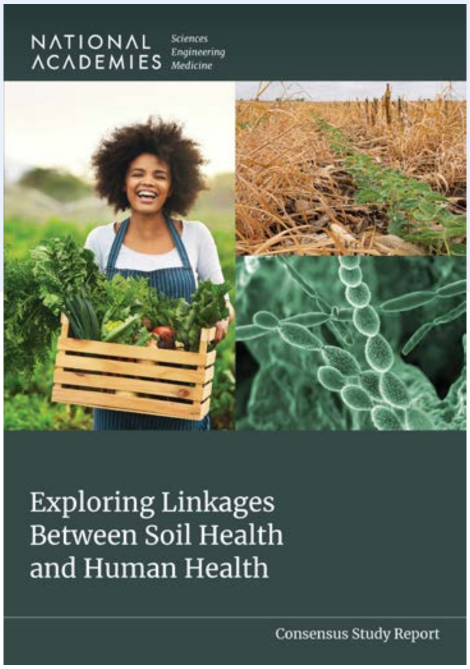
NATIONAL ACADEMIES *Sciences Engineering Medicine*

Consensus Study Report
Highlights

Exploring Linkages Between Soil Health and Human Health



The United States is an important food producer globally, in part because of its abundance of agriculturally productive soils. However, management practices that maximize yields have caused losses in soil organic matter, poor soil structure and water-holding capacity, and increased salinity on millions of acres of land. Microbial communities, the drivers of many soil processes, have been adversely affected by excessive use of tillage, nutrient applications, and pesticides. Considerable efforts are underway to mitigate these problems through management practices that improve soil health.

Furthermore, recent scientific advances have facilitated exploration of the microbiome and are spurring interest in how microbial communities are connected among species and how attention to microbiomes can support soil health, food quality, and human health. There is also the possibility that new discoveries in the soil microbiome could facilitate drug development and address threats to human health, including antibiotic resistance, contaminants, and soil-borne pathogens.

Finally, there are questions about whether management practices are linked with the nutrient density of the food produced and about the interactions of the soil microbiome with soil contaminants. Therefore, the U.S. Department of Agriculture's National Institute of Food and Agriculture asked the National Academies of Sciences, Engineering, and Medicine to convene a committee of experts to explore the linkages between soil health and human health (see Figure 1). The committee approached its task from a One Health concept, which posits that soil should be valued as an ecosystem that, when healthy, contributes to the health of other ecosystems, plants, humans, and other animals.

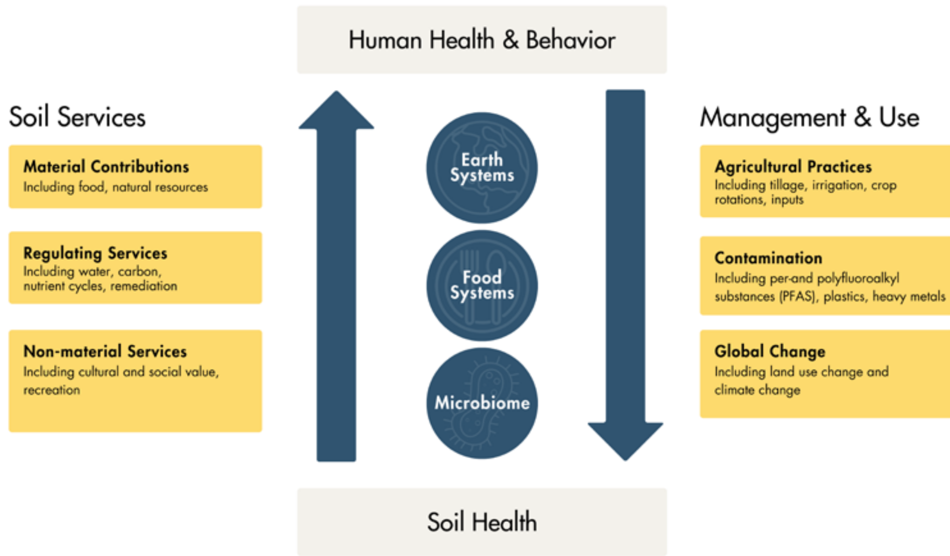


FIGURE 1 Soil health, its connection to ecosystem services and human management and use, and its interaction with earth systems, food systems, and the microbiome.

