Science Societies

Closing the loop: The soil health cycle and the future of sustainable agriculture

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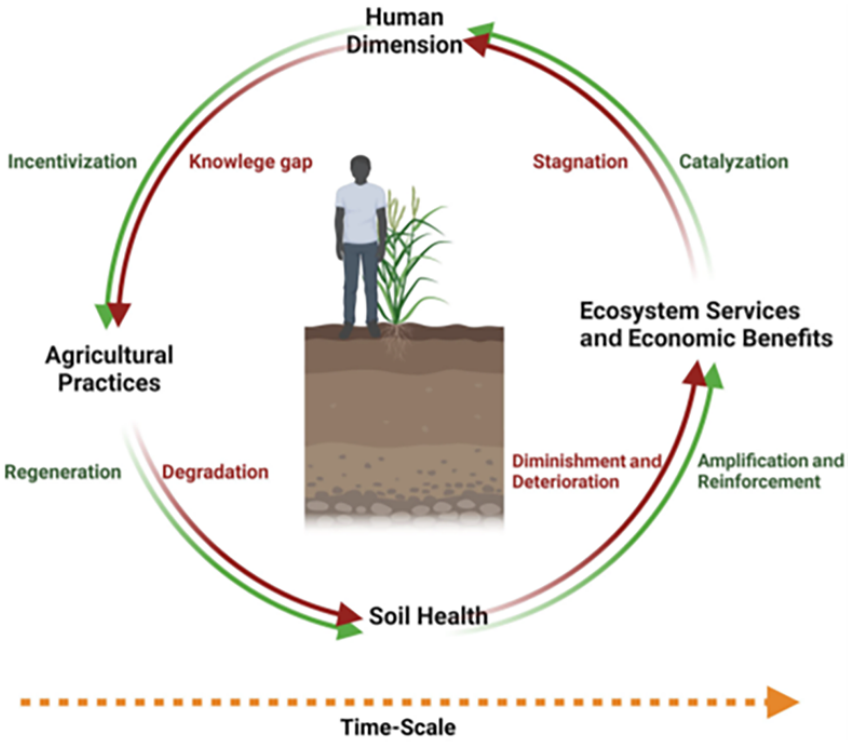

The soil health cycle—the feedback cycle in soil health management.

The soil health cycle is a framework developed in Nebraska that links human behavior, agricultural practices, soil indicators, and ecosystem outcomes in a feedback loop to guide sustainable farming. When science, community engagement, and long-term monitoring are integrated, this can improve soil resilience, farm profitability, and environmental sustainability.

The phrase “soil health” has become a rallying cry for 21st-century agriculture. Yet despite the surge in global attention, the science behind how soil health improves or deteriorates over time remains fragmented. In Nebraska, a new way of thinking about soil health is taking root—one that links science, community, and the human dimension of stewardship in a feedback, iterative driven model.

There is a broad consensus regarding management practices like no-till, cover crop, crop rotation, and livestock integration that enhance soil health. Photo courtesy of USDA-NRCS South Dakota. CC BY-SA 2.0.

At the center of this movement is Dr. Bijesh Maharjan, an associate professor and extension soil scientist at the University of Nebraska–Lincoln (UNL). In 2024, he and his colleagues published a paper in *Agrosystems, Geosciences & Environment*, "Soil Health Cycle ," which offers a unifying framework to understand the complexity of soil health as a living, adaptive system.

There is a broad consensus among researchers, industry professionals, producers, and agencies such as the USDA Natural Resource Conservation Service (NRCS) regarding management practices like no-till, cover crop, crop rotation, and livestock integration that enhance soil health. However, Maharjan and colleagues contend that while these practices are well known, the link between management, measurable soil health indicators (SHIs), and soil function outcomes—yield, profitability, or sustainability—remain weakly quantified. They present a feedback loop characterizing soil health management as a self-reinforcing cycle: a living loop of cause and effect that ultimately regenerates or degrades the soil resource depending on the direction of feedback.

The SHC connects four interdependent components in a continuous loop over time:

1. **Human Dimension:** encompassing knowledge, motivation, economics, and policy incentives that drive decision-making at the farm and societal levels.

