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FEATURE

Reflections for enhancing participatory research and outreach from a multistakeholder soil health program

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There is a growing recognition that soil health should be embraced not only as a property to measure and monitor but also as an overarching principle aligned with sustainability goals (Lehmann et al. 2020). This requires integrating different but complementary knowledge, skills, and values shaping the conceptualization and application of soil health among researchers, farmers, policymakers, and conservation professionals (Wade et al. 2021). Collaborative approaches that emphasize applied research where stakeholders such as farmers are included as active participants represent an effective method of technology and innovation transfer required to address several agricultural challenges (Thompson et al. 2019; Wood et al. 2014).

The University of Nebraska-Lincoln (UNL)/USDA Natural Resources Conservation Service (NRCS) Soil Health Initiative (SHI) was an example of applied research efforts integrated with extension involving farmers, extension educators, and other partners across the state (Krupek et al. 2019a, 2019b). This collaborative project conducted from 2017 to 2022 has been a catalyst for successful and ongoing state-wide research collaborations that have continued to evolve (UNL 2023a, 2023b). Reflections and synthesis of information observed and collected from different time points throughout the five-year project demonstrated consistent improvements in soil health and limited negative yield impacts, aligning with other long-term on-farm research studies. Additionally, we found evidence confirmed by prior literature of who are the trusted arbiters of soil health that can be expanded on. Finally, Nebraska stakeholders who attended on-farm research meetings—including growers, agronomists, industry, and government employees—gained valuable insights into soil health. Our reflections at the end of this project highlight the value of participatory research and outreach. We conclude with a framework based on our learnings for future initiatives supporting soil conservation in agricultural landscapes.

LEARNINGS FROM THE FIVE-YEAR ON-FARM EXPERIMENTATION ON SOIL HEALTH MANAGEMENT

Farmers participating in the SHI conducted five-year strip trials with treatments selected by farmers based on their unanswered soil health-related research questions and land management goals. All experiments included cover crops in some capacity, with some introducing cover crops for the first time in their operations, some including different species comparisons, and others with grazing or crop rotation in field-wide treatments. On-farm studies rationale, objectives, results, and observations were compiled yearly into annual research reports, and final cumulative reports were included in *2021 On-Farm Research Results* (Nebraska Extension On-Farm Research 2021), along with all other on-farm studies. Data collection and analysis presented in each individual on-farm report were a collaborative endeavor involving students, faculty, staff, NRCS specialists, and extension educators within the UNL system. On-farm reports were reviewed internally to verify the data review process before publication at the university's online repository (UNL 2023c).

On-farm studies that were part of the SHI as well as all those within Nebraska Extension were presented and discussed as part of the Nebraska On-Farm Research Network (NOFRN) annual meetings. These are a series of events hosted at several locations across the state to share on-farm research findings (Thompson et al. 2019). These gatherings bring together a broader audience of farmers, university, and agricultural stakeholders (e.g., agronomists, industry, and government employees) than those that were involved in the SHI and provide farmers with the opportunity to present their on-farm research projects as speakers, followed by presentations by specialists and roundtable discussions among attendees.

Multiple soil, agronomic, and economic responses were documented as part of the five-year SHI on-farm trials (figure 1). These include findings accumulated over time on how cover crops impact soil properties, crop performance (i.e., yields), and partial net returns at the farm field scale. Overall, cover crops resulted in neutral impacts on subsequent corn (*Zea mays* L.), soybean (*Glycine max* [L.] Merr.), and small grain yields on 32 of 37 farm-year comparisons, but both slightly positive and negative yield impacts were documented (figure 1). In the remaining cases, corn, soybean, and small grain yields were mostly not affected by cover crops (figure 1). Like yield impacts, marginal net returns were in most cases either neutral or positive, with some negative economic impacts also documented (figure 1). The observed limited negative yield impacts, particularly for corn and soybean, align with other numerous long-term on-farm research studies conducted in the region (Practical Farmers of Iowa 2019).

