**Mental models of soil health in the Midwest: Does everyone have the same understanding?**

Margaret A. Beetstra[1]

School of Environment and Natural Resources, The Ohio State University

**Abstract**

Having a different understanding of soil health and what else it relates to can lead to divergent mental models of the concept. In turn, having these differing mental models may impede communication and the ability to answer applied research questions. To explore this idea, we used a large survey across three targeted groups, farmers, Natural Resources Conservation Service (NRCS) employees, and agricultural researchers from the Midwest, to provide evidence that soil health is equally prominent within the mental models of all three of these groups. However, NRCS personnel and researchers consistently undervalue the importance of soil health to farmers and do not consider soil health as holistically as farmers do. The differences in how groups conceptualize the relationships between soil health and related factors suggest that soil health plays a more central role in causal relationships for farmers than it does for NRCS personnel or researchers. Our results underscore that a greater understanding of these relationships is essential for effective communication about on-farm practices that build soil health, the development of applied research programs, and efficient use of research and extension resources.

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[1] Other authors include: Jordon Wade (School of Environment and Natural Resources, The Ohio State University; Department of Crop Sciences, University of Illinois at Urbana-Champaign), Matthew L. Hamilton (School of Environment and Natural Resources, The Ohio State University; Sustainability Institute; The Ohio State University), and Steve W. Culman (School of Environment and Natural Resources, The Ohio State University).

**Introduction**

Soil health is becoming an overarching framework amongst farmers, policymakers and the agricultural research community to conceptualize soil conservation and management. The increased use of this concept is important to consider in more depth, though, because its usage can be inconsistent. More specifically, soil health has biological, chemical, and physical components and is used in a variety of different contexts (Arias et al., 2005; Cardoso et al., 2013; Fine et al., 2017; van Bruggen and Semenov, 2000), making it difficult to know if everyone using the term is thinking about it in the exactly same way. Increased discussion of soil health among various entities like farmers, policymakers, and researchers, as well as in the farm press (Arbuckle, 2016), illustrates that soil heath knowledge is transmitted through complex networks of information, rather than originating from a single source (Wick et al., 2019). This is emblematic of a transition from the traditional model where knowledge is produced "by scientists, repackaged by extension officers, and launched at farmers" (Carr and Wilkinson, 2005) to a more interactive, network-based model where farmers and researchers stand on more equal footing (Lubell et al., 2014). As these networks broaden, thought patterns may diverge to yield pronounced differences between groups (Mathevet et al., 2011). At present, there is no systematic description of how different stakeholders conceptualize soil health.

In the context of soil health, this divergence was described early on by Romig et al. (1995) and has produced distinct knowledge patterns where farmers possess the "know how" and agricultural researchers possess the "know why" (Ingram et al., 2010). These distinct patterns might stem more deeply from differences in the psychological distance of knowledge by farmers, researchers, and other groups. Farmers tend to have minimal psychological distance from their work as they are actively managing their operation and working the land themselves. This makes aspects of the soil and its health more spatially and temporally close and makes understanding of the soils very context-specific. In comparison, most agronomic researchers also engage with soils, but many do it in a more distant way in a laboratory or via short visits to agricultural lands. This distance has the potential to result in an understanding of the soil in a less context-specific way that allows researchers to think about soils in very specific biological, chemical, and physical ways. These diverging thought patterns suggest that the mental models surrounding soil health may differ among farmers, outreach educators, and scientists (Lobry de Bruyn and Andrews, 2016). Mental models are representations of how people make sense of the world around them by testing assumptions about causal relationships among states of affairs, concepts, or factors (Craik, 1967; Johnson-Laird, 1983; Byrne and Johnson-Laird, 2009). They act as a filter through which the external world is perceived, informing the assessment of risks and benefits, the assimilation of knowledge, and ultimately, decision-making. Accounting for farmer mental models in extension programming increases the likelihood that the advice will be implemented (Eckert and Bell, 2005).

