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Soil balancing within organic farming: negotiating meanings and boundaries in an alternative agricultural community of practice

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Abstract

Soil balancing is widely used in organic farming, but little is known about the practice because technical knowledge and goals for the practice are produced and negotiated within an alternative community of practice (CoP). We used a review of the private soil balancing literature and semi-structured interviews with farmers and consultants to document the knowledge, shared meanings, and goals of key actors within the soil balancing CoP. Our findings suggest this CoP is dominated by discourse between private consultants and farmers, with few contributions to or from scientists or the peer reviewed literature. The idea of soil balancing is centered around improving soil quality through adjustments in Base Cation Saturation Ratios (BCSR), and practitioners report a wide range of positive agronomic outcomes. For most soil balancers, however, BCSR is only one part of a broader approach to soil health management that also utilizes traditional soil fertility recommendations and soil health-building cultural management practices. Meanwhile, a survey of land grant university soil fertility specialists and the peer-reviewed literature documented a high degree of skepticism and a lack of scientific evidence that BCSR can boost crop yields. We conclude that this scientific discourse reflects a disconnect from the practices and meanings used in the soil balancing CoP. While tensions between the dominant and niche agricultural knowledge systems are not unique, we believe a better appreciation for the nuanced meanings and goals within the soil balancing CoP present an opening for expanded collaborations with scientists doing research on soil health.

Keywords Soil balancing · Organic farming · Community of practice · Ways of knowing · Soil science · Farmer experience

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Introduction

For decades, the development of new knowledge and innovations in agricultural systems was thought of as a linear process wherein discoveries from scientists are transferred through various channels to farmers (Blackburn 1989; Leeuwis and Van Den Ban 2004; Rogers 1995). More recently, researchers have recognized the importance of farmer-generated local or tacit knowledge and expertise (Kloppenberg 1991; Morgan and Murdoch 2000). There is growing attention to the use of social learning approaches or co-production of agricultural knowledge that better integrates farmer observational experience with scientific methods and expertise (Knickel et al. 2009; Leeuwis and Van Den Ban 2004; Wood et al. 2014).

While significant progress has been made to expand collaborations between agricultural scientists and farmers (Sumane et al. 2018), most agricultural research is still done with traditional randomized experimental trials under scientifically controlled conditions. Many scientists and practitioners struggle when farmer experiential knowledge conflicts with results of scientific studies (Eshuis and Stuiver 2005; Francis 2010). The tensions between farmer and scientific ways of knowing have often emerged in discussions of soil fertility management and soil health (Doran 2002; Fairhead and Scoones 2005). In response, several recent papers have demonstrated the value of farmer experience to develop better indicators for measuring and managing soil quality (Barrios et al. 2006; Mairura et al. 2007) and to help build a common language between scientists and farmers (Richelle et al. 2018).

To add further complexity, there is growing appreciation for the role of private sector advisors and consultants in agricultural knowledge generation and dissemination in the U.S. and Europe, a trend that is related to a steady decline in funding for public science and extension since the mid-1990s (Eanes et al. 2017; Hejnowicz et al. 2016; Prokopy et al. 2015; Wolf 1995). While private sector actors have been identified as potential brokers of knowledge between farmers and scientists (Klerkx and Jansen 2010; Oreszczyn et al. 2010), some worry that their profit motive and competitive nature may lead to exclusive markets for knowledge and potentially limit open public sharing of information (Compagnone and Simon 2018).

Both the linear and co-production models of innovation and knowledge diffusion have emphasized the importance of technical agricultural knowledge (Krzywoszynska 2019). However, scholars using a Communities of Practice (CoP) (Wenger 2000) approach have demonstrated that the trajectory of innovation and new knowledge creation is shaped as much by socio-cultural as by technical factors (Eshuis and Stuiver 2005; Schneider et al. 2010; Vanclay 2004). In particular, the framework focuses attention on the social learning processes through which shared meanings and values are developed among practitioners that are reflected in their objects of study, the goals or purposes of their efforts, and the emergent boundaries between their work and other CoPs (Wenger 2000). In this way, learning is viewed as "a process of social construction and knowledge sharing, rather than a process of knowledge transfer" (Morgan 2011; p. 101). These processes can include patterns of mutual engagement, the recognition that they are engaged in a joint enterprise, and the emergence of practices, words, and concepts that represent a shared repertoire (Wenger 1998).

The CoP approach has been applied to agricultural settings where scholars have shown how epistemologies, knowledge, meaning, and shared goals for agricultural practices are negotiated and co-produced by different groups of farmers, consultants, and scientists (Krzywoszynska 2019; Morgan 2011). Importantly, the CoP framework recognizes that there are always multiple communities of practice in agriculture, with some being more dominant than others (Ingram 2018; Krzywoszynska 2019). The institutions and actors in mainstream agricultural supply chains comprise the dominant agricultural knowledge system (DAKS) which produces and shares information relevant for most of those involved in conventional agriculture. Alternative or niche agricultural knowledge systems (NAKS) also exist within CoPs in agriculture where farmers reject components of the dominant production system. For example, by relying more on agroecological processes than purchased agrichemical inputs, organic, biodynamic, eco-agriculture and permaculture (Ingram and Morris 2007; Ingram et al. 2018), and sustainable soil health management practices (Krzywoszynska 2019) are examples of approaches that have developed their own CoP. Because they often operate outside of the mainstream DAKS, NAKS engage in active processes to define the goals and boundaries of their production systems and use these to generate knowledge and information that reflects their unique production practices, problems, and goals (Ingram 2008, 2018; Ingram and Morris 2007; Noy and Jabbour 2019; Toffolini et al. 2017).

Niche knowledge systems have different degrees of overlap or integration with the mainstream DAKS. While still a small fraction of the public and private sector agricultural research portfolio, organic agriculture is gaining a significant share of the food market in the United States (US) and European Union (EU) (Monke 2016; Rahmann et al. 2017), and there is growing interest among mainstream agricultural scientists to study organic systems as a model for improving the environmental sustainability of conventional crop agriculture (Lorenz and Lal 2016). Similarly, increased attention to the importance of soil health as a way to promote resilience in the face of climate change has led to an explosion of scientific research on the impacts of alternative cultural management practices such as crop rotations, cover crops, and use of manure on soil quality (Arbuckle and Roesch-McNally 2015; Blanco-Canqui et al. 2015; Dhaliwal et al. 2019; Haynes and Naidu 1998; Keene et al. 2017; Liebman et al. 2018; Spargo et al. 2016). The emergence of new CoPs around sustainable soil management has demonstrated opportunities for greater integration and exchange between farmers and agricultural scientists (Krzywoszynska 2019).

Meanwhile, CoPs around agricultural practices like permaculture, biodynamics, and soil balancing have had a more estranged relationship with the DAKS, with relatively little attention and general dismissal from mainstream agricultural scientists despite the persistent and widespread use of these approaches among farmers (Ingram 2007; Ingram et al. 2018). As a result, most knowledge creation, innovation, and discourse among practitioners have taken place outside of scientific disciplines and DAKS institutions. In contrast, they have relied more on farmer innovators and private sector consulting and agribusiness firms for guidance (Crawford et al. 2015; Morgan and Murdoch 2000; Niggli et al. 2008). A CoP that consists mainly of farmers may emphasize information around whether a management practice works in specific contexts, whereas a CoP that is comprised mainly of scientists may focus more on why something happens (Ingram et al. 2010; Romig et al. 1995).

This paper uses a CoP framework to explore the growth and development of a farming practice known as soil balancing. The practice is often seen as particularly compatible with organic farming, where there is a heavy emphasis on holistic approaches to managing soils and crops and a shared concern about the perceived negative effects of synthetic fertilizers used in conventional agriculture (Ingram 2007). Recent research indicates that upwards of 50 percent of organic farmers use some form of soil balancing (Brock et al. 2019).

Soil balancing is usually represented as a distinctive approach to managing soil fertility for crop production and is often contrasted with two mainstream approaches used by nearly all land grant university scientists and private crop consultants to make fertilizer recommendations: Sufficiency Level of Available Nutrients (SLAN) and Buildup and Maintenance (B&M). SLAN refers to applying nutrients when soil tests indicate deficiencies relative to crop requirements. Sufficiency is defined as the level beyond which it is unlikely there will be a yield response. Under the B&M approach, once a field contains sufficient nutrient levels, farmers are recommended to apply nutrients equivalent to levels removed by harvested crops (Chaganti and Culman 2017; Eckert and McLean 1981). In both cases, most attention and fertilizer amendments target three primary nutrients: nitrogen (N), phosphorus (P), and potassium (K), while also including secondary nutrients like magnesium (Mg) and sulfur (S) in situations when soil tests indicate surpluses or deficiencies (Espinoza et al. 2018). Calcium (Ca) is most often added as agricultural lime (calcium carbonate) to raise pH.

