Understanding soil health

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Soil is a crucial ecosystem that underpins the survival of plants, animals, and humans. While climate change is expected to significantly impact soil communities, geochemical cycling, and nutrient availability, there remains a lack of consensus on the precise nature of these effects. A fundamental and pressing question concerns the definition of soil health regarding what properties constitute healthy soil. This Voices asks: what property must be urgently consolidated into the soil health framework to support broader sustainability?

Karen Johnson
University of Durham

A nation that rebuilds its soils rebuilds itself

The most important property to be consolidated into the soil health framework does not lie in soil, it lies within people. That property is soil literacy. Johnson et al. define soil literacy as a combination of attitudes, behaviors, and competencies required to make sound decisions that prevent soil degradation, promote soil health, and ultimately contribute to the maintenance and enhancement of the natural environment. If nations are to reverse soil degradation and start rebuilding soil health to support broader sustainability, nations must become soil literate.

Soil health, like human health, is complicated to define, and like in human health where the gut microbiome is underpinning, the soil microbiome underpins soil health. Indeed, the links are more direct, touching soil is actively good for our immune systems and improves human health. In recent decades, with increasing urbanization, societies have become more and more disconnected from the soil. The long-term negative implications for human health should not be underestimated.

Soil is so much more: soil stores water and carbon. Soil underpins all terrestrial life, indeed it is home to around 59% of all life on earth. Yet, without having sufficient basic knowledge of soil, how can we expect anyone—child, engineer, or Head of State—to think that soil is anything other than a medium in which to grow food?

To rebuild soil, we must embed soil literacy into our school curricula and in doing so benefit society across education, environment, and health. We can turn Roosevelt's famous quote on its head and into "A nation that rebuilds its soils rebuilds itself" if we put the soil microbiome at the heart of how we work with soil and teach our children to care for soil and to touch soil.

Job Kihara
Alliance of Bioversity International and CIAT; Excellence in Agronomy (EiA) Initiative; CGIAR Science Program on Sustainable Farming

ZERO is good for soil health

Regenerating degraded soils and building soil health is critical for sustainable food systems transformation. In soil health, Zero Erosion and Run-On/off, which I call ZERO, should become a key goal. In Africa, 50 kg/ha of soil nutrients (e.g., nitrogen, phosphorus, and potassium, which are key elements to support plant growth) are lost every year through soil erosion, the same quantity that has remained the target since the Abuja Fertilizer Summit of 2006. The 2024 summit, resulting in the Africa fertilizer and soil health declaration, has laid emphasis beyond fertilizer to include soil health. While working extensively across Africa on soil health, I realize that the known practices of conservation agriculture, integrated soil fertility management, 4Rs of nutrient stewardship (right source, right rate, right time, and right place), and others, as promoted and practiced, will not achieve their full benefits. We must transition from implementing them in isolation to implementing them as complementary with other measures to arrest soil erosion. I call for promoting practices as integrations of different bundled solutions, and scaling efforts that embrace a broader set of practices according to contexts. Policy efforts should focus on such complementary interventions and support farmers and other stakeholders by enabling conditions to implement the appropriate bundles of practices. These may include provisioning of incentives for long-term sustainable management efforts against soil erosion. Then, farmers will realize that ZERO is good for soil health.

Mingsheng Fan
China Agricultural University

Innovation needed to increase soil organic carbon

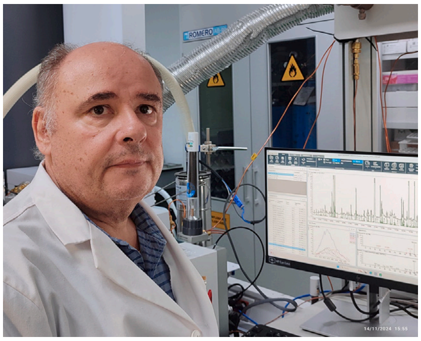
Soil organic carbon (SOC) has been identified as one of the indispensable indicators for measuring soil health. It is well known that increasing carbon in soil would help mitigate climate change while also improving soil health and crop yield. However, intensive agriculture practices has led to substantial loss of SOC. Currently, SOC contents in most arable land are far from their optimum levels, prohibiting further increase of crop yield even when other production constraints have already been addressed. For example, research showed that by increasing SOC to optimum levels, global production of the three most important staple crops (maize, wheat, and rice) could rise by 4.3%, enough to feed an additional 640 million people. However, the anticipated yield increases are less likely to be fully realized with current scalable SOC sequestration practices, including cover cropping, zero tillage, and residue returns.

Thus, building up healthy and productive soils by increasing SOC is urgent. The most practical route is to apply good governance to address social and economic barriers toward adoption of current soil carbon sequestration practices. This is especially important for hotspot regions featured by low soil carbon and food deficit, where even incremental SOC increases could yield large food security co-benefits. Meanwhile, it is crucial to explore the novel practices to extend the boundary of achievable SOC sequestration to optimum levels. New technologies aimed at retaining more organic C in soil might include biochar application, breeding new varieties with increased underground production, or engineering the soil microbiome toward carbon-stabilizing taxa.

