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REVIEW

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Soil health cycle

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Abstract

Soil health is pivotal to agricultural sustainability. Promoting and sustaining soil health management is challenging since it involves many interdependent components and steps and is an iterative process. Herein, the soil health cycle (SHC) is proposed as a soil health management cycle encompassing human dimensions, management practices, and their effects on soil health indicators (SHIs), leading to subsequent impacts on soil functions. The SHC provides a structure for an iterative testing of changes to improve soil health. A systematic review of research publications was also conducted using the Web of Science database supplemented by Elicit AI and Scopus API searches to determine the status of research reports connecting SHIs to soil function outcomes, a critical component in the SHC. The review focused on publications from 2000 to 2022 and highlighted that most soil health studies separately report the potential roles of soil health practices such as cover cropping, no-tillage or reduced tillage, crop rotation, and crop–livestock integration in improving SHIs or soil function outcomes such as productivity and sustainability. The confidence in the causality of improved SHIs due to practices can be increased by demonstrably linking them to soil function outcomes such as productivity, environmental quality, and profitability. Presenting such evidence might allow us to tease confounding factors apart and present and contextually recommend soil health practices. It will also affect the human dimension in the SHC through informed and beneficial policies and incentives.

1 | INTRODUCTION

Soil health is defined as the continued capacity of the soil to function as a vital living ecosystem that sustains plants, animals, and humans (NRCS, 2023). It also serves as an overarching principle guiding production agriculture toward its goals of sustainability and climate adaptation and mitigation. As a movement, soil health has spurred efforts, policies, and innovations to identify and promote conservation practices and monitor, measure, and verify soil health gains in managed land over the years.

Scores of soil physical, chemical, and biological properties and processes, that is, soil health indicators (SHIs), can measure soil health in croplands. Most SHIs are interrelated and can be mutually predictive (Das et al., 2023). The Soil Health Institute identified soil organic C (SOC), C mineralization potential, and aggregate stability as critical SHIs based on evaluating over 30 SHIs at 124 long-term agricultural research sites across North America (Bagnall et al., 2023). Microbial biomass is another sensitive and effective indicator, as it is

Abbreviations: CCs, cover crops; NT, no-till; PDSA, plan-do-study-act; SDG, sustainable development goal; SHC, soil health cycle; SHI, soil health indicator; SOC, soil organic carbon.

directly influenced by biotic and abiotic factors (J. S. Nunes et al., 2012; M. R. Nunes et al., 2021). Critical SHIs may also be determined by regional and management goal specificity (DuPont et al., 2021).

When it comes to soil health management, there is a consensus among researchers, agencies, farmers, and industries on practices such as cover cropping, no-tillage (NT) or reduced tillage, crop rotation, and integrating crop–livestock systems that promote soil health (Bansal et al., 2022; Blanco-Canqui, 2022; M. R. Nunes et al., 2018). Diversifying nutrient sources through strategic integration of cover crops (CCs), utilization of agricultural residues and byproducts, incorporation of compost and manures, and fostering microbial diversity using microbial consortia are some innovative techniques to enhance soil health (Shahane & Shivay, 2021). Soil health practices play a pivotal role in achieving United Nation's Sustainable Development Goals (SDGs), including addressing hunger (Goal 2), promoting human well-being (Goal 3), ensuring clean water (Goal 6), advancing climate action (Goal 13), combating desertification, conserving biodiversity, and reversing land degradation (Goal 15), and aligning with recent initiatives such as USDA's climate-smart commodities initiative and the European Green Deal aiming for no net greenhouse gas emissions by 2050 (Bonfante et al., 2020).

Besides initiatives and policies, a human dimension at farm levels needs to be accounted for in our soil health management efforts. A recent survey by the Trust in Food (Farm Journal Initiative) reported that 93% of farmers in the United States have heard of the C market, but 97% of them are not ready to participate (Urban & Skoczlas Cole, 2022). A primary challenge for farmers' participation is the uncertainty of financial payoff, as evidenced by the underreporting of soil health practices' contributions to farm productivity and profitability (Ma et al., 2023; Urban & Skoczlas Cole, 2022). While reporting the effects of management on SHIs, the subsequent impacts on desired outcomes of soil functions, particularly, productivity, profitability, and environmental quality, are seldom reported together.