Figure 1 also shows the impact of soil management comparisons on soil health,

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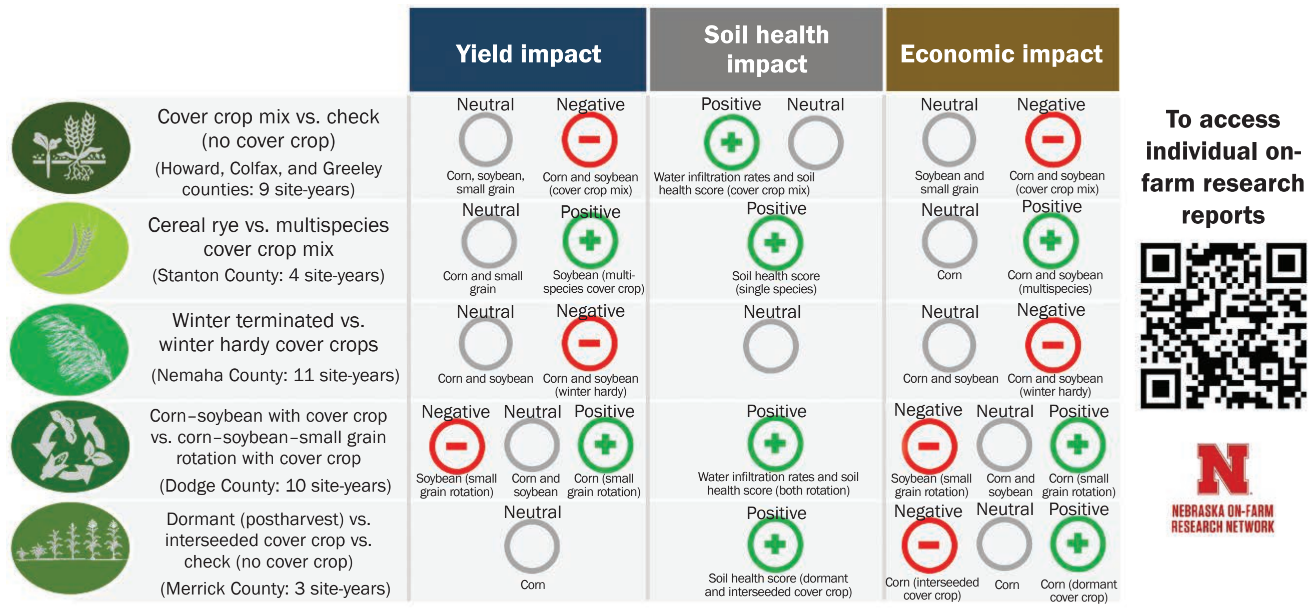
Figure 1

Summary of 37 site-year reports on yield, soil health, and economic impacts of management comparisons conducted as part of the Soil Health Initiative five-year demonstration projects. Information on number of site-years, treatments, and field county location are included. Soil health properties in the assessment included infiltration, soil moisture, bulk density, soil temperature, soil respiration (Modified Solvita burst test), and observational soil health score. Soil health score was based on a field assessment of the following eight indicators: soil structure, structure type, surface condition, soil management, soil pores, earthworms, biological activity, and smell. Net revenue calculations considered input costs provided by producers, application costs from Nebraska Extension's Nebraska Farm Custom Rates, and average commodity market prices for each growing season.



which was assessed considering properties such as water infiltration rate, soil moisture, bulk density, soil temperature, and soil respiration (Modified Solvita burst test), as well as an observational soil health assessment based on field inspections performed during soil sampling. Generally, we observed either neutral or positive impacts of management comparisons on soil health across the five-year experimentation on farms. Many changes in physical, chemical, and biological soil properties, as well as agronomic and marginal net return responses, are complex and variable, as shown in our five-year summary results (figure 1) and reported in the literature (Giannini et al. 2023). For example, soil aggregate stability, infiltration rates, and microbial indicators quantified using meta-analysis are shown to be very responsive (fewer than three years) to changes in cover crop and no-tillage use (Stewart et al. 2018). Similarly, Wood and Bowman (2021), quantifying the impact of on-farm use of cover crops at both temporal (two to five years) and spatial (regional to national) scales, found that active carbon (C) concentration was the most responsive indicator of soil health. Other soil properties, such as soil organic C accumulation, might take greater than five years to detect significant changes due to management interventions that reverse soil degradation (Angers and Eriksen-Hamel 2008).