By comparison, soil balancing has often been described as an approach to managing soil fertility based on maintaining an ideal Base Cation Saturation Ratio (BCSR) for soil Ca, Mg and K (Black 1993) and has been promoted by a significant number of private sector soil balancing consultants and organizations. In theory, soil balancing emphasizes the important role played by Ca on both crop growth and soil physical and chemical properties. Because soil particles have a fixed capacity to hold cations (cation exchange capacity, or CEC), practitioners recommend *balancing* the level of calcium in conjunction with levels of two other base cations (Mg and K) to achieve ratios that are believed to optimize soil health and nutrient availability. Currently, most soil balancing consultants recommend using soil amendments (particularly gypsum and high-Ca forms of lime) to achieve soil base cation saturation levels of roughly 60–75% Ca, 10–20% Mg, 3–5% K, and 15% of other cations (Kinsey and Walters 2006; Zimmer and Zimmer-Durand 2017).

Many of the ideas around soil balancing are attributed to William Albrecht, a soil scientist from the University of Missouri in the mid-twentieth century who believed that a heavy reliance on inorganic chemical fertilizers in modern agriculture was depleting soils of adequate levels of nutrients, particularly Ca. He argued that declines in soil Ca levels were adversely affecting soil health, crop/forage quality, and animal and human health (Albrecht 1975). Albrecht's work on soil balancing was dismissed by his colleagues at the time (Astera 2014). Currently, soil balancing methods are being developed and disseminated by a small but influential group of soil and crop consultants and soil testing organizations that are loosely affiliated with a private organization (ACRES, U.S.A) founded by Charles Walters (Ingram 2007). These ideas are frequently referenced by key consultants and organizations (such as Gary Zimmer with Midwestern Bio-Ag, and Neal Kinsey of Kinsey's Agricultural Services) who regularly speak at agricultural meetings and have independently published books on the subject that will be further discussed in this paper.

Although the soil balancing approach has been promoted and practiced for several decades, it has received relatively little attention from the scientific community (Kopittke and Menzies 2007). As we explore below, the definition of the term "soil balancing" has been the subject of much negotiation and discussion among farmers, consultants, and scientists. It appears to have different meanings to different actors, and its application by consultants and farmers can be somewhat variable. For purposes of clarity, in this paper, we use the term "soil balancing" to refer to an approach to soil management that (at minimum) seeks to achieve recommended levels of soil BCSR as one of the core goals.

This article is the first study of its kind to describe the practice known as soil balancing using a CoP framework. We use data from key informant interviews, literature reviews, and surveys to explore the following research questions:

- What are the shared meanings or understandings of soil balancing within the soil balancing CoP?
- What outcomes are used by the CoP to evaluate the performance of soil balancing?
- What are the primary sources of information and the role of science within the soil balancing CoP?

We focus mainly on the ways that private consultants, farmers, and scientists have or have not developed a shared repertoire or understanding of the key concepts, practices, and outcomes associated with soil balancing. We also explore an apparent gap between the observations and reported experiences of soil balancing practitioners and mainstream university soil scientists. In this way, we document both the emergence of technical and empirical knowledge around soil balancing, but also highlight the social learning processes that have created boundaries and meanings that hinder the integration of multiple ways of knowing in this sphere.

Methods

Data for this paper were drawn from 28 semi-structured interviews with 33 private consultants and farmers conducted between June 2017 and August 2018.[1] The same interview questionnaire was used for farmers and consultants and the format of their interviews was identical (see supplementary materials for the interview questionnaire). Given that much of the meanings and understandings of soil balancing have not been codified in an academic context, semi-structured interviews with more open ended questions are especially appropriate (Greenhalgh and Taylor 1997). The interviews were located primarily in Ohio but included several from Illinois (one farmer), Michigan (one consultant), and Pennsylvania (one group interview with two consultants and three farmers). The majority of the interviews were conducted in person, typically at the farm or residence of the interviewee. Seven of the interviews were conducted over the phone. Interviewees were recruited because they were identified as a soil balancing practitioner or consultant by organic farming organizations, organic farmers, private consultants, and/or university researchers working on soil balancing research. Of the 33 participants, 11 worked primarily as consultants,[2] and 23 were farmers who ran a diverse mix of operations.[3] It should also be noted that 11 of the 33 participants were members of different types of Plain Anabaptist communities (Old Order Amish, Mennonite, or Apostolic).[4] Interviews lasted from 30 min to several hours but averaged 1.5 h. Topics included respondent background and characteristics of their farm operation, details on how they manage soil on their farm, and information about changes they had observed in their soils over the last 5 to 10 years. After capturing a respondent's general approach to soil management, we asked a detailed set of questions about their familiarity with, and conception and use of so-called "soil balancing" practices. If they reported the use of soil balancing methods, they were invited to share their observations about the effects or impacts of soil balancing on their soils, crops, weeds, and other outcomes. Interviewees were asked to describe their understanding and use of soil balancing and report on their observations about its effects on farms.

Interviews were recorded with the permission of the respondents. The digital recordings were transcribed and reviewed for accuracy, then uploaded to NVivo 11 (Saldana 2016). We conducted a structured analysis of the interview transcripts to capture farmers' and consultants' conceptions of soil balancing and to document specific practices they used as part of their soil balancing approach. We also identified the types of outcomes practitioners observed from the use of soil balancing methods. The primary author constructed a codebook that identified key themes in the answers to these questions and defined decision-criteria for coding farmers using these themes. The second author reviewed the codebook against the transcripts, and areas of disagreement or ambiguity were discussed. The codebook was updated iteratively until consensus was reached about the proper definition and application of key themes (Creswell and Miller 2000).

Another key source of data came from a systematic review of the key soil balancing trade publications, including books and websites associated with some of the most prominent regional and national advocates of the approach. Most of the core texts on soil balancing, including collections of Albrecht's original papers, are published by ACRES, U.S.A., an organization that disseminates information about production-scale organic, eco-agricultural, and sustainable farming practices. The practitioner literature was used to help us understand some of the material from the interviews, particularly concerning certain technical aspects of soil balancing that would not naturally come up in an interview setting.

We also report results from a targeted survey of 105 state soil fertility specialists identified from land grant university websites across the U.S. In the spring of 2017, these specialists were sent an emailed invitation to complete a Qualtrics survey, with an email reminder one week later. This survey was designed to identify examples of published and unpublished research on soil balancing, as well as to better understand the attitudes and perspectives of land grant university soil scientists on the practice. Fifty-one people responded to that survey (a 45.5% response rate), and 32 provided additional written comments. Only three of the respondents had done research on soil balancing themselves, but most were

[1] The researchers obtained permission from the Institutional Review Board at The Ohio State University to conduct this research.

[2] Five of the consultants were also active farmers. One person was classified as a consultant because of their reputation and influence with the farm community, although they did not do actual paid consultancy work (hence 11 and 23 not adding up to 33). Of the consultants who were also farmers, two were vegetable farmers, one was a dairy farmer and three were crop farmers.

[3] Farmers who were interviewed operated diverse types of farm enterprises: vegetable/berries (9); cash grain (5); dairy (6); diversified vegetable and livestock (2); retired dairy farmer (1).

[4] Anabaptists are Christians who formed in the Protestant Reformation period based on their emphasis on adult baptism as a conscious choice and ideas of separation of church and state. The word "Plain" refers to groups who have made collective restrictions on certain types of clothing and/or technology because of commonly held values.

familiar with the concept of soil balancing and had strong impressions of the scientific literature on the topic. Because few had direct experience with the practice, we did not conduct follow up interviews with scientists but rather relied on a formal review of the published literature and their written comments in the survey to capture the perspectives of the scientific community. Comments were coded using Excel to identify the most common topics and themes using the structured qualitative analysis approach described above.

Results

Consultant understandings of soil balancing

We used a review of privately published books and articles authored by soil balancing consultants and interviews with 11 soil balancing consultants to document their understanding of and experience with soil balancing. These books and some of the consultants who were interviewed are well-known in the organic community, and the consultants are often keynote speakers at organic and sustainable agriculture conferences across the US.

Soil chemistry management

According to the consultant literature and our interviews, a soil balancing approach usually begins by targeting a specific range of BCSRs, using Albrecht's recommended levels as a rule of thumb. Calcium received the most attention and is viewed as having a vital role in promoting crop growth, shaping soil physical properties, and facilitating the availability and utilization of other soil macro- and micronutrients. Albrecht argued that Ca deficiency, rather than soil acidity, was the root cause of many soil and crop problems in the latter half of the twentieth century (Albrecht 2011). In their book, Kinsey and Walters note that farmers "need to understand that a good pH does not guarantee a balanced soil" (Kinsey and Walters 2006, p. 68). Brunetti and McKibben discuss how Ca interacts with other nutrients to influence their availability to plants (Brunetti 2014; McKibben 2012). BCSR consultants and organizations frequently recommend the use of specific forms of Ca amendments (gypsum and "Hi-Cal" lime) which are believed to have higher and more plant-available levels of Ca than traditional agricultural lime. Many soil balancing organizations sell or recommend specific branded Hi-Cal products.

In the books and our interviews, consultants often stressed how the effectiveness of a BCSR approach can be influenced by a soil's cation exchange capacity (CEC). In the words of one interviewee, "You can think of your soil's CEC as its nutrient gas tank, it is the amount of fuel the soil could hold often translated as yield potential." Kinsey wrote that the CEC "affects the soil's capacity to hold nutrients such as calcium, magnesium, and ammonia nitrogen" and determining the CEC is "the first thing we need to know" (Kinsey and Walters 2006, pp. 33–50). For some consultants, farms with low CEC soils may be poor candidates for a BCSR approach because there are not enough cation exchange sites to hold sufficient K and Mg if Ca levels are elevated.