Understanding how different groups conceptualize soil health is a key step towards continued and more effective collaborations to improve agricultural sustainability. To this end, we focused on three groups within the Midwestern US—grain crop farmers, Natural Resource Conservation Service (NRCS) personnel, and agricultural researchers with soil health expertise—to: 1) evaluate the perceived importance of soil health to farmers by each group, and 2) investigate differences and similarities in their mental models surrounding soil health.

## Materials and Methods

### Survey development and mental model construction

We used a survey to understand how three distinct groups of agricultural stakeholders conceptualized soil health. To inform the survey, we first conducted semi-structured phone interviews lasting 30-60 minutes with 5-10 members of each group of interest. In the interviews, we asked questions about potential factors that contribute to soil health in natural, socio-cultural, knowledge, and economic categories in an effort to understand how different individuals think about the soil health and its relationship to other important concepts. Using these recorded interviews, we performed content analysis and identified 19 emergent themes that at least two interview participants had discussed. From there, we combined and eliminated themes to reduce the complexity of the set, resulting in six final emergent themes related to soil health: soil fertility and biological functioning, soil physical functioning, crop productivity, profitability, environmental harm, and agrochemical inputs.

Using these six themes, we developed a novel survey structure to capture mental models of our three participant populations. Typically, data collection for mental models occurs in-person, either via interviews or focus groups, and captures the ideas of a small number of individuals within a limited geographic scope (e.g., Eckert and Bell, 2005; Jabbour et al., 2014). The resulting mental models produced from this type of data collection include dozens and dozens of different connected ideas, people, or organizations. However, the external validity of this form of mental modeling is exceedingly low, as the methodology more closely take on a case study approach. In the present study, we were more interested in understanding the mental models of multiple, large groups of people across an entire region of the United States. Therefore, the new mental model approach used here with fewer connected ideas (the six emergent themes plus soil health), but was asked over much larger samples. This both increases the external validity and allows for a broader picture of what is occurring across the Midwest.

We created two versions of the survey, one for farmers and the other for NRCS employees and researchers. In the farmer survey, we first asked respondents to rank the priority of soil health on their farm from 0 (not a priority) to 10 (highest priority). Similarly, we asked NRCS and researcher respondents in their survey to evaluate the degree to which they believed farmers prioritize soil health. Second, to better understand the mental models surrounding soil health within each group, we wanted to explore perceived causal linkages among emergent themes, including soil health. In both versions of the survey, for each pair of themes (X,Y), multiple choice questions asked what effect an increase in X causes on Y, where the provided responses were “increases” (+1), “decreases” (-1), or “they are not related” (0). We used each respondent’s answers to these answers to construct a network comprised of causal linkages among the themes (i.e. depict the individual’s mental model).

The surveys were sent out to 650 farmers, 1,427 NRCS employees, and 381 agricultural researchers from the greater Midwest in early 2019. We purchased the farmer survey sample from Farm Market ID (farmmarketid.com), which was comprised of corn, soybean, and wheat farmers that were stratified based on farm size, with equal representation of farmers with 50-250 acres, 500-1000 acres, and 1000+ acres. We compiled NRCS employee contacts from publicly available databases, including all employees with “soil” or “agronomy” in their position title. Agricultural researcher contacts were compiled from departmental and extension websites of 1862 land grant institutions. Inclusion was based on stated research expertise where available, as well as the topic of publications from 2013 to 2018. All sample populations were drawn from Ohio, Michigan, Indiana, Illinois, Iowa, Wisconsin, Minnesota, Nebraska, North Dakota, and South Dakota. Farmer surveys were sent by mail, while NRCS and researcher surveys were sent via email. Farmers could complete the survey on paper, but all participants had the option to complete the study online.

Farmers were first contacted with a letter explaining the study that included a link to complete the questionnaire online using the platform Qualtrics. About a week later, those farmers who had not yet responded to the survey online received a paper version of the survey in the mail. A week and a half later, farmers who had not completed the survey online or on paper received a postcard reminder. Finally, another week and a half later, a second and final version of the survey was mailed to farmers. The NRCS and researcher data collection structure was slightly different because it occurred completely online. NRCS employees and researchers received four total email notifications about the study with the survey link embedded in each one over an approximately five week period. The first and third emails were longer, explaining the study in more detail, while the second and fourth emails were shorter to mirror the structure of the postcard sent to farmers in the mail. In total, we received complete, usable responses from 89 farmers, 134 NRCS employees, and 42 researchers, giving response rates of 13.7%, 9.4%, and 11.0%, respectively.