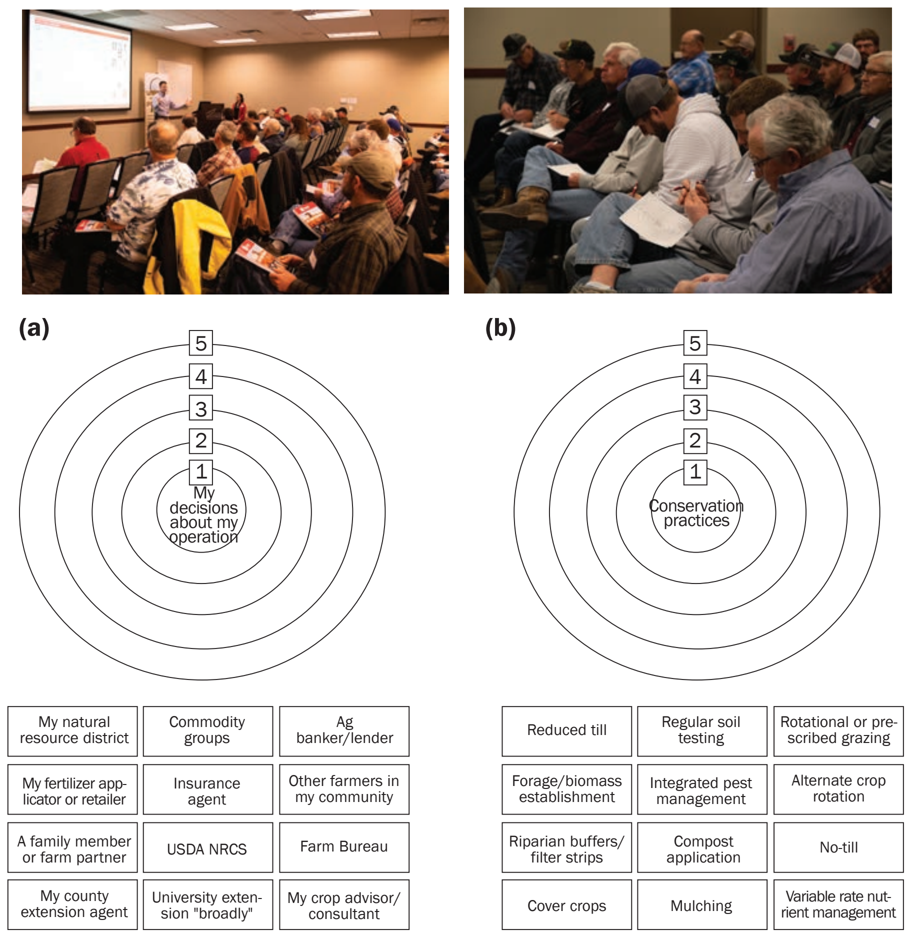
Using a farmer-initiated approach to on-farm experimentation, research questions related to cover crop use for soil health management were generated by the farmers based on their natural resource concerns and management goals (Ranjan et al. 2020). While some farmer partners introduced cover crops into their operations for the first time, others who were familiar with the practice decided to test adjustments to species composition, livestock integration, and cash crop rotation by joining the five-year SHI trials. This provided them with hands-on learning opportunities in the environment where changes in management practices were implemented, which is seen as an effective way to encourage voluntary behavior change among farmers (Dayer et al. 2018). Recent syntheses of the literature identified factors such as habit forming, farmer cognition (e.g., perception of control over the conservation practice and positive experiences with the program), and resource availability (e.g., time, capital, labor, knowledge, and equipment) as possible pathways for promoting behavioral persistence beyond the spatial and temporal scope of conservation programs (Dayer et al. 2018). While the learning and experiences with the five-year SHI project could support factors leading toward conservation behavioral persistence, farmers make decisions in social contexts. Thus, social network plays another important role—in this case, affecting not only farmers' decision to take soil conservation action, but also their post-initiative behavior of practice persistence or disadoption.