2. **Agricultural Practices:** from conservation methods like cover crops, no-till, and crop rotation to soil amendments and others.

3. **Soil Health:** determined using measurable SHIs (e.g., soil organic carbon, microbial biomass, and aggregate stability) that reflect the soil's biological, chemical, and physical condition.

4. **Ecosystem and Economic Services:** outcomes such as productivity, profitability, and environmental sustainability that close the feedback to human behavior.

Positive feedback, driven by conservation-oriented management, enhances soil functions and delivers tangible ecosystem services—higher yields, reduced erosion, and increased carbon storage, which, in turn, reinforce supportive policies and motivation. Conversely, negative feedback, often spurred by economic or knowledge barriers, accelerates degradation, leading to reduced soil resilience and stagnation of stewardship.

The soil health cycle helps us see soil health as an adaptive, iterative process. It's about testing, learning, and adjusting—just like any other system that strives for continuous improvement.

At its core, the SHC bridges three persistent divides in soil science:

1. **Between Measurement and Meaning:** moving beyond static indicator checklists toward dynamic cause-and-effect relationships.

2. **Between Short-Term and Long-Term Thinking:** acknowledging lag time and intergenerational responsibility as design principles for sustainable systems.

3. **Between Science and Society**: incorporating farmer behavior, economics, and policy feedback as integral to soil processes.

By framing soil health management as an iterative system rather than a one-time intervention, the SHC repositions soil science within a broader systems-theory context closer to adaptive management in ecology or continuous-improvement models in human health and medicine.

Human behavior as a soil variable

The SHC distinguishes itself by explicitly weaving the human dimension into the biophysical fabric of soil science. Traditional soil research often isolates field-level variables; however, the adoption of conservation practices hinges as much on economics and psychology as on agronomy. Surveys underscore this reality.

This disconnect has policy consequences. Without credible data linking soil improvements to farm profitability or measurable sustainability outcomes, participation in sustainability programs remains tepid. Maharjan and colleagues call for simultaneous reporting of SHIs and soil function outcomes, a dual-track evidence base that can underpin both scientific confidence and economic justification.

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By placing people at the center of soil health management, the SHC recognizes that behavior, economics, and policy shape outcomes just as much as biology or chemistry. Farmers make decisions based on productivity and profit, not abstract metrics. This makes it necessary to measure both soil indicators and the outcomes they produce—yields, profitability, and ecosystem resilience.

This dual-track approach—monitoring both SHIs and functional outcomes—strengthens the scientific basis for soil health while grounding it in economic reality.

The missing variable: Time

Another critical dimension of the SHC's framework is the role of time. Soil transformation is inherently gradual; organic matter accrues and microbial diversification unfolds over years or even decades.

Lag time is part of the process. It takes persistence to see the rewards of soil structure and organic matter improvements, but those benefits compound over time.

Short-term interventions, such as irrigation management, may yield rapid results, but structural and biological improvements demand persistence. The authors advocate for longitudinal monitoring and a generational perspective, noting that present-day decisions shape soil resilience for decades.

Recognizing this time scale, the SHC calls for long-term monitoring and a generational perspective, aligning agricultural management with the slower rhythms of ecological recovery. Bridging the mismatch between ecological time and financial time will be essential for sustaining positive feedback in the SHC strategy.

Turning theory into practice: The Nebraska soil health school

The SHC offers more than a metaphor. It is a roadmap for translating scientific understanding into sustainable practice. It reminds researchers that soil is both a biophysical entity and a social construct: its health depends as much on microbial respiration as on human aspiration.

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In an era of climate volatility, water scarcity, and food-system strain, the SHC provides a conceptual framework to synchronize agronomy, economics, and policy around a single, cyclical vision of regeneration. Whether this vision can be operationalized depends on the very feedback it describes; between science and society, data and decision, action and adaptation.

An extension effort, the Nebraska Soil Health School (SHS), is expanding to bridge this divide. It is led by Maharjan and Nicole Heldt, UNL research project coordinator.

The SHS was sponsored by the USDA-NRCS and held throughout 2023–2024. It was modeled and developed to meet the needs of agricultural communities across Nebraska's contesting climates. Traveling to seven locations in two years, the school shared applicable soil-health-related knowledge to more than 600 stakeholders. The SHC was inspired by feedback from one such event coordinated by Maharjan.