After sending out all of the surveys and creating the mental models, we also conducted three focus groups, one with each of the three groups of interest, among individuals working in Ohio. Each focus group included approximately 5-8 individuals. Each participant individually defined soil health and each of the six emergent themes and then considered how each of the seven nodes might be related to each other. Then, the participants discussed their responses in pairs and finally as a full group. In total, each focus group lasted approximately 60 minutes. Content analysis of the results from the focus groups is ongoing in an effort to validate the mental models built from the survey responses.

### Statistical analyses

All analyses were performed in R v1.2.5001 (R Core Team, 2019) using RStudio (RStudio Team, 2019). Mental models were represented as directed networks and were analyzed using the *sna* package (Butts, 2019). Links between nodes in that directed network represent a causal path that connects the themes or concepts. The nodes in the present analysis were the six emergent themes and soil health, so the mental models quantitatively illustrate the relationships between these concepts. In network analyses, the importance of a given node is often evaluated using network centrality measures (Wasserman and Faust, 1994), which can be quantified in several ways. The betweenness of a node is a measure of its presence in the shortest path or set of linkages between other nodes, i.e. its importance in connecting themes that would otherwise be linked less directly. Betweenness is therefore interpreted as the tendency of a node to exclusively mediate causal paths. Information centrality is a measure of the number of links originating with a given node and is interpreted as the tendency of a node to initiate causal paths within the network. Prestige is a measure of the incoming links to a given node and is interpreted as the importance of that node.

## Results and Discussion

### How important is soil health to farmers?

Our results indicate that soil health is a high priority to farmers in their on-farm operations, but NRCS employees and researchers undervalue this importance to farmers. Farmers rated soil health an 8.5 out of 10 priority on their farms (lowest reported value was a 5), while both NRCS personnel and researchers had statistically lower ratings for farmers—4.9 and 5.7, respectively. This result largely aligns with the findings of Arbuckle (2016), who found that more than 70% of Iowa farmers had already taken steps to improve soil health on their farms and wanted more information. The attitudes informing this systematic undervaluation were captured in a comment from one NRCS respondent who said, *"I think the 'how valuable is soil health to Farmers' question could be split into two questions. How valuable is it to them and how valuable should it be. I answered 3 in your survey which might be high. How valuable should it be....12!"*. These results illustrate that farmers prioritize improving soil health to a degree not recognized by educators or researchers.

<u>Mental models of soil health between groups</u>

Our analysis showed limited variation between members of the three groups in the centrality of soil health in their mental models (Table 1). On the whole, soil health was similarly prominent in each group's mental models. However, a large degree of within-group heterogeneity may obscure potentially meaningful differences. Previous work has shown that farmer attitudes and beliefs are highly heterogeneous (Wilson et al., 2014; Zhang et al., 2016; Carlisle, 2016; Ranjan et al., 2019), likely informing heterogeneous mental models surrounding soil health. Although there is a lack of data on NRCS and agricultural researchers as distinct groups, our results indicate similar within-group heterogeneity in their conceptualizations of soil health.

To assess within-group agreement and between-group variation, we developed consensus graphs to examine the structural features of mental models that were shared among members of each group (Figure 1). Consensus graphs aggregate the mental models of all members of each group into a single graph, where each linkage within the consensus graphs represents at least 80% within-group agreement. While the consensus graphs do not allow for statistical comparisons across groups, we can still perform qualitative analyses of the shared mental model for each group.