Sulfur and boron were also frequently mentioned as vital to the function and role of Ca within the soil balancing approach. One consultant stated that when Ca is already at target levels, "what I wanna do is apply sulfur and boron to get that calcium working." Midwestern BioAg's website uses the analogy that "calcium is a truck" and "boron is the steering wheel" because it works hand-in-hand with Ca to "build cell walls and get nutrients into the plant" (Zimmer and Zimmer-Durand 2017, p. 290). There appears to be more emphasis on trace elements within the soil balancing CoP compared to a conventional SLAN fertility management approach. While SLAN does pay attention to the role of micronutrients, they do not play as central of a role as primary and secondary nutrients. Soil scientists do not see trace element deficiencies as an issue in this region (Vitosh et al. 1995).

A common view among soil balancing consultants is that the availability and absorption of many individual nutrients or minerals are influenced by the presence or absence of other soil nutrients. These complex interconnections are illustrated in the Mulder Mineral Wheel, a graphic that originally appeared in Watts (1995) and is reproduced in several contemporary books on soil balancing (Brunetti 2014, p. 64; Kinsey and Walters 2006, p. 192; Zimmer and Zimmer-Durand 2017, p. 94). Kinsey Ag's website explains that adding a nutrient can alleviate a shortfall or excess of another nutrient, and this "is the meaning of soil balance using Albrecht Model." One informant noted that ideal BCSR ratios not only increased Ca absorption but also provided "better absorption of the entire trace mineral profile."

Beyond chemistry: the three-legged stool

While BCSR chemistry is at the core of a soil balancing approach, most consultants and farmers reported using a wide range of other soil health management practices under the umbrella of soil balancing. This was commonly expressed as a "three-legged stool" which begins with BCSR chemistry but also incorporates management of the biological and physical structure of soils, recognizing that "each of these is related and influences each other" and if you throw one of the three "out of balance…it will affect the health of the entire soil system" (Zimmer and Zimmer-Durand 2017, p. 27). One consultant in our interviews emphasized that growers need to be aware that "everything works together" so that if you "focus solely on one and forget the other two, you won't have success."

For some contemporary soil balancing consultants, managing biology is particularly important. In one interview, a consultant stated that "biology trumps chemistry" and even if you have a soil that is "perfectly balanced from an Albrecht perspective," you can still have a "disastrous crop if you do not have good biology to have good nutrient availability in the soil profile." Another consultant expressed the belief that because of deteriorating soil biology due to conventional farming practices, the Albrecht BCSR-only approach may not be "as strong today as it was 40 years ago when it was first developed."

Most soil balancing consultants recommended using cultural management practices in addition to Ca amendments. The predominant view was that some periodic tillage is necessary within a soil balancing approach to mix nutrients throughout the soil profile and address stratification problems associated with no-till (Zimmer and Zimmer-Durand 2017). One consultant shared that when he was starting his career as an agronomist, he was all about "getting away from moldboard plowing." But now "40 years later," he thinks periodic plowing and/or tillage can be a positive thing. Another consultant explained that if you have tight soil, you may need "to loosen it up" through some deep tillage by using "steel and iron" to "rip it up" and "get the air down" and "get the water draining, and get your minerals in there and the biology working."

Some cultural management practices are prescribed explicitly because of their influence on soil biology. Examples are the use of crop rotations and cover crops. In the words of one consultant, they are a way to "foster biology not inhibit biology." Zimmer and Zimmer-Durand (2017, p. 362) wrote that "both green manure crops and other types of cover crops provide a lot of benefits to soil quality and to soil life" since they facilitate building humus and "holding nutrients that might otherwise leach away, such as nitrogen." Another consultant explained that "different crops are essential for feeding different types of soil biology." The application of manure and compost was also commonly cited as part of a good soil balancing management program, particularly in organic operations. Zimmer and Zimmer-Durand (2017, p. 366) note that "without animal manures, it is more difficult and more expensive to provide the necessary nitrogen for crops…(and) animal manures really do make biological farming work better—as long as they are managed properly." Kinsey and Walters (2006) repeat the idea that manure application is an important way to improve soil structure under a balancing program.

A common theme in our interviews and review of consultant publications was the view that conventional SLAN/B&M approaches often fail to appreciate how soil chemical, physical, and biological conditions mediate the *availability* of soil nutrients to the plant. This emphasis on availability is linked to the idea of the three-legged stool. One consultant felt that practicing soil balancing went beyond BCSR since "the air and the biology makes a huge difference in the availability of these nutrients…" He emphasized the importance of "soil tilth, biology, and fungals so that all these nutrients are more available to plants." Another noted that "availability, storage, those things are really important, because if you don't have a real balance there, you may not get the value out of adding minerals."

The emphasis on availability was connected to views about the importance of micronutrient deficiencies that could prevent primary and secondary nutrients from getting absorbed by the plant. One soil balancing book notes that "what matters most is what gets into the plant not what gets into the soil" (Zimmer and Zimmer-Durand 2017, p. 89). Similarly, McKibben (2012, p. 58) has written about "restrictors that may be present, preventing nutrients from going into solution and being available to the plants."

Importance of context

Another important theme expressed by consultants was that soil balancing practices need to be adapted to the unique qualities of specific fields, farms, and farmers. In addition to the importance of soil CEC mentioned above, one consultant noted that "recommendations are going to vary, depending on if it's a high magnesium situation, a high calcium situation, et cetera." It is also important to consider the farm's management history and soil biological state. One consultant noted that farmers who have high organic matter could "start paying a lot less attention to the ratios." Farm type can also influence soil balancing recommendations. Vegetable farmers raise higher value crops and thus have a larger budget to purchase amendments. One consultant stated that he generally runs an "Albrecht type soil analysis every year for his vegetable and fruit growers." In contrast, he runs these soil analyses for broadacre crops every three years. This consultant went on to say, "dairy farmers are the number one users of our high calcium lime…[because] they sell their calcium every day. It leaves in the truck."

Comparison of BCSR and SLAN/B&M

While soil balancing consultants are frequently critical of the traditional SLAN/B&M approaches, it would be misleading to suggest that they view these approaches as mutually exclusive. Indeed, most soil balancing books regularly incorporated information from standard soil science textbooks, and most consultants still pay close attention to levels of pH and standard crop macronutrients (N, P, and K). Zimmer and Zimmer-Durand discussed the complementarities of the standard approach and the soil balancing approach, writing that "most scientists agree that twenty plus nutrients are needed for crop production; they also agree on certain sufficiency levels of those nutrients." Those levels of sufficiency "will also give you ratios' of those nutrients in the soil. Thus, either approach is "very similar as long as you also deal with excesses" (Zimmer and Zimmer-Durand 2017, p. 120). One soil balancing consultant stated that "we did not overlook the fundamentals of sufficiency or excess. Particularly phosphorous and potassium. We need to have sufficient levels in a soil." Aside from BCSR chemistry, one consultant talked in his interview about the importance of "NPK type materials" as the fourth group of nutrients which he would include in his soil balancing recommendations.

Farmer understandings and use of soil balancing

While the consultants painted a nuanced picture of the ideas and practices associated with soil balancing, the understandings and implementations of soil balancing described by farmers in our interviews were even more diverse. Among the 23 working organic farmers we interviewed,[5] most reported using a blend of approaches to soil fertility management, and only a few described using a strict BCSR approach that focused only on targeting specific Ca:Mg:K ratios. While few of the farmers framed soil balancing solely around a strict BCSR approach when pressed, 18 of the 24 farmers expressed general adherence to the idea that maintaining appropriate cation levels (particularly for Ca and Mg) were important to a "balanced soil." Farmers were less likely to mention numeric target ratios than consultants. Rather than trying to achieve exact percentages, farmers were more likely to seek a general target range of saturation values. As one farmer stated, "you don't have to thread the needle on soil balancing, but you have to be…in those good ranges".

When asked to define "soil balancing," farmers typically responded by listing the practices they use, particularly the application of high-Ca soil amendments. In the interview transcripts, farmers used words describing amendments three times more frequently than words involving BCSR concepts (like cations and saturation ratios). Farmers were less likely than consultants to distinguish between forms of Ca amendments (particularly Hi-Cal vs. agricultural lime). Compared to consultants, farmers were less likely to talk about the importance of CEC, but several pointed at soil type as related to the effectiveness of soil balancing.

Soil balancing farmers frequently blurred the distinction between SLAN/B&M and BCSR approaches to soil fertility and most described management strategies that combined elements of each approach. For example, when asked how they would define soil balancing, most farmers first described it as a general approach to managing soil fertility through the use of soil tests to achieve desired crop performance results. As one farmer stated, soil balancing is like "taking a test and…checking what's low…and applying… lime or phosphorus…". Another farmer explicitly linked soil balancing to SLAN/B&M approaches when he noted that "the first thing I think of is what the state universities put out for recommendations for NPK and micronutrients." He added that he also checks tests to get information about "organic matter and cation exchange capacity–the CEC." A third farmer stated that when he thinks of soil balancing, he looks for a "benchmark…we want our phosphorous levels here, we want our potassium levels there, and our calcium levels and… we want our pH and our CEC and base saturation."