In 2025, Maharjan combined the principles of the school with the SHC concept to create a community event developed to meet agricultural producers where they are—both geographically and educationally—through targeted, need-based soil health education.

In this form, the school had evolved into a traveling “on-demand” event, bringing UNL faculty, USDA-NRCS specialists, and soil health experts directly to local communities. Producers help plan the agenda, set up the event, and invite their peers, creating real engagement.

The program’s flexibility allows it to address specific regional needs. One notable event took place in Brunswick, NE, where presentations covered topics from no-till systems, soil structure, and cover crops to manure management, biochar use, and the economics of regenerative farming. The format—small group sessions, discussions, and local networking—fostered hands-on learning and peer collaboration.

Completing the circle: The Nebraska Soil Health Coalition

The Nebraska Soil Health Coalition (NSHC), an independent nonprofit 501(c)(3), was launched in May 2023 to advance producer-centered education, outreach, and adoption of soil health principles that build resilient farms, ranches, and communities across Nebraska. The Coalition's long-term success and community impact focus on tangible steps that benefit communities across the agricultural spectrum.

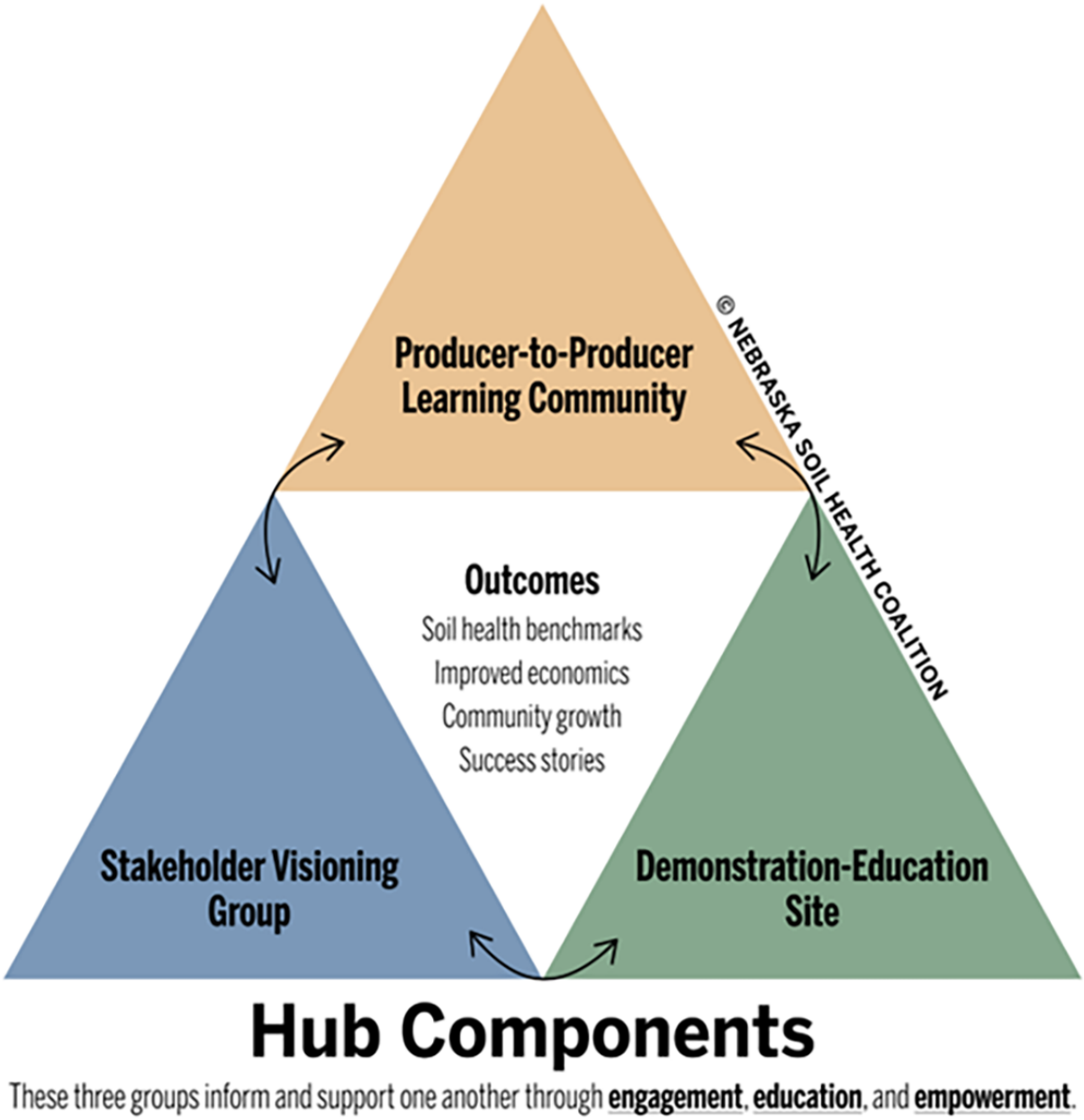
Specifically, the NSHC strives to:

- Increase awareness of the interconnectivity of soil health–plant health–animal health–human health–environmental health–planet health.

- Enhance the relationships between people in production systems, food systems, and their personal community and beyond.

- Facilitate an atmosphere that helps all believe that this is not just a producer opportunity, but also a community opportunity where all will benefit.

The NSHC operates on a “three prong, four outcome approach.” The three core stakeholder groups include producer learning communities, demonstration-education sites, and a stakeholder visioning group. This collaborative process succeeds through partnerships with intentional community partners such as Maharjan and others detailed at https://nesoilhealth.org.



Primary components in individual Hub envisioned by the Nebraska Soil Health Coalition. The NSHC operates on a "three prong, four outcome approach."

The Coalition tracks four interconnected outcomes that form the NSHC loop:

1. **Soil health benchmarking:** Establishing baseline metrics and measuring progress.

2. **Economic return on investment:** Analyzing the financial viability of soil health practices.

3. **Socio-behavioral research:** Conducting interviews to identify incentives and barriers to community adoption.

4. **Stories of success:** Documenting and sharing real-world results from participating producers.

Through this comprehensive approach, the NSHC creates pathways for lasting agricultural and community transformation across Nebraska.

The pilot soil health benchmarking initiative launched this summer in Hub 1, a 10-county region in south-central Nebraska surrounding Hastings. Hub 1 is the first of five eventual hubs planned across the state. These sites serve as the foundation for long-term demonstration and education efforts that integrate systemic learning and build deep relationships within agricultural communities.

In August 2025, Maharjan and his team at the UNL Panhandle Research, Extension, and Education Center partnered with the USDA-NRCS to sample soil from five paired sites across four counties in Hub 1. Each pair included a working agricultural field and a nearby undisturbed reference site representing the region's natural soil conditions. This comparison approach allows researchers to measure the impact of management practices against baseline ecosystem health.

These initial steps support the broader NSHC goal of creating statewide soil health measurements, establishing benchmarks at the beginning of a five-year soil health journey across Nebraska's diverse ecosystems, and then measuring progress over

time. Through this work, the NSHC ensures that Nebraska thrives from Omaha to Scottsbluff and everywhere in between.

A collaborative framework

In many ways, the soil health cycle, the Nebraska Soil Health School, and the Nebraska Soil Health Coalition represent three stages of the same journey—from theory, to education, and to practice. Each initiative reinforces the others in a feedback system that mirrors the very cycle Maharjan's research describes. By merging scientific insight with community-driven implementation, Maharjan and his collaborators have built a model for soil regeneration that transcends disciplines.

In an era defined by climate volatility, resource constraints, and shifting market pressures, the soil health cycle serves as a roadmap—linking agronomy, economics, and education in a shared vision of resilience. These tools are critical to helping farmers, ranchers, and policymakers balance productivity with long-term stewardship while fostering the growth of rural communities.

The challenge now is simple: keep the cycle moving forward—positively toward a future of sustainable agriculture.

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Maharjan, B., Das, S., Thapa, V. R., & Sharma Acharya, B. (2024). Soil health cycle. *Agrosystems, Geosciences & Environment*, *7*, e20504. https://doi.org/10.1002/agg2.20504

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