Farm productivity and profitability are critical to farmers' management decisions, while certain agencies and policies may focus on nutrient cycling and environmental stewardship. It is, therefore, paramount to simultaneously report improvements in SHIs and associated soil function outcomes due to soil health practices. Monitoring and reporting these effects would guide policies, incentive programs, and resource investments to improve soil health. Soil function benefits are more straightforward to communicate, aiding in raising public awareness, conservation advocacy, and the broader adoption of soil health practices. Understanding whether soil health practices provide (1) co-benefits, leading to increased SHI values and desired outcome of soil functions; (2) trade-offs; or (3) co-costs, potentially resulting in the degradation of both SHIs and soil function outcomes (Vendig et al., 2023), would be essential to inform soil health management.

Core Ideas

- A very few studies reports soil health indicators and soil function benefits of practices simultaneously.
- Soil health cycle is a feedback cycle to achieve iterative soil health improvement.
- Soil health cycle integrates human dimension, practices, and their impacts on soil health and functions.

In essence, comprehensive soil health management involves several interdependent components, and each of them is crucial for achieving agricultural sustainability, and it will be an iterative process over time. In the field of healthcare management, service quality and safety assessment are driven by methods such as a plan-do-study-act (PDSA) cycle, consisting of a series of interdependent steps that involve planning, executing, and assessing practices and making inferences to iterate the process accounting for local context and complex social systems to achieve iterative quality improvement (Taylor et al., 2013). Analogous to this, soil health management can be better understood and informed using a feedback cycle involving human dimensions, agricultural practices, SHI measurement, and outcome assessment.

The primary objective of this perspective paper is to present and justify the feedback cycle in soil health management, termed soil health cycle (SHC), to achieve iterative soil health improvement. Given that the desired outcome of soil function is central to the feedback cycle, the secondary objective is to present a review of scientific literature determining the current state of research that reports the effects of soil health practices on SHIs and soil function outcomes. Additionally, we acknowledge that site- and resource-concern specificity should be considered during soil health management. There is also a temporal aspect regarding how long soil health practices take to manifest tangible benefits in terms of soil functions.

2 | DEFINITION: SOIL HEALTH CYCLE

The SHC is a feedback cycle in soil health management consisting of a series of interdependent entities and steps that involve human dimensions affecting decisions on agricultural practices, their impact assessment, and making inferences to iterate the process accounting for site-specific resource constraint and complex agroecosystems to achieve iterative soil

