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Defining, Measuring, and Applying Soil Quality: An Unresolved Debate

Salvador Ramirez II
University of Nebraska - Lincoln, salvador.ramirez@huskers.unl.edu

Defining, Measuring, and Applying Soil Quality: An Unresolved Debate

by

Salvador Ramirez II

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Defining, Measuring, and Applying Soil Quality: An Unresolved Debate

Salvador Ramirez II, D.P.H.

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Advisor: Gary L. Hein

Paradigm shifts occur periodically in the sciences. Proposed paradigm shifts offer opportunities to reexamine extant paradigms and evaluate new ones. Soil science experienced a controversy resembling a proposed paradigm shift in the late 1990s and early 2000s when it grappled with the idea of soil quality (SQ). The most contentious points in the SQ debates were (1) the word “quality” itself and designing a functional definition, (2) identifying appropriate soil quality indicators, (3) the integration of soil quality indicators, and (4) the interpretation of soil quality indicators. The latter three disagreements were rooted in the established, fundamental, soil science paradigm. The latter three were argued using inherent and dynamic soil properties and the statistical integration of those properties. Defining SQ, however, was much more complicated. While the ‘quality soil management vs soil quality management’ debates of the late 1990s were never resolved, the terms SQ and subsequent term soil health (SH) are still used today. Soil quality and SH have been institutionalized by several groups, including the U.S. government, private industry, and academic institutions. The concept should not be erased from the soil science vernacular. However, if the scientific community is to continue to use these terms, these concepts, and the debates of the late 1990s, must be revisited.

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Introduction

"Philosophy of science without history of science is empty; history of science without philosophy of science is blind" (Lakatos, 1971).

Scientific paradigms are fundamentally important to science. They guide research questions and objectives, and they provide an agreed upon framework within which experiments can be designed and results compared. According to the Merriam-Webster dictionary (2019), the word paradigm is a noun "derived from the late Latin word paradigma and from the Greek word paradeigma which meant to show side by side." In English, definitions include (1) "especially: an outstandingly clear or typical example or archetype," (2) "an example of a conjugation or declension showing a word in all its inflectional forms," and (3) "a philosophical and theoretical framework of a scientific school or discipline within which theories, laws, and generalizations and the experiments performed in support of them are formulated." These "philosophical and theoretical frameworks" play a central role in the evolution of science. Guerra, Capitelli, & Longo (2012) loosely define paradigms as a "sort of methodological and conceptual universe in which the scientist can operate" (p. 20). As in a cosmic universe, the only thing constant in the "conceptual universe" of a paradigm is change.

Paradigm shifts occur periodically in the sciences. Proposed paradigm shifts offer opportunities to reexamine extant paradigms and evaluate new ones. It is natural for scientists to disagree during proposed paradigm shifts or challenges to the current paradigm. Soil science experienced such a controversy in the late 1990s and early 2000s when it grappled with the idea of soil quality (SQ). While SQ had been discussed before, this paper will summarize the arguments concerning SQ between 1997 and 2003 (Figure 1.1). This document refers to those defending SQ as proponents and those expressing reservations about SQ as opponents.

Among soil scientists, proponents included Douglas Karlen, John W. Doran, and Timothy B. Parkin, among others, while opponents included Robert E. Sojka, Dan R. Upchurch, John Letey, and others. This paper outlines the arguments found in the major SQ and soil health (SH) publications published by these individuals between 1997 and 2003. A cornerstone publication defending SQ was "Soil quality: A concept, definition, and framework for evaluation" by Karlen et al. (1997) (Table 1.1). The earliest publication formally challenging SQ was an article by Sojka and Upchurch (1999) titled "Reservations regarding the soil quality concept" (Table 1.1). In response, Karlen, Andrews, & Doran (2001) published "Soil quality: Current concepts and applications" (Table 1.1). In 2003, Sojka, Upchurch, and Borlaug published "Quality soil management or soil quality management: Performance versus semantics" and Letey et al. published "Deficiencies in the soil quality concept and its application" (Table 1.1). In response to these dissenting views, Karlen, Andrews, Weinhold, & Doran published "Soil quality: Humankind's foundation for survival", also in 2003 (Table 1.1).

While proponents did not view SQ as a proposed paradigm shift, opponents did, as is evident in the first major publication challenging SQ:

> Thus, we are attempting to articulate the concerns of many of our colleagues who are reluctant to endorse redefining the soil science paradigm away from the value-

> neutral tradition of edaphology and specific problem solving to a paradigm based on variable, and often subjective societal perceptions of environmental holism. (Sojka & Upchurch, 1999, p. 1039)

Whether SQ was a proposed paradigm shift, whether an agreed upon definition of SQ has been achieved, and whether the disagreements that arose in attempting to define and measure SQ were resolved, it is clear that SQ and the subsequent term SH currently are used in soil science, by government agencies, and in public language. For example, in the Agriculture Improvement Act of 2018 (the "Farm Bill"), SH is referenced as an integral concept in various action plans. The goal of the Soil Health and Income Protection Pilot Program found in the Farm Bill is to assist "owners and operators of eligible land to conserve and improve the soil, water, and wildlife resources of the eligible land" (p. 54). Eligible land is land "verified to be less productive land, as compared to other land on the applicable farm" (p. 53). In the Environmental Quality Incentives Program and Conservation Stewardship Program also found in the farm bill, "soil health planning, including increasing soil organic matter and use of cover crops" is described as an "incentive practice" (p. 69). An incentive practice is "a practice or set of practices approved by the Secretary that, when implemented and maintained on eligible land, address 1 or more priority resource concerns" (p. 68). Evidently, the United States government views SH as an institutionalized soil science paradigm.

One can also search in an academic journal database using the key phrases "soil quality" or "soil health," or view the USDA soil health campaign "Unlock the secrets in the soil," (USDA-NRCS) or visit the Soil Health Institute's webpage (Soil Health Institute) to see the terms SQ and SH used. If the use of SQ and SH is to continue, it may be useful to remember how SQ and SH came about, understand the concerns expressed about these terms, and revisit the disagreements over SQ and SH.

The most contentious points in the SQ debates were (1) the word "quality" itself and designing a functional definition, (2) identifying appropriate soil quality indicators, (3) the integration of soil quality indicators, and (4) the interpretation of soil quality indicators. The latter three disagreements were rooted in the established, fundamental, soil science paradigm and were argued using inherent and dynamic soil properties and the statistical integration of those properties. Defining SQ, however, was much more complicated.

Defining Soil Quality and Soil Health

While there had been previous attempts to define SQ (Larson & Pierce 1991; Mausel, 1971; Parr, Papendick, Hornick, & Meyer, 1992; Power & Meyers, 1990), the National Research Council (NRC) sparked national interest in SQ in 1993 by stating "protecting soil quality, like protecting air and water quality, should be a fundamental goal of national environmental policy" (National Research Council, 1993, p. 1). This political public spotlight cast on soil resources engendered resurgent interest in defining and applying SQ.

Some proponents argued SQ must be defined in order to protect soil resources. Others expressed a desire to elevate soil science in recognition (to that of air and water). Others suggested that a functional SQ definition could be used to organize soil test data. Doran and Parkin (1996) stated:

> Perceptions of what constitutes a good soil vary depending on individual priorities for soil function and intended land use; however, to manage and maintain our

> soils in an acceptable state for future generations, soil quality must be defined, and the definition must be broad enough to encompass the many functions of soil. (p. 26)

Herein lies a fundamental contradiction in the SQ philosophy: The definition must be broad enough to encompass the multitude of soil functions which occur in diverse environments without specifically stating the use of that soil. Nevertheless, proponents felt SQ must be defined to advance SQ as a concept. In the Soil Science Society of America (SSSA) special publication no. 35 (Table 1.1), the president of SSSA states:

> The concept of soil quality will not be in the mainstream of soil or environmental science programs until there is wide acceptance of the definition for the term and quantitative indicators of soil quality are developed. Air and water quality are well recognized concepts that have standards established by law and regulation. A great deal of study and education will be necessary before soil quality becomes an important national natural resource issue. (Doran, 1994, p. vii)

These justifications for defining SQ, which were (1) so that SQ could be used to protect soil resources, (2) to elevate the importance of soil resources and gain parity with air and water as important resources, and (3) to be used as a decision-making management tool to protect an undervalued natural resource, are common in the writings of many proponents in the early 1990s.

Before delineating the philosophical and scientific dissent opponents communicated concerning the SQ and SH definitions, it is important to discuss proposed SQ definitions. The SQ definition most commonly referred to in literature opposing SQ can be found in SSSA’s Special Publication Number 35 (Doran, Coleman, Bezdick, &

Stewart, 1994). This publication was the result of a 14-person committee meeting (S-581) appointed in 1994 by SSSA's president L. P. Wilding. The purpose of this committee was to define SQ and examining its justification. That definition, shared by Doran and Parkin (1994, p.7) and endorsed by the SSSA, is: "Soil Quality—The capacity of soil to function within ecosystem boundaries to sustain biological productivity, maintain environmental quality, and promote plant and animal health". This is the SQ definition most commonly referred to today. A definition for SH, proposed by Mausbach and Tugel (1995) (as cited by Sojka & Upchurch, 1999, pp. 1041-1042) in contrast to SQ, was: "Soil Condition (Health)—is the ability of the soil to perform according to its potential. Soil condition changes over time due to human use and management or to unusual natural events." SQ and SH will not be used interchangeably in this document, and the major focus of this document will be SQ as opposed to SH.

