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Mental Models of Soil Management for Food Security in Peri-Urban India

Claire N. Friedrichsen,* Samira H. Daroub, Martha C. Monroe, John R. Stepp, and Suhas P. Wani

CORE IDEAS

- There is a perceived link between soil, plant, and human health.
- Soil health and food security are culturally influenced concepts.
- Stakeholders' mental models provide insight into culturally appropriate technology.
- Soil management for food security needs to be culturally appropriate.
- Stakeholders' mental models offer insight to enhance extension communication.

ABSTRACT

Agricultural development during the Green Revolution brought India food sovereignty but food insecurity persists. Increased crop production was promoted without considering the more holistic impact on food security. Scientists, extension agents, and farmers have different perspectives on how soil health relates to food security. Understanding stakeholders' perspectives is essential to improving extension communication and mitigating consequences. This study uses qualitative interviews to construct mental models of soil health for food security. The study site is a peri-urban watershed, which is currently participating in the Integrated Farmer Participatory Watershed Management Model (IFPWM). Our study details and defines stakeholders' mental models of soil health, soil nutrient management, soil sodicity, and food security. A triad belief held by farmers shows the strongly perceived causal relationship between soil health, plant health, and human health. Healthy soil produces healthy food and humans that eat such food will be healthy. Scientists only perceive one condition to achieving food security in the community—food quantity. However, all other stakeholders perceived another risk to food security—food quality. Eating poor quality food is perceived as linked to human health problems in the community. This research suggests the importance of including a fifth dimension of food security, cultural acceptability, within agricultural technology development and dissemination.

International development has met its goals for increasing agricultural yields in India. For example, wheat production increased more than sevenfold from 1961 to 2009 (Sen, 2014). Despite successfully investing billions of dollars to increase yields, India is still a hungry nation. Food insecurity continues in India, which has one-fourth of the world's undernourished, including the highest rate of malnourished children in the world (FAO, 2016). In 2013, India's government recognized its problem of a failing food system and passed the National Food Security Act, giving Indian citizens the right to a sufficient quantity and quality of food (Narayanan, 2015). India's food system is failing

C.N. Friedrichsen, Dep. of Soil and Water Sciences, Univ. of Florida, Gainesville, FL 32611; S.H. Daroub, Dep. of Soil and Water Sciences, Univ. of Florida, Everglades Research and Education Center, 3200 East Palm Beach Rd., Belle Glade, FL 33430; M.C. Monroe, School of Forest Resources and Conservation, Univ. of Florida, Gainesville, FL 32611; J.R. Stepp, Dep. of Anthropology, Univ. of Florida, Gainesville, FL 32611; S.P. Wani, International Crops Research Inst. for the Semi-Arid Tropics, Patancheru Telangana, 502324 India. Received 30 Aug. 2017. Accepted 20 Dec. 2017. *Corresponding author (cfriedrichsen@ufl.edu).

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due to growing urbanization, population growth, decrease in agricultural biodiversity, limited food access, improper food storage and distribution (Upadhyay and Palanivel, 2011), yield gaps (Godfray et al., 2010), environmental degradation (Singh, 2016), increasing irrigation demands (Kumar et al., 2012), and structural problems as a result of a transition to a market-oriented economy (Robins, 2010).

Introduced technology intended to increase food security in communities can have unintended consequences on the food system (Barrett, 2006) or have poor adoption rates. Adoption rates and their improvements have been explored through efforts to understand attitudes such as the theory of planned behavior (Ajzen, 1991) and communication, such as the diffusion of innovations (Rogers, 2010). Limited literature has looked at how cognition affects technology adoption and natural resource management (Jones et al., 2011). Mental models are a tool used to explore an individual's cognition (Jones et al., 2011). Mental models are individualized perceptions of how the world works (Prager and Curfs, 2016).

An individual's mental model will determine if they reject or accept new information presented to them. If new information aligns with an individual's existing mental model, an individual will accept the information and integrate it. But if the new information causes dissonance, cognitively it is easier for the individual to reject the new information. Thus, effective communication between two people is more likely to occur when their mental models overlap (Denzau and North, 1994) or when one appreciates and understands the other's mental model (Abel et al., 1998a). As stakeholders spend more time collaborating, their mental models should become more similar (Mathevet et al., 2011).

Participatory research and development helps to build common mental models. It was created when scientists acknowledged that they bring different perceptions to local communities and that local knowledge can facilitate technology development and dissemination (Chambers, 1997). Participatory research and development activity engages participants in the research and development process. The active engagement of community members can occur in many forms, from aiding in dissemination of technologies to empowerment of the community to solve their own challenges (Chambers, 1994).

MENTAL MODEL FRAMEWORK

Mental models include perceptions of cause and effects of how the world works (Prager and Curfs, 2016) and are used in decision making to predict outcomes. Individuals develop their own mental models through experiences and their perception of cultural norms (D'Andrade, 1995). Increased interaction between individuals leads to increased overlap of their mental models (Denzau and North, 1994). Stakeholder mental model comparison has been used to facilitate stakeholder communication among natural resource managers (Abel et al., 1998b; Jabbour et al., 2014; Carlton and Jacobson, 2016), to resolve conflict in management between stakeholders, and to improve technology adoption by farmers by improving communication between farmers, scientists, and extension agents (Eckert and Bell, 2005). Halbrendt et al. (2014) used mental model comparison between scientists and farmers to identify soil conservation practices that would be effective to local soil conditions in Nepal. Prager and Curfs (2016) identified focus areas for communication in fire management and soil degradation in olive orchards in Spain. This research begins to use these techniques to further understand extension communication to alleviate food insecurity and promote soil health management.

Lines of mental model research have developed independently in cognitive anthropology (D'Andrade, 1995), environmental psychology (Kearney and Kaplan, 1997), psychology (Johnson-Laird, 1983), and risk analysis (Wood et al., 2012). A common aim of mental model research is to reveal individuals' or groups of individuals' cognitive structures of causes and effects in decision making. This study uses a framework developed in cognitive anthropology, which suggests that cultural groups with similar backgrounds, economic status, and education hold similar mental models. Each mental model is held in consensus within the group, with each group member possessing parts of the larger group's cultural model, depending on their role within the system (D'Andrade, 1995). How to best elicit mental models is highly dependent on stakeholder and context (Jones et al., 2011; Grenier and Dudzinska-Przesmitzki, 2015). Limited research has looked at how best to analyze mental model data.

Defining Food Security

The Food and Agricultural Organization (FAO) defines food security as "when all people, at all times, have physical, social, and economic access to sufficient, safe, and nutritious food which meets their dietary needs and food preferences for an active and healthy life" (FAO, 2016). Food security typically has four dimensions: (i) food utilization, (ii) access, (iii) food availability (Ericksen et al., 2009), and (iv) stability of the other dimensions (FAO, 2008). A fifth dimension has been added to the operationalized definition of food security to express 'cultural acceptability' (Coates, 2013). This research examines the dimension of 'cultural acceptability' by defining food security as no perceived threats to food and water that an individual consumes. This enables the participants to define food security for themselves, capturing what they determine to be culturally acceptable.

Soil health is the ability for the soil to function as a living body and to provide ecosystem services for plants, animals, and society (Doran and Zeiss, 2000). An ecosystem service that soil provides society is food production. Globally, soils are degrading. To produce more food and high quality food to increase food security, global soil resources will need to be sustainably managed (Godfray et al., 2010). We provide evidence here that soil health is a culturally influenced concept.

The objectives of this research are to: (i) determine the mental models of soil health and food security of scientists, extension agents, and farmers in a peri-urban watershed in

India; and (ii) examine the use of mental models in technology development and dissemination for participatory agricultural development. To answer these objectives, the research questions are: What are stakeholders' mental models of soil health as related to food security and how do they differ? What components in the mental model are important to these stakeholders and how do they differ? How does information exchange occur in the watershed? Mental models allow for a different perspective of food insecurity than what is traditionally used in agricultural extension, and provides new insights.