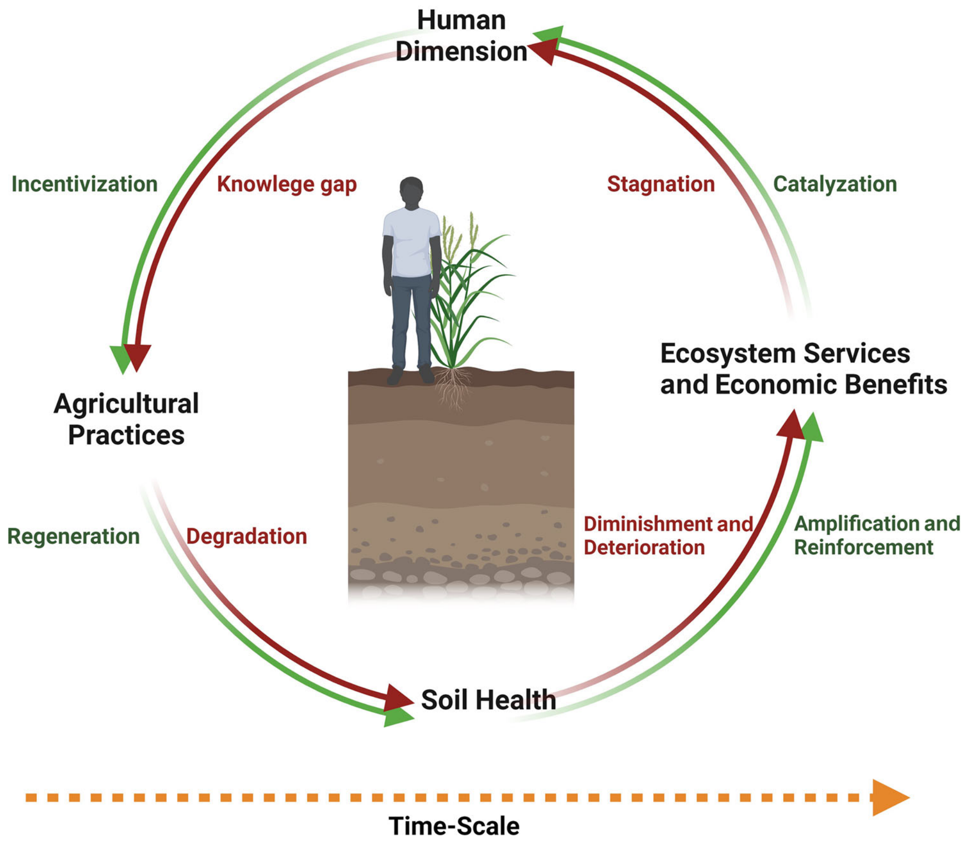

FIGURE 1 Soil health cycle—the feedback cycle in soil health management involving human dimension, agricultural practices, soil health measurement, and ecosystem service benefits. Positive and negative feedback cycles are denoted by arrows and descriptions in green and red, respectively. Positive feedback starts with intentional human decisions based on incentivization (regulation, stewardship, payback, and others), leading to conservation practices, which regenerate soil with measurable soil health improvement using selected soil health indicators. Healthy soil supports, sustains, and enhances ecosystem services, delivering desired outcomes such as profitability and sustainability. The latter catalyzes a further positive human dimension, including individual farm-level decisions, beneficial policies, and incentive programs. A negative feedback cycle, in lack of knowledge or necessary incentive and stewardship, perpetrates soil degradation via conventional practices, leading to diminishing and deterioration of ecosystem services and associated impacts, resulting in the stagnation of human dimensions. The orange dashed arrow line represents the time scale, emphasizing the iterative nature of these feedback cycles over time to achieve agricultural sustainability.

health improvement. In contrast to soil nutrient cycles, where a specific nutrient, its transformations, phases, and transport pathways through soil, plants, microbes, and environment are explored, the SHC is more analogous to management cycles such as the PDSA cycle, which provides a structure for iterative testing of changes to improve the quality of systems. The SHC offers a systematic approach to integrating soil health practices, measuring soil health benefits due to soil health management in terms of productivity, profitability, and environmental benefits and their cumulative impact on policy, economic factors, and human dimensions, which sets the cycle revolving. The cycle consists of four interdependent components: (a) human dimension, (b) agricultural practices, (c) soil health, and (d) ecosystem services and economic benefits (Figure 1).

(a) Human dimension: it is closely linked to agricultural practices through an array of elements, including knowledge, motivations, economic advantages, and regulations, collectively referred to as *incentives*. These incentives encourage farmers to adopt conservation or soil health practices. Conversely, in the negative feedback cycle, obstacles such as knowledge gaps and economic and other challenges hinder the adoption of conservation practices, a condition encapsulated as a *knowledge gap*. The *knowledge gap* scenario could be due to a lack of research and education, imbalanced resource distribution, and incoordination among involved entities such as researchers, advisors, policymakers, farmers, landowners, and others (Vanino et al., 2023).

(b) Agricultural practices: conventional practices such as mono-cropping, tillage, residue removal, and fallow degrade soil properties and processes and, subsequently, limit soil functions (Blanco-Canqui & Lal, 2009; Boincean et al., 2021; Nielsen & Calderón, 2011). The mono-cropping system depletes beneficial soil biota and heavily relies on agrochemicals (Gupta et al., 2022; Pervaiz et al., 2020; Singh et al., 2020). Tillage disrupts soil structure and breaks aggregates, accelerating runoff and erosion (Weidhuner et al., 2021). Removing crop residue exposes soils to erosive forces, increasing the risk of soil erosion. Fallow ground is exposed and lacks biodiversity (Blanco-Canqui & Lal, 2009). In contrast, soil health practices such as no-till (NT), cover crops (CC), and crop rotation improve soil properties and processes individually or synergistically (Agomoh et al., 2021; Blanco-Canqui, 2022; M. R. Nunes et al., 2018; Vendig et al., 2023). Soil health practices should be chosen based on identified resource concerns, climate, site-specificity, and opportunities. A chosen agricultural practice can only either *regenerate* or *degrade* soil health.

(c) Soil health: it will deteriorate if conventional practices such as mono-cropping, tillage, residue removal, and fallow are continued. In contrast, if soil health practices are introduced and continued, soil health benefits can compound over time, building soil resilience. Depending on practices, soil health benefits or impacts can be determined using key and responsive SHIs. Currently, most research literature reports the benefits of soil health practices in improving a selected few SHIs. However, it is crucial to establish the outcome of soil ecosystem services due to soil health practices. The confidence in the causality of improved SHIs due to practices can be increased by demonstrably linking them to soil function outcomes such as productivity, environmental quality, and profitability.