SOCIAL NETWORKS IMPACT ON FARMERS' DECISION-MAKING AND CONSIDERATIONS OF SOIL HEALTH IMPROVING PRACTICES

Creating socially supportive environments is more likely to yield long-term environmental gains and successfully encourage on-farm adoption of agricultural conservation practices (Dayer et al. 2018). The annual meetings promoted by the NOFRN were an important vehicle to share learnings from the SHI yearly reports and project results and network with a broader community of farmers and stakeholders. Mapping activities were performed with farmers and stakeholder groups to consider the impact of social networks on conservation decision-making at the 2020 OFRN Annual Meeting, when most of the SHI demonstration fields were reaching the halfway point of the five-year project (figure 2). At the meeting, the OFRN and NRCS led a special soil health and cover crop update focus with 101 attendees present. Activities were facilitated by the project personnel and voluntarily performed by a total of 30 farmers and a broader range of participants, including 19 extension personnel, conservationists, and crop advisors.

Figure 2

(a) Decision-making and (b) conservation practice mapping exercises performed with farmers, extension personnel, conservationists, and crop advisors at the 2020 On-Farm Research Network Annual Meeting, the year when most of the Soil Health Initiative demonstration fields were reaching the halfway point of the five-year project. Photos courtesy of Laura Thompson.