METHODS

Integrated Farmer Participatory Watershed Management Model

The goal of the Integrated Farmer Participatory Watershed Management Model (IFPWM) is to improve local livelihood through implementation of soil and water conservation techniques via participatory development in a rain-fed agricultural system (Wani et al., 2003). The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) first implemented IFPWM in the Kothapally community in Telangana, India (1999–2001) (Wani et al., 2003, 2012), achieving yield increases between 1.5 and 3 times pre-IFPWM yields (Wani, 2008). From 2001 to 2008, Wani (2008) reported that 368 watersheds in Asia have replicated the model. Since then, IFPWM was replicated across the entire state of Karnataka involving 5 million farmers (Wani et al., 2017). IFPWM actively engages the community in the development process in two ways: (i) with watershed community boards, who decide what and where technology will be disseminated, and (ii) through farmers conducting field trials of technology as a means of technology dissemination (Wani, 2008). This study looks at one watershed participating in the IFPWM (Wani et al., 2003).

Research Site: Peri-urban Watershed Model

In 2014, ICRISAT started the implementation of IFPWM at the research site, located in Telangana, India. Farmers in Telangana's semiarid climate rely on rain-fed agriculture. As the impacts of climate change continue, food systems reliant on rain-fed agriculture become more vulnerable with changing precipitation patterns. The research site is a peri-urban watershed, located 14 km from the center of Patancheru (population = 150,000), a large industrial area and 45 km from Hyderabad, India (population = 6.81 million). As India's population continues to grow and rural areas are converted to peri-urban, these areas will be important sources for food production.

The watershed is comprised of six villages with 4639 households and a population of 18,270 (ICRISAT, 2016). The community speaks Telugu; individuals practice Hinduism, Islam, or Christianity. The area receives enough rain to meet its agricultural needs, but not at the time needed during the growing cycle. In 2015, 84% of the agricultural land was rain-fed, 9% was irrigated, and 6% was fallow (ICRISAT, 2016).

The majority of households within the watershed earn their primary income from non-agricultural activity. Many men work in the industrial area as daily laborers or derive their income from selling inherited land for development. Nevertheless, nearly all households in the watershed produce food: 56% are small farmer households farming two hectares or less, 34% are medium or large farms with more than two hectares of land, and 8% are landless farmer households (ICRISAT, 2016). In 2015, the major crops of the area were maize (*Zea mays* L.), vegetables, sorghum [*Sorghum bicolor* (L.) Moench], and red lentil (*Cajanus cajan* (L.) Millsp.) (ICRISAT, 2016).

At our study site, the farmers describe four types of soil: black, red, black-white, and white soils. The Vertisols (black soils) and ferrous Alfisols (red soils) associated landscapes are a relic of the humid climate of the Pleistocene (Pal, 2017). The participants also describe black-white and white soils, whose characteristics can be associated with soil sodicity. Soil sodicity occurs when there is a high ratio of sodium to magnesium and calcium cations in the soil, known as the sodium adsorption ratio (SAR). Soil sodicity can develop by anthropogenic factors such as use of poor quality irrigation water and application of fertilizers, or due to natural causes such as the soil's mineralogy and local climatic conditions (Brady and Weil, 2008). Soil sodicity causes soil degradation and decreased yield potential through deterioration of soil structure, decreased plant available water, and limited plant available nutrients.

Study Design and Sampling

This is a cross-sectional, observational research study in which four groups were compared at one period of time. Consent protocols were approved by the University of Florida Institutional Review Board (#2016-00674). The accessible population was stakeholders involved in the IFPWM program at the research site. The sampling was purposeful (Bernard, 2011) to select for participants directly involved in IFPWM and to represent a variety of farmers' soil conditions to compare individuals who would normally communicate with one another. The a-priori groups were extension agents, scientists, and farmers. Extension agents and scientists were selected based on their direct involvement in IFPWM in the watershed. A census sample of extension agents ($n = 6$), and scientists ($n = 6$) was taken.

The selection criteria for farmers included a strong relationship with ICRISAT extension agents, involvement in a watershed committee, opinion leaders in the watershed, sodic soil, or low pH soils. Extension agents in the community helped the researchers develop strata criteria to obtain a representative sample of farmers based on their role in the food system within the watershed and their soil conditions (Bernard, 2011). The strata were resource-rich females ($n = 5$), resource-rich males ($n = 7$), medium resource males ($n = 8$), resource-poor females ($n = 6$), medium resource females ($n = 6$), farmers with sodic soil ($n = 4$), farmers with abnormally low soil pH ($n = 3$), livestock owners (n = 3), and watershed committee members (n = 4). Four participants fit within multiple strata. To increase the number of resource-poor females, intercept sampling was used. Resource-poor males were not sampled for the study, because they commuted outside the watershed for urban jobs (factories or auto drivers), and did not engage in daily farming activities

During preliminary data analysis in the field it became clear that there were two sub-groups of farmers: progressive and conventional. Upon identifying the two sub-groups, the extension agent helped the researcher identify other individuals in the community who matched the progressive farmer sub-group to increase sample size. Farmers who expressed the following characteristics were assigned to the progressive farmer stakeholder group: (i) practiced soil organism management, (ii) practiced in situ soil and water conservation practices, and (iii) emphasized the belief in maintaining balance between their soil health and crop production. The progressive farmers (n = 6) were in their thirties, well educated, male, with high social capital, and from a farming background. They tried pursuing other careers before choosing to return to farming. Conventional farmers were all other farmers.

Data Collection

This study uses semi-structured interviews (Laukkanen and Wang, 2015) and observational data. All interviews were completed by the first author to increase reliability (Morgan, 2002). The second author observed a subsample of the interviews being conducted and engaged in de-briefing discussions with the first author.

Data were collected over a 7-wk period in summer 2016. An extension agent working within the research site collaborated with the first author to develop the interview guide, assured it was contextually and culturally accurate (Zahnd and Willis, 2007), provided translation between the first author and the participant, established rapport for the researcher with farmers in the watershed, and helped identify research participants. Interviews were conducted in either English or Telugu. The translation was done with one translator to increase reliability (Wallin and Ahlström, 2006), and clarification was sought from the participant if a language problem occurred (Esposito, 2001). An independent translator confirmed accurate translation of a sample of interview transcripts. The strong relationship and input of the extension agent within the data collection process ensured that trust (Warren and Tracy, 2015) and rapport (Esterberg, 2002) were maintained with research participants, increasing reliability and validity of the data collected.

A semi-structured interview was used to collect the participants' oral histories of soil management practices and food system perspectives. The semi-structured interview format encouraged the participant to control the interview but kept the interview focused (Laukkanen and Wang, 2015) on soil health as related to food security. Interview elicitation of mental models allows participants to bring up new topics and gives them power over the data collection process (Grenier and Dudzinska-Przesmitzki, 2015). Prompts from the researcher helped the participants explore their mental models of the system, from soil health to food security. Topics of the interview guide included the step-by-step farming process, why each soil management practice was being practiced, pedogensis, characteristics of good soil, technology development and dissemination in IFPWM, characteristics of good food, and water management. Unpublished soil health data provided by ICRISAT of most farmers' fields (% organic matter, pH, electrical conductivity, macro, and micro nutrients) were also used to guide the interview. Because different individuals hold roles in different parts of the food system, participants discussed different parts of the system. For example, men explained which fertilizers were applied because they buy and apply fertilizers.