A few producers indicated that micronutrients (particularly boron) were important to their practice of soil balancing, but others made it clear that macronutrients are the priority. One farmer stated that "I'm a firm believer in trace minerals and balancing our soils by base saturation levels." Another expressed his interest in micronutrients while simultaneously having a greater emphasis on macronutrients when he stated, "Most soil nutritionists will tell you that… there's no point in addressing them until you get everything else in line."

In general, soil balancing farmers focused as much on soil biology as chemistry. One discussed how "I had a lot of agronomists look at my soil analysis and say, 'Wow, you know you're doing good. That soil's balanced." But the farmer noticed that the soil was "not producing anything." He attributed this to a lack of healthy soil microbes. These farmers also described using farm cultural management practices, like crop rotations, cover crops, and the use of manure or compost as part of a successful soil balancing program perhaps even more than the consultants. One suggested that "management is key; that's what defines a farmer. It's one who knows how to manage that soil, not one that knows all about the amendments and stuff." Another drew on advice from "old timers" like his grandfather who taught him the saying, "lime, manure, and clover, make the farm rich all over." Another farmer likened the amendments he uses to "Band-Aids" and pointed to cover cropping as "more of a long-term cure."

Soil balancing outcomes

In our interviews, nearly all farmers and consultants reported observing changes in soil chemistry, physics, and biology that they associated at least to some degree with their use of soil balancing practices. Improvements in soil physical properties were among the most common outcomes mentioned (discussed in 17 of the interviews). Many used adjectives

[5] Although some of the consultants we interviewed were also active farmers, they are not included here.

describing positive physical changes in the soil that occurred after applying soil balancing amendments. Three farmers talked about their soil being "mellow" to indicate a positive state of soil tilth. Two farmers used the word "flocculated" to indicate a state of balance. One stated their goal to "move that calcium into those high 60 s first, flocculate that soil to where you can get some leachability with it." Another farmer stated that the sulfur in gypsum helped to "loosen" soil. One consultant discussed how soil balancing improves resilience, saying the soil is "basically softer, and it holds up better to adverse conditions."

Conversely, an unbalanced soil was described with negative physical qualities. At least thirteen of the interviews contained a description of "unbalanced" soils using adjectives including "tight," "tied up," and/or "locked up." For example, one stated that if the Ca:Mg ratio is off, then soil "is real tight and can't absorb the air and water." Another related that when the ratio of Ca and Mg is correct, there is "less compaction or locking [soil] up." A third stated if you have your soil balanced, "the various nutrients then can be released, and they're not tied up in the soil."

These positive physical properties were often connected with reduced weed pressure. About half of the interviews mentioned reductions in weed populations from soil balancing, and most of these specifically discussed how grasses such as foxtail were less common. The connection between weeds and soil balancing was generally associated with reduced compaction, which provided a less desirable environment for weeds. One farmer claimed to have significantly reduced a quackgrass problem by correcting the "high magnesium levels, tighter soils" and using "a lot of cover crops over the years."

A few interviewees reported improvements in plant health and reduced insect pest pressure linked to soil balancing practices. For these individuals, these outcomes were connected to perceived improvements in soil physical and biological properties. One consultant observed that improved soil health could benefit plant health in that we have "less bug pressure than we did the first year that we were farming." He also felt that improvements in "the soil structure, the soil microbes" had led to better plant health and provided "immunity towards pests and diseases." One farmer echoed this same idea by saying, "you get the soil balancing right; you get the biology right," and then "you can have less weeds, less insects, less disease."

Consultants often focused on how soil balancing can improve crop quality. Echoing Albrecht's original work, modern soil balancing consultants have argued that although crop yields have risen over the years, crop quality has gone down (Zimmer and Zimmer-Durand 2017). In his book, McKibben documents a drop in Ca levels from 1963 to 1999 in major food crops (McKibben 2012). In our interviews, one consultant stated that his focus "is not necessarily yield… (rather it) is the quality of the crop, and so as we achieve that the yield takes care of itself."

Farmers and consultants struggled in the interviews to identify the *single most important* benefit associated with soil balancing. Responses were wide-ranging: soil structure, plant health, crop quality, yield, and profitability. Outcomes associated with soil balancing practices were often described by farmers and consultants as a set of interlocking and related effects, and they argued that discussing one outcome in isolation ignores the complex and integrated dynamics of their farming systems. When asked to list some of the "benefits of soil balancing," eight respondents focused on the importance of system integration, because the benefits were clearly intertwined and related to other management practices. For example, one consultant stated that with soil balancing, he got "better aeration" and he saw "less weed control problems, especially in the grasses when we get a better soil balance." Another talked about how improvement in "the soil structure" and "the soil microbes" was connected to providing immunity toward pests and diseases.

The role of science in the soil balancing CoP

Scientists' understandings of soil balancing

Compared to most other soil science topics, there is a relatively small body of scientific literature examining soil balancing, and the handful of published peer-reviewed studies have been unable to reproduce the benefits reported by farmers and soil balancing consultants. There are two major reviews of the scientific literature on BCSR. Kopittke and Menzies (2007) summarize early BCSR theories based on research by Bear and Albrecht from early to mid-twentieth century that supported the idea that achieving an ideal cation balance would boost crop yields. They criticize the methodologies used in that early work for confounding pH and Ca:Mg ratio effects and present more recent published work (mainly from the 1970s to 1990s) that failed to reproduce any significant impacts on yield, soil physical properties, or soil biology from adjusting Ca:Mg ratios. A more recent review identified 15 peer-reviewed studies that explicitly tested the effects of Ca:Mg ratios on agronomic outcomes (Chaganti and Culman 2017). These papers were published from 1930 to 2008, with only three papers published since 1985. All of these papers focused on yield impacts, and none found significant differences in crop yield. They were all based on controlled experimental trials in the greenhouse ($n=8$) and experiment station field plots ($n=7$). None of the past experiments were conducted in the context of a working farm. Importantly, the scientific community and research literature have approached the study of soil balancing with a nearly singular focus on evaluating whether achieving "ideal" base cation saturation ratios of Ca, Mg, and K is associated with statistically different agronomic outcomes.

To identify any additional studies and to capture scientists' perspectives on soil balancing, we conducted a Qualtrics online survey of 101 state soil fertility specialists from land grant universities across the USA. The results documented a high level of scientific community skepticism about soil balancing which reflects the consensus of the peer reviewed literature. Nearly 80% of respondents agreed with the statement that "there is no scientific merit to (the soil balancing) approach, and this has been shown repeatedly." Only a minority (22%) thought it was possible that farmers would see benefits from BCSR.

This sentiment was further elaborated in their written comments. Typical comments included phrases like, "This has been going on for more than 50 years, and yet no credible research has been able to document anything," "The question of yield response has been thoroughly researched and Ca:Mg ratio management found to be irrelevant over a wide range," "I think there is enough published research already on this topic…we should not waste anymore money refuting one paper published in the early 1940s…." Like the peer reviewed literature, most of the soil fertility specialists focused on BSCR as the core idea, and yield as the best indicator of whether soil balancing works.

Not surprisingly, many scientists shared concerns that soil balancing programs are a waste of money. One stated that soil balancing "is the province of charlatans who wish to sell unneeded soil amendments." Another wrote that "more often than not I see private soil testing labs pushing the BCSR concept as a way to sell fertilizer products that are not needed to optimize crop yield." Another expressed that soil balancing "has become accepted fact for many farmers because consultants sell it that way." This is echoed in Kopittke and Menzies' (2007, p. 259) literature review that concluded, "the continued promotion of the BCSR will result in the inefficient use of resources in agriculture and horticulture."

A little over a third of scientists (36%) felt there should be more scientific research on this topic, but their written comments illustrated that most of them wanted research to solidify the case that soil balancing does not work. As one wrote, "I think research is needed so once and for all the concept of balance is abandoned by companies and dealers wanting to use it." At the same time, many scientists were skeptical that scientific research would change the minds of soil balancing farmers and consultants. One noted that "you cannot refute religion with science" and another referenced soil balancing as "popular modern soil alchemy."

While the peer reviewed literature did not seem to acknowledge the importance of contextual factors, a few survey respondents noted that there might be potential for soil balancing methods to work in certain restricted situations. Some felt that improved soil structure outcomes are theoretically possible as base cations "facilitate soil binding and promote soil aggregation." One wrote that "soil physical dispersion properties are sensitive in some 2:1 clay soils." Another felt that BCSR could be used to "help fine-tune soil-test K or Mg calibrations with yield response" particularly on "VERY CONTRASTING soils (mainly texture and clay type). Two soil fertility specialists saw the potential for using BCSR to improve forage quality for livestock nutrition. One wrote that "livestock nutrition and the BCSR is the area I receive the most questions that I cannot fully answer."

Soil balancer ways of knowing and views on science

Based on our interviews and reviews of their privately published books, soil balancing consultants acquire most of their knowledge of soil balancing through observations of outcomes on their clients' farms, as well as the use of simple field trials where interventions are compared to a control strip or field. While the majority of consultants in our study had university training in soil science and/or agronomy, the organizations they work for and soil testing labs they often affiliate with are not typically supported by land grant university scientists. In our interviews, consultants rarely referenced peer reviewed research and appear to rely mainly on their own experiences, with clients as well as information exchanged among soil balancing consultants and associated organizations to inform their work. One consultant stated that "the peer-reviewed published literature has been of very limited usefulness." Several consultants and a few farmers expressed a perception that most scientific experiments were too focused on yield and overlooked other important outcomes (like soil tilth and crop quality). They also believed that most of the scientific work on soil balancing was too short in duration and needed to be three years or longer to detect benefits.