(d) Ecosystem services and economic benefits: conventional practices lead to a precarious condition, accompanied by an acute loss of soil functions (Harkes et al., 2019). In contrast, because of introduced soil health practices, soil grows healthier over time; resists degradation otherwise inflicted by weather impacts and conventional practices; and supports, sustains, and enhances its function as a vital living system providing essential and desired outcomes such as productivity, profitability, and sustainability. The connection between this phase of the cycle and the human dimension is mediated through "catalyzation" in the positive and "stagnation" in the negative cycle. Enhanced ecosystem services and positive economic gains catalyze beneficial policy decisions, prompting governments, industries, and other stakeholders to invest in conservation practices. This investment can, in turn, catalyze behavioral change among farmers to adopt conservation practices. Conversely, in the negative feedback cycle, a deterioration in ecosystem services can result in stagnation, arresting stakeholders' capabilities and willingness to change practices and further intensifying conventional practices, aggravating soil degradation.

The SHC runs in iterative steps through a time scale, and therefore, one should account for time aspects such as lag time, short-term, long-term, and generational perspectives. Lag time refers to the delay between implementing soil health practices and the observable effects on soil health and soil function outcomes. This understanding is critical in managing expectations and planning practices, as some soil health benefits, particularly those related to biological and structural changes, may take years to manifest (Lehman et al., 2015). The cycle encompasses immediate (short-term) and enduring (long-term) effects of agricultural practices. A generational perspective in the SHC acknowledges that the impacts of current practices will extend to future generations (Borda et al., 2023). Pivoting the efforts and growth of soil health research and outreach into exploring and understanding all components of SHC is essential to achieving the goal of agricultural sustainability.

3 | LITERATURE REVIEW—MATERIALS AND METHODS

The data and literature were extensively searched through the Web of Science Core Collection and Scopus database for a systematic review to explore the intricate relationships between SHIs and their impacts on soil functions, economic returns, and environmental health.

3.1 | Keywords

Our research strategy incorporated a wide array of keyword combinations to discuss the topic comprehensively. Initially, we searched the Web of Science Core Collection to identify the number of papers published between 2000 and 2022 that used "soil health" in the title and the trend for such publications over the years. Then, we used "soil health" in our search criteria, specifically using keywords like "soil health + crop yield," "soil health + ecosystem services," "soil health + soil function," "soil health + economic," "soil health + environment," "soil health + challenges," "soil health + future," "soil carbon + crop yield," "soil carbon + ecosystem services," "soil carbon + soil function," "soil carbon + economics," "soil respiration + crop yield," "soil respiration + soil function," "soil respiration + ecosystem services," "microbial biomass + crop yield," "microbial biomass + ecosystem service," and "microbial biomass + environment." This extensive approach aimed to fetch a broad spectrum of publications, allowing a holistic understanding of the subject matter. The search was made using an advanced search query; for example, to search publications on NT and crop yield for the data range of 2000–2022, we used [(TI = (soil health)) AND TI = (crop yield); date range: 2000-01-01 to 2022-12-31]. The exact search option was selected to reduce the number of papers that were not related. We also used Elicit AI (https://elicit.com/) to search for and summarize the abstracts from relevant studies.

We also used Scopus for our research, acknowledging that Scopus indexes a higher number of journals. We employed the "rscopus" package, in conjunction with the Scopus developer API (which can be requested for academic use at https://dev.elsevier.com/), to download manuscripts published in Scopus-indexed journals from 2000 to 2022, along with their abstracts. We sorted the manuscripts and counted the publications that utilized combinations such as "soil health + crop yield" and "soil health + economics" from 2000 to 2022. The codes used in the study are available in the GitHub repository (Das, 2023).

3.2 | Inclusion and exclusion criteria

Our inclusion criteria focused on manuscripts that explicitly discussed the application of soil management practices and their subsequent impacts on SHIs, ultimately leading to improved ecosystem services. We also included studies on the challenges, benefits, and future recommendations associated with soil health and indicators. The exclusion criteria were set to omit manuscripts not directly related to the study's scope, those focusing solely on soil health without establishing links to ecosystem services or other defined outcomes, and manuscripts lacking empirical evidence or purely theoretical without providing applicable results.