Transect walks were used as prompts during the semi-structured interviews to activate participants' mental models (Jones et al., 2014). Transect walks (Abel et al., 1998b) occurred during some interviews with extension agents (n = 3) and farmers (n = 19) and were conducted in farmers' fields and throughout the watershed. During the transect walks, participants were asked to comment on any of the following observed conditions: soil crusting, soil compaction, crop discoloration, water ponding on soil surface, soil type, soil texture, soil structure, fertilizer packaging, compost residue, composting structures, soil color, soil smell, soil erosion, irrigation water quality, presence of cover crops, type of crops growing, water storage structures, vegetative cover, planting patterns, health of crops, livestock, alternative agricultural implements, effective microorganism fermentation, and soil moisture. The proceeding conditions were recorded as observational data during the transect walk with photographs and note-taking immediately after the interview. All interviews were audio recorded.

Data Analysis

Interviews were transcribed or notes were taken while listening to the audio recording. During the note-taking process, memos were written, documenting emerging themes, constructs, and relationships between constructs. All interviews for one comparison group were processed and analyzed before proceeding to the next group. Most literature suggests analyzing expert interviews first and then using the expert mental model to guide the data collection and analysis of other stakeholders (eg., Wood et al., 2012). This is done by using the scientists' mental model as an interview guide and having the other stakeholders either confirm or deny the scientists' mental model. During data analysis the codes and structure of the scientists' mental model is then used to analyze the local knowledge (Morgan, 2002). This study contributes to the literature by utilizing a new method for analyzing mental model data, which limits the power of the scientists' mental model in data collection and analysis of the other stakeholders' mental models. To avoid significant power during data collection, scientists and stakeholders' mental models were alternated, allowing for new emerging topics to be explored by all stakeholders. To avoid significant power of the scientists' mental model over the data analysis, the researchers analyzed the progressive farmers first, because interviews revealed they had the richest mental model; then scientists, extension agents, and, finally, conventional farmers were analyzed.

The notes and transcribed interviews were coded for content, using a system of structural and theme codes and memo writing (Bernard and Ryan, 2010). A new set of codes was created for each group of participants to avoid problems related to giving more power to scientific beliefs. Composite group influence diagrams (Morgan, 2002) were used to represent the collective mental models. Influence diagrams were constructed by placing codes on note cards and arranging them until they reflected the expressed mental models (Morgan, 2002). The interview notes were re-read, cross-checking against the influence diagrams. All constructs and relationships expressed in the composite group diagrams were expressed by at least one-third of the individuals of the group, which resulted in $2 \leq n \leq 13$ (Vuillot et al., 2016) unless there was significant observational data to justifying the inclusion of the relationship or construct in the final diagram. Influence diagrams (Morgan, 2002) enabled a visual version of the mental models to facilitate identification of gaps and overlaps among stakeholders.

The first author coded the interviews but the third author read a subsample and met with the coding researcher to discuss emerging codes and connections between categories, allowing the coding researcher to reflect and articulate emerging connections and themes (Strauss, 1987; Saldaña, 2009). In addition, researchers discussed the impact of their own power and the power that each stakeholder's emerging themes had on the overall analysis of the data. An independent researcher read a subsample of each stakeholder interviews to confirm analysis.

One influence diagram for each stakeholder group was constructed that included data from soil management and food security. These mental models were large and contained many concepts and connections. The number of concepts of each of these mental models for each comparison group was progressive (37), scientist (34), extensive agents (40), and conventional farmers (40). The large size made it difficult to see where the mental models aligned and where gaps existed, so the mental models were broken up into smaller concepts (Abel et al., 1998a). The scientists' and extension agents' mental models were member checked to verify their representations.

RESULTS

The results are organized around the four salient concepts: soil health, soil nutrient management, soil sodicity, and food security. For each of these concepts, a mental model is shown for each group: progressive farmers, scientists, extension agents, and conventional farmers. At the end of this section, information dissemination within the watershed is described.

Soil Health Mental Models

Each stakeholder group operationalized soil health differently and these differences are captured in their mental models (Fig. 1). Progressive farmers had the richest operationalization of soil health with five components, while the conventional farmers had the least rich mental model with two components of soil health. Scientists, extension agents, and conventional farmers perceived limitations to achieving all components of their soil health mental models whereas progressive farmers saw no limitations. The only component of soil health that was perceived as possible to manage effectively across all stakeholders was soil nutrient management.

Mental Models of Soil Nutrient Management

The mental models of nutrient management vary considerably between each stakeholder group by number, types of limitations, soil management techniques, outcomes, and outputs (Fig. 2a and 2b). All stakeholders' mental models included micronutrient management. The differences between the models included: (i) cow manure, (ii) *jeevamrutha*, a compost tea, (iii) soil organism management, and (iv) green manure.

IFPWM had conducted soil testing in the watershed and had painted their soil fertility recommendations onto the wall of the central watershed community center. This allowed easy visibility to all watershed community members. The soil test results showed micronutrient deficiencies in zinc, sulfur, and boron in the watershed and recommended application of micronutrient fertilizers to improve yields. The mental models showed that micronutrient management was present in all stakeholders' mental models. The effort to convey the science was explicitly disseminated to the farmers.

> To farmers, we are telling (soil health) in terms of nutrients and organic carbon, and we do make it in simple packages. We do not discuss so many things with farmers. We tell them only the implementation; otherwise they get confused, so as of now, as in soil health point of view, we are only telling farmers, secondary and micronutrients. They are already adding NPK. Where there is need to optimize, we are telling that also, but we are concentrating on secondary and micronutrients and recycling of organic waste. (Scientist 1)

Scientists focused on secondary (Ca, Mg, and S) and micronutrient management for soil health (see Fig. 2a) since it is an easy behavior to adopt as farmers already apply nitrogen, phosphorous, and potassium. The use of micronutrients disseminated quickly in the mental models of the stakeholders in the watershed. Eleven conventional farmers specifically stated that they were using micronutrients (see Fig. 2b). No conventional farmers said that they were not using micronutrients. Farmers reported yield increases with application of micronutrients. Conversations with scientists suggest that they are focusing on secondary and micronutrient management for soil health as an entry point activity (Wani et al., 2017) since it is an easy behavior to adopt because fertilizer application is already in their mental model.