Some consultants see their work as a direct response to bias or gaps in conventional science. Walters and Fenzau (2003, p. xiii) have argued that soil balancing involves the use of "scientific farming principles that USDA, extension, and land grant colleges have refused to teach," while Wheeler and Ward (1998, p. 214) believe that scientists "blindly followed reductionist science procedures without observing the whole picture or relating to the reality of nature." Another talked about how he "got laughed at for talking about it" at a conference. He thinks that the academic community feels that soil balancing is "fringe agriculture" and to them, we "are a bunch of kooks." These sentiments echo those reported by Ingram (2007), who noted that alternative agriculturalists "more frequently reflect the opinion that conventional science is a lost cause" (p. 306).

When asked whether more scientific research was needed to improve soil balancing approaches, most soil balancer interviewees were either uninterested ("I don't need to wait for science to acknowledge it") or had doubts that traditional scientific methods could capture the complex dynamics of working farming systems. One noted that scientific experiments focus "almost exclusively on single factor analysis. And there is no such thing as single factor analysis in agriculture," so we need "multi-factor analyses" to address the "root cause of problems." Another said that "reductionist thinking (attempts) to break whole things down into component parts and rarely comes up with an impressive result in…putting it all back together." A few interviewees did share a desire to see scientists do more on-farm research, but more as a way for scientists to "go out and follow the progressive farmers, and document what they've done" than to test whether it works.

Valued sources of information within soil balancing CoP

When asked where they get information to guide their soil balancing decisions, farmers did not mention the use of information from scientific studies or university research and extension systems, while 17 of 24 farmers mentioned using soil balancing consultants. Three deferred entirely to their consultants and referred us to their consultants to answer our questions about what was being done on their fields. Seven of the farmers who used soil balancing consultants mentioned using more than one consultant. Soil testing labs (particularly Brookside Labs in New Bremen, OH, which is popular among soil balancing consultants) and agricultural input suppliers were each mentioned as important sources of information in eight of the farmer interviews. Four farmers mentioned reading and using material from the original soil balancing books written by people like Albrecht.

Importantly, most farmers described how they rely principally on their own as well as other farmers' experiences and observations about whether or not a given soil management practice seems to be working. Five farmers explicitly referred to the role of intuition or observation in working to balance their soils, with one noting that "I do soil tests about every three years, but I do more balancing with visual…" Yet another stated he relies on "trial and error out on the farm to see what works…." A third emphasized the importance of "personal conversations with other producers."

Farmers' varied and complex understandings of soil balancing likely reflect their use of diverse information sources to guide their soil management decisions. In our interviews, it was clear that most farmers were not necessarily married to any particular approach or consultant, and merged advice from different sources with wisdom gleaned from their own accumulated experiences. The use of multiple sources of information on soil balancing shows that farmers are seeking and comparing diverse opinions about best soil management strategies. One farmer described this process as using half of one person's advice and half of another and ending up "somewhere in between."

Discussion

For decades, soil balancing has been recommended by many crop consultants and advisors and practiced by a significant number of farmers, particularly in the organic sector (Brock et al. 2019). Our study found that the soil balancing CoP in the eastern US is organized around a network of private consultants and farmers who have collectively shaped the meaning and goals for soil balancing, as well as refining technical farming approaches to implement these ideas. In the context of soil balancing, private sector consultants play a central role in the soil balancing CoP and regularly engage in dialogue and partnerships with farmers to use soil balancing principles to address common farming systems challenges. Our findings underscore the importance of crop consultants and advisers in the development and dissemination of agricultural knowledge (Eanes et al. 2017; Hejnowicz et al. 2016; Prokopy et al. 2015; Wolf 1995). Consultants have not been a major focus of past studies of knowledge co-production, which have instead emphasized the integration of scientific and tacit local ways of knowing in alternative agriculture (Hassanein and Kloppenberg 1995; Ingram 2008; Morgan and Murdoch 2000).

When viewed through the lens of the Community of Practice framework, it is clear that consultants and farmers have used patterns of mutual engagement based on experiential and observational knowledge to construct a shared repertoire that defines the meanings, boundaries, and goals for soil balancing. By contrast, mainstream agricultural scientists utilize ways of knowing and an understanding of soil balancing that deviate significantly from those expressed by farmers and consultants in our study. A summary of soil balancing knowledge and understandings for each of these three sets of actors are highlighted in Table 1 below.

Initially, the definition of soil balancing used by most members of the soil balancing CoP appears to be more complex than has been represented in the published scientific literature. Soil balancing consultants emphasized how Ca interacts with other nutrients and reported that when ideal BCSR levels are achieved in soils on their clients' farms, the availability and resulting plant uptake of other nutrients can improve. While consultants mentioned BCSR as a key component of their idea of soil balancing, nearly all articulated a much broader approach that involved managing soil amendments and cultural practices to impact the chemistry, biology, and physical properties of soils as part of a holistic soil health management system. Farmers who we interviewed had a more practical working definition of soil balancing that focused on the use of Ca amendments but also included

Table 1 Concepts, outcomes, information sources and views of science in and outside the soil balancing (sb) community of practice

	SB consultants	SB farmers	Soil scientists
Definition of Soil Balancing	BCSR is central, but emphasize how other chemical, physical, or biological soil properties affect nutrient availability	Practice based. Develop their own ideas based on personal experience. Defer to consultants to define	Defined as use of BCSR to achieve target Ca:Mg:K saturation ratios in soil
BCSR vs SLAN/B&M	Views BCSR as compatible with SLAN/B&M. Difference mainly in approach to Ca amendment recommendations	Many focus on balancing all nutrients (including NPK) to meet crop needs; Sees SLAN as compatible with or a part of soil balancing	Views BCSR (a radical unproven idea) as a competitor to SLAN/B&M (a proven method)
Links to broader soil health	Soil balancing recommendations combine BCSR and common soil health management practices	More interested in improving soil health through cultural management than just BCSR/chemistry per se	Large and expanding peer reviewed literature on soil health rarely mentions BCSR or soil balancing
Outcomes	Focused more on soil and crop qualities than yield (per se) but imply that yield benefits occur	Focused on wide range of observable outcomes related to soil properties and agronomic performance	Most studies measure crop yield outcomes; a few measure impacts on soil properties and crop quality
Experimental designs & research goal	Uses farmer client observations and case study field comparisons over longer periods of time (3 + years). Focus on holistic system dynamics within specific contexts	Informal trial and error and field-based observations. Focus on mix of individual practice effects and holistic system dynamics on their own farm	Controlled experiments that manipulate Ca and Mg levels. Developing generalized understanding of Ca:Mg effects on soil and crops
Assessment	Very positive	Mixed	Highly skeptical
Role for future scientific research	Know SB works but interested in having scientists explain *how* it works (not if it works). Prefer on-farm field-scale research	Few soil balancing farmers were looking to scientific community to provide guidance on soil balancing	Most see no reason to do more scientific study. Some see need only to debunk modern SB proponents

"balancing" a wide range of nutrients to address specific crop needs in their fields over time. Both consultants and farmers in the soil balancing CoP emphasized that reliance only on BCSR management would be unlikely to generate productive results. In contrast, results from our survey of soil scientists and a review of the published scientific literature demonstrated that scientists have utilized a narrower definition of soil balancing that focuses exclusively on manipulating BCSR soil levels (Chaganti and Culman 2017).

Interestingly, while scientists have often viewed soil balancing as a competitor to traditional SLAN and B&M approaches to soil fertility management (Chaganti and Culman 2017), our study found that most consultants and farmers in the soil balancing CoP did not see these as mutually exclusive (Table 1). Soil balancing recommendations did encourage farmers to apply Ca amendments at levels that can be higher than SLAN recommendations (which are typically aimed at meeting crop Ca needs and adjusting pH). However, consultants and farmers in the soil balancing CoP also mentioned using SLAN/B&M concepts to address other crop nutrient requirements (particularly N, P, and K) and were generally supportive of using lime to maintain optimal pH levels for crop growth. Farmers seem to be operating at the boundaries of soil balancing and SLAN (Oreszczyn et al. 2010) such that they often failed to even distinguish between the two.

More broadly, consultants and farmers active in the soil balancing CoP operationalized soil balancing through the use of a wide range of soil amendments (e.g., manure/composts, NPK, and micronutrients) and cultural management practices (cover crops, crop rotations, and tillage) to achieve broad improvements in soil health. The majority of consultants emphasized the need to manage micronutrients and other chemical components in the soil in addition to base cations. They also stressed the importance of managing the physical and biological properties of soils as a core component of an effective soil balancing program. In our study, we found no consultant who implemented a simple BCSR management system in isolation from the use of other soil health management practices. The technical approaches to soil balancing by farmers in the soil balancing CoP relied even more heavily on practices designed to broadly improve soil health. Meanwhile, scientists who have studied and discussed soil balancing have largely seen BCSR as different and disconnected from the growing field of soil health research.