Disagreements about the SQ Definition

Opponents argued SQ was too difficult to define because "quality" definitions were rooted in value judgments and were value-laden. Sojka and Upchurch (1999) argued that the word "quality" could lead to confusion and abuse of SQ as a concept because "quality" has multiple definitions:

> Some key words in the soil quality vocabulary bear heavy burdens of multiple meaning. Quality can mean degree of excellence, as in the conformance to a measurable standard; or it can mean a categorical attribute or characteristic; in the environmental context, it has come largely to mean free of pollution. (p. 1040)

While the word quality can have multiple meanings, none can effectively describe soil. Opponents argued this multiplicity of meaning was anti-science; "science strives to eliminate any doubt as to the facts determined" (Sojka & Upchurch, 1999, p. 1040). They argued that the multiple ways to interpret the word "quality" would create confusion. Opponents argued that at best, few users of SQ as a concept would possess the fundamental training to understand its subtleties. At worst, individuals with hidden agendas, vested interests, or ulterior motives could abuse a concept with multiple meanings to fit their needs. As Sojka and Upchurch (1999) put it, "The lack of specificity of soil quality definition could encourage promotion of wonder products and questionable practices touting claims of improved soil quality" (p. 1049).

In defending the need to define SQ, proponents compared SQ to air and water quality. Many indicated that air and water quality standards exist and that government regulations were developed based on those quality standards, but no SQ standards existed. To proponents, SQ was the logical next step.

Opponents, however, argued that there are few parallels between air/water quality and SQ. Nortcliff (2002) suggested that decreases in air and water quality are simple to assess because humans are frequently evaluating their fitness; can one drink this water, or can one breathe this air? Opponents argued SQ was not a next logical step to follow existing air and water quality standards because (1) air and water have a "pure" state that can be used as a standard, soil does not, (2) air and water quality are easier to assess in terms of function (to breathe and to drink) while soil has many uses, (3) one does not need to integrate static and dynamic biological, chemical, and physical parameters to determine an ideal state across diverse scenarios in order to assess air and water quality, and (4) changes in soil can occur over longer periods of time before they are noticed (Nortcliff 2002; Sojka and Upchurch, 1999; Letey et al., 2003).

Furthermore, opponents argued proposed SQ definitions were too broad and failed to integrate the various simultaneous functions soil perform. Sojka et al. (2003) argued that SQ definitions listed at least six diverse simultaneous functions that would have to be optimized to earn a high SQ score. Those were “to sustain (1) plant and (2) animal productivity, maintain or enhance (3) water and (4) air quality, and support human (5) health and (6) habitation” (Sojka et al., 2003, p. 11). They argued that no soil quality index could integrate these various functions and appropriately score a soil without first (1) specifying its use and without (2) assigning worth to either of the listed soil functions. Assigning worth to any soil function, or weighing soil functions and ranking them in importance, inevitably involved value judgments. In summary, opponents argued that “soil performs several functions simultaneously, not separately” (Sojka et al., 2003, p. 12). In other words, soils contain systems within the system soil exists. In reference to the failure of SQ definitions to account for soil’s various simultaneous functions, Sojka et al. (2003) state: “It would be impossible to integrate the mixture of scientific and non-scientific judgments needed to “score” soil quality or condition, or to properly weight conflicting simultaneous functions, especially in soil systems that have high spatial variability” (p. 12). The attempts to make SQ an “all-encompassing concept” resulted in definitions that fail when considering both specific circumstances and function-dependent scenarios. Due to the complexity of soils (and the complexity of the environment soils exist in), the permutative possibilities that exist considering the potential interaction of circumstance and functions are massive. Because soil is so complex and because it performs several functions simultaneously, Sojka et al. (2003) concluded that “anything that is infinitely defined is, ultimately, undefined and undefinable” (p. 12). Opponents pointed to existing nomenclature that was less ambiguous. Soil classifications (e.g., drainage classes, erosion susceptibility indices, aeration indices, nutritional indices, compaction indices) were extant concepts which integrated various soil parameters with specific goals—key concept: specific goals. These indices can integrate chemical, physical, and biological, dynamic and inherent, soil properties while considering function and intended use. Opponents argued this was lost when trying to assess soil across various functions and uses within ecosystem boundaries.

Proponents responded to these claims that SQ definitions failed to integrate the various simultaneous functions soils perform. In their response to Sojka et al. (2003), Karlen et al. (2003) stated:

> Sojka and Upchurch (1999) and Sojka et al. (2003) contend that the practical realities associated with interpreting indicators of the multiple functions that soils perform have not been addressed. We feel this perception is incorrect because even though Sojka et al. (2003) cite more than 340 references, they ignore Andrews and Carroll (2001), Andrews et al. (2001, 2002), Herrick et al. (2002), Karlen et al. (1998), Karlen et al. (1999) and numerous international websites where those challenge have been recognized. (pp. 174-175)

Opponents' concerns were recognized but not resolved. Karlen, Gardner, and Rosek (1998) is an article included by Karlen et al. (2003) as a report that effectively addressed opponents' claims that SQ definitions fail to integrate the several simultaneous functions soils perform. Karlen et al. (1998) state:

> A major challenge that has not been adequately addressed, however, is how these various indicators will be evaluated and combined to make an overall soil quality

> assessment that is meaningful and useful to several different groups of people. This is important since soil quality can be assessed with varying levels of accuracy and precision at the point, plot, field, farm, watershed, or larger areas. (p. 9)

In this publication, Karlen et al. (1998) applied the SQ concept to assess the impact of tillage and the efficacy of public policies such as the USDA's Conservation Reserve Program (CRP). They concluded that using a structured framework could be used to assess SQ. They also concluded "CRP generally increased soil microbial biomass, organic C and N, long-term infiltration, and aggregate stability" (p. 10) and that inorganic N and soil bulk densities were reduced (Karlen et al., 1998).

Yet, Karlen et al. (1998) only reinforced what they had previously concluded concerning indicator selection and the many simultaneous functions soils perform:

> The purpose of this framework is to show that soil quality can be assessed at different scales by selecting appropriate indicators. Also, regardless of the scale at which a soil quality evaluation is made, the process for selecting and interpreting indicators remains constant, namely focusing on soil properties or processes that have an impact on the critical function(s). (p. 57)

Finally, in describing that framework Karlen et al. (1998) state: "After defining the goals for soil quality assessment and selecting appropriate indicators, the next steps will be to establish acceptable ranges for each of the indicators and to examine trends and rates of change over time" (p. 58). This statement directly contradicts the SQ definition. "Defining the goals for soil quality assessment and selecting appropriate indicators" is, in essence, specifying soil use. The SQ definition does not specify use. "Establishing acceptable ranges for each of the indicators" is weighing soil functions which involves value judgments, which is exactly what opponents were saying. Finally, defining a goal for SQ, selecting appropriate indicators, and establishing acceptable ranges for each of them fails to account for the various simultaneous functions soils perform.

There was no resolution to the debate on how to (1) select appropriate SQ indicators, (2) interpret the integration of any given soil properties while (3) accounting for the several, simultaneous functions soil performs and (4) without weighing soil functions and adhering to the SQ definition that did not specify soil use. Likewise, there was consensus on how one could use SQ indicators that were simply crop production indices to determine if a soil is functioning within ecosystem boundaries to simultaneously sustain biological productivity, maintain environmental quality, and promote plant and animal health. Today, the most common application of SQ is to assess the impact of management on managed ecosystems with an explicit use: plant growth.

Soil Quality vs. Soil Health

Soil quality and SH are different terms that were often used interchangeably, adding confusion to the SQ debates. SH has been widely used but a definition for SH has not been agreed upon. Romig, Garlynd, Harris, and McSweeney (1995) conducted surveys in the 1990s and reported that farmers preferred the term 'soil health' as opposed to 'soil quality.' Romig et al. reported that farmers used descriptive and qualitative properties, as well as direct value judgments, to describe SH. Conversely, scientists preferred the term 'soil quality' because of the potential to measure and statistically integrate quantitative physical, chemical, and biological soil properties (Romig et al.).

