, remote sensing, and other tools can assist in targeting soils that are highly susceptible to erosion, nutrient leaching, and overall degradation.

The time to invest more in soil health is now, when we face frequent droughts, floods, wildfires, and other extreme events. Refining, designing, or redesigning our current management practices are not a choice but a necessity. Note that our current practices were designed for relatively normal conditions and not for frequent droughts, floods, and excessive heat. The collection of articles in this special issue timely addresses numerous themes related to the health of soils, including the role of soil conservation practices (e.g., prairie strips and cover crops) as well as the challenges and opportunities for the adoption of soil health practices under different climatic zones.

THE NEED FOR BETTER METRICS AND COMMUNICATION FOR SOIL HEALTH

Cristine L. S. Morgan, Soil Health Institute

To date, much of the scientific inquiry around soil health has focused on identifying measurements to monitor changes in soil condition and function, evaluating the impact of soil health practices, and understanding how amendments influence these indicators. As the field matures, researchers are increasingly investigating what is happening on commercial farms, how growers perceive—or overlook—soil health and its outcomes, and the economic value proposition of improving it.

Key knowledge gaps remain for those aiming to understand and expand soil health practices across the landscape, including

- recognizing soil health as a multidimensional and multidisciplinary concept, shaped by interactions among social networks, on-farm economics, the natural capital of soil condition, and policy (see McBratney, Field, and Koch 2014);
- developing effective ways to measure and assess changes in soil condition on commercial farms and across broader regional scales; and
- translating changes in measurable soil indicators into estimates of soil function and ecosystem services to better communicate soil's natural capital and ecosystem contributions.

The articles in this special issue directly address the first two of these challenges. Four of the articles explore knowledge gaps related to the complexity of soil health. Grinnell, Jones, and Epstein (this issue) examine the multifunctionality of soil in managed systems. Ulbrich, Marquart-Pyatt, and Evans (this issue), along with Hill-Sullins et al. (this issue), investigate growers' perceptions, challenges in adopting soil health practices, and how information is shared. These insights into social and institutional dynamics are essential for informing outreach strategies and policies that support adoption. Katz (this issue) builds on this theme by evaluating the role of federal conservation plans in advancing soil health through easement programs.

Other articles address technical barriers and the need for improved information exchange. Starr et al. (this issue) provide practical, farm-level insights into cover crop performance and related economic considerations—critical knowledge for producers operating within diverse climates, cropping systems, and soil types. Given this wide variation, we must continue building a strong foundation of practice-informed data to guide decision-making.

Two additional articles illustrate what soil health progress looks like in practice. Looker et al. (this issue) quantify improvements across multiple Major Land Resource Areas where cotton is produced. Dutter et al. (this issue) demonstrate how prairie strips can enhance soil health, raising the question: could these strips serve as local benchmarks for assessing soil health progress in nearby croplands?

Scaling soil health assessments across regions will require more cost-effective and efficient tools. Fortuna, Starks, and Moriasi (this issue) address this by evaluating the use of VisNIR proximal sensing as a practical approach to measuring soil condition.

Noble-Strohm et al. (this issue) examine a critical yet often overlooked issue: how to improve soil health in water-limited environments. Enhancing soil condition in dryland or heavily irrigated systems presents persistent challenges. Wilson et al. (this issue) demonstrate the value of adding compost onto rangeland to improve soil health, especially on degraded soils. Having seen the difficulties in regenerating soil health in such systems myself, I am especially eager to learn from others' successes and insights.

Soil conservation has long depended on collaboration between soil scientists and agronomists. In this special issue, Montgomery provides a timely review of how farming systems are categorized by their management strategies, offering a foundation for interpreting soil health outcomes across diverse geographies and production systems. In my current role at the Soil Health Institute, I've spent far more time on this topic than I anticipated—an experience likely shared by many working across varied agricultural contexts.

At its core, the concept of soil health is grounded in optimism—the belief that degraded soils can regenerate. The articles in this special issue reflect a shared commitment to exploring the many dimensions of that hopeful vision. We are pleased to share this collection and hope it meaningfully advances both science and practice in soil and water conservation.

DISCLOSURE STATEMENT

No potential conflict of interest was reported by the author(s).

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