Leaders in the soil balancing CoP articulated the view that the goal of soil balancing is to create a soil environment that requires fewer external inputs, is resilient to pest pressure and climate extremes, and can produce high quality crops. In the interviews and consultant publications we reviewed, consultants and farmers rarely emphasized yield as a primary metric for assessing progress towards a balanced soil. Rather, they emphasized soil physical properties, soil biological activity, and crop quality as the best indicators (though they did imply that once these attributes were achieved, improved and more stable yields should follow). In contrast, the peer-reviewed soil science literature has focused predominantly on evaluating the effects of Ca:Mg manipulations on yield (Chaganti and Culman 2017).

The members of the soil balancing CoP utilized a range of sources of information and ways of knowing to understand and improve the performance of soil balancing practices. Consultants relied heavily on their multiple years of experience working with numerous farmer clients to inform their knowledge of soil balancing. In interviews, they stressed the importance of long-term observations, a focus on the whole farm system, and accounting for the unique features of every individual farms' biophysical context when making soil balancing recommendations. As observed in other studies, farmers relied heavily on personal experience, other farmers, and private consultants to guide their soil management decisions (Delate et al. 2017; Delate and DeWitt 2004; Gloy et al. 2000; Hassanein and Kloppenberg 1995; Ingram 2007; Kroma 2006; Laforge and McLachlan 2018; Morgan and Murdoch 2000). Farmers typically deferred to consultants to explain the basic principles and theory behind soil balancing.

Both consultants and farmers were reluctant to suggest that soil balancing methods can be easily generalized without careful adaptation to individual contexts. In this way, while they have a "shared repertoire" that defines the broad boundaries and goals for the approach, they also appear comfortable with the idea there are diverse ways that soil balancing practices should be implemented, depending on local conditions. The importance of site specificity for members of the soil balancing CoP is similar to what (Ingram et al. 2014) found in the context of permaculture. It also represents an approach that relies much more on local and tacit knowledge to develop an understanding of the impacts of management practices on soil processes in a working farm context.

By contrast, scientists who have done research on soil balancing have relied on standard scientific epistemologies and methods to conduct controlled experiments with the goal of generating generalizable knowledge that can be replicable across time and space (Clark and Murdoch 1997; Pickstone 2001). By manipulating treatments and narrowing the focus to only one or two factors, randomized experimental designs can help isolate the distinctive effects of a single factor (e.g., Ca:Mg saturation levels) from the influence of other potentially confounding factors. The preference of scientists to employ a narrow definition of soil balancing is closely related to their desire to isolate the specific role of Ca:Mg ratios in their experimental designs.

Overall soil balancing consultants in our study were quite positive about the practice of soil balancing and regularly promote it to farmers and others. Farmers generally had a positive view of soil balancing but expressed more concerns about the costs of soil balancing amendments and whether the costs were always worth the benefits. Most farmers saw soil balancing as only one of several combined strategies that they could use to improve their soil. At the other end of the spectrum, scientists were extremely skeptical of the benefits of soil balancing, basing their assessment on the peer-reviewed literature.

Consultants, farmers, and scientists expressed different ideas about the form and role of scientific research in the soil balancing practice. Typically, consultants and farmers would like scientific research to verify *why* soil balancing works (not *if* it works), a finding consistent with previous research (Krzywoszynska 2019). Attention from scientists is thus valued principally as a source of epistemic authority that can benefit consultants (Herbst 2003). Meanwhile, many of the scientists in our survey expressed the view that soil balancing has already been proven not to work, and those supporting more science were simply looking for more evidence to finally convince practitioners about the ineffectiveness of BCSR.

Taken as a whole, the soil balancing CoP appears to be a good exemplar of a NAKS in which farmers and consultants regularly interact to advance their knowledge with relatively little interaction with scientists in the DAKS. While a few agronomists and soil scientists have conducted studies of soil balancing, they have been unable to reproduce evidence that manipulating Ca:Mg levels in soil can have a systematic impact on crop outcomes. While relatively few currently active soil scientists have conducted their own research on the topic, they appear to share an understanding that the question of whether or not it works has been answered. As a result, scientists have been relatively invisible and unimportant in shaping discourse and practice in the soil balancing CoP. These dynamics reflect similar tensions between the DAKS and NAKS around topics like permaculture and biodynamics (Ingram and Morris 2007; Ingram 2018). As Ingram has noted (2018, p. 130), NAKS display a "tendency to circulate internally with boundaries maintained by these shared internal understandings, a common epistemological language, and invested knowledge." Internal knowledge can be "hard to standardize and codify" and therefore creates challenges for communicating with communities outside the NAKS, leading to divergent paths for the development and growth of knowledge (ibid).

Conclusions and recommendations

Alternative agricultural practices and systems have long had a fraught and complicated relationship to science, and this tension is certainly visible with soil balancing. A Communities of Practice (CoP) (Wenger 2000) framework can help explain how knowledge, meanings, shared values, and goals are negotiated and co-produced within a bounded learning community (Krzywoszynska 2019). While poorly integrated with the mainstream agricultural scientific community, the tensions between different agricultural knowledge systems have the potential to be leveraged as a source of innovation and learning (Eshuis and Stuiver 2005; Schneider et al. 2010; Vanclay 2004).

Our research team (and many of the farmers and consultants involved in our study) see opportunities to build better linkages between the soil balancing CoP and the scientific community. One opportunity is to take steps to apply greater scientific observation and methods to explore the practices actually used by soil balancing consultants and farmers. The complex character of soil balancing practices among farmers and consultants suggests an opportunity to design and implement new scientific research on the interactions among BCSR amendments, broader soil management practices, and local contextual conditions. Studies that explore a range of intermediate outcomes (e.g., soil chemistry, soil physics, soil biology, and crop health/quality) associated with manipulations of base cations in the presence and absence of other soil health-building practices could provide insights into the complex dynamics of soil balancing systems (in particular) and soil quality (in general).

More broadly, scientists could better integrate farmer and consultant observations and experiences about qualitative changes in soil into their work (Eshuis and Stuiver 2005; Lobry de Bruyn and Andrews 2016). To open the dialogue, scientists could more explicitly recognize the limitations and biases inherent in traditional experimental designs and signal respect for and trust in the observations and tacit knowledge of practitioners (Noe et al. 2015). Likewise, private consultants and farmers would need to be open to collaborations with scientists to further refine their understanding of local processes and outcomes, and to improve their recommendations and practices. This type of research program could benefit from using more innovative and participatory approaches to research and engagement that capitalize on both the power of rigorous scientific research design and instrumentation and the in-depth knowledge and observational skills of practicing farmers and consultants (Delate et al. 2017; Leeuwis and Van den Ban 2004).

There is perhaps a good role model in the rapidly growing and productive CoP surrounding the concept of soil health (Bhardwaj et al. 2011; Larkin 2015; Lehman et al. 2015; Reeve et al. 2016). While some of the best examples of this work are taking place in developing country contexts (Barrios et al. 2006; Mairura et al. 2007; Richelle et al. 2018), their use of interdisciplinary collaborations among scientists working on different aspects of complex farming systems, and between scientists and farmers seem like a productive approach to improve our understanding of the dynamics that hinder or promote long-term improvement in soil health (Doran 2002; Krzywoszynska 2019; Lobry de Bruyn and Andrews 2016). Because many of the concepts and practices within the soil balancing CoP focus on soil health, there are likely many areas of possible overlap and potential synergy.

Finally, it is also important to recognize that the DAKS and NAKS are often diverse, fluid, and diffuse (Morgan 2011). This quality has led some scholars to denote them as networks of practice or constellations of practice—rather than CoPs (Brown and Duguid 2001; Oreszczyn et al. 2010). The diffuse nature of CoPs provides opportunities for growth and innovation and opens spaces for potential collaboration with other CoPs (Ingram 2018). Since we interviewed farmers and consultants individually and captured individual scientists' quotes, we were able to capture some of this heterogeneity. Farmers, consultants, and scientists who were more open to each other's approaches and different possibilities could be identified and mutual collaboration could be forged.

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Data availability Data available on request due to privacy/ethical restrictions given the nature of the interview data. The IRB (see below) confidentiality agreement (under which the data were collected) prevents us from releasing information that reveals the identity of informants. We would need to remove all identifying information before sharing with other researchers.

Compliance with ethical standards

Conflict of interest There are no financial interests or conflict of interests, in general, involving this research.

Ethics approval This research was approved by the Institutional Review Board of the Ohio State University.

Consent to participate Informed consent was obtained from all individual participants included in the study with the understanding that it would be published.

References

Albrecht, W. 1975. *The Albrecht papers, vol. 1: Foundation concepts*. Kansas City, MO: Acres U.S.A.

Albrecht, W. 2011. *Albrecht on calcium*, vol. II. Austin, TX: Acres U.S.A.

Arbuckle, J.G., and G. Roesch-McNally. 2015. Cover crop adoption in Iowa: The role of perceived practice characteristics. *Journal of Soil and Water Conservation* 70 (6): 418–429. https://doi.org/10.2489/jswc.70.6.418.

Astera, Michael. 2014. *The ideal soil v2.0: A handbook for new agriculture*. https://www.soilminerals.com/ Accessed 9 Sept 2020.

Barrios, E., R.J. Delve, M. Bekunda, J. Mowo, J. Agunda, J. Ramisch, M. Trejo, and R.J. Thomas. 2006. Indicators of soil quality: A South-South development of a methodological guide for linking local and technical knowledge. *Geoderma* 135: 248–259.