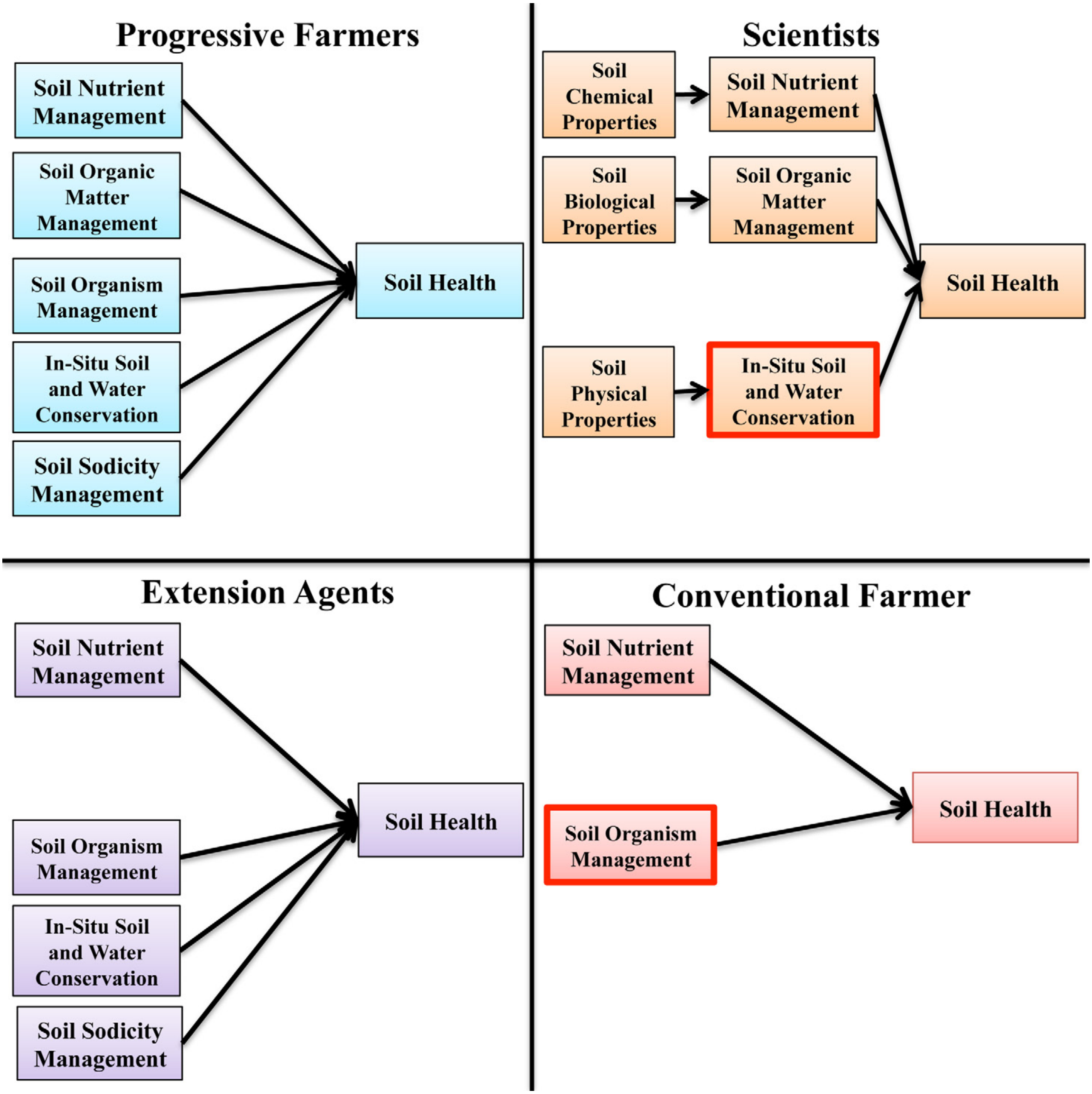

Fig. 1. Stakeholders' mental models of soil health. Black lines represent possible cause and effect relationships. Red lines represent perceived relationships with limitations.

Progressive farmers have a different perception of nutrient management (see Fig. 2a). First, they do not perceive any limitations to applying sufficient cow manure to their soils. Five of the six progressive farmers own cows. Conventional farmers and extension agents cited the unavailability of manure, and the lack of on-farm labor to support livestock as limitations to having sufficient cow manure. In addition to the three livestock owners, only one other conventional farmer owned a cow.

Farmers buy fertilizer, but they don't buy manure. [This is] because the result is fast, because the metabolism is faster [with fertilizer, even though] cow dung is cheaper, but there is no supply of cow dung. Before every household had livestock. So [now] they depend on other farmers for cow dung, and the other farmer says I don't even have enough cow dung for myself. Cow dung is not available on the market. The solution is to start raising animals again. (Extension Agent 3)

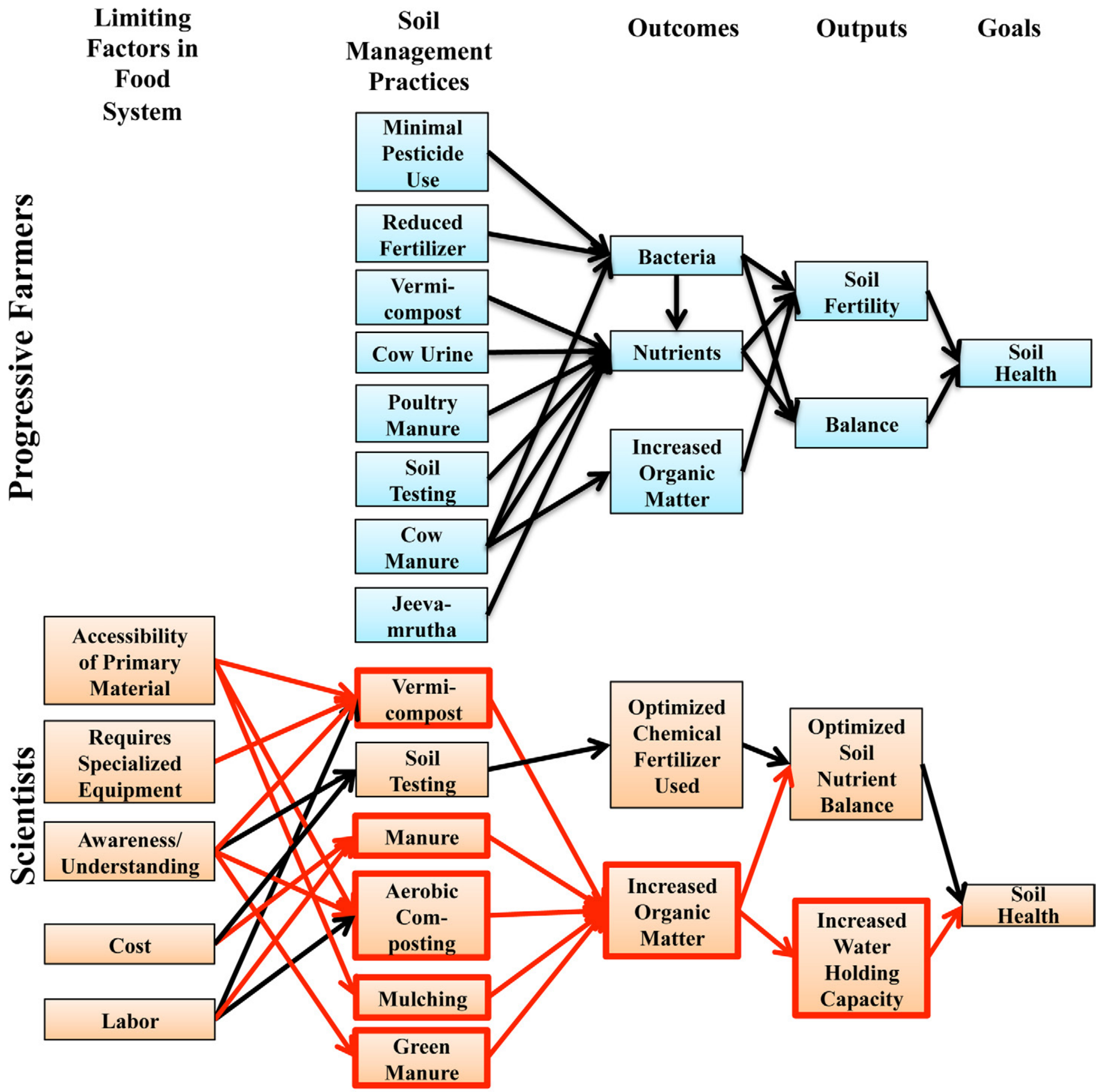

Fig. 2a. Stakeholders' mental models of soil nutrient management. Black lines represent possible cause and effect relationships. Red lines represent perceived relationships with limitations. Boxes outlined in red represent constructs with perceived limitations.

Conventional farmers and extension agents perceived that there is a limited supply of manure available in the watershed. The farmers said that traditionally, children took care of livestock in the watershed. Now, children are attending school with the hopes that they will have urban jobs after receiving their education. However, progressive farmers saw the value of cow manure, were willing to go outside the watershed to find a supplier of cow manure, and were willing to pay more for cow manure. "Money is not a matter here [for buying manure]. I want good soil health," said Progressive Farmer 37.