Consensus graphs showed that the overall structure of NRCS and researchers' mental models of soil health diverged from farmer mental models of soil health (Figure 1). Most notably, farmer mental models showed soil health as the only connection to environmental harm or agrochemical inputs—both of which were negative causal relationships. Conversely, NRCS and researchers perceived many connections to these concepts, indicating multiple potential connections to be leveraged when communicating on these topics. This position of soil health in causal paths to environmental harm and agrochemical inputs contributes to a higher betweenness values of soil health in farmer consensus mental models than in researcher or NRCS consensus mental models (Table 2). Moreover, soil health had a higher information centrality in farmer mental models. Collectively, this suggests that soil health is more likely to be the initiator and intermediary in farmer mental models than for NRCS personnel or agricultural researchers. However, soil health was only of median importance to farmers in terms of receiving linkages (i.e. prestige), relative to NRCS personnel and researchers. Given the qualitative nature of these findings, we caution against overgeneralization and encourage future work to identify potential drivers of between- and within-group heterogeneity in mental models.

**Conclusions**

A ten-state survey of Midwestern farmers, NRCS personnel, and agricultural researchers showed that soil health is equally central in mental models of all three groups. Despite the consistent centrality of soil health, mental models were differently structured between groups. Notably, soil health was the sole link to several themes with important environmental and agronomic implications. Paired with the consistent underestimation of the importance of soil health to farmers by NRCS personnel and agricultural researchers, this work suggests that using the language of soil health may be an undervalued way to communicate with farmers on these topics.

### Limitations and Future Work

With these results, there is the potential concern that farmers are succumbing to social desirability bias, reporting higher levels of concern about soil health on their operations than they actually believe in order to not be perceived negatively. With so many current efforts underway to increase use of on-farm conservation practices in order to improve soil health (e.g., 4R Nutrient Stewardship Certification Program), many farmers may feel social pressure to use these practices. Otherwise, they may not be perceived as stewards of the land who care about maintaining the soil for food production and for future generations. Likewise, NRCS employees and researchers may have undervalued farmer concern about soil health. Any negative experiences with farmers related to soil health may overshadow their perceptions of farmer concern. Additionally, NRCS and researcher understanding of soil health is different than the understanding of farmers as indicated by the mental models. This difference in understanding by farmers may also be systematically misinterpreted by NRCS and researchers as a lack of concern when in reality, the conceptualization of the term is just different for farmers. Even though all of these scenarios are possibilities, the mental models results, which are much less likely to be subject to this bias, still show that farmers consider soil health more holistically than do NRCS employees or agronomic researchers. This seems to signal that even if farmer self-evaluation of concern about soil health was too high and NRCS and researcher evaluation of farmers was too low, there are still important differences between these groups that are reflected in their evaluation of farmer concern about soil health.

Another potential limitation of this work is an issue that all agricultural decision-making work faces when studying farmers. Specifically, only certain farmers are willing to participate in research, whether that be via an interview, survey, focus group, or another format. Those farmers most willing to participate are often the ones who already care about conservation and who have an interest in giving back to the research community. As a result, though, there is a portion of the farming population that researchers do not contact, many of who are predicted to make decisions more often that do not align with conservation concerns. This leads to a systematic bias in this type of data collection with farmers, with results likely representing the more engaged, conservation-minded farmers to a larger extent than the full farming population. One farmer touched on this issue, saying *"We have a very hard rule. We do not do surveys. This one seemed to be very interesting and important".* Even though this farmer chose to participate in the present study, it seems as though they do not participate in others, so their perspective is not included in other research. This general concern is one that is not specific to the current paper, but it is important to keep in mind when results from farmer decision-making work are used to make policy and programming decisions.

A third consideration of the present work comes as a result of the novel methodology used for the mental models. The new methodology did work as expected, and each mental model captures a much larger sample size than is typical for this type of work. Also, there were meaningful differences between the mental models, signaling that the new methodology captured the phenomenon of different groups conceptualizing soil health in distinctive ways. As with any new methodology, there were considerations to pay careful attention to the next time it is employed. The six emergent themes chosen to act as nodes in the mental models were carefully chosen to be both specific and broad enough that all participants would understand their meaning. Not all participants felt that these efforts were successful, however, with some (mostly NRCS and researchers) expressing that the terms were too vague and others (mostly farmers) noting that the terms were too specific. The final six themes were chosen because we wanted to limit the number of relationships respondents were forced to consider in the survey, as each concept had a question where it was related to every other concept. It is difficult to know if the terms chosen influenced the results in any meaningful way, but the fact that some respondents considered the terms too simple and others thought they were too complex signals that we succeeded in selecting terms near the specific/broad boundary.