3.3 | Data extraction

For this review, we meticulously extracted relevant information, highlighted challenges, underscored associated benefits, and gathered future recommendations from the selected manuscripts. Currently, most soil health assessment frameworks incorporate measurements such as soil organic matter content, pH, and the availability of essential plant nutrients, including macro- and micro-nutrients. Soil C and N-related indicators and structural and physical properties constitute over one-third of the reported SHIs. Another one-third suggest evaluating soil respiration, microbial biomass, or N mineralization rates to assess soil biological and structural integrity. In this review, we selected soil C, respiration, and microbial biomass as the SHIs due to their ability to capture the fundamental processes that underlie soil productivity and ecosystem functioning (Doran & Parkin, 1994; Schloter et al., 2003). Soil C, for example, reflects organic matter content and fertility, while respiration indicates microbial activity and rates of nutrient cycling (Reeves, 1997; Schloter et al., 2003). Microbial biomass, on the other hand, provides insights into microbial community dynamics, which are essential for soil processes (Schloter et al., 2003).

4 | LITERATURE REVIEW—RESULTS

A search in the Web of Science Core Collection gave 541 papers published between 2000 and 2022 that used the terms either "soil health" or SHIs (soil C, respiration, or microbial biomass) in combination with soil function-related phrases such as "crop yield," "economics," "environment," or others as listed in Table 1. The combination of "soil C" + "crop yield" had the most papers published (161), followed by the combination of "soil C" + "soil function" (123) in that period. The combination of "soil respiration" or "microbial biomass" plus "ecosystem service" had none.

The number of publications with "soil health" in the title has consistently grown over the years (Figure 2). A search in the Scopus database indicates a similar upward trend in publications discussing both soil health and crop yield, as observed in recent years (Figure 3A). Similarly, the number of publications assessing the economic benefits of soil health has also seen a rise in recent times (Figure 3B). In 2022, the Scopus database listed 82 publications addressing "soil health and crop yield" (46 in the Web of Science) compared to 15 that used "soil health and economics" (eight in the Web of Science). Although there were output mismatches between the two search portals, there was an encouraging trend of a growing interest in the relationships between soil health practices, SHIs, and soil functional outcomes like productivity, with an increasing number of publications focusing on this area, including the economic aspects (Che et al., 2023; Lampkin & Padel, 1994; Mosquera et al., 2019; Rejesus et al., 2021; Sainju et al., 2021).

5 | DISCUSSION

Most published research reports present the management effects on either SHIs or soil function outcomes separately (Agomoh et al., 2021; M. R. Nunes et al., 2018) (Figure 4). Therefore, how often soil health practices simultaneously improve SHIs and soil function outcomes is not well known. Confidence in the causality of improved SHIs due to soil health practices can be increased by demonstrably linking them to desired soil function outcomes such as productivity, environmental quality, and profitability. Presenting such evidence will affect the human dimension and inform policy and incentive programs to promote the adoption of soil health practices. Therefore, this missing linkage of management effect simultaneously on SHIs and soil function outcomes is

TABLE 1 Number of published papers with specific search keyword combinations in the publication titles in the Web of Science Core Collection in the data range of 2000 to 2022.

Keyword combination	Search query[a]	Search output (number of published papers)
soil carbon + crop yield	(TI = (soil health)) AND TI = (economic)	161
soil carbon + soil function	(TI = (soil health)) AND TI = (economic)	123
soil health + crop yield	(TI = (soil health)) AND TI = (crop yield)	46
soil carbon + economics	(TI = (soil health)) AND TI = (economic)	35
soil health + environment	(TI = (soil health)) AND TI = (economic)	31
soil carbon + ecosystem services	(TI = (soil health)) AND TI = (economic)	29
soil health + challenges	(TI = (soil health)) AND TI = (economic)	21
soil health + future	(TI = (soil health)) AND TI = (economic)	17
soil health + ecosystem service	(TI = (soil health)) AND TI = (ecosystem service)	14
soil health + soil function	(TI = (soil health)) AND TI = (soil function)	14
soil respiration + soil function	(TI = (soil health)) AND TI = (economic)	14
microbial biomass + crop yield	(TI = (soil health)) AND TI = (economic)	12
microbial biomass + environment	(TI = (soil health)) AND TI = (economic)	11
soil health + economic	(TI = (soil health)) AND TI = (economic)	8
soil respiration + crop yield	(TI = (soil health)) AND TI = (economic)	5
soil respiration + ecosystem services	(TI = (soil health)) AND TI = (economic)	0
microbial biomass + ecosystem service	(TI = (soil health)) AND TI = (economic)	0

[a]TI = Title of the paper, and "AND" is a logical operator used in the search query.