To stretch the limited cow manure, five of the six progressive farmers created *jeevamrutha*, made from water, a sugar source, anthill soil, cow manure, and pulse grain, which is mixed and anaerobically fermented. The farmers applied *jeevamrutha* through drip irrigation or poured it directly into the flooded rice every 2 wk. *Jeevamrutha* is perceived to activate and promote beneficial soil organisms. The progressive farmers said that manure from one cow could make enough *jeevamrutha* for 30 ha. The sixth progressive farmer had a biodigester,

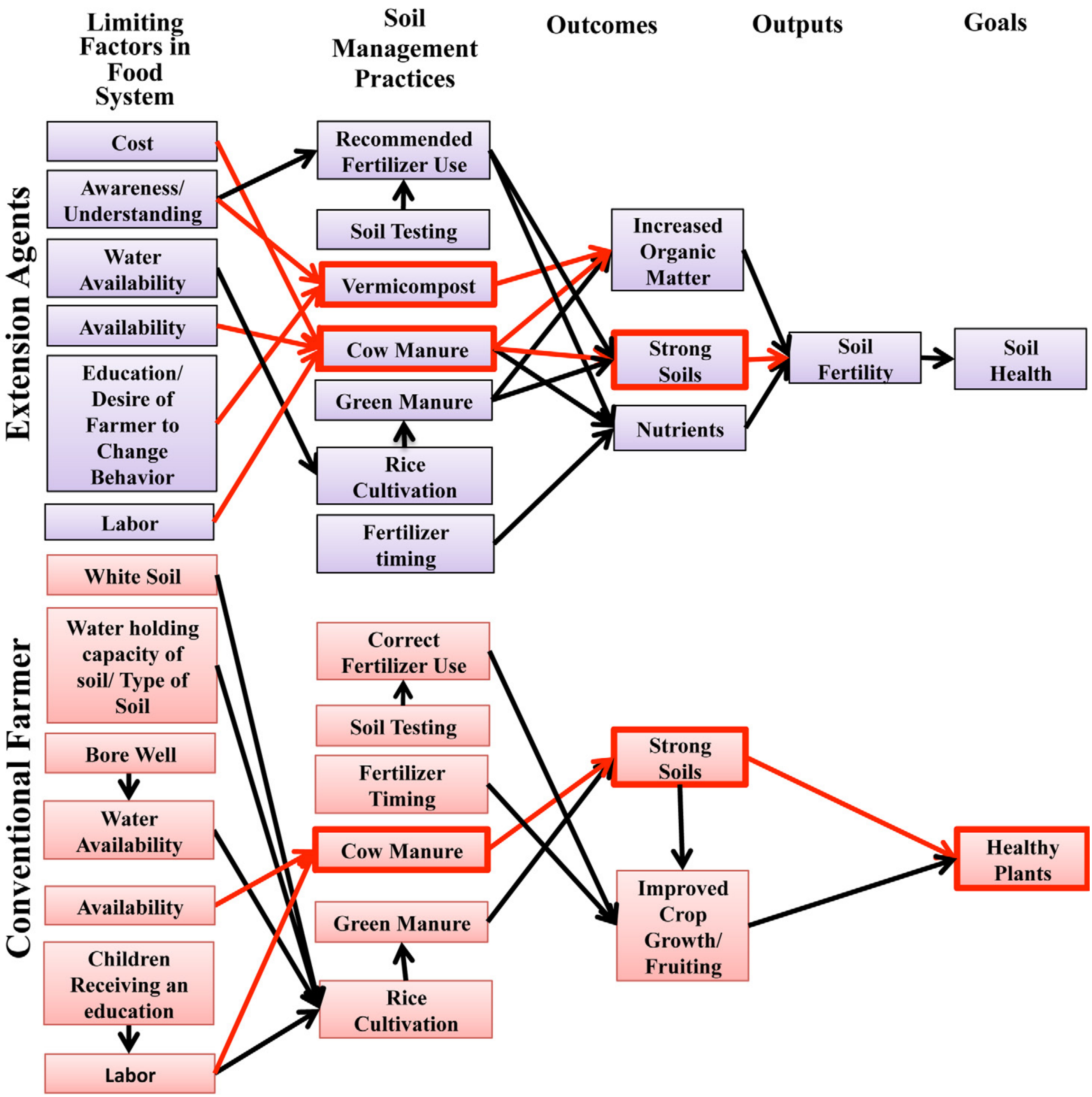

Fig. 2b. Stakeholders' mental models of soil nutrient management. Black lines represent possible cause and effect relationships. Red lines represent perceived relationships with limitations. Boxes outlined in red represent constructs with perceived limitations.

which he used to ferment cow manure to create biogas and biodigester liquid that he applied to his fields.

Progressive farmers actively managed their soil to promote beneficial organisms. No other stakeholders mentioned beneficial soil organism management, except for one scientist. The progressive farmers also use management techniques to improve soil organisms, including *jeevamrutha*, planting legumes for supporting rhizobia, sun exposure, application of commercial rhizobium with seed, and limited pesticide and fertilizer use. Pesticides and fertilizers are seen to harm beneficial soil organisms. Consequently, after fertilizer application, soil bacteria must be repopulated with the application of *jeevamrutha*.

In contrast, conventional farmers said they regularly use a pesticide called *gulcalu* for the last 20 yr. *Gulcalu* is applied directly to the soil before planting to kill perceived harmful pests that reside in the soil. Conventional farmers are also using sun exposure as a pest management strategy. Progressive farmers understand that there are beneficial soil organisms and pests, and that beneficial soil organisms can be managed to improve soil health. Conventional farmers only mentioned soil pests. Two out of the 38 conventional farmers mentioned earthworms, but in the context that they no longer exist due to overuse of fertilizers.

Green manure is not in the mental model of the progressive farmer, although one progressive farmer did explain the use of a nine-seed mixture of leguminous plants. For conventional farmers, green manure is seen as an alternative to limited cow manure availability. Conventional farmers only perceived green manure as a soil management strategy in rice cultivation. Fifteen of 38 conventional farmers described the use of green manure. The green manure is planted directly in the field in May and is allowed to grow for 1 mo while the rice nursery is growing. The field is flooded, the green manure is incorporated into the soil, and the farmer waits three to 7 d before planting to let the green manure "disappear" before transferring the rice seedlings. Farmers stated that depending on the water availability they plant green manure. Farmer 12 said, "green manure, now a days we are using only in [irrigated] paddy fields…because it is easy to decompose in soil… It works faster in paddy, so paddy only. Other crops will take 1-yr time to decompose." Extension agent mental models of green manure and that of the conventional farmer do overlap.

> [For] rain-fed crops, we use cow dung or vermi-compost. It is impossible to grow green manure, because there is not enough water for the green manure to decompose. The un-decomposed green manure will affect the crop. If water is available, then you can grow green manure because only with water will the green manure decompose. If there is no water, the green manure will not decompose, so for rain-fed crops, no green manure. (Extension Agent 2)

Both extension agents and conventional farmers' mental models include two very distinct rules that must be followed when using green manure: (i) green manure needs to be fully decomposed before planting, and (ii) green manure can only be used in irrigated fields such as flooded paddies. In contrast, scientists did not perceive that farmers were growing green manure at all. Scientists said that farmers had a lack of awareness and understanding that prevented them from growing green manure.

Mental Models of Sodic Soils

The underlying difference among stakeholders' mental models of sodicity is a lack of agreement in the source of the sodicity and thus subsequent solutions (Fig. 3). Fourteen of the 38 conventional farmers acknowledge the existence of white soil in the watershed. Of the soil samples taken, less than 10% (18 of the 189 samples) had a pH > 8.5 qualifying as a sodic soil if the SAR > 13. No progressive farmer had a soil pH > 8.5. Four conventional farmers who were interviewed had a soil pH > 8.5, which they identified as a white soil.