A final limitation and starting point for future work is the limited explanatory ability of the consensus graphs. We thought it was important to start a conversation about the different mental models of soil health using formal quantitative tools. The consensus graphs are an excellent starting point because they provide a clear visual depiction of the differences between three major groups. However, there is a whole host of other potential analyses to explore the mental models themselves in more detail but also to evaluate the relationships between the mental models and other behavioral, personal, and land-based characteristics. Additional research is planned that will begin to dive into these other, more nuanced relationships. Overall, this work represents a significant opportunity to continue to engage with farmers through the development of soil health methodologies to inform applied research questions and extension programming. Future work is needed to understand if and how this communication can lead to changes in decision-making or adoption of preferred management techniques. Careful consideration of current soil health communication strategies is also needed. Since farmers tend to think about soil health more holistically than NRCS or researchers, others working on soil health issues may want to consider tailoring their communication to align more closely with the farmer conceptualization of soil health. If all groups begin to use this term in the same way, then we might be able to reduce soil health miscommunication and improve soil and water quality across the Midwest.

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## Acknowledgements

We would like to thank all of the survey participants and preliminary interviewees who helped to develop the survey. We would also like to thank Andrew Margenot, Robyn Wilson, and Eric Toman for their assistance in developing the survey instrument. This material is based upon work that is supported by the National Institute of Food and Agriculture, U.S. Department of Agriculture, under award number 2016-38640-25381 through the North Central Region SARE program under project number GNC18-272. USDA is an equal opportunity employer and service provider. Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the author and do not necessarily reflect the view of the U.S. Department of Agriculture.

## Tables and Figures

Table 1. Measures of centrality of the "soil health" node in mental models of each group for all respondents. Standard errors are shown in parentheses, with letters indicating differences between groups using Tukey's honest significant difference test ($p < 0.10$). Effect size refers to F-test for overall differences between groups.