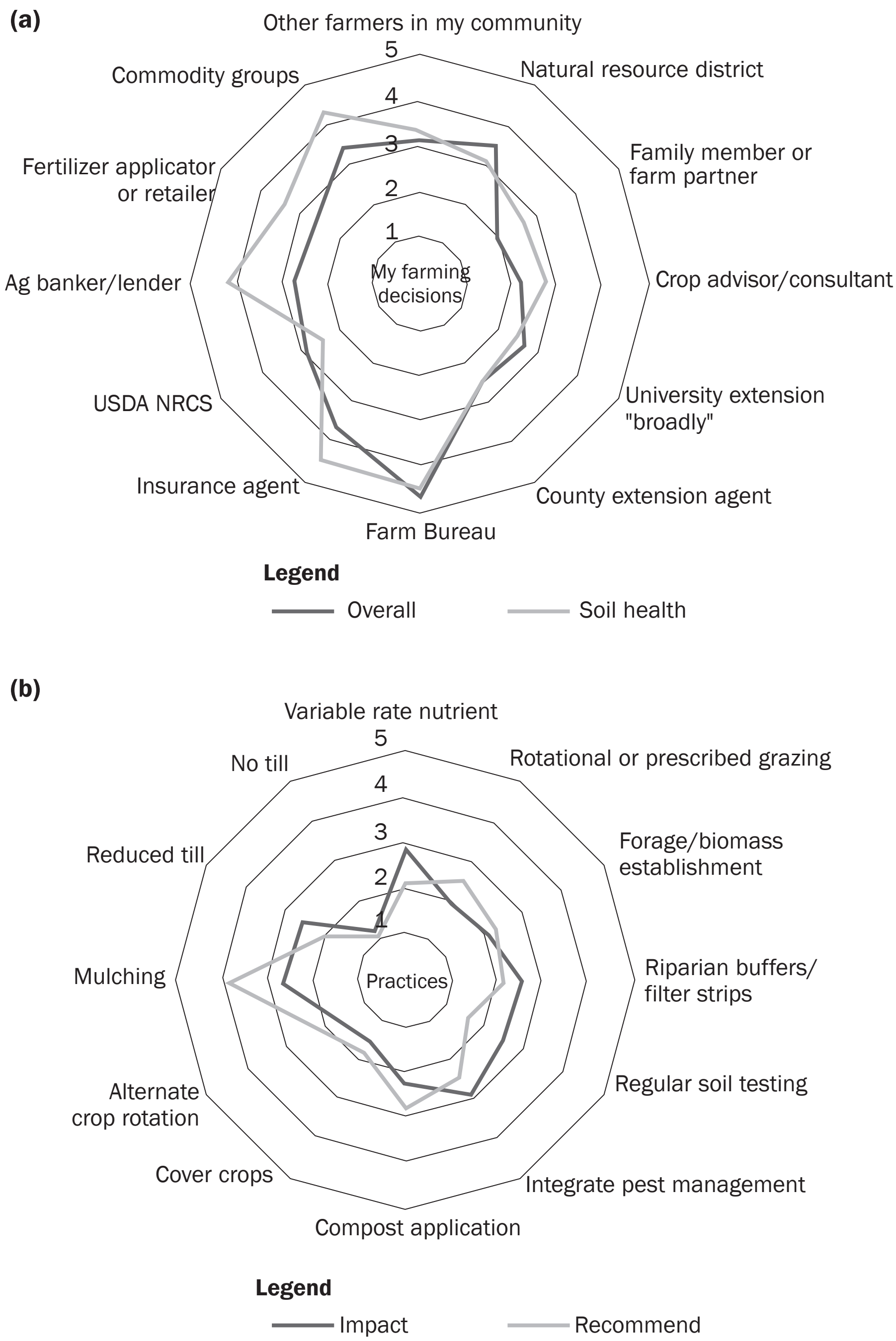


The decision-making mapping activity provided farmers with several sheets of paper indicating different groups of people (e.g., natural resource district, commodity groups, family members or farm partner, and commodity groups) along with circular grid paper consisting of concentric circles labeled with a scale from 1 to 5 moving outwards and with "My decisions about my operation" at the center. Farmers were asked to complete a two-part task: score how large of an impact the groups of people have (1) on their overall decision-making and (2) on their decision-making related to soil health management, by placing higher-impact groups closer to the center of the circular grid (figure 2a). Similarly, as part of the conservation practice activity, extension personnel, conservationists, and crop advisors were asked to (1) evaluate their perception of the impact of management practices (e.g., no-tillage, cover crops, mulching, alternate crop rotation, and compost) on improving soil health and (2) their willingness to recommend those practices to a farmer. Practices placed closer to the center of the grid were assigned a lower score on a 1 to 5-point scale and viewed as having a larger impact on soil health or more likely to be recommended (figure 2b). Mapping activities followed methodology proposed by Oreszczyn et al. (2010) in a study focusing on the role of influential networks on farmers' engagement with and learning about agricultural innovations.

Figure 3a illustrates the priority ranking of each group among participants. Family member or farm partner (mean response of 2.0/5.0 for overall decisions and 2.7/5.0 for soil health decisions), other farmers in the community (mean response of 3.1/5.0 for overall and 3.3/5.0 for soil health decisions), crop advisor/consultant (means response of 2.3/5.0 overall and 2.8/5.0 for soil health decisions), university extension (mean response of 2.7/5.0 overall and 2.5/5.0 for soil health decisions), and conservationists within NRCS (mean response of 2.9/5.0 for overall and 2.5/5.0 for soil health decisions) were the groups with the greatest impact on farmers' both overall decision-making as well as decisions related to soil health (figure 3a). The second activity focused on practices that extension personnel, NRCS conservationists, and certified professional advisers perceived to have the greatest impact on soil health and were most willing to recommend to farmers. Figure 3b illustrates the priority ranking of each management practice among partici-