The SSSA Ad Hoc committee (S-581) reported that 'soil health' and 'soil quality' are terms that should not be used interchangeably (as cited by Karlen et al., 2001). However, some proponents felt using SQ and SH interchangeably was not a problem. Harris & Bezdicek (1994) state: "We favor using the joint term soil quality/health in the interest of promoting communication, knowledge sharing, and developing an understanding of the language and methods used to manage soil quality/health by farmers and scientists." (p. 23)

Furthermore, some proponents preferred the term 'soil health.' Doran et al. (1996) described how attempting to define SH pitted two distinct populations, those outside of agriculture and academics:

> On the one hand are those, typically speaking from outside agriculture, who view maintenance of soil health as an absolute moral imperative-critical to our very survival as a species. On the other hand is the attitude, perhaps ironically expressed most adamantly by academics, that the term is a misnomer-a viewpoint seated, in part, in fear that the concept requires value judgments which go beyond scientific or technical fact. (p. 10)

Doran et al. (1996) suggested that in the middle of these opposing views were producers and society's management of soil. They also suggested that SQ, as opposed to SH, was defined by its function and use while SH should be defined as "the continued capacity of soil to function as a vital living system, within ecosystem and land-use boundaries, to sustain biological productivity, maintain the quality of air and water environments, and promote plant, animal, and human health" (Doran et al., 1996, p. 11). That SH definition is very similar to the SQ definition. Doran et al. (1996) then informed the reader SQ and

SH will be used synonymously for the remainder of their chapter, but that they prefer the term SH because:

> It [soil health] more clearly portrays the idea of soil as a living dynamic organism that functions in a holistic way depending on its condition or state rather than as an inanimate object whose value depends on its innate characteristics and intended use. (p. 11)

The lack of agreement as to the difference between SQ and SH within the proponent community alone added confusion to the SQ debates.

Soil Quality Indicators/Parameters and Soil Quality Assessment Tools

Proponents compared assessing SQ to a medical examination of humans. They described how a medical doctor can measure basic indicators of body system function, assess status of said indicators within an acceptable range, and use that data to either identify a problem or monitor management effects (Larson & Pierce, 1991). They provided examples of indicators of body system function such as body temperature, blood pressure, pulse rate, and blood or urine chemistry, as well as observation of visible outward signs of health (Doran and Parkin, 1994). High blood pressure (there is a range within which human blood pressure i.e. indictor of health should lie), can indicate the potential for system failure i.e. death through stroke or cardiac arrest (Doran and Parkin, 1994). It is understood that high blood pressure can result from an improper diet or high levels of stress, and a medical doctor can continue to measure blood pressure to monitor the effects of any prescribed medication. Proponents the same set of steps could be used to assess the health or quality of soil systems.

Opponents were unconvinced by this analogy. They pointed out doctors have standards that indicate health in human beings. Those norms do not deviate substantially for a specific human's "function," climate, neighborhood, etc. (Letey et al., 2003). Furthermore, opponents pointed out that medical doctors do not use "health" indicators to rate patient health with a score, but instead integrate that indicator with others to determine a treatment to sustain an individual's health. Finally, opponents called attention to how medical practice must accommodate each patient's personal value system.

Analogies aside, SQ proponents summarized indicators of SQ and SH in what they referred to as a minimum data set (MDS), proposed by Larson and Pierce (1991) (Table 2.1). The goal of creating an MDS was to assess the health of world soils by assessing changes in those SQ indicators through standardized methodologies and established procedures. Doran & Parkin (1996) listed SQ indicator characteristics that would render them practical for use by practitioners, extension workers, conservationists, scientists, and policy makers. That list included:

> (1) correlate well with ecosystem processes (this also increases their utility in process oriented modeling), (2) integrate soil physical, chemical, and biological properties and processes and serve as basic inputs needed for estimation of soil properties or functions which are more difficult to measure directly, (3) be relatively easy to use under field conditions and be accessible by both specialists and producers, (4) be sensitive to variations in management and climate; the indicators should be sensitive enough to reflect the influence of management and climate on long-term changes in soil quality but not be so sensitive as to be

> influenced by short-term weather patterns, and (5) be components of existing soil data bases where possible. (Doran & Parkin, 1996, p. 28)

Opponents argued that indices selected by proponents were simply crop yield or productivity indices which contradicted the broad SQ definition. In reference to this contradiction, Sojka et al. (2003) stated, “High soil quality for crop production [a SQ quality score calculated using crop yield SQ indices] does not guarantee high quality for environmental protection or for biodiversity or sustainability, regardless of its definition” (p. 21). Opponents emphasized that those productivity indices used in agriculture can be correlated to specific management and inputs, and that “to arrive at recommendations the indexes must first be deconstructed to use individual reductionist predictive elements to achieve individual parameter responses” (Sojka et al., 2003, p. 17). To use those crop production-centric indicators to draw conclusions for environmental protection or for biodiversity would complicate the interpretation of those quality indicators (Stenberg, 1999). Lastly, opponents criticized the use of MDS. Sojka et al. (2003) state:

> What is new is the unproven assertion that comprehensive, holistic characterization can be routinely done quickly, affordably, at adequate spatial intensity by minimally trained (or even untrained) individuals using simple soil quality test kits and interpretive guides… Assessment of such comprehensive data collections cannot be properly and meaningfully interpreted for timely practical use by today’s mainstream farmers, managing thousands of acres each season, without consulting a team of cooperating scientists researching the topic. (p. 23)

In other words, one size does not fit all. Any given SQ parameter could be interpreted differently based on use-dependent scenarios. Sojka et al (2003) elaborate:

> In production agriculture, forest management, or wetland management, how many microorganism biodiversity samples would adequately characterize soil condition under a half-mile center pivot, in a single timber stand, or for a coastal wetland? Is one characterization per hectare sufficient? How do you decide where, when, how, etc. to take the sample? Which of a dozen analytical approaches should be used and who will adjudicate the choice of analysis? How long will this take? What will the assessment cost? (p. 24)

Once again, one size does not fit all. So, how can one assess the "capacity of soil to function within ecosystem boundaries, sustain biological productivity, maintain environmental quality, and promote plant and animal health" (Doran & Parkin, 1994, p.7) using soil parameters when the vast majority of research for soil properties has been done in the context of crop production? Interestingly, Sojka and Upchurch (1999) concluded that the use of soil properties whose research has been mostly to maximize crop productivity makes sense because crop production has been the most important <u>use</u> of soil.

> Realistically, this is probably appropriate, despite contradicting the stated vision [being able to define SQ in a way that encompasses the diversity of soil function] since, after all, the overwhelming direct emphasis of global land management is for a narrow purpose: plant growth, be that range, forest, crops, or habitat—with increasing consideration of sustainability and environmental impacts. (Sojka & Upchurch, 1999, p. 1042)

Which again exposes the major criticism in the SQ definition—specified use. If the term would have been "soil quality for growing crops," fewer soil scientists would have disagreed with assessment tools that integrated soil indices mostly connected to crop production. As Letey et al. (2003) put it, "If the soil quality concept is retained, we suggest precisely specifying soil use, not function or capacity, as the criteria for attribute evaluation" (p. 180).

Proponents responded to the criticism of selected indictors. Karlen et al. (2003) stated that indicator selection is often based on either expert opinion or statistical procedures. They argued that the use of dimension reducing techniques which identified variable importance (such as principal components or factor analysis) could be used to develop a list of appropriate soil properties to serve as indicators. They go on to note that both approaches (expert opinions and statistical analysis) produced similar results in a comparison of vegetable production (Andrews, Karlen, & Michell, 2002).

To aid in indicator selection and indicator integration, Karlen et al. (2003) referred the reader to the Soil Management Assessment Framework proposed and tested by Andrews et al. (2001) and Karlen and Stott (1994). That framework consisted of three basic steps: (1) indicator selection, which suggests appropriate chemical, biological and physical indicators, (2) indicator interpretation, offering site-specific interpretations of those indicators in relation to soil function, and (3) integration into an index, which provides an overall assessment of the indicator interpretations (Karlen et al., 2003). They described this framework as using nested hierarchy for expert opinion-based indicator selection, allowing it the flexibility to be used for different lands, scales, and soils. The framework, based on an MDS, is still in use today.

The indicator selection debates were never resolved. There is no agreement concerning use of production indices to assess a soil's ability to function within ecosystem boundaries to simultaneously sustain biological productivity, maintain environmental quality, and promote plant and animal health. And, again, the SQ indicators proposed in the form of an MDS are still used today as they have been used in the past, to determine the impact of management on soils used to grow plants for any given reason.

The Interpretation of Soil Quality Scores

Opponents argued that the interpretation of SQ scores were inherently flawed for two reasons: (1) the SQ parameters proposed were crop-centric and (2) there was regional bias in how those SQ parameters were valued. They also argued that, up until the 1990s, SQ assessment tools focused on soil attributes most commonly associated with Mollisols. Sojka et al. (1999) cite Sinclair, Waltman, Waltman, Terpstra, and Reed-Margetan. (1996) as an example of SQ regional and soil taxonomical bias. Sinclair et al. (1996) (as cited by Sojka & Upchurch 1999) published a map entitled “The soil ratings for plant growth (SRPG) model for rain-fed, nonirrigated production throughout the United States (USDA-NRCS, 1996.)” (Figure 1.2). Sojka et al. (1999) compared Sinclair’s index of SQ to a map of the dominant soil orders in the U.S. For said comparison, the soils with the greatest SQ score were visibly in the Midwestern U.S. If SQ was not taxonomically biased, SQ opponents argued, then maybe this overlap in soils with high SQ scores in the Midwest arose from the fact that SQ was a concept that emerged from mostly Midwestern research. SQ was a paradigm, Sojka and Upchurch (1999) argued, that was “based on an analysis of regional agricultural productivity” (p. 1047).