The conventional farmers perceived the white soil as a preexisting condition, dating back to the time of their forefathers. "The soil is not increasing salty, it is constant, my father's period also [has the] same [saltiness]," said Conventional Farmer 22. Extension agents and scientists perceive it is a result of poor irrigation water quality. Extension agents perceive there is poor groundwater quality due to pollution from the nearby industrial area. Scientists viewed poor water quality as a result of dropping groundwater levels and withdrawing water from a saltier, deeper aquifer. Progressive farmers saw chemical fertilizers as the source of salts. As of the time of data collection, scientists had not yet taken groundwater quality samples and analyzed them. However, there is evidence of poor ground water quality as the Indian government installed osmosis water treatment plants to treat the groundwater to drinking water quality for the residents of the watershed. The participants said that this was a result of recent industrial pollution.

Progressive farmers reduced their own use of chemical fertilizers and thus perceived no threat of sodicity to their soil health. Scientists did not perceive soil sodicity as a factor limiting soil health in the watershed, and had not provided soil fertility recommendations for white soil. Scientists perceive the solution to reduce soil sodicity is to increase ground water levels by installing water harvesting structures to bring the upper level of the aquifer out of the saltier bedrock. A main objective of IFPWM is the installation of water harvesting structures.

Farmers with white soil said they could only farm their soil if they had access to a bore well that would allow them to grow rice in a flooded paddy fields in summer and pulses during winter. Farmers who did not have bore wells left their white soil fallow or grew a meager crop as a buffer to keep wild animals out of their main crop. In the mental models of conventional farmers and extension agents, zinc sulfate and green manure were soil amendments that could be used to improve crop production in white soil. In addition, extension agents saw the use of dam silt to cover the white soil, the use of gypsum, or the use of high quality water for irrigation as sodicity management strategies. But their mental models perceived limitations to those management strategies. Extension agents and scientists did not perceive sodicity as a major challenge nor as a major hindrance to improve the soil health in the watershed.

Mental Models of Food Security

Conventional farmers and extension agents perceived that there is a risk to food security in the watershed (Fig. 4). Progressive farmers perceived that they personally have food security but that there is food insecurity in the watershed. Scientists perceived the watershed as having food security. The differences in perception of the watershed being food secure can be attributed to the belief that scientists do not perceive health problems due to poor food quality in the watershed as a threat, whereas the other stakeholders do. Some progressive farmers, conventional farmers, and extension agents perceived the consumption of food grown in soil degraded by fertilizers and pesticides as poor quality food.

Progressive farmers see the overuse of chemical fertilizers and pesticides as risk to their food security in the watershed.

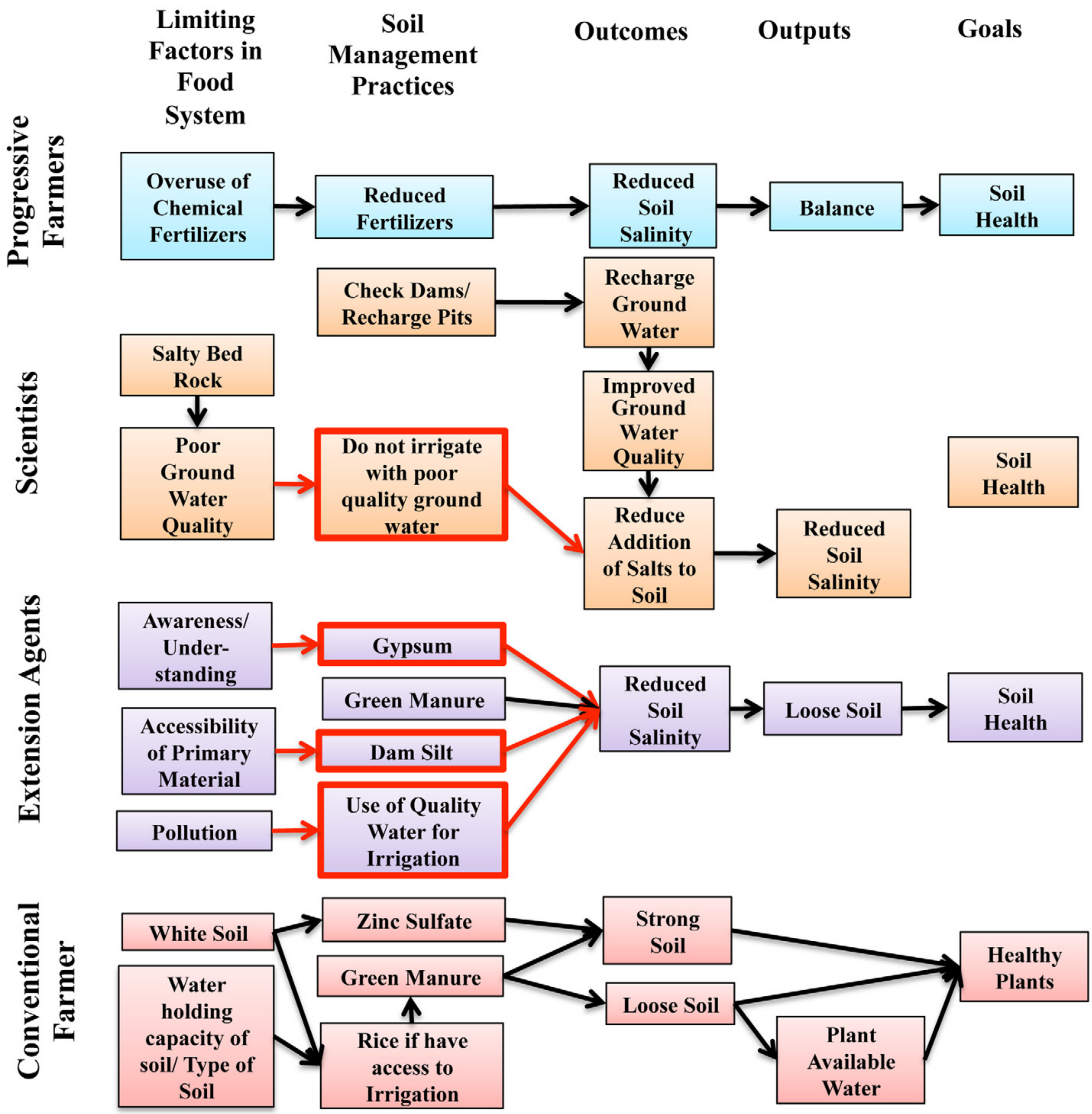

Fig. 3. Stakeholders' mental models of soil sodicity. Black lines represent possible cause and effect relationships. Red lines represent perceived relationships with limitations. Boxes outlined in red represent constructs with perceived limitations. If there are no arrows between construct there is no perceived relationship.

To secure their own food security they limit chemical fertilizers and pesticides. Progressive Farmer 17 said, "I am reducing this (pesticides), because I will eat [this crop]." Progressive farmers saw a strong link between soil health, crop quality, tastier crops, and improved human health.

Conventional farmers saw food quality as affected by the use of fertilizers and thus a threat to their food security. Conventional farmers said they used chemical fertilizers as a soil nutrient amendment because they did not have sufficient access to cow manure.