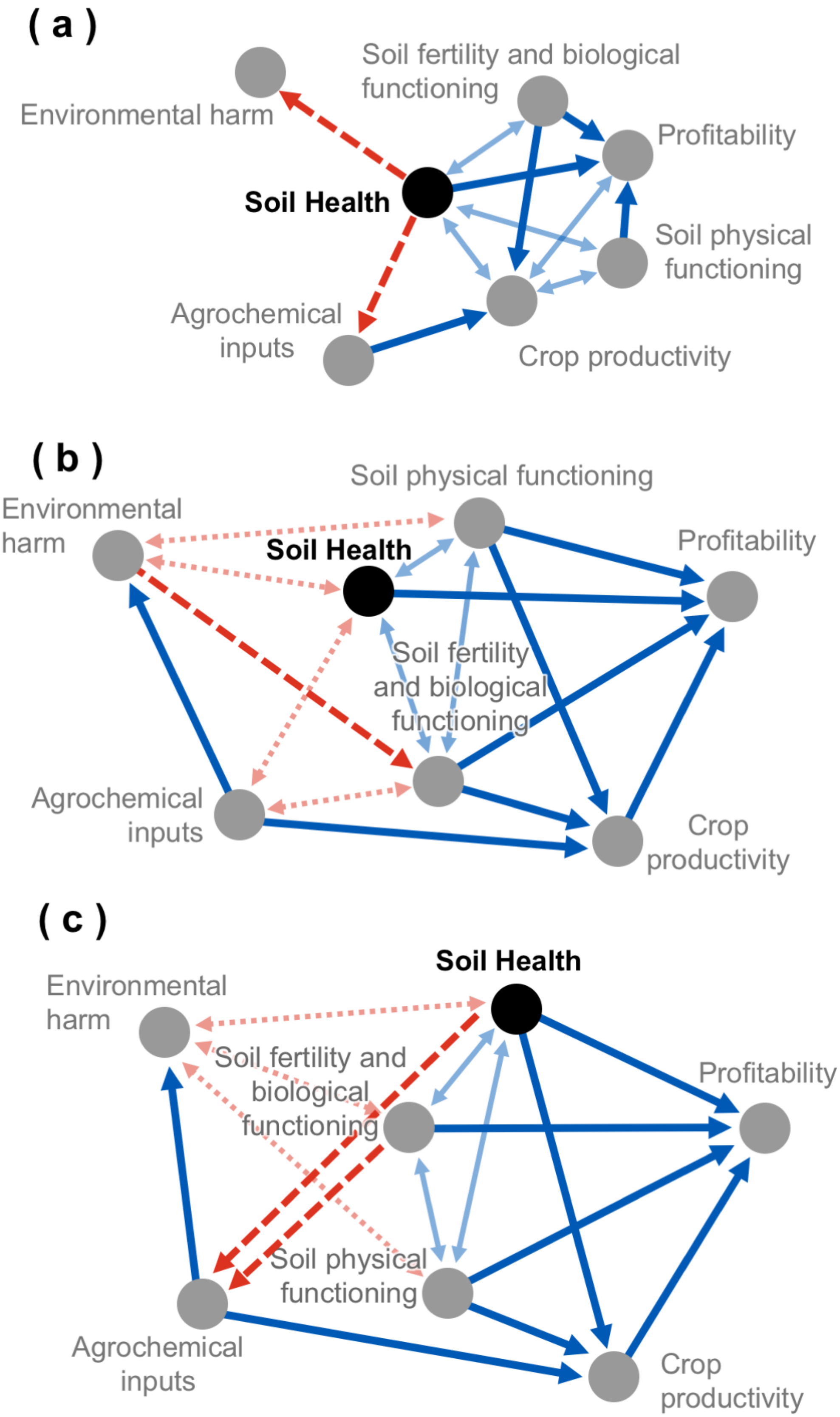
| | Farmers | NRCS | Researchers | Effect Size |
|---|---|---|---|---|
| Betweenness | 0.242 (0.028) a | 0.296 (0.024) a | 0.216 (0.041) a | $F_{2,221} = 1.93$ $p = 0.148$ |
| Information centrality | 0.144 (0.001) a | 0.145 (0.001) a | 0.146 (0.001) a | $F_{2,259} = 2.23$ $p = 0.109$ |
| Prestige | 0.317 (0.031) a | 0.303 (0.025) a | 0.252 (0.045) a | $F_{2,262} = 0.73$ $p = 0.483$ |

Table 2. Group-level differences in centrality of soil health in the mental models. The values come from the consensus graphs, which represent 80% within-group agreement. Values in parentheses are standard errors, where letters within a row indicate differences between groups using Tukey's honest significant difference test ($p < 0.10$).

| | **Farmers** | **NRCS** | **Researchers** |
|---|---|---|---|
| Betweenness [a] | 0.477 | 0.333 | 0.208 |
| Information centrality [b] | 0.188 | 0.157 | 0.161 |
| Prestige [c] | 0.406 | 0.426 | 0.386 |

[a] Betweenness: the tendency of a node to exclusively mediate causal paths (scale: 0-1)
[b] Information centrality: the tendency of a node to initiate causal paths within the network (scale: 0-1)
[c] Prestige: importance of a node (scale: 0-1)

Figure 1. Consensus graphs of mental models for (a) farmers, (b) NRCS personnel, and (c) agricultural researchers. Each linkage represents ≥ 80% agreement on the presence, directionality, and nature (i.e. positive or negative value) of a tie. Solid blue lines indicate a positive relationships (+1) and dashed red lines indicate a negative relationship (-1). Lighter ties indicate bidirectional relationships. The threshold of 80% agreement was chosen to appropriately balance within-group agreement and between-group differences. Note that node placement and distance between nodes is based on ease of visualization and should not be interpreted as conceptual closeness or centrality within the network (Fruchterman and Reingold, 1991).


( a )
Environmental harm
Soil fertility and biological functioning
Profitability
Soil Health
Soil physical functioning
Agrochemical inputs
Crop productivity
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