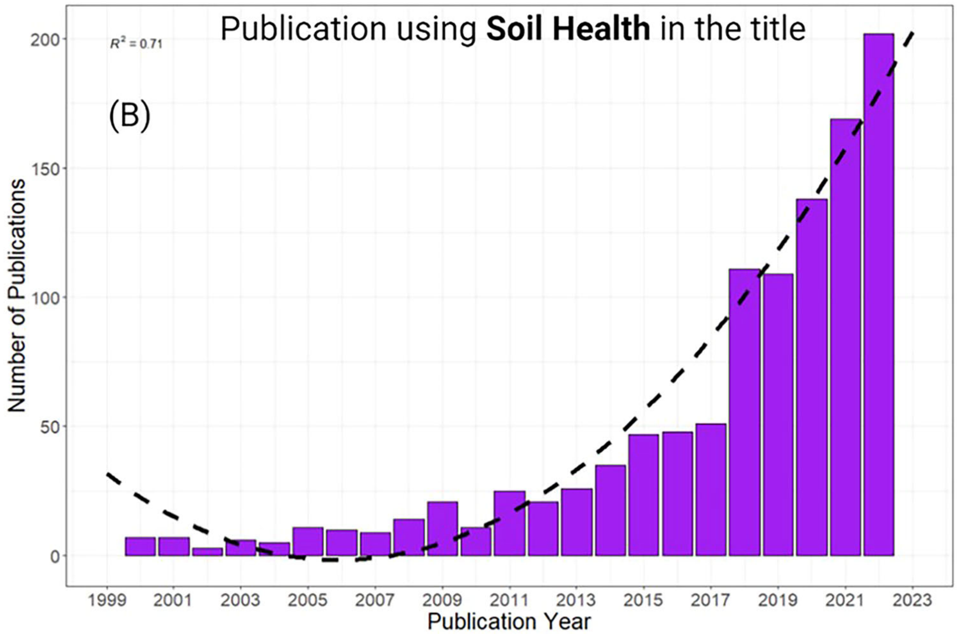

FIGURE 2 Papers published from 2000 to 2022 with Soil Health in the title.

critical to enhancing the positive feedback in the proposed SHC.

The premise of linking SHIs to soil function outcomes relies on the assumption that a gain in soil health will improve nutrient cycling, water retention, and biotic and abiotic stress suppression, eventually leading to increased productivity and sustainability. However, the empirical evidence connecting SHIs to such functional outcomes is minimal, and the