> Manure food is good...they are getting side effects eating the food [grown with fertilizers]. Diabetes, high blood pressure, body pains, leg pains from fertilizer food. This one is good (manure food). There are no side effects; they are having good health. (Conventional Farmer 41)

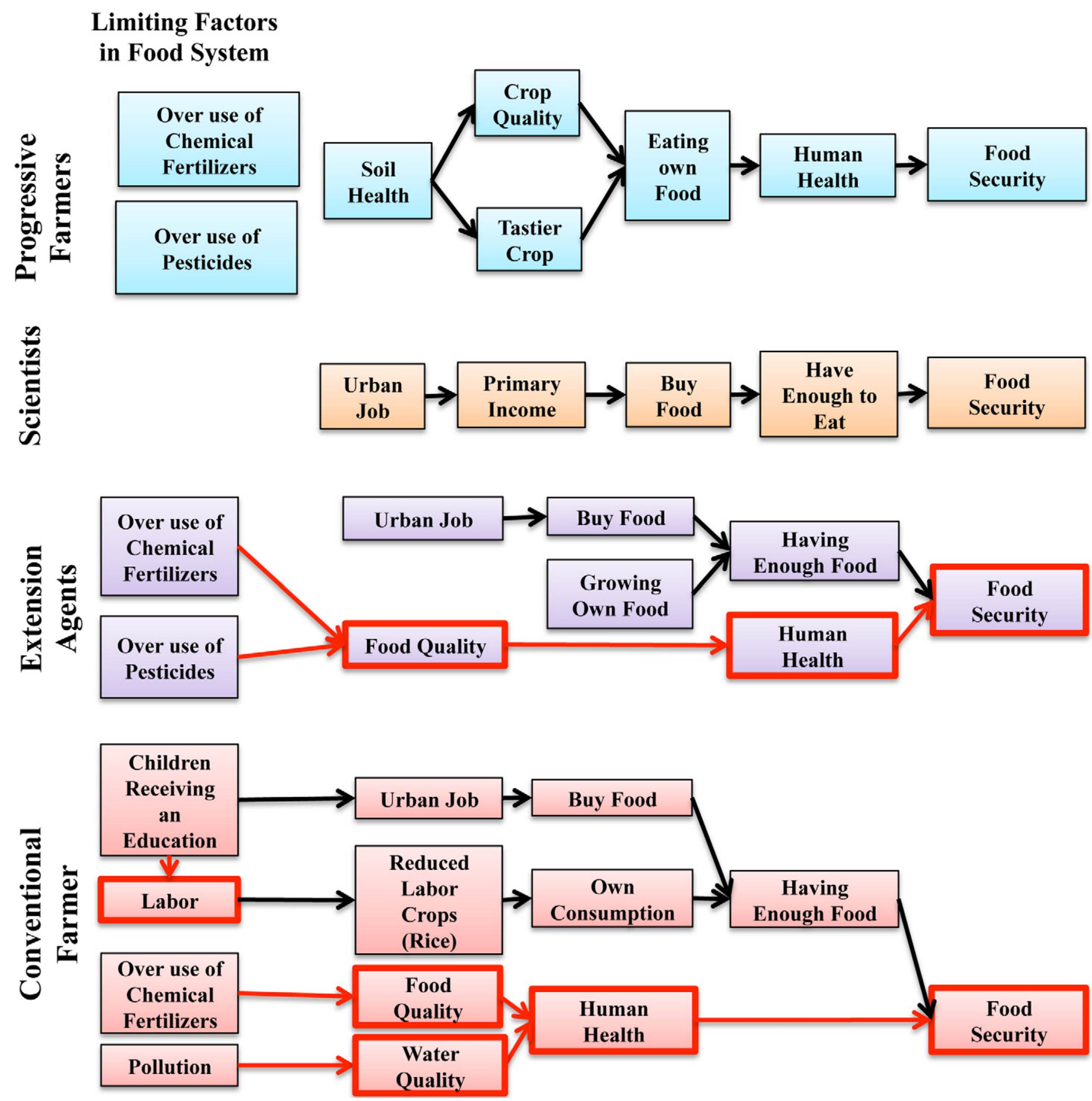

Fig. 4. Stakeholders' mental models of food security. Black lines represent possible cause and effect relationships. Red lines represent perceived relationships with limitations. Boxes outlined in red represent constructs with perceived limitations. If there are no arrows between construct there is no perceived relationship.

> Whichever field has used fertilizers, the food is also harmful to our health. The forefathers are very strong and their wives are also very strong, they are doing many things so that they are very strong. Now days, people are very weak. They cannot see clear, ears are broken, we are observing so many things from using these fertilizers. I am facing lots of problems from using of fertilizers. Women are suffering from knee pains, body pains, so many health problems. So that is what we are facing. We are using vegetables, vermi-compost, the vegetables are very tasty. She is cooking, that time I observed, that time very tasty and healthy. Buffalos give manure, animals are eating grass, so inputs are strong and the outputs are strong. (Conventional Farmer 7)

Chemical fertilizers were perceived to cause health issues, ranging from flu-like symptoms to hearing loss. Fourteen of the 38 conventional farmers mentioned poor quality food as a result of chemical fertilizers. Five conventional farmers mentioned that food grown with cow manure was tastier. No farmer mentioned that they preferred to use chemical fertilizers instead of manures.

Information Dissemination

In the IPFWM program, extension agents perceive it is their role to facilitate technology dissemination, but not to share new information from farmers with scientists.

> [Farmers] want contact with correct, qualified person, like scientists. He will tell the right information… [If] scientists will go directly to fields, once in a month. Then farmers will get results, the right information. 90% will get more yields… [Scientists'] duty is to come to the fields. But they don't do it…The communication gap is very high. (Extension Agent 2)

Extension agents think the scientists need to be visiting the fields regularly to give qualified, professional advice. Here the extension agent talks about what they think the scientist should be doing in an ideal situation.

> They (scientist) will listen, they will write it down, and actually, they will maintain notes. They will write the issues, the problems they are facing with crops, they will make a brief note. So they will find a solution and communicate through us or directly to the farmers or a community member. (Extension Agent 3)

This quote shows that the extension agents perceive that the scientist should come to the field, listen to farmers, and develop solutions. Extension agents perceived that it is the job of scientists to come to the field and identify the challenges. However, scientists do not see their role as interacting with farmers "My job is research and it is the job of the extension agent to talk with the farmer," said Scientist 3.

DISCUSSION

Creation of Ethno-Scientific Knowledge

There has been limited research on how cognitive structures and cognitive dissonance among stakeholders hinders agricultural technology development and dissemination. Recently, Dawoe et al. (2012) created a literature-based framework for how ethno-scientific soil knowledge is created. The framework shows feedback loops between local soil knowledge, farmer technical practices, agro-ecosystem structures, and scientific soil knowledge (Dawoe et al., 2012). Extension agents serve as facilitators of the integration of local soil knowledge and scientific knowledge. Farmers are the users and evaluators of the ethno-scientific knowledge. Local soil knowledge and scientific soil knowledge is integrated through "participatory learning and knowledge sharing activities using genuinely gender sensitive, collegial, and collaborative approaches" (Dawoe et al., 2012). However, this framework does not indicate how mental models affect the creation of ethno-scientific knowledge. Differences in mental models could lead to dissonance as well as ineffective technology development and dissemination (Halbrendt et al., 2014).

We have identified four cognitive dissonance mechanisms that could facilitate or hinder the creation of ethno-scientific soil knowledge.

1. There are different perceptions of problems or limitations in the watershed.
2. Technology may not solve some perceived problems.
3. Local farmers may not perceive some technologies to be feasible.
4. Local knowledge can inform new technology.

The first three themes align with the finding of Prager and Curfs (2016) that mental models are useful in identifying research priorities. When scientists have overlapping mental models with farmers, they are more likely to generate appropriate technology development that meets the needs of farmers (Prager and Curfs, 2016). This study contributes to the literature by delving deeper into what aspects of mental models of soil management cause differing perceptions of problems. In our study, scientists did not see sodicity as a problem preventing the achievement of soil health in the watershed, which may be why the IFPWM program had not disseminated any information on sodicity. Extension agents should be aware that progressive farmers perceive fertilizers as the source of sodicity. Thus, when extension agents made soil fertilizer recommendations for soil nutrient management, the progressive farmers were likely to ignore that information or may only partially adopt the recommendations.

Participatory development is a way to increase overlapping mental models (Mathevet et al., 2011). The IFPWM extension system relies on extension agents to communicate to scientists the challenges faced by the community and the limitations the community has in adopting technologies. Possibly due to the lack of empowerment, or gaps in their mental models of job expectations, extension agents are not reporting back to scientists, but instead rely on scientists to visit the community and discover the challenges and limitations for themselves. Some scientists may not have training nor are they available to spend significant time in each community to understand farmers' perspectives. This has possibly hindered the development of overlapping mental models in the watershed. The fourth theme, local knowledge can inform new technology, is an additional way that ethno-scientific soil knowledge can be created. How to effectively identify and integrate traditional ecology knowledge with scientific knowledge is still unknown (Huntington, 2000).