Figure 3

(a) Farmer (n = 30) evaluation of people or groups impacting their farming decisions overall and related to soil health. A score closer to one (center of the grid) indicates groups viewed as having a larger impact, whereas a score closer to five (toward the outer edge of the grid) indicates groups viewed as having a lesser impact on farmers' decision-making. (b) Extension professionals', conservationists', and crop advisors' (n = 19) evaluation of the impact of management practices on improving soil health and their willingness to recommend the practices to a farmer. Scores closer to one (the center of the grid) indicate practices viewed as having a larger impact on soil health or are more likely to recommend. Scores closer to five (toward the outer edge of the grid) indicate practices with a lesser impact or are less likely to recommend.



pants. No-tillage (mean response of 1.3/5.0 for practice impact and 1.2/5.0 for practice recommendation) and cover crops (mean response of 1.5/5.0 for practice impact and 1.8/5.0 for practice recommendation) were the practices ranked as both greatest impact on soil health and most likely to be recommended to farmers.

Consistent with prior research (Eanes et al. 2019), certified professional advisers held positive attitudes toward soil health-promoting practices, particularly cover crops and no-tillage in our study, and were willing to facilitate practice adoption by recommending them to their clientele. Also aligned with prior literature, family members and farming neighbors are also members of the farmer's web of influencers that, according to our findings, could represent trusted arbiters of soil health that can be expanded on (Oreszczyn et al. 2010). Interaction with agricultural advisors and other farmers coupled with trust in different information sources influence farmers' climate change beliefs and adaptation strategies, including the adoption of soil health practices (Arbuckle et al. 2015; Roesch-McNally et al. 2018; Prokopy et al. 2015). Farmers' knowledge of soil health is a social relation that comes about through interactions with trusted sources (Bell 2004). Thus, understanding the role these "intermediaries" play in farmers' decision-making is critical for leveraging networks of trusted, on-farm professionals to meet both informational and technical assistance needs related to soil health management. These include, but are not limited to, cooperative extension and NRCS employees working alongside industry professional advisers (e.g., certified crop and professional soil advisors) to bring the latest soil health information, techniques, and technologies to farmers.

Additionally, our results demonstrating positive perceptions toward practices such as no-tillage and cover crops on improving soil health (figure 3) align with prior studies documenting increased interest in practices supporting ecologically based production systems (Baumgart-Getz et al. 2012; Knowler and Bradshaw 2007; Oliveira et al. 2019). Overall, insights from decision-making and conservation practice mapping exercises add a new dimension to the role

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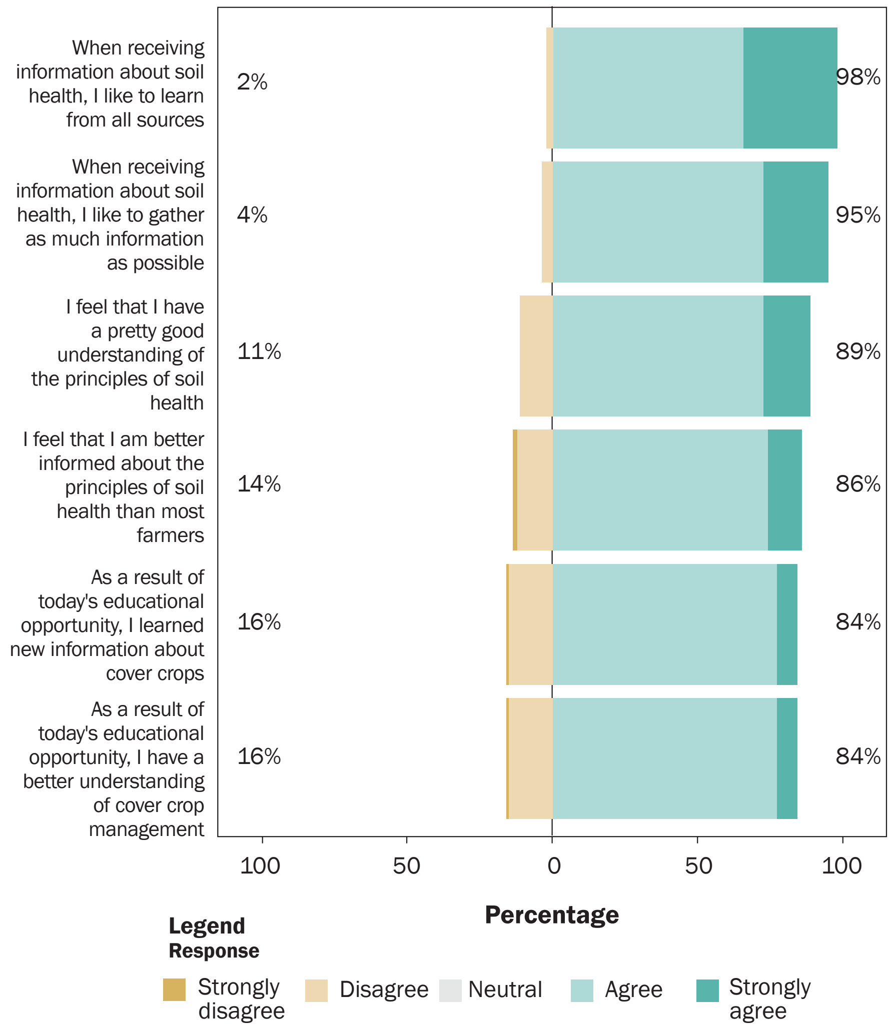
of central and trusted organizations such as extension and government conservation agencies in fostering networking opportunities between well and less-connected farmers, particularly across ecoregions, to establish new, trusting relationships for information exchange while leveraging the existing network structure. Considering the average age of farmers in the United States is 57.5 and continues to increase (USDA NASS 2019), beginning and young farmers may represent a key group who could be leveraged to help spread information about soil health by virtue of having more connections to others (Parks 2022).