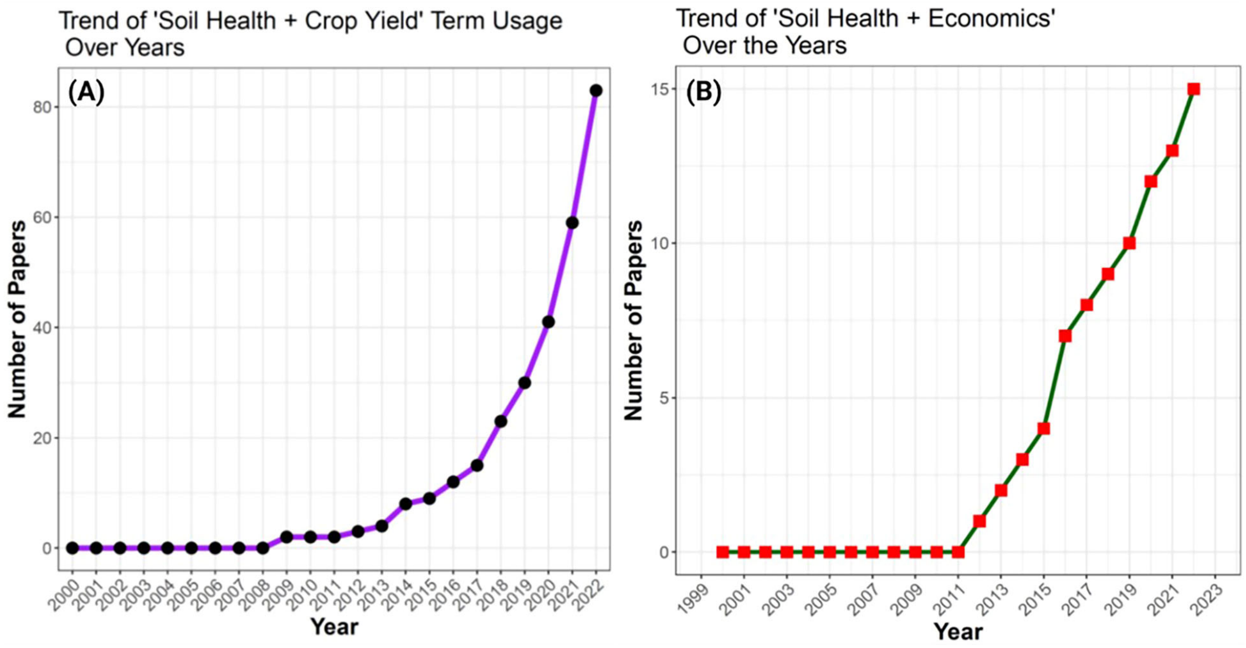

FIGURE 3 Number of Scopus-indexed publications using soil health plus (A) crop yield and (B) economics in their abstracts from 2000 to 2022.

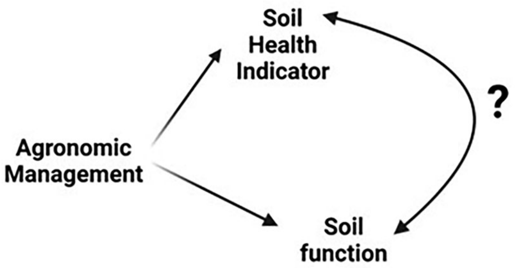

FIGURE 4 The under-reported link (identified by a question mark) in soil health management.

spatiotemporal variations and nonlinear nature of soil health practices and their effects on soil functions are still unclear and uncertain. As we review available separate reports on SHIs and soil functions, soil health practices such as NT are found to improve SHIs and reduce erosion, retain nutrient-rich topsoil, and improve runoff capture and water retention (M. R. Nunes et al., 2018), yet the yield impacts of NT are nuanced, context-dependent, and reliant on the duration of management (Daigh et al., 2019; Giller et al., 2015; Nouri et al., 2019). Similarly, with CCs, maintaining ground cover year-round using CCs is known to improve SHIs such as aggregate stability and infiltration (Acharya et al., 2019; Blanco-Canqui, 2022; Nilahyane et al., 2023). However, the impact of CCs on crop yields is also context-dependent, influenced by factors such as climate, soil type, and management practices (Blanco-Canqui et al., 2015; Snapp et al., 2005). Unless the management effects on both SHIs and soil function outcomes are reported together, it is not easy to know if soil management practices would have trade-offs, co-costs, or co-benefits on SHIs and soil functions. With such a lack of comprehensive data, it is also hard to tease apart the complex interaction of management with edaphic and environmental conditions affecting SHIs and soil functions (Vendig et al., 2023).

There are a few instances where research reports highlighted the link between soil health practices and their influence on SHIs, subsequently enhancing soil functions. A meta-analysis by Vendig et al. (2023) demonstrated direct yield benefits from SOC enhancement through CC in soils with initial SOC levels below 9.2 g kg^{-1}, based on 434 paired observations. In Ontario, Canada, Agomoh et al. (2021) discovered that incorporating cereal crops into continuous soybean (*Glycine max* L.) rotations led to notable improvements in SHIs such as soil respiration, particulate organic matter C and N, and inorganic and potentially mineralizable N. These enhancements accounted for 34% of the soybean yield gain compared to continuous soybean cultivation. Another study by Wade et al. (2020) evaluated the link between soil biological health and crop response to N fertilization through 29 replicated fertilizer N rate trials across the central and eastern Corn (*Zea mays* L.) Belt of the Midwestern United States. They demonstrated that biologically healthier soils produced greater corn yields than unhealthy soils by 18%. Similarly, a recent study exploring the linkage of SHIs to management history and soybean yield, utilizing data from 323 producer-managed soybean fields throughout Wisconsin, identified labile C pool, particularly permanganate oxidizable C, as positively correlated with soybean yield (Malone et al., 2023). All these results illustrate the potential for productivity gains through investment in soil health practices. Such positive feedback for soil health practices catalyzes the human dimension to adopt and sustain soil health management, setting the SHC in motion toward achieving agricultural sustainability.