In this study, progressive farmers found a way to overcome limitations of available manure in the watershed by using *jeevamrutha* to increase the number of beneficial soil organisms and as a soil nutrient. Sreenivasa et al. (2011) reported 20.4×10^5 cfu bacteria and 13.8×10^4 cfu fungi per mL of *jeevamrutha*. *Jeevamrutha* is an essential soil management technique in Zero Budget Natural Farming (Münster, 2015). Limited research has been conducted on the effect of *jeevamrutha*, but it has shown positive results in improved crop yield in rice (Amareswari and Sujathamma, 2014), peanut, pomegranate (Upperi et al., 2009), and pest management (Upperi et al., 2009). *Jeevamrutha* can be prepared easily by farmers with ingredients regularly available in rural areas (Devakumar et al., 2014), and it reduces the cost of production (Amareswari and Sujathamma, 2014). Our results contribute to the literature by showing that mental models may help identify local soil management practices that may be useful when combined with scientific knowledge to provide solutions to problems faced by the community.

Triad Belief: The Interconnectedness Between Soil, Plant, and Human Health

How an individual manages (praxis) their environment is a result of their beliefs (*kosmos*) and knowledge (*corpus*) of that system (Toledo, 2002). This research provides supporting evidence to suggest that soil health (de Bruyn and Abbey, 2003) and food security (Coates, 2013) are culturally influenced concepts mediated by *kosmos* and *corpus*. This study contributes to the literature because it examines soil health from the lens of food security as perceived by the participant. Food security is perceived as having two conditions by the farmers–having enough food to eat and having quality food that does not cause human health problems.

Farmers in this study perceived links between fertilizer and pesticide use, soil health, food quality, and human health. Those results confirm results reported by Gupta (1998) where farmers in rural Punjab, India also perceived that fertilizers made soil "weak," led to tall but less hardy plants, and cultivation of tasteless, non-nutritious food. Gupta (1998) reports a triad belief of the interconnectedness between soil health, plant health, and human health. This connection parallels Vedic science (Münster, 2015) which suggests that if soil health is poor, plant and human health will also be poor (Gupta, 1998; Münster, 2015).

Identifying universal indicators of soil health is a recent agenda in the soil health community. Obalum et al. (2017) propose using one sole indicator, soil organic matter, as an indicator of soil health. Some soil health assessments integrate a suite of soil chemical, physical, and biological properties, e.g., the Comprehensive Assessment of Soil Health (CASH) (Moebius-Clune et al., 2016). Some assessments add soil conservation management as part of an integrated soil health assessment, e.g., the CATIE (Padilla and Suchini, 2001). However, these assessments fail to suggest soil health as a culturally influenced concept. Local knowledge may have preexistent culturally influenced concepts that should be taken into consideration with soil health technology development and dissemination. Some local soil health indicators or cultural perceptions include soil as living, absence of soil degradation characteristics, soil feel, plant growth (de Bruyn and Abbey, 2003), and the presence or absence of macrofauna (Lima et al., 2011).

The belief that harm to soils will result in health problems (Gupta, 1998; Münster, 2015) is present in the watershed in this study and may influence how farmers adopt technologies. For nutrient management, scientists and extension agents offer fertilizer recommendations to the farmers because they perceive too many limitations to farmers using organic nutrient sources. Farmers, especially the progressive farmers, partially adopt or reluctantly use fertilizers in the watershed because of the perceived ill effects fertilizers have on soil health and subsequent human health. Smith and Sullivan (2014) also observed a strong belief that chemical fertilizers are a threat to soil health in Australia. To improve soil nutrient management in the watershed in this study while achieving the fifth dimension of food security, an organic nutrient management technology may better align with the mental models of some farmers, although availability of manure in the community is a barrier (Motavalli et al., 1994).

Food security is a concept with many threats, not all of which have been identified. The mental models of scientists in this study did not include food insecurity as a challenge facing the watershed, whereas other stakeholders did. The difference in the various stakeholders' mental models was due to the differing definitions of food security. Scientists saw the only risk to food security as having enough food to eat. However, other stakeholders viewed food security as a more complex concept that requires two conditions: (i) having enough to eat, and (ii) having food that does not harm human health. The definition aligns with the fifth dimension of food security, cultural acceptability (Coates, 2013). This study contributes to the literature by providing an example of how cultural acceptability of food production may be essential for food security.

The second definition of food security, having food that does not harm human health, is consistent with other communities experiencing the transition from a local to global foodshed. This occurs through a process of globalization and where the local community, once self-sufficient, becomes dependent on outside food sources (Loring and Gerlach, 2009). Loring and Gerlach (2009) found an increase in diabetes and human health problems as a rural, indigenous population in Alaska transitioned from a local foodshed reliant on foraging wild foods to a global foodshed reliant on supermarkets. The importance of cultural acceptability of how food was grown within the concept of food security aligns with the concept of food sovereignty. Food sovereignty is "the right of consumers to decide what they consume, and how and by whom it is produced" (Windfuhr and Jonsén, 2005).

Limitations to this study include lack of access to the farmers for member checking to verify the representations of their mental models. In 2016, when the data were collected, it was the second year of the 5-yr IFPWM program. This program was not specifically designed to address food security but was designed to improve livelihood, which is being measured by increased income and crop productivity (Wani et al., 2003).

CONCLUSION

Using stakeholders' mental models in agricultural development research may provide insight into barriers to technology adoption and even new directions for agricultural technology development. Mental models could be used prior to program implementation to identify: (i) entry point activities, (ii) technologies that fit within the needs of the community, (iii) needed research, and (iv) gaps in belief systems that need to be addressed in adoption communication to improve adoption rates of new technology. This study contributes to the literature as it provides data collection and analysis techniques to avoid unintentionally giving power to Western scientific knowledge in mental model research.

The results suggest that the stakeholders' mental models of: (i) soil health, (ii) soil nutrient management, (iii) soil sodicity, and (iv) food security do not overlap, causing a lack of appropriate communication to produce ethno-scientific knowledge. Because of the scientists' position of privilege, context of the situation, power, and access to funding, scientists are in a position to adapt their mental models to match that of the farmers. Scientists can adapt their mental models of soil health and food security to match that of the communities through: (i) empowerment of extension agents to report back to them; and (ii) use of mental models or other qualitative data collection methods before and during program implementation. Qualitative studies give participants freedom to express their perspective without the constraints of expressing their perspective in a pre-written quantitative index written from the perspective of the scientist.

Future research should explore the potential of *jeevamrutha* as a microbial inoculant, organic carbon source, and nutrient source that could be used in place of synthetic fertilizer in areas with limited access to manure. This study contributes to the literature as it provides confirming evidence that soil health is a culturally influenced concept. Communities may have their own way of perceiving, indicating, and measuring soil health, which may provide important information and perspective for scientists as they aim to foster the improvement of soil characteristics in communities.

Food security is also a culturally influenced concept; therefore, operationalizing food security should be done in collaboration with the community. Soil management is often the stated solution to food insecurity, so soil management technologies should be developed to fit the community's food security needs. This study contributes to the literature as it explores how soil health is related to food security from the perspective of the local community. If a soil management technology, such as synthetic fertilizer, is disseminated to a community to address food security, the researchers need to be aware that the fifth dimension of food security, cultural acceptability of introduced technologies, may diminish the value of the technology and exacerbate food insecurity. Understanding and sharing mental models is one strategy to assure cultural acceptability. CGIAR needs to continue support for non-economist social science researchers to conduct future research alongside technology development and dissemination (Cernea, 2005; Price and Palis, 2016).

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