LEARNINGS FROM A BROADER STAKEHOLDER COMMUNITY INTERESTED IN SOIL HEALTH

We also examined post-meeting evaluation survey data from the 2020 and 2021 NOFRN annual meetings. Data from the SHI reports covering the fourth and fifth years of implementation, monitoring, and evaluation of soil health management practices on farms (figure 1) were presented and discussed as part of the 2020 (hosted in January and February in person) and 2021 (hosted mostly online) NOFRN annual meetings, respectively. A post-meeting evaluation survey instrument was distributed to event attendees (*N* = 101 and 300 for the 2020 and 2021 meetings, respectively), and the survey included several types of questions, from yes/no and rating statements, to open-ended questions to gauge meeting attendees' demographics and general program evaluation and feedback. We focused on summarizing post-meeting survey question results related to cover crops and soil health, which are the possible SHI contributions to attendees' knowledge exchange from these annual meetings. A total of 47 and 62 attendees completed the survey in the 2020 and 2021 meetings, respectively.

Post-event survey results from the 2020 and 2021 annual meeting impact reports included 84% participant agreement for the statements "As a result of today's educational opportunity, I have a better understanding of cover crop management" and "I learned new information about cover crops" (figure 4). To the extent which this collaboratively designed on-farm research provided farmers with an improved understanding of the benefits of management practices utilizing principles of soil health (e.g., maximizing biodiversity, soil cover, growing continuous living roots, and minimizing soil disturbance), experiences with this partnership could translate into farming benefits in the long term as farmers are exposed to experiments tailored to individual farming operations.

Figure 4
Summary of 2020 and 2021 impact reports from post-event survey at the annual meetings of the Nebraska On-Farm Research Network.



LEARNINGS ABOUT DATA COLLECTION, COMMUNICATION, AND PROJECT PARTNERS' INVOLVEMENT FOR ENHANCING PARTICIPATORY ON-FARM RESEARCH