Kate A. Congreves
University of Saskatchewan

An agricultural ethic for soil health frameworks

Motivating collective action and designing policy for sustainability requires the development and application of a system of values—an ethic—and we urgently need one that is applicable to agriculture. Traditional environmental ethics consider nature and agriculture as separate entities, so it has been difficult to force concepts of nature conservation and preservation directly into a system that is inextricably anthropogenic. We must look toward other philosophies to guide us if we are to practice agriculture sustainably. Regenerative agriculture offers a philosophical framework that affirms agriculture's place within the environment and presents a value system centered around soil health to support broader sustainability. I would define regenerative agriculture as an ecosystem-based approach to producing food where our practices embody reciprocity with the land to support ecological health, with the goal of counteracting negative anthropogenic impacts. We would do well to consolidate agricultural ethics into soil health frameworks, moving beyond the list-making of which soil properties should be measured and managed as indicators of a healthy ecosystem. Agricultural ethics will help us to navigate through difficult issues, recognize points of disagreement, encourage us to think deeply about the problems, identify what is valued and why, and enable us to collectively make better decisions to support broader sustainability.



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The need to assess the quality of soil organic carbon

Soils store vast amounts of organic carbon (OC), exceeding that in the planet's living plants, animals, and the atmosphere. Human activities have resulted in the loss of c. 116 Gt of soil carbon (C). Soil C sequestration—the removal of CO_2 from the atmosphere and storage in soil—has the potential to mitigate global climate change. Also, soil organic carbon (SOC) is paramount in maintaining soil quality and ecosystem services. Therefore, the use of soils in sequestering CO_2 is a win-win strategy and considered a key component to meet the UN SDGs and EU Green Deal objectives, mainly promoting nature-based solutions like sustainable soil management and conservation practices.

However, increasing total SOC does not ensure CO_2 sequestration. SOC is highly dynamic and influenced by many interlaced factors. As a result, only a small proportion—if any—of OC may remain a few months or years after entering the soil. Thus, the form and the time SOC is stored is pivotal for its impact on climate and soil health. In this context, the assessment of SOC quality—understood in terms of properties that enhance its stability in the soil and resistance to mineralization—is crucial for policymakers and stakeholders in need of parameters to assess the effectiveness of C sequestration practices. Among these properties are physicochemical and structural characteristics as well as several poorly known overlapped SOC stabilization mechanisms. However, this is a highly complex area that demands clarification and urgent multidisciplinary research efforts to know how and how much CO_2 has been and can be effectively stored in soils.

Shovik Deb
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Deep soil carbon as a soil quality parameter

Surface soil carbon is a well-established soil health parameter due to its role in betterment of soil physical, chemical, and biological qualities. However, subsoil carbon is ignored while discussing soil health, despite the fact that deep layers store about half of the soil carbon. The deep soil receives carbon at a slow rate and the carbon composition there is very different from the surface soil. Plant litter and freshly added organic matter dominate the surface soil carbon pool while deep soil carbon is mainly enriched by translocated organic matter, root exudates, and microbial necromass.

The deep soil also releases carbon at a very slow pace and thus carbon becomes stable there, attaining millennial age. Fewer anthropogenic disturbances, low microbial presence, and oligotrophic conditions are some of the factors behind this. Higher arresting of carbon within aggregates and strong attachment to mineral matrix also results in high physical protection and less accessibility of carbon to microbial oxidation in deep soils. In this way, deep soil performs as a niche for carbon sequestration. Carbon stored in deep layers also keeps the soil resilient against erosion and pollution, among others.

Conversion of natural land covers to croplands, intensification of agricultural practices, and rapid translocation of fresh plant-originated carbon to the subsoil can decline the deep soil carbon stability. Consideration of deep soil carbon within soil quality framework can widen our understanding about their ecosystem services and will help to keep this global recalcitrant carbon reserve protected.

Franciska de Vries
University of Amsterdam (Photo credit: Sara Kerklaan)

Understanding the belowground half of ecosystems

Soils are the belowground half of ecosystems, with the total biomass of roots and soil organisms and their diversity equaling or even surpassing that of the aboveground half. Just as it is impossible to identify one property that defines "a healthy ecosystem," it is impossible to define one property that defines healthy soil. A healthy, well-functioning soil is a healthy belowground ecosystem, and this will be very different between a heathland or a cropland, a forest or a grassland.

Most soil health indicators, monitoring initiatives, and laws focus on agricultural soils. It is relatively easy to define healthy agricultural soil—fertile soil that stably supports optimal plant growth and yield. But defining one soil health metric that works for agricultural soils ignores the fact that soils under different natural ecosystems, in different regions of the world, have vastly different properties and soil biodiversity, and that the processes that determine the functioning of those can be very different from those that we value in agricultural soils.

The fact that we try to capture soil health in a simple metric to me signifies how far the field of belowground ecology is lagging behind that of aboveground ecology. To improve our understanding of the properties that constitute healthy belowground ecosystems we need to set up and expand national and global soil monitoring networks, such as SoilBON, that don't just focus on agricultural soils. This will help us include crucial properties of the belowground part of ecosystems in frameworks for assessing ecosystem quality.

DECLARATION OF INTERESTS

The authors declare no competing interests.