Bhardwaj, A.K., P. Jasrotia, S.K. Hamilton, and G.P. Robertson. 2011. Ecological management of intensively cropped agro-ecosystems improves soil quality with sustained productivity. *Agriculture Ecosystems & Environment* 140 (3): 419–429. https://doi.org/10.1016/j.agee.2011.01.005.

Black, C.A. 1993. *Soil fertility evaluation and control*. Boca Raton, FL: CRS Press.

Blackburn, D. 1989. *Foundations and changing practices in extension*. Guelph, ON: University of Guelph.

Blanco-Canqui, Humberto, T.S. Shaver, J.L. Lindquist, C. Shapiro, R. Elmore, C. Francis, and G. Hergert. 2015. Cover crops and ecosystem services: Insights from studies in temperate soils. *Agronomy Journal* 107 (6): 2449–2474. https://doi.org/10.2134/agronj15.0086.

Brock, C., D. Jackson-Smith, S. Kumarappan, C. Brown. 2019 (July). Farmer and practitioner conceptions and experiences with soil balancing. The Ohio State University. Soil Team Resources https://offer.osu.edu/sites/offer/files/imce/Files/SB%20Practices%20Report_FINAL.pdf. Accessed 24 Sept 2020

Brown, J.S., and P. Duguid. 2001. Knowledge and organization: A social-practice perspective. *Organization Science* 12 (2): 198.

Brunetti, J. 2014. *The farm as ecosystem: Tapping nature's reservoir-biology, geology, diversity Greeley*. CO: Acres U.S.A.

Chaganti, V., and S. Culman. 2017. Historical perspective of soil balancing theory and identifying knowledge gaps: A review. *Crops & Soils* 51 (1): 40–47. https://doi.org/10.2134/cftm2016.10.0072.

Clark, J., and J. Murdoch. 1997. Local knowledge and the precarious extension of scientific networks: A reflection on three case studies. *Sociologia Ruralis* 37 (1): 38–60. https://doi.org/10.1111/1467-9523.00035.

Compagnone, C., and B. Simon. 2018. Cooperation and competition among agricultural advisory service providers. The case of pesticide use. *Journal of Rural Studies* 59: 10–20. https://doi.org/10.1016/j.jrurstud.2018.01.006.

Crawford, C., J. Grossman, S. Warren, and F. Cubbage. 2015. Grower communication networks: Information sources for organic farmers. *Journal of Extension* 53 (3): 3.

Creswell, J.W., and D.L. Miller. 2000. Determining validity in qualitative inquiry theory into practice. *Theory Into Practice* 39 (3): 124–130. https://doi.org/10.1207/s15430421tip3903_2.

Delate, K., S. Canali, L. Colombo, R. Turnbull, and R. Tan. 2017. Participatory organic research in the USA and Italy: Across a continuum of farmer-researcher partnerships. *Renewable*

Agriculture and Food Systems 32 (4): 331–348. https://doi.org/10.1079/rafs200365.

Delate, K., and J. DeWitt. 2004. Building a farmer-centered land grant university organic agriculture program: A Midwestern partnership. *Renewable Agriculture and Food Systems* 19 (2): 80–91. https://doi.org/10.1079/RAFS200365.

Dhaliwal, S., R. Naresh, A. Mandal, M. Walia, R. Gupta, R. Singh, and M. Dhaliwal. 2019. Effect of manures and fertilizers on soil physical properties, build-up of macro and micronutrients, and uptake in soil under different cropping systems: A review. *Journal of Plant Nutrition* 42 (20): 2873–2900.

Doran, John W. 2002. Soil health and global sustainability: Translating science into practice. *Agriculture, Ecosystems & Environment* 88 (2): 119–127. https://doi.org/10.1016/S0167-8809(01)00246-8.

Eanes, F., A. Singh, B. Bulla, P. Ranjan, L. Prokopy, M. Fales, B. Wickerham, and P. Doran. 2017. Midwestern US farmers perceive crop advisers as conduits of information on agricultural conservation practices. *Environmental Management* 60 (5): 974–988. https://doi.org/10.1007/s00267-017-0927-z.

Eckert, D.J., and E.O. McLean. 1981. Basic cation saturation ratios as a basis for fertilizing and liming agronomic crops: I. Growth chamber studies. *Agronomy Journal* 73 (5): 795. https://doi.org/10.2134/agronj1981.00021962007300050012x.

Eshuis, J., and M. Stuiver. 2005. Learning in context through conflict and alignment: Farmers and scientists in search of sustainable agriculture. *Agriculture and Human Values* 22 (2): 137–148. https://doi.org/10.1007/s10460-004-8274-0.

Espinoza, L., N. Slaton, and M. Mozaffari. 2018. Understanding the numbers on your soil test report FSA2118-PD-1-12RV. University of Arkansas Cooperative Extension Service Printing Services: University of Arkansas Division of Agriculture Research and Extension

Fairhead, J., and I. Scoones. 2005. Local knowledge and the social shaping of soil investments: Critical perspectives on the assessment of soil degradation in Africa. *Land Use Policy* 22 (1): 33–41.

Francis, C. 2010. Conventional research on controversial issues: An exercise in futility? *Renewable Agriculture and Food Systems* 25 (1): 3–7.

Gloy, B., J. Akridge, and L. Whipker. 2000. Sources of information for commercial farms: Usefulness of media and personal sources. *International Food and Agribusiness Management Review* 3 (2): 245–260.

Greenhalgh, T., and R. Taylor. 1997. How to read a paper: Papers that go beyond numbers (qualitative research). *BMJ* 315 (7110): 740–743. https://doi.org/10.1136/bmj.315.7110.740.

Hassanein, N., and J. Kloppenberg. 1995. When the grass grows again: Knowledge exchange in the sustainable agriculture movement. *Rural Sociology* 60 (4): 721–740. https://doi.org/10.1111/j.1549-0831.1995.tb00603.x.

Haynes, R.J., and R. Naidu. 1998. Influence of lime, fertilizer and manure applications on soil organic matter content and soil physical conditions: A review. *Nutrient Cycling in Agroecosystems* 51 (2): 123–137. https://doi.org/10.1023/a:1009738307837.

Hejnowicz, A.P., M.A. Rudd, and P.C.L. White. 2016. A survey exploring private farm advisor perspectives of agri-environment schemes: The case of England's environmental stewardship programme. *Land Use Policy* 55: 240–256. https://doi.org/10.1016/j.landusepol.2016.04.005.

Herbst, Susan. 2003. Political authority in a mediated age. *Theory and Society* 32 (4): 481–503.

Ingram, Julie. 2008. Agronomist–farmer knowledge encounters: An analysis of knowledge exchange in the context of best management practices in England. *Agriculture and Human Values* 25 (3): 405–418. https://doi.org/10.1007/s10460-008-9134-0.

Ingram, J. 2018. Agricultural transition: Niche and regime knowledge systems' boundary dynamics. *Environmental Innovation and Societal Transitions* 26: 117–135.

Ingram, J., J. Dwyer, P. Gaskell, J. Mills, and P. de Wolf. 2018. Reconceptualising translation in agricultural innovation: A co-translation approach to bring research knowledge and practice closer together. *Land Use Policy* 70: 38–51.

Ingram, J., P. Fry, and A. Mathieu. 2010. Revealing different understandings of soil held by scientists and farmers in the context of soil protection and management. *Land Use Policy* 27 (1): 51–60. https://doi.org/10.1016/j.landusepol.2008.07.005.

Ingram, M. 2007. Biology and beyond: The science of "back to nature" farming in the United States. *Annals of the Association of American Geographers* 97 (2): 298–312. https://doi.org/10.1111/j.1467-8306.2007.00537.x.

Ingram, J., and C. Morris. 2007. The knowledge challenge within the transition towards sustainable soil management: An analysis of agricultural advisors in England. *Land Use Policy* 24 (1): 100–117. https://doi.org/10.1016/j.landusepol.2005.07.002.

Ingram, J., D. Maye, J. Kirwan, N. Curry, and K. Kubinakova. 2014. Learning in the permaculture community of practice in England: an analysis of the relationship between core practices and boundary processes. *The Journal of Agricultural Education and Extension* 20 (3): 275–290. https://doi.org/10.1080/1389224X.2014.887756.

Keene, C.L., W.S. Curran, J.M. Wallace, M.R. Ryan, S.B. Mirsky, M.J. VanGessel, and M.E. Barbercheck. 2017. Cover crop termination timing is critical in organic rotational no-till systems. *Agronomy Journal* 109 (1): 272–282. https://doi.org/10.2134/agronj2016.05.0266.

Kinsey, N., and C. Walters. 2006. *Neal Kinsey's hands-on agronomy: Feeding & balancing your soil*. Austin, TX: Acres U.S.A.

Klerkx, L., and J. Jansen. 2010. Building knowledge systems for sustainable agriculture: Supporting private advisors to adequately address sustainable farm management in regular service contacts. *International Journal of Agricultural Sustainability* 8 (3): 148–163. https://doi.org/10.3763/ijas.2009.0457.