Farmers reported that in 32 of 37 site-year comparisons, cover crops had no effect on corn, soybean, and small grain yields. Significant yield increases or decreases following cover crop management practice adoption on farms were site-specific, with yield reductions in the range of 315 to 940 kg ha^{-1} for corn and 60 to 400 kg ha^{-1} for soybeans. Similarly, significant yield increases were site-specific and in the range of 470 kg ha^{-1} for soybeans and 1,255 kg ha^{-1} for corn (figure 1). In the context of soil health improvements, we observed either neutral or positive impacts of management comparisons on soil health across the five-year experimentation on farms (figure 1). We also identified other farmers in the community, family members, university extension, crop advisors/consultants, and conservationists, who were perceived to have a greater impact on farmers' decision-making than other stakeholder groups. Some of these influential groups ranked cover crops and no-tillage as practices having the largest impact on soil health and were more likely to recommend them to farmers (figure 3). Further, we found that annual networking meetings were an important vehicle for presenting on-farm research results to a broader community of farmers and stakeholders interested in learning about cover crops and soil health (figure 4).

While implementation of the SHI encountered many of the complex challenges reported by other colleagues involved in similar state-wide soil health programs (Kladivko et al. 2019), multistakeholder initiatives for soil health research and education are collaborative efforts with the potential to serve as a bridge between scientific and applied knowledge. According to Hardie Hale et al. (2022), many factors of the collaborative research process influence effective learning and networking amongst project partners: having mutually beneficial goals, sharing ownership of the collaborative research process, building trust, integrating knowledge, and institutional alignment.

As we reflect on the design and implementation of the SHI, there are several opportunities for future research projects and partnerships to closely connect academia, practitioners, and communities to advance the study and implementation of soil health practices using on-farm research. Breaking up the collaborative research process into before, during, and after research activities as displayed in table 1 may help to conduct on-farm research that recognizes the project partner's pre-existing knowledge and strengths, as well as engage in reciprocal partnership and participatory processes.

Even though soil health initiatives across the United States have historically focused on cultivating stewardship ethics and pro-environmental values, not all farmers willing to adopt or already adopting soil health-promoting practices consider land stewardship as their primary motivating factor (Dayer et al. 2018; Prokopy et al. 2019). Thus, activities suggested "before" the research cycle are intended for interactive relationship-building, which can help to understand farmers' perceptions and motivations about soil health as well as facilitate the adoption of new practices and technologies (Oreszczyn et al. 2010). Activities conducted "during" the research process include the design of the on-farm treatments, regular formal and informal meetings with project partners to provide updates on the data collection process, and preliminary results, as well as learning about things happening on the farmers' side (needs, concerns, or changes in management plans). "After" the research cycle activities include communicating all (or key) research findings back to community partners and practitioners in a timely fashion and in a format that is understandable to them, as well as conducting hands-on workshops or field days to facilitate adaptive management decisions following the research cycle. While this framework is not meant to be prescriptive, comprehensive, or a list of rules, it might be a starting point for dialogue and reflection for advancing the participatory, interdisciplinary, and collaborative research addressing soil health.

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Table 1

On-farm research framework for designing investigations of farming enterprises supporting soil health through an agroecology lens.

Before	During	After
✓ Relationship-building, site visits, and periodic communication with farmers, extension educators, industry representatives, scientists, and community stakeholders. ✓ Engage in stakeholder meetings for research needs assessments. ✓ Identify available/ongoing research efforts and build capacity from those resources. ✓ Support targeted education for professionals on conducting multiyear inter/transdisciplinary on-farm research to help address issues from diverse perspectives (e.g., environmental, social, ecological, economic).	✓ Identify the practitioners' most pressing needs or interests and opportunities that would improve production and farming systems enterprises. ✓ Establish research projects to address identified needs and opportunities. ✓ Promote the involvement of practitioners in the project design, establishment, and data collection. ✓ Adapt to practitioner's availability, farming system, equipment, reservations, and preferences for research participation.	✓ Communicate research findings in a timely manner via diversified outlets capable of capturing a broader audience (e.g., field days, videos, workshops, seminars, written reports, and fact sheets). ✓ Create experiential learning opportunities to demonstrate the use of agroecological practices, highlighting key findings for improved management practices. ✓ Seek periodic feedback from stakeholders (e.g., research feedback on what went well/wrong, and what is still needed).

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