LINKAGES BETWEEN SOIL MICROORGANISMS AND HUMAN HEALTH

The most obvious linkage between soil microorganisms and human health rests on the fact that soil microorganisms do the work needed to produce food, including cycling nutrients and carbon, filtering water, and building soil structure and organic matter. Perhaps less recognized is the critical role the soil microbiome plays in climate regulation, including carbon sequestration, and the ability of soil microbes to metabolize many organic contaminants into harmless byproducts, which limits exposure to humans.

There are other connections between soil microbiomes and human microbiomes that remain underexplored. Indirect evidence supports the importance of exposure to environmental microorganisms for human health, notably on the immune, metabolic, and central nervous systems, but more research is needed. Additionally, because microbial actions are responsible for many chemical indices currently used as health indicators, the microbiome may provide early indicators of health changes. However, the ability to define and interpret microbial health indicators is currently limited by a sparse understanding of the ecology and function of microorganisms in both soil and human systems.

Though soils are a source of antibiotics and other medicinal natural products in soils, less than 5 percent of the estimated hundreds of thousands of antibiotic substances in soil have been characterized. Continued development of molecular methods and cultivation techniques could offer efficient ways to screen soils for promising medicinal compounds.

To advance understanding of the linkages between soil microorganisms and human health, researchers should improve sampling design to better capture the spatial and temporal aspects of the microbiome and enhance universal methodologies (e.g., sampling, documentation) for microbiome analysis across different sample materials. Funding agencies should support inter- and intradisciplinary research to explore the existence of the microbiome continuum spanning soils to human health. Federal funders should also:

- Include resources for metadata collection, storage, and reusability
- Support the discovery of scalable microbiome diagnostics in soils and humans
- Support research that investigates causal relationships in soil and human microbiomes toward the development of microbial therapeutics

LINKAGES BETWEEN AGRICULTURAL MANAGEMENT PRACTICES AND HUMAN HEALTH

Common agricultural management practices have increased crop yield and food security, but this productivity has often come at the expense of soil health, with detrimental effects on the environment and human health. For example, synthetic fertilizer use has greatly increased crop production but also caused excess nutrients to leach from agricultural fields, sometimes resulting in contaminated groundwater, algal blooms, and production of potent greenhouse gases that contribute to climate change. At its most fundamental level, agricultural management practices often create trade-offs between the many services soils provide to people; for example, food production on the one hand and, on the other, the ability of ecosystems to sustain biodiversity, sequester carbon, and perform myriad other functions that are equally, even if less obviously, essential to human health.

To advance understanding of agricultural management practices that enhance benefits to and reduce adverse effects on human health, federal agencies should prioritize research to better characterize and monitor the benefits that soils provide to people, with the goal that this research can be translated into tools land managers can use to inform decisions that involve trade-offs between different benefits from soil. Similarly, federal agencies should support research that develops novel strategies or management combinations to overcome potential trade-offs among common agricultural management practices.

LINKAGES BETWEEN AGRICULTURAL MANAGEMENT PRACTICES AND THE NUTRITIVE VALUE OF FOOD

Although there is a common perception that healthy, well-managed soils produce healthier foods, the connection is not always clear. Nutrient availability in the soil, environmental conditions, management practices, and plant genetics all play a part in determining the nutritional quality of food. Comparative studies of different production systems (e.g., conventional versus organic) have tried to assess the interplay of these factors, but variations in experimental design, soil types, crop species, and environmental conditions have yielded divergent results.

What ultimately determines the nutritional quality of food crops is the amount of essential nutrients with health-promoting potential that are transported to, or synthesized within, the edible portion of the plant. These include minerals and biosynthesized macromolecules such as amino acids/proteins, carbohydrates, lipids, vitamins, and phytochemicals.