Kloppenberg, J. 1991. Social theory and de/reconstruction of agricultural science local knowledge for alternative agriculture. *Rural Sociology* 56 (4): 519–548. https://doi.org/10.1111/j.1549-0831.1991.tb00445.x.

Knickel, K., G. Brunori, S. Rand, and J. Proost. 2009. Towards a better conceptual framework for innovation processes in agriculture and rural development: From linear models to systemic approaches. *Journal of Agricultural Education and Extension* 15 (2): 131–146. https://doi.org/10.1080/13892240902909064.

Kopittke, P., and N. Menzies. 2007. A review of the use of the basic cation saturation ratio and the "ideal" soil. *Soil Science Society of America Journal* 71 (2): 259–265. https://doi.org/10.2136/sssaj2006.0186.

Kroma, M. 2006. Organic farmer networks: Facilitating learning and innovation for sustainable agriculture. *Journal of Sustainable Agriculture* 28 (4): 5–28. https://doi.org/10.1300/J064v28n04_03.

Krzywoszynska, A. 2019. Making knowledge and meaning in communities of practice: What role may science play? The case of sustainable soil management in England. *Soil Use and Management* 35 (1): 160–168.

Laforge, J., and S. McLachlan. 2018. Learning communities and new farmer knowledge in Canada. *Geoforum* 96: 256–267. https://doi.org/10.1016/j.geoforum.2018.07.022.

Larkin, R. 2015. Soil health paradigms and implications for disease management. *Annual Review of Phytopathology* 53: 199–221.

Leeuwis, C., and A. Van Den Ban. 2004. *Communication for rural innovation: Rethinking agricultural extension*. Oxford: Blackwell Science.

Lehman, R., C. Cambardella, D. Stott, V. Acosta-Martinez, D. Manter, J. Buyer, J. Maul, J. Smith, H. Collins, and J. Halvorson. 2015. Understanding and enhancing soil biological health: The solution for reversing soil degradation. *Sustainability* 7 (1): 988–1027.

Liebman, A.M., J. Grossman, M. Brown, M.S. Wells, S.C. Reberg-Horton, and W. Shi. 2018. Legume cover crops and tillage impact nitrogen dynamics in organic corn production. *Agronomy Journal* 110: 1046–1057. https://doi.org/10.2134/agronj2017.08.0474.

Lobry de Bruyn, L., and S. Andrews. 2016. Are Australian and United States farmers using soil information for soil health management? *Sustainability* 8 (4): 304.

Lorenz, K., and R. Lal. 2016. Environmental impact of organic agriculture. In *Advances in agronomy*, ed. D.L. Sparks, 99–152. Cambridge, MA: Elsevier.

Mairura, F.S., D.N. Mugendi, J. Mwanje, J. Ramisch, P. Mbugua, and J.N. Chianu. 2007. Integrating scientific and farmers' evaluation of soil quality indicators in Central Kenya. *Geoderma* 139 (1–2): 134–143.

McKibben, W. 2012. *The art of soil balancing: A practical guide to interpreting soil tests*. Austin, TX: Acres U.S.A.

Monke, J. 2016. Agricultural research: Background and issues. Congressional Research Service Report 7–5700.

Morgan, K., and J. Murdoch. 2000. Organic versus conventional agriculture: Knowledge, power, innovation in the food chain. *Geoforum* 31: 159–173.

Morgan, S. 2011. Social learning among organic farmers and the application of the communities of practice framework. *The Journal of Agricultural Education and Extension* 17 (1): 99–112. https://doi.org/10.1080/1389224X.2011.536362.

Niggli, U., N. Slabe, O. Halberg, O. Schmid, and M. Schlüter. 2008. *Vision for an organic food and farming research agenda to 2025*. Brussels: IFOAM Regional Group European Union (IFOAM EU Group); International Society of Organic Agriculture Research (ISOFAR).

Noe, E., H. Alrøe, M. Thorsøe, J. Olesen, P. Sørensen, B. Melander, and E. Fog. 2015. Knowledge asymmetries between research and practice: A social systems approach to implementation barriers in organic arable farming. *Sociologia Ruralis* 55 (4): 460–482. https://doi.org/10.1111/soru.12078.

Noy, S., and R. Jabbour. 2019. Decision-making in local context: Expertise, experience, and the importance of neighbours in farmers' insect pest management. *Sociologia Ruralis*. https://doi.org/10.1111/soru.12267.

Oreszczyn, S., A. Lane, and S. Carr. 2010. The role of networks of practice and webs of influencers on farmers' engagement with and learning about agricultural innovations. *Journal of Rural Studies* 26 (4): 404–417. https://doi.org/10.1016/j.jrurstud.2010.03.003.

Pickstone, J.V. 2001. *Ways of knowing: A new history of science, technology, and medicine*. Chicago, IL: University of Chicago Press.

Prokopy, L., J. Carlton, J. Arbuckle, T. Haigh, M. Lemos, A. Mase, N. Babin, et al. 2015. Extension′s role in disseminating information about climate change to agricultural stakeholders in the United States. *Climatic Change* 130 (2): 261–272.

Rahmann, G., M. Reza Ardakani, P. Bàrberi, H. Boehm, S. Canali, M. Chander, W. David, L. Dengel, J. Willem Erisman, and A. Galvis-Martinez. 2017. Organic agriculture 3.0 is innovation with research. *Organic Agriculture* 7 (3): 169–197. https://doi.org/10.1007/s13165-016-0171-5.

Reeve, J., L. Hoagland, J. Villalba, P. Carr, A. Atucha, C. Cambardella, D. Davis, and K. Delate. 2016. Organic farming, soil health, and food quality: Considering possible links. In *Advances in agronomy*, ed. D.L. Sparks, 319–367. Cambridge, MA: Elsevier.

Richelle, L., M. Visser, L. Bock, P. Walpole, F. Mialhe, G. Colinet, and N. Dendoncker. 2018. Looking for a dialogue between farmers and scientific soil knowledge: Learnings from an ethno-geomorphopedological study in a Philippine's upland village. *Agroecology and Sustainable Food Systems* 42 (1): 2–27.

Rogers, E. 1995. *Diffusion of innovations*, 4th ed. New York, NY: The Free Press.

Romig, D.E., M. Garlynd, R. Harris, and K. McSweeney. 1995. How farmers assess soil health and quality. *Journal of Soil and Water Conservation* 50 (3): 229.

Saldana, J. 2016. *The coding manual for qualitative researchers*. Thousand Oaks, CA: SAGE Publications Inc.

Schneider, F., T. Ledermann, P. Fry, and S. Rist. 2010. Soil conservation in Swiss agriculture—Approaching abstract and symbolic meanings in farmers' life-worlds. *Forest transitions* 27 (2): 332–339. https://doi.org/10.1016/j.landusepol.2009.04.007.

Spargo, J.T., M.A. Cavigelli, S.B. Mirsky, J.J. Meisinger, and V.J. Ackroyd. 2016. Organic supplemental Nitrogen sources for field corn production after a hairy vetch cover crop. *Agronomy Journal* 108 (5): 1992–2002. https://doi.org/10.2134/agronj2015.0485.

Sumane, S., I. Kunda, K. Knickel, A. Strauss, T. Tisenkopfs, I. des Rios, M. Rivera, T. Chebach, and A. Ashkenazy. 2018. Local and farmers' knowledge matters! How integrating informal and formal knowledge enhances sustainable and resilient agriculture. *Journal of Rural Studies* 59: 232–241. https://doi.org/10.1016/j.jrurstud.2017.01.020.

Toffolini, Q., M. Jeuffroy, P. Mischler, J. Pernel, and L. Prost. 2017. Farmers' use of fundamental knowledge to re-design their cropping systems: Situated contextualisation processes. *NJAS-Wageningen Journal of Life Sciences* 80: 37–47.

Vanclay, F. 2004. Social principles for agricultural extension to assist in the promotion of natural resource management. *Australian Journal of Experimental Agriculture* 44 (3): 213–222.

Vitosh, M. L., Johnson, J. W., & Mengel, D. B. (1995). Tristate fertilizer recommendations for corn, soybeans, wheat & alfalfa, *Extension Bulletin E-2567* , vol. July .

Walters, C., and C.J. Fenzau. 2003. *Eco-farm*. Austin, TX: Acres U.S.A.

Watts, D. 1995. *Trace elements and essential nutrients: clinical applications of tissue mineral analysis*. Henderson, NV: Writer's B-L-O-C-K.

Wenger, E. 1998. *Communities of practice: Learning, meaning and identity*. New York: Cambridge University Press.

Wenger, E. 2000. Communities of practice and social learning systems. *Organization Articles* 7 (2): 225–226.

Wheeler, P., and R. Ward. 1998. *The non-toxic farming handbook*. Metairie, LA: Acres U.S.A.

Wolf, S. 1995. Cropping systems and conservation policy: The roles of agrichemical dealers and independent crop consultants. *Journal of Soil and Water Conservation* 50 (3): 263.

Wood, B., H. Blair, D. Gray, P. Kemp, P. Kenyon, S. Morris, and A. Sewell. 2014. Agricultural science in the wild: A social network analysis of farmer knowledge exchange. *PLoS ONE* 9 (8): 1–10.

Zimmer, G., and L. Zimmer-Durand. 2017. *The biological farmer: A complete guide to the sustainable and profitable biological system of farming*. Austin, TX: Acres U.S.A.

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