At first, SQ proponents defended Sinclair's report. Karlen et al. (2001) argued Sinclair's figure of inherent soil quality conveyed just that, "inherent" SQ. Karlen et al. (2001) added to this inherent SQ idea by stating:

> Furthermore, the relative index of inherent soil quality (Sinclair et al., 1996), criticized by Sojka and Upchurch (1999) as being biased toward U.S. Midwestern Mollisols, is an accurate reflection of the soil resource potential in the absence of human intervention and external input of energy resources (e.g., fossil fuel, water). (p. 6)

Karlen et al. (2001) argued the economic value of products produced may not always correlate to inherent soil quality, and that high levels of production could occur on soils with low inherent SQ by "creating a dynamic soil quality through external energy inputs and high-value crops" (p. 6).

SQ opponents responded that Karlen's defense of the mapped illustration of Sinclair's relative index of inherent soil quality contradicted previously published statements about SQ. Sojka et al. (2003) state, "The Sinclair "relative index of inherent soil quality" (p. 19) is a direct contradiction to Karlen et al. (2001) in that "there never was nor can be a single value for rating all soils or land uses" (p. 5). Furthermore, SQ opponents argued "quality soil management," more so than "inherent" soil properties, control productivity. ""In the absence of human intervention" Mollisols and Alfisols would be canopied in tall grass or forests and have fertility and productivity far lower than the currently managed manifestations of these soil orders interpreted by the Sinclair et al. (1996) model" (Sojka et al., 2003, p. 19). Lastly, Sojka et al. (2003) reiterate that "As institutionally defined, a true assessment of soil quality must "sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation"" (p. 27). They argued that proponents' defense of Sinclair's figure, a defense based on cropping inputs, contradicted a SQ definition that did not include terms of productivity.

Proponents responded to Sojka's response concerning Sinclair's figure. In their 2003 rebuttal, Karlen et al. (2003) state:

> The misconception put forward was that the soil ratings for plant growth map (Figure l), termed the Sinclair index by Sojka and Upchurch (1999), is an example of how the soil quality concept was prematurely institutionalized (U.S. Department of Agriculture-Natural Resources Conservation Service [USDA-NRCS], 1996) and therefore not subjected to the rigors of scientific evaluation. The map in question was not developed as an index of soil quality, as defined by Larson and Pierce (1991), Doran et al. (1996), Karlen et al. (2001), or any scientist considered to be a student of soil quality. (p. 173)

Karlen et al. (2003) go on to describe how the model used to create Sinclair's figure uses inherent soil properties. In contrast, they argued, "efforts to develop indices of relative soil quality (Karlen et al., 2001) have focused on dynamic soil properties" (p. 174).

In any event, the interpretation of SQ indicators remains contentions. How to integrate any SQ indicators in a way that represents "the capacity of soil to function within ecosystem boundaries to sustain biological productivity, maintain environmental quality, and promote plant and animal health" (Doran and Parkin, 1994, p.7) remains as elusive as an agreed upon definition of SQ and the selection of SQ indicators.

Today

While the 'quality soil management vs soil quality management' debates of the late 1990s were never resolved, the terms SQ and SH are still used today. Lal (2016) state that "soil quality is defined as the "fitness for use" (Larson and Pierce 1991) and "capacity of the soil to function" (Karlen et al. 1997)" (p. 213). However, Buenemann et al. (2018) state:

> In contrast [to air and water quality], soil quality is not limited to the degree of soil pollution, but is commonly defined much more broadly as "the capacity of a soil to function within ecosystem and land-use boundaries to sustain biological productivity, maintain environmental quality, and promote plant and animal health" (Doran and Parkin, 1994, 1996). (p. 105)

These two current publications define SQ differently.

Lal (2016) differentiates SQ from SH. He argues SQ is related to soil function and that SH is related to how soil is a dynamic living entity. Lal states:

> Terms soil quality and soil health, while similar, should not be used interchangeably. Soil quality is related to soil functions or what it does, whereas soil health presents the soil as a finite and dynamic living soil resource, and is directly related to plant health. More specifically, soil health is defined as "capacity of soil to function as a vital living system to sustain biological productivity, maintain environment quality and promote plant, animal and human health (Doran et al. 1996; Doran and Zeiss 2000). (p. 213)

Furthermore, Lal (2016) suggests that separate from SH and SQ, soil function (SF) is a different, but interrelated, term. However, Reeve et al. (2016) state the following:

> The concept of soil quality or health has received considerable scientific attention over the years (Parr et al., 1992; Karlen et al., 1997; Arshad and Martin, 2002). Soil quality or health is most often defined as the “capacity of a soil to function within ecosystem boundaries to sustain biological productivity, maintain environmental quality and promote plant and animal health” (Doran and Parkin, 1994). (p. 323)

In contrast to Lal (2016), Reeve et al. (2016) argue SQ and SH are synonymously defined.

Bünemann et al. (2018) reviewed SQ and identified the most frequently used SQ indicators to assess soils used for agriculture. They concluded that “explicit evaluation of soil quality with respect to specific soil threats, soil functions, and ecosystem services has rarely been implemented, and few approaches provide clear interpretation schemes of measured indicator values” (Bünemann et al., p. 105). In their review of SQ assessment approaches (n=65) they found that soil organic matter, pH, available P, and water storage were the most commonly used indicators, and that biological indicators were under-represented. They concluded clear objectives were needed for soil assessments, “whether soil assessment is meant as a basis for management recommendations, seen as an educational tool, or as part of a monitoring system” (p. 119). Moreover, target users for said soil assessments should be clearly identified and included from the beginning (Bünemann et al.). They also concluded “selection of soil quality indicators needs to be based on mechanistic linkages between indicators and soil functions or ecosystem services that have sometimes been proposed (Creamer et al., 2016) but rarely established firmly through experimental validation (e.g. van Eekeren et al., 2010)” (p. 119). The researchers then state the following: “An asset of a novel soil quality framework would be the possibility to choose indicators based on the targeted soil threats, soil functions and ecosystem services, which is deemed possible by using the logical-sieve method (Stone et al., 2016a)” (p. 119). Finally, they conclude that how the values of SQ indicators need to be well-defined.

So, in other words, SQ needs to have clear objectives, selection of SQ indicators needs to be based on soil use, and how SQ values are interpreted needs to be well defined. Sound familiar?

Conclusion

SQ as a concept was embraced for its potential upside while its contentious attributes were ignored. The benefits of SQ as a concept were the elevation of the importance of soil resources, political attention which could lead to an increase in funding, and a user-friendly way to communicate the integration of physical, chemical, and biological soil properties to make management decisions. Its contentious attributes were a dysfunctional definition, value-laden selection and weighing of soil properties to serve as SQ indicators, and problematic oversimplification of soil science in a “one size fits all” approach to make it more accessible to non-soil scientists.

SQ as a concept has been applied without an agreed upon definition. Many have integrated SQ parameters (which, arguably, was and is nothing new) in appropriate ways because they have specified soil use. That soil use was plant production and the soil properties used as indicators had been investigated in the context of crop production. Interestingly, as suggested by opponents, the major use of SQ as a concept has been production agriculture because production agriculture is the major use of soil.

Finally, it seems there are those who did not want to struggle with SQ's deficiencies and instead used the term SH. Now, even more ambiguous and much less accepted, SH is used to convey a positive outlook on soil resources. It can be difficult to argue with such concepts; who doesn't want a *healthy* soil?

SQ and SH are here to stay. They have been institutionalized by several groups, including the U.S. government, private industry, and academic institutions. The concept should not be erased from the soil science vernacular. However, the SQ definition must account for the complexity of soil and it's simultaneous functions by specifying soil use. The previous attempt to define SQ by encompassing its multiple uses was a well-intentioned, multidisciplinary, systems-thinking description of soil as a system. However, soil, unlike air and water, is used with circumstance-specific goals. Its quality should be assessed with those goals in mind. Furthermore, the soil quality indicators previously proposed were also well-intentioned in that they were meant to be used by people with varying levels of expertise. However, soil quality indicators must be selected in a site-specific and use-specific manner. In other words, one cannot measure the same soil quality indicators in every soil system and expect them to reflect the same management effect. For example, a soil bulk density in Midwestern Mollisols may reflect the influence of several site and management-specific effects compared to a soil bulk density measured in a Brazilian Oxisol. These simply don't mean the same thing. The tradeoff to having to select site specific, soil type/texture specific, ecoregion specific, and management specific indicators of soil quality include decreasing the user-friendliness of this concept. The tradeoff of measuring a set list of soil quality indicators across all soil systems for widely diverse uses may be greater: an inaccurate assessment of management on important soil resources. Interestingly, one could argue selecting indictors of soil status to assess the impact of management with an expert understanding of how each of those soil indicators are measured, analyzed and interpreted and how they are influenced by inherent and dynamic soil factors within specific management strategies and soil use is nothing new.

If as a scientific community we are to continue to use these terms, then we must revisit what was disagreed upon and, almost twenty years later, attempt to address those disagreements. Karlen et al. (2003) stated the following:

> Indeed, advocates and early adopters of the soil quality concept totally agree with Sojka and Upchurch (1999) that "our children and grandchildren of 2030 will not care whether we crafted our definitions or diagnostics well. They will care if they are well fed, whether there are still woods to walk in and streams to splash in—in short, whether or not we helped solve their problems, especially given a 30-year warning." (p. 3)

Almost twenty years later, we can care about both.

References

Agriculture Improvement Act 2018

Andrews, S. S., Karlen, D. L., & Mitchell, J. P. (2002). A comparison of soil quality indexing methods for vegetable production systems in Northern California. *Agriculture, Ecosystems & Environment, 90*(1), 25-45. Doi: 10.1016/S0167-8809(01)00174-8

Bünemann, E. K., Bongiorno, G., Bai, Z., Creamer, R. E., De Deyn, G., de Goede, R., Fleskens, L., Geissen, V., Kuyper, T. W., Mäder, P., Pulleman, M., Sukkel, W., van Groenigen, J. W., & Brussard, L. (2018). Soil quality–A critical review. *Soil Biology and Biochemistry*, *120*, 105-125. Doi: 10.1016/j.soilbio.2018.01.030

Doran, J. W., & Parkin, T. B. (1994). Defining and assessing soil quality. In J. W. Doran, D. C. Coleman, D. F. Bezdick & B. A. Stewart (Eds.), *Defining soil quality for a sustainable environment* (pp. 1-21). Location: Soil Science Society of America and American Society of Agronomy.

Doran, J. W., & Parkin, T. B. (1996). Quantitative indicators of soil quality: A minimum data set. In J. W. Doran, & A. J. Jones (Eds.), *Methods for assessing soil quality* (pp. 25-37). Location: Soil Science Society of America.

Doran, J. W., Coleman, D. C., Bezdick, D. F., & Stewart, B. A (Eds). (1994). Defining soil quality for sustainable environment. Location: Soil Science Society of America.

Guerra, C., Capitelli, M., & Longo, S. (2012). The role of paradigms in science: A historical perspective. In L'Abate, L. (ed.), *Paradigms in theory construction* (pp. 19-30). Doi: 10.1007/978-1-4614-0914-4

Harris, R., & Bezdicek, D. (1994). Descriptive aspects of soil quality/health. In J. W. Doran, D.C. Coleman, D.F. Bezdicek, & B.A. Stewart (Eds.), *Defining soil quality for a sustainable environment* (pp. 23-35). Location: Soil Science Society of America.

Karlen, D., Andrews, S., & Doran, J. (2001). Soil quality: Current concepts and applications. In *Advances in Agronomy*, (Vol. 74, pp. 1-40).

Karlen, D., Gardner, J., & Rosek, M. (1998). A soil quality framework for evaluating the impact of CRP. *Journal of Production Agriculture, 11*(1), 56-60. Doi:10.2134/jpa1998.0056

Karlen, D. L., Mausbach, M. J., Doran, J. W., Cline, R. G., Harris, R. F., & Schuman, G. E. (1997). Soil quality: A concept, definition, and framework for evaluation (a guest editorial). *Soil Science Society of America Journal, 61*(1), 4-10. Doi: 10.2136/sssaj1997.03615995006100010001x

Karlen, D. L., Andrews, S. S., Weinhold, B. J., & Doran, J. W. (2003). Soil quality: Humankind's foundation for survival a research editorial by conservation professionals. *Journal of Soil and Water Conservation, 58*(4), 171-179.

Karlen, D. L., & Stott, D. E. (1994). A framework for evaluating physical and chemical indicators of soil quality. In J. W. Doran, D. C. Coleman, D. F. Bezdick & B. A. Stewart (Eds.), *Defining soil quality for a sustainable environment* (pp. 53-72). Location: Soil Science Society of America and American Society of Agronomy.

Lal, R. (2016). Soil health and carbon management. *Food and Energy Security*, *5*(4), 212-222. Doi: 10.1002/fes3.96

Lakatos, I. (1971). History of science and its rational reconstructions. In PSA 1970 (pp. 91-136). Springer, Dordrecht.

Larson, W., & Pierce, F. (1991, September). Conservation and enhancement of soil quality. In *Evaluation for Sustainable Land Management in the Developing World: Proceedings of the International Workshop on Evaluation for Sustainable Land Management in the Developing World, Chiang Rai, Thailand*. Bangkok: International Board for Soil Research and Management.

Mausel, P. W. (1971). Soil quality in Illinois—an example of a soils geography resource analysis. *The Professional Geographer*, *23*(2), 127-136.

Merriam-Webster. (2019). Paradigm. Retrieved from https://www.merriam-webster.com/dictionary

National Research Council. (1993). *Soil and water quality: An agenda for agriculture*. Washington, DC: National Academies Press.

Nortcliff, S. (2002). Standardisation of soil quality attributes. *Agriculture, Ecosystems & Environment*, *88*(2), 161-168. Doi: 10.1016/S0167-8809(01)00253-5

Parr, J. F., Papendick, R. I., Hornick, S. B., & Meyer, R E. (1992). Soil quality: Attributes and relationship to alternative and sustainable agriculture. *American Journal of Alternative Agriculture*, *7*(1-2), 5-11. Doi: 10.1017/S0889189300004367

Power, J., & Myers, R. (1990). The maintenance or improvement of farming systems in North America and Australia. In J. W. B. Stewart (Ed.), *Soil quality in semi-arid agriculture* (pp. 273-92). Saskatoon, Canada: Saskatchewan Institute of Pedology.

Reeve, J. R., Hoagland, L. A., Villalba, J. J., Carr, P. M., Atucha, A., Cambardella, C., … & Delate, K. (2016). Organic farming, soil health, and food quality: considering possible links. In *Advances in Agronomy* (Vol. 137, pp. 319-367). Doi: 10.1016/bs.agron.2015.12.003

Romig, D. E., Garlynd, M. J., Harris, R. F., & McSweeney, K. (1995). How farmers assess soil health and quality. *Journal of Soil and Water Conservation*, *50*(3), 229-236.

Soil Health Institute (2019). Retrieved from: https://soilhealthinstitute.org/

Sojka, R., & Upchurch, D. (1999). Reservations regarding the soil quality concept. *Soil Science Society of America Journal*, *63*(5), 1039-1054. Doi: 10.2136/sssaj1999.6351039x

Sojka, R. E., Upchurch, D. R., & Borlaug, N. E. (2003). Quality soil management or soil quality management: Performance versus semantics. *Advances in Agronomy*, *79*, 1-68. Doi: 10.1016/S0065-2113(02)79001-9

Stenberg, B. (1999). Monitoring soil quality of arable land: microbiological indicators. Acta Agriculturae Scandinavica, Section B-plant Soil Science, 49(1), 1-24.

United States Department of Agriculture Natural Resources Conservation Service (2019). Retrieved from: https://www.nrcs.usda.gov/wps/portal/nrcs/main/national/soils/health/

Figure 1.1. A timeline of the soil quality and soil health debates of the late the 1990s and early 2000s.

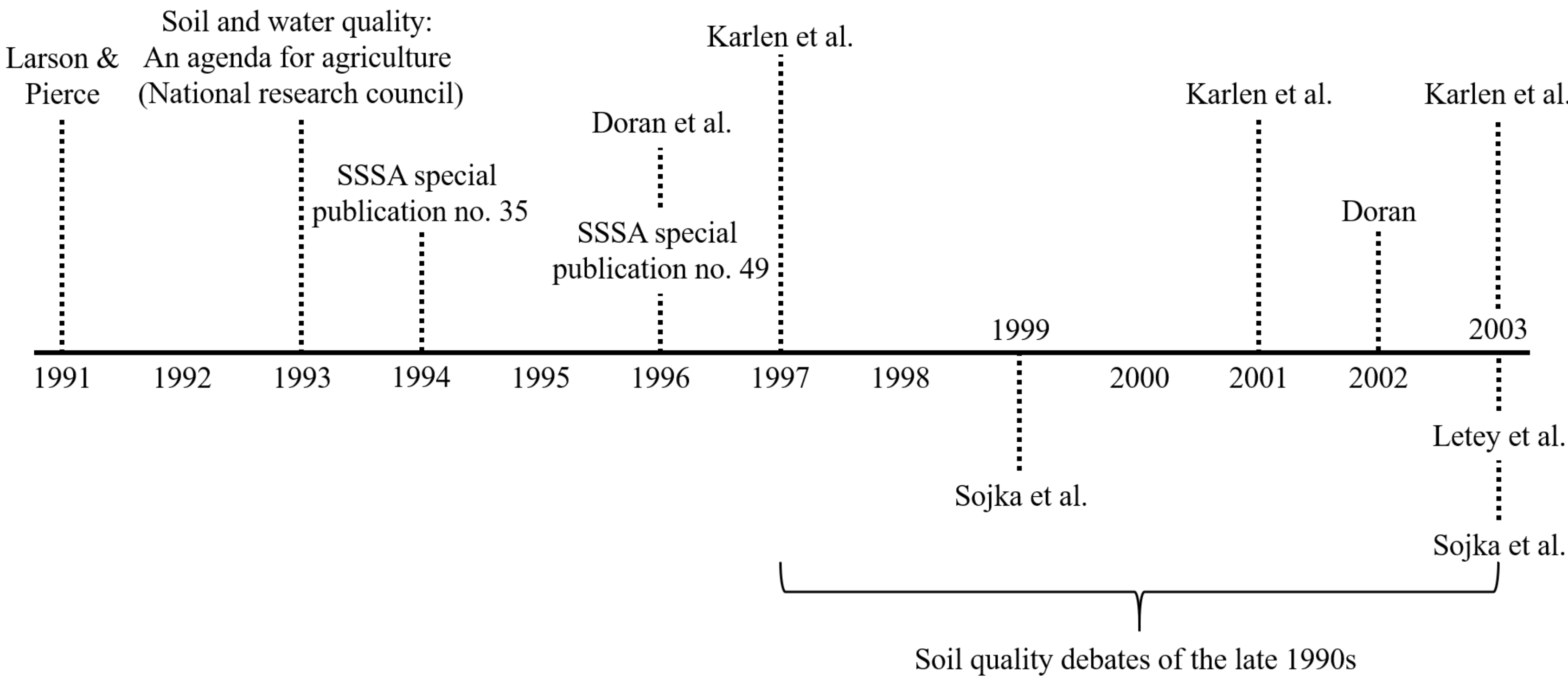


Table 1.1. A key to figure 1.

Year	Authors/organization	Title
1991	Larson and Pierce	Conservation and enhancement of soil quality
1993	National research council	Soil and water quality: An agenda for agriculture
1994	SSSA special publication no. 35	Defining soil quality for a sustainable environment
1996	SSSA special publication no. 39	Methods for assessing soil quality
1996	Doran et al.	Soil health and sustainability
1997	Karlen et al.	Soil quality: A concept, definition, and framework for evaluation
1999	Sojka et al.	Reservations regarding the soil quality concept
2001	Karlen et al.	Soil quality: Current concepts and applications
2002	Doran	Soil health and global sustainability: translating science in to practice
2003	Letey et al.	Deficiencies in the soil quality concept and its application
2003	Sojka et al.	Quality soil management or soil quality management: performance versus semantics
2003	Karlen et al.	Soil quality: Humankind’s foundation for survival

Table 1.2. Proposed minimum data set of physical, chemical, and biological indicators for screening the condition, quality, and health of soil (after Doran & Parkin, 1994; Larson & Pierce, 1994) (table from Doran and Parkin, 1996)

Indicators of soil condition	Relationship to soil condition and function; rational as a priority measurement	Ecologically relevant values or units; comparisons for evaluation
	Physical	
Texture	Retention and transport of water and chemicals; modeling use, soil erosion, and variability estimate	% sand, silt, & clay; less eroded sites or landscape positions
Depth of soil, topsoil, rooting	Estimate of productivity potential and erosion; normalizes landscape and geographic variability	cm or m; non cultivated sites or varying landscape positions
Infiltration and soil bulk density (SBD)	Potential for leaching, productivity, and erosivity; SBD needed to adjust analyses to volumetric basis	Minutes/2.5 cm of water and g/cm^3 row and/or landscape
Water holding capacity (water retention characteristic)	Related to water retention, transport, and erosivity; available H_2O: Calculate from SBD, texture, and OM	% (cm^3/cm^3), cm of available H_2O cm; precipitation intensity
	Chemical	
Soil organic matter (OM) (total organic C and N)	Defines soil fertility, stability, and erosion extent; use in process models and for site normalization	kg C or N/ha-30 cm; noncultivated or native control
pH	Defines biological and chemical activity thresholds; essential to process modeling	Compared with upper and lower limits for plant and microbial activity
Electrical conductivity	Defines plant and microbial activity thresholds; presently lacking in most process models	dS/m^1; compared with upper and lower limits for plant and microbial activity
Extractable N, P, and K	Plant available nutrients and potential for N loss; productivity and environmental quality indicators	kg/ha or C/ha-30 cm; seasonal sufficiency levels for crop growth
	Biological	
Microbial biomass C and N	Microbial catalytic potential and repository for C and N; modeling: Early warning of management effects on OM	kg N or C/ha-30cm; relative to total C and N or CO_2 produced
Potentially mineralizable N (anaerobic incubation)	Soil productivity and N supplying potential; Process modeling; (surrogate indicator of biomass)	kg N/ha-30 cm/d; relative to total C or total N contents
Soil respiration, water content, and temperature	kg C/ha/d; relative microbial biomass activity, C loss vs. inputs and total C pool	Microbial activity measure (in some cases plants) process modeling; estimates of biomass activity

Figure 1.2. Soil ratings for plant growth (as cited by Sojka & Upchurch, 1999)

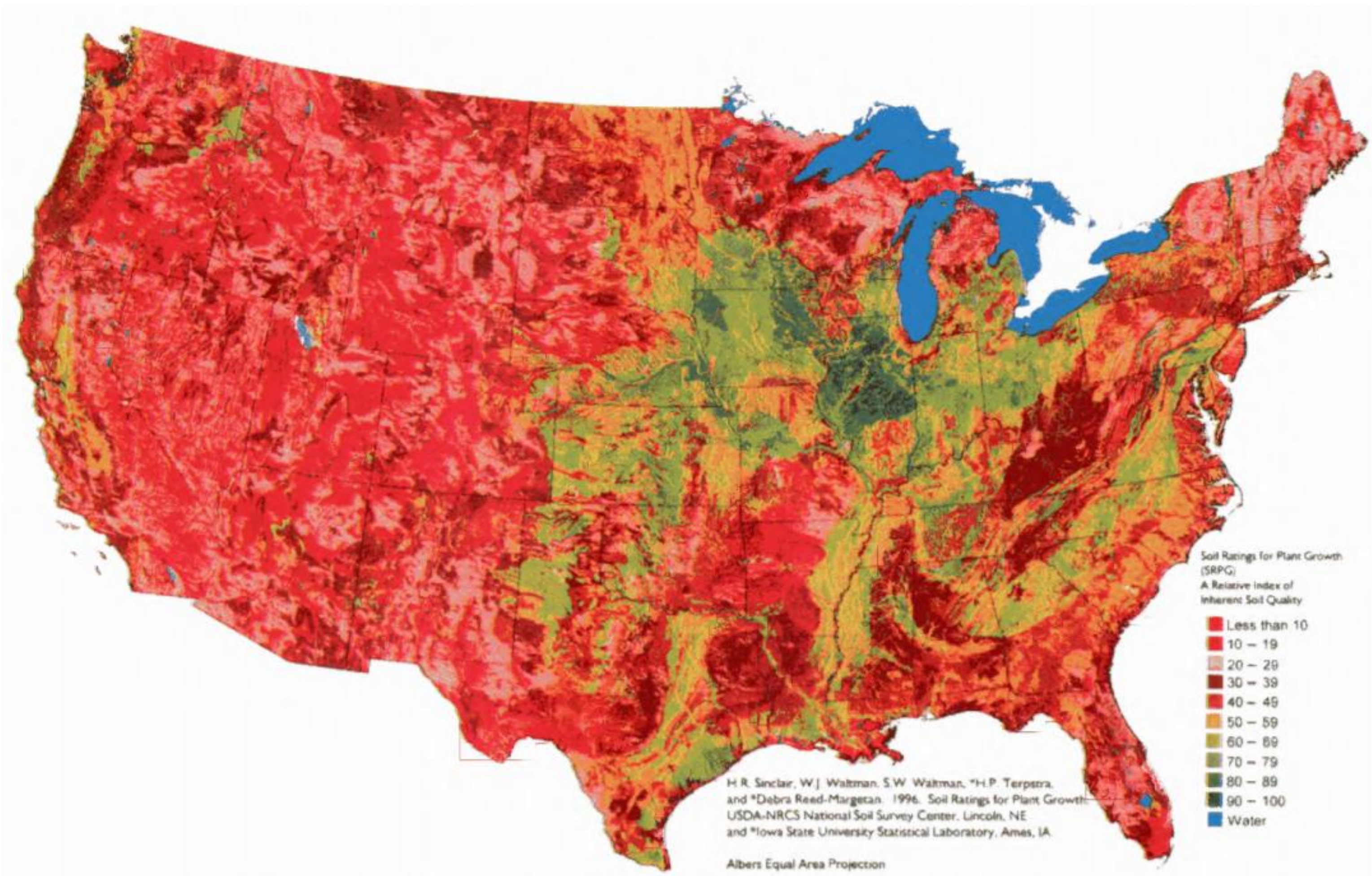


Figure 1 A relative index of inherent soil quality for the USA, adapted from Sinclair *et al.* (1996).

Chapter 2: A Tool to Assess Soil Quality and Soil Health Perceptions of Nebraska Producers

Relevance/Importance

Understanding how farmers perceive the concepts of soil quality (SQ) and soil health (SH) can improve how scientists communicate with farmers about depletable soil resources. Academic disagreements arouse in the late 1990s concerning SQ and SH. Those disagreements were over (1) the definition of soil quality, (2) appropriate SQ indicators, (3) methods to integrate SQ indicators and (4) the interpretation of integrated SQ indicators. Proponents defined SQ as "*the capacity of soil to function within ecosystem boundaries to sustain biological productivity, maintain environmental quality, and promote plant and animal health"* (Doran and Parkin, 1994, p.7). Proponents proposed a list of soil physical, chemical, and biological properties to serve as basic indicators of SQ which was referred to as a minimum data set (MDS) (Doran and Parkin, 1994). Finally, proponents integrated soil properties from said MDS using tools such as the Soil Management Assessment Framework which culminated in a SQ score (Andrews et al. 2002; Karlen et al., 2001). Opponents argued the SQ definition was too broad, failed to specify soil use, and failed to account for the various simultaneous functions soils perform (Sojka and Upchurch, 1999; Sojka et al., 2003; Letey et al., 2003). Furthermore, opponents argued integrating soil properties involved a mixture of scientific and non-scientific judgments, and that weighing simultaneous, often conflicting, soil functions was value laden (Sojka and Upchurch, 1999; Sojka et al., 2003; Letey et al., 2003).

While these SQ and SH debates were never conclusively resolved, SQ as a concept has been institutionalized within government agencies, academic institutions, and private industry. An example of how SH has been institutionalized as a concept can be seen in the Agriculture Improvement Act of 2018 (the ‘farm bill’), in which “soil health planning, including increasing soil organic matter and use of cover crops” is described as an “incentive practice” (p. 69). Furthermore, the United States Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) has a webpage devoted to their SH campaign “Unlock the Secrets in the Soil.” In it, on can find statements such as “By farming using soil principles and systems that include no-till, cover cropping, and diverse rotation, more and more farmers are actually increasing their soil’s organic matter and improving microbial activity” (USDA-NRCS). As a result of the various institutions embracing and communicating SQ and SH, farmers have been continuously exposed to these concepts.

How farmers assess SQ and SH was investigated during the SQ debates of the 1990s. Romig et al. (1995) interviewed 28 farmers in 1993 through a series of open- and closed-ended questions related to their central question: “How do you recognize a healthy soil?” Romig et al. (1995) reported that farmers rely almost entirely on sensory observations to assess SH. Furthermore, they reported that farmers used a diversity of indicators outside soil properties to determine SH (Romig et al., 1995). Whereas academics were concerned with quantitatively integrating soil biological, chemical, and physical properties, farmers observed how soil interacted with plants, animal and human health, and the quality of water to determine SH (Romig et al., 1995). Romig et al. (1995) referred to farmers’ agroecosystems and systems thinking approach to SH as “holistic.”

An example of this "holistic" approach is evident in one farmer's response to assessing indicators of SH: "A healthy plant is a healthy cow is a healthy milk check. It's all related to me" (p. 231). As mentioned before, these surveys were conducted in the 1990s. How do farmers feel about SQ and SH today?

A major goal of SQ and SH in the late 1990s was to create a concept that could be used to communicate the importance of soil resources with farmers and the public (Karlen et al., 2001). While how farmers assess SQ and SH has been investigated in the past, fewer investigators have given farmers an opportunity to challenge the validity of SQ and SH or attempted to correlate personal factors or management decisions to their perceptions of SQ and SH. The goal of this three-part survey is to assess how that communication has influenced farmers' perceptions of SQ/SH almost twenty years later. This three-part survey was created to assess how farmers currently perceive SQ/SH, and if those perceptions depend on either personal demographic factors or operation characteristics. Understanding how farmers perceive SQ/SH, and what influences those perceptions can be used to decide if (1) the continued use of SQ/SH is appropriate in communicating with farmers and (2) how to improve communication of SQ/SH if they are still appropriate concepts to use.

Materials and Methods

Survey questions

To assess how personal demographics and operation characteristics influence farmers' perception of SQ/SH, the survey was split into three parts. The first part consisted of sixteen demographic questions collecting both personal information and operation characteristics. Personal information questions collected information such as age, gender, education, and role within the operation. Operation characteristics questions collected information such as operation size and location within a NE county, as well as grazing, crop rotation, tillage, cover crop, and irrigation practices.

The second part of the survey consists of SH/SQ questions. SH/SQ questions were designed to measure (1) farmers' perception of the validity SH/SQ as a concept, (2) farmers' willingness to assess SQ/SH if they believe it can be measured, (3) farmers' perception of how SH/SQ is communicated to them, and (4) farmers' use of SH/SQ when making management decisions. Answer options to these questions were on a Likert scale.

The third part of the survey consisted of two free response questions: (1) How would you define soil health/soil quality? and (2) Is there anything else you want to add about soil health/soil quality that we should know about in understanding your use of these concepts? The purpose of these questions to so provide survey takers with a platform to communicate their ideas concerning SQ/SH if survey questions failed to do so.

Survey questions were approved by the International Review Board (IRB, IRB number 20181218270 EX).

Statistical analysis

How demographic factors (part 1 of survey) influence farmer perceptions of SQ/SH (part 2 of survey) will be individually assessed using a proportional odds (PO) regression model (Bilder & Loughin, 2014). PO models will be used to analyze the cumulative probabilities that farmer survey responses are equal to or less than the previous category found in a Likert scale set of responses. These cumulative probabilities can be written as:

$$logit[P(Y \leq j)] = \log\left[\frac{P(Y \leq j)}{1 - P(Y \leq j)}\right] = \log\left[\frac{\pi_1 + \cdots + \pi_j}{\pi_{j+1} + \cdots + \pi_j}\right]$$

In other words, the PO models model the odds a farmer survey response is category j versus the odds a farmer survey response is greater than category j. To assess if these log odds change as a function of demographic factors the following PO models will created:

For demographic factor 1 (DF1):

$$logit[P(Y \leq j)] = \beta_{j0} - \eta_1 DFlv1 - \eta_2 DFlv2 - \eta_3 DFlv3 \text{ for j=1,…,J}$$

Individual models will be created relating one demographic factor to one set of responses to any give SQ/SH question. The Proportional Odds Logistic Regression (polr) function, in the Modern Applied Statistics with S (MASS) package in r will be used to estimate these models. To assess the significance of demographic factors on farmer survey responses, likelihood ratio tests (LRT) will be conducted on the polr models using the Analysis of Variance (Anova) function in the Comparison of Applied Regression (car) package in r. Significant differences in farmer survey responses due to demographic factors will be reported significant at the 0.05 level.

Odds ratios will be constructed for farmer demographic factors found significant at the 0.05 level as such:

$$\frac{Odds_{x+C}(Y \leq j)}{Odds_x(Y \leq j)} = \frac{e^{\beta_{j0} + \eta_1(x+c)}}{e^{\beta_{j0} + \eta_1 x}}$$

for a c unit increase of x (demographic factors). If a survey taker fails to answer any part of any question, they will removed from model only assessing that individual question.

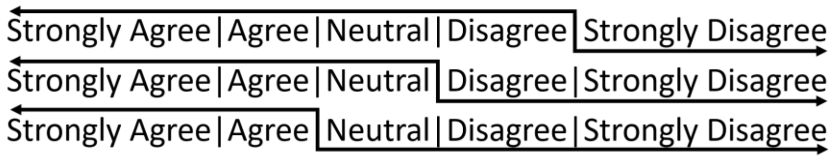
The third part of the survey consisting of two free response questions which analyzed using textural analysis.

Discussion

The first objective, which is to assess how farmers currently perceive SQ and SH, can be easily achieved contingent on survey participation. Questions will elucidate if famers (1) believe SQ and SH are terms that can be used interchangeably, (2) if they believe soil is a depletable resource, (3) if they believe it's important to make management decision based on SQ/SH, or if (4) they believe they do not need to measure SQ/SH and that (5) SG/SH are concepts that do not help them manage their farms. Other questions will elucidate if farmers believe SQ/SH can be measured and their willingness to measure it.

The second and third objectives, which is to investigate how personal demographic factors and operation characteristics influence farmers perceptions of SQ/SH, will be accomplished using odds ratios. Odds ratios will be constructed correlating any given personal or operation demographic factors to any given SQ/SH perception. For example, if answers to statement "Soil is a depletable resources" are found to significantly depend, on say, personal demographic question 11 (If you a rancher or farmer, how long have you been in production?), then odds ratios will be constructed for that combination alone. If the odds ratio comparing, for example, a farmer that has been in production for 20-25 years to a famer that has been in production for 25-30 years is 4.0, than that can be interpreted as the following: *The estimated odds of a farmer answering 'neutral' to the statement 'soil is a depletable resource' or anything before (agree, strongly agree) vs answering 'disagree' or anything after (strongly disagree) are 4 as large for a farmer who has been in production for 25-30 years compared to one that has been in production* *for 20-25 years.* That odds ratio of 4 remains the same for every comparison of categories on the Likert scale response (Figure 2.1).

Figure 2.1. The interpretation of odds ratios around Likert scales.



Each question must be individually analyzed for significance when correlating it to any given personal or operation demographic factor.

Conclusion

If soil scientists are to continue to use the concepts SQ and SH to communicate with farmers, how farmers perceive those concepts must be understood. Gaining this understanding of famers can guide academic research questions and research communication, as well as improve the assessment of extension efforts. Even if the SQ debates of 1990s were never resolved, the terms SQ and SH are extensively used today, and how farmers respond to this term must be characterized.

References

Agriculture Improvement Act of 2018

Andrews, S. S., Karlen, D. L., & Mitchell, J. P. (2002). A comparison of soil quality indexing methods for vegetable production systems in Northern California. *Agriculture, Ecosystems & Environment, 90*(1), 25-45. doi: 10.1016/S0167-8809(01)00174-8

Bilder, C. R., & Loughin, T. M. (2014). Analysis of categorical data with R. Chapman and Hall/CRC.

Doran, J. W., & Parkin, T. B. (1994). Defining and assessing soil quality. In J. W. Doran, D. C. Coleman, D. F. Bezdick & B. A. Stewart (Eds.), *Defining soil quality for a sustainable environment* (pp. 1-21). Location: Soil Science Society of America and American Society of Agronomy.

Karlen, D., Andrews, S., & Doran, J. (2001). Soil quality: Current concepts and applications. In *Advances in Agronomy*, (Vol. 74, pp. 1-40).

Letey, J., Sojka, R. E., Upchurch, D. R., Cassel, D. K., Olson, K. R., Payne, W. A., Petrie, S.E., Price, G.H., & Reginato, R.J., Scott, H. D., Smethurst, P. J., Triplett, G.B. (2003). Deficiencies in the soil quality concept and its application. *Journal of Soil and Water Conservation, 58*(4), 180-187.

Romig, D. E., Garlynd, M. J., Harris, R. F., & McSweeney, K. (1995). How farmers assess soil health and quality. *Journal of Soil and Water Conservation*, *50*(3), 229-236.

Sojka, R., & Upchurch, D. (1999). Reservations regarding the soil quality concept. *Soil Science Society of America Journal, 63*(5), 1039-1054. doi: 10.2136/sssaj1999.6351039x

Sojka, R. E., Upchurch, D. R., & Borlaug, N. E. (2003). Quality soil management or soil quality management: Performance versus semantics. *Advances in Agronomy*, *79,* 1-68. doi: 10.1016/S0065-2113(02)79001-9

United States Department of Agriculture Natural Resources Conservation Service (2019). Retrieved from: https://www.nrcs.usda.gov/wps/portal/nrcs/main/national/soils/health/

Addendum - Soil Quality/Soil Health Survey

Introduction

Hello,

You have been selected to participate in this study because of your experience with soil health/soil quality. The terms 'soil health' and 'soil quality' have been debated within the academic community for the past 50 years; how they are defined, how they may be measured, and their implications for management are often in contention. The purpose of this questionnaire is to ascertain how those who deal with these concepts on a production level, as the basis of their livelihoods, view these concepts by gathering various attitudes of soil health/soil quality, summarizing these attitudes, correlating them to demographic factors, and communicating these attitudes to academics and extension specialists so we may improve our communication of these concepts with its most important population: farmers.

Procedure
Answer the following questions to the best of your ability. It is better to go with your first instinct rather than dwell on any question. Your responses are entirely anonymous, and nowhere in the questionnaire will you be asked to provide your name. **Participants must be 19 years of age or older to participate in this survey.** The survey should take you about 20-30 minutes to complete. Only the questionnaire team will have access to the dataset

Risks and/or Discomforts
There are no known risks or discomforts associated with participating in this research study.

Confidentiality
Any information obtained during this study which might identify you will be kept strictly confidential. The data will be summarized and analyzed and kept on Dr. Speth's and graduate student Salvador Ramirez's computer for no more than four years after the study. The group data may be published in scientific journals or presented at scientific meetings, but all participants will be kept anonymous.

Questions
For questions concerning your rights or plaints about the research contact the Institutional Review Board (IRB) Phone: 1(402) 472-6965 or Email: irb@unl.edu.
For questions concerning they study, you can contact the PIs Dr. Martha Mamo at mmamo3@unl.edu and Salvador Ramirez II at salvador.ramriez@huskers.unl.edu.

Freedom to Withdraw
You are free to decide not to participate in this study or to withdraw at any time without adversely affecting your relationship with the investigators or the University of Nebraska.

Benefits
There are no benefits to participants for completing this survey.

Consent
Please keep this page for your records. If you agree to participate, go to the next page. Thank you for your responses. We value your input, and we hope it will help us grow.

The University of Nebraska-Lincoln wants to know about your research experience. This 14 question, multiple-choice survey is anonymous. This survey should be completed after your participation in this research. Please complete this optional online survey at: http://bit.ly/UNLresearchfeedback.

Personal demographic questions

1. What is your age?

[ ]

2. What is your gender?

[ ]

3. What is your highest level of education?

Less than high school	☐
High school	☐
Associate's degree	☐
Bachelor's degree	☐
Master's degree	☐
Doctoral degree	☐

4. Please select the following title that best describes your occupation? Select all that apply.

Farmer/rancher	☐
Industry representative	☐
Independent crop consultant	☐
Banker/insurer	☐
Land owner	☐

5. What is your role in the in operation you are filling out this questionnaire for? Select all that apply.

Operator	☐
Owner	☐
Spouse	☐
Son or daughter of operator	☐
Other	☐

Operation demographic questions (if farmer or rancher)

6. In what Nebraska county is your operation in?

Drop down menu

7. Of the following options, which describes your operation? Select all that apply.

Commodity crops	☐
Horticulture or vegetable crops	☐
Rangeland	☐
Pastureland	☐
Organic	☐
Integrated crop livestock system	☐
Other	☐

8. If you graze any of your acres, what percentage of your acres do you graze?

I do not graze any of my acres	☐
0-20%	☐
20%-40%	☐
40%-60%	☐
More than 60%	☐

9. If you practice a crop rotation, how many commodity crops do you rotate in your crop rotation?

2 crops	☐
3 crops	☐
4 crops	☐
More than 4 crops	☐
I do not practice a crop rotation	☐

10. What is the size, in acres, of the cropland in your operation?

	Number of acres owned	Number of acres rented
Commodity crops		
Horticulture or vegetable crops		
Rangeland		
Pastureland		
Organic		
Other		

11. If you are a rancher or farmer, how long have you been in production?

Less than 1 year	☐
1-5 years	☐
5-10 years	☐
15-20 years	☐
20-25 years	☐
25-30 years	☐
More than 30 years	☐

12. Of the following options, which best describes your tillage practices? Select all that apply.

Does not apply	☐
Continuous no-till	☐
Rotational no-till	☐
Reduced tillage	☐
Vertical tillage	☐
Conventional tillage	☐
Other	☐

13. If you use cover crops, how long have you planted cover crops?

Does not apply	☐
1 year or less	☐
2-5 years	☐
6-10 years	☐
More than 10 years	☐

14. If you use cover crops, what percentage of your cropland is planted to cover crops on an annual basis?

I do not use cover crops	☐
0-20%	☐
20%-40%	☐
40%-60%	☐
More than 60%	☐

15. What percentage of your cropland do you irrigate?

I do not irrigate	☐
0-25%	☐
25-50%	☐
50-75%	☐
75-100%	☐

16. How influential are the following groups or individuals in your perceptions of soil health/soil quality. Select all that apply.

		I talk to, and they have…			
	No contact	No influence	Slight influence	Moderate influence	Strong influence
Independent crop consultants	☐	☐	☐	☐	☐
Extension specialist	☐	☐	☐	☐	☐
Industry representative	☐	☐	☐	☐	☐
Academic materials	☐	☐	☐	☐	☐
USDA	☐	☐	☐	☐	☐
Farm press	☐	☐	☐	☐	☐
Other farmers	☐	☐	☐	☐	☐
Other (please specify)	☐	☐	☐	☐	☐

Questions related to soil health/soil quality as concepts

The following statements are related to soil quality/soil health as concepts. For each statement below, please select one category that best describes your level of agreement.

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
'Soil health' and 'soil quality' can be used interchangeably.	☐	☐	☐	☐	☐
Soil is a depletable resource.	☐	☐	☐	☐	☐
It is important to make management decisions based on soil health/soil quality.	☐	☐	☐	☐	☐
I do not need to measure/test soil health/soil quality.	☐	☐	☐	☐	☐
I do not feel soil health/soil quality concepts help me manage my farm.	☐	☐	☐	☐	☐

The following statements are related to if and how soil quality/soil health can be measured. For each statement below, please select on category that best describes your level of agreement.

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
Soil health/soil quality can