Changes in yields due to management practices can affect the concentrations of certain nutrients and health-beneficial phytochemicals. If yields increase, the concentrations may decrease because nutrients do not necessarily accumulate within edible plant tissues at the same rate. The lack of a clear relationship between nutritional quality and management practices in studies could also be because the diversity of phytochemicals in plants is complex. Many compounds function as signaling or defensive molecules that can be differentially biosynthesized in response to biotic or abiotic environmental stress. Therefore, a reduction in plant stress may in some instances lead to lower concentrations of these phytochemical compounds.

Furthermore, nearly all commercially harvested plant foods are processed to make them safe to consume and improve their palatability and shelf life. Food processing can make nutrients more or less bioavailable. Thus, it is always important to consider the final form of edible plant tissue that is consumed when evaluating soil–plant–human health interactions.

To advance understanding of the linkages between agricultural management practices and the nutritive value of food, federal agencies should support translational research to better understand the effect of agricultural management practices on the nutrient and bioactive density of crops. They should also cooperate to support research on the biosynthetic pathways and environmental cues that influence food composition, so that crops can be managed or bred for higher levels of target compounds, even in the absence of promotive environmental signals.

IMPROVING SOIL HEALTH TO IMPROVE HUMAN HEALTH

A healthy soil sustains biological processes, decomposes organic matter, and recycles nutrients, water, and energy, reducing the need for synthetic fertilizers and irrigation. It helps mitigate exposure to some chemical contaminants and sustains food production. All of these functions make the prioritization of soil health for human health benefits even more important in the face of climate change, which will adversely affect soil nutrient cycling and exacerbate the detrimental effects of flooding or drought on soil stability and water-holding capacity.

Biodiversity maintenance is an essential constituent for soil health, prompting the urgent need to preserve soil microorganisms (as well as meso- and macrofauna). Agricultural management practices that minimize disturbance and maximize crop biodiversity, maintain continuous living plants, and keep the soil covered, wherever possible, also build soil health. The incorporation into planting rotations of cover crops, perennial crops, or crops bred specifically for root system development or rhizosphere interactions with soil biota are all options for increasing belowground biomass. More research and development will be needed to make these crops viable choices in the diverse soils and climates of the United States.

Soil health faces many threats, including chemical contamination from multiple sources. For example, high levels of lead and cadmium in soils reduce microbial activity and plant biomass. Microplastics can change soil structure, affect water-holding capacity, and may enrich pathogens and antibiotic resistance genes in soil microbial communities. Per- and polyfluoroalkyl substances, a large group of synthetic, organofluorine chemicals that are highly persistent in the environment, are of increasing concern as environmental contaminants. Because these and other soil contaminants have not been strategically mapped in the United States, there is a lack of comprehensive knowledge regarding their geographic distribution in U.S. soils and the specifics of their co-occurrence in mixed forms. Immediate action should be taken to map and mitigate current soil chemical contamination, which can overwhelm the capacity of soil to mitigate contaminant risks to human health.

There are abundant underutilized organic resources in the United States—food waste, compost, agroindustrial and forestry byproducts, manure, biosolids, and source-separated human excreta—that could be used to increase soil nutrients and organic matter and reduce demand for synthetic fertilizer. Current challenges involving geographic distribution, quantification of nutrient content, and contaminant removal must be solved to make the most effective use of these resources. Federal agencies and public and private entities should invest in technologies to turn these waste streams into safe, effective resources.

Finally, federal agencies should promote the importance of soil health and develop a coordinated national approach to monitor soil health over time and space. This approach would allow for broad comparisons across locations and an ability to identify areas of concern. They should also fund research projects that identify the underlying mechanisms of soil health; these should include collaborative, on-farm research with scientists, farmers, and industry that take into account historical and current land management practices.

GOING FORWARD

Shifting the perception of soil to a valued ecosystem that is interconnected with the health of plants, humans, and other animals will be spurred on by a better knowledge of underlying mechanisms contributing to soil health and its connectedness to plant and human health, and a continued optimization of ways to quantify and compare health. It will require changes in farm-support programs to value soil health as a metric of success and to transition toward more complex and perennial cropping systems as well as increased circularity where waste streams are turned into safe resources. Finally, societal awareness of the role soil health plays in human health beyond food production must increase, which will require the involvement of many federal agencies, scientific societies, companies, and international organizations.

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FOR MORE INFORMATION

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Division on Earth and Life Studies

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