In addition, such linkage of practices with SHIs and soil function outcomes would inform policy and incentive programs and initiatives at different levels. The current incentive programs from industries and federal initiatives, such as USDA's Partnerships for Climate-Smart Commodities, unequivocally add substantial weight to the positive feedback cycle in the SHC. Particularly, USDA's initiative focuses on expanding markets for climate-smart commodities and supporting small and underserved producers and exemplifies how policy decisions and substantial financial commitments can catalyze behavioral changes in producers, fostering more widespread adoption of climate-smart practices, which, in essence, can be soil health practices. One of the primary objectives of the Climate-Smart Commodities Initiative is to measure, monitor, report, and verify the practice benefits. All these initiatives and future research efforts could generate data to fill the missing linkage between practices, measured soil variables such as C, and soil function outcomes such as environmental sustainability and others.

5.1 | Outreach and time aspect

A European survey by Vanino et al. (2023) identified several barriers or knowledge gaps impeding the adoption of soil (health) management practices. These include a lack of communication and coordination among researchers, advisors, farmers, and other stakeholders, including inadequate training for advisors and farmers, shortcomings in knowledge dissemination due to insufficient or lack of helpful information, and the absence of a standard data policy. Another study showed that >30% of producers in the Midwestern United States are hesitant to participate in the carbon credit market due to insufficient information about the costs and benefits of carbon farming practices and the lack of verified data on the amount of carbon sequestration, which further enhances uncertainty (Wang et al., 2023). There is a notable lack of quantitative data connecting SHIs to crop–yield outcomes or any other soil function outcomes, which is crucial for producers to make well-informed decisions that balance conservation, stewardship, and economic gain. Providing necessary educational materials regarding the relevant cost-benefit of the conservation practices and carbon sequestration potentials of the land will help producers reduce the uncertainties related to the carbon program, which could help increase participation (Wang et al., 2023). These factors associated with the human dimension highlight another critical area where improvement is needed to bridge the knowledge gap and improve the adoption of soil health management practices.

Lastly, the temporal dimensions within the SHC are complex and multifaceted. While certain practices, such as irrigation adjustments, can show immediate results, others, such as building organic matter content, are inherently long-term processes. Balancing short-term needs with long-term sustainability is a key challenge in soil health management. In an iterative SHC, management practices need adjustment and adaptation based on continuous monitoring and learning. This approach is critical given the variable time scales at which different soil processes and management impacts occur. It allows for the refinement of strategies in response to observed changes and emerging challenges. The influence of policy and market dynamics on soil health practices also often unfolds over varying time frames. The long-term view emphasizes the importance of sustainable practices that not only meet present-day needs but also ensure the health, productivity, and sustainability of soils for future generations. A survey by Das et al. (2022) in Nebraska showed that leaving a healthy land for future generations is one of the top motivations for adopting soil health management. Understanding these time-dependent components is essential for developing effective, sustainable soil health strategies responsive to immediate challenges and long-term goals. By considering the full spectrum of temporal factors, from lag time to generational impacts, we can better navigate the intricacies of SHC for enduring agricultural sustainability.

6 | CONCLUSION

There has been a growing body of literature on soil health over the past two decades. Soil health principles have been progressively integrated into agricultural policies, educational programs, and extension services, reflecting a broader acceptance and adoption of these management practices within the farming community and beyond. Evaluating the impacts of soil health practices on SHIs is a preliminary step in our efforts to enhance soil health practice adoption. The confidence in the causality of improved SHI can be increased by demonstrably linking them to soil functions such as productivity, sustainability, and profitability. Such presentations will inform policy, incentive programs, and initiatives affecting the human dimension to adopt and sustain soil health practices. Therefore, besides reporting SHIs, soil health experiments and reports should include one or more of the soil function benefits, specifically crop productivity (for food security), environmental quality and stewardship (for climate adaptation and mitigation), and economics (for farm profitability and social equity). Such an extensive database may also allow us to tease confounding factors apart and present and contextually recommend soil health practices. The SHC proposed herein encompasses all interdependent components and steps in soil health management and acknowledges the inherent challenges in promoting and sustaining soil health practices. Particularly, it emphasizes the necessity to bridge the gaps in relationships between practices, SHIs, and soil function benefits.

AUTHOR CONTRIBUTIONS

Bijesh Maharjan: Conceptualization; investigation; methodology; project administration; resources; supervision; validation; writing—original draft; writing—review and editing. **Saurav Das**: Conceptualization; data curation; formal analysis; investigation; methodology; software; validation; visualization; writing—original draft; writing—review and editing. **Vesh Thapa**: Methodology; software; validation; writing—original draft; writing—review and editing. **Bharat Sharma Acharya**: Methodology; writing—original draft; writing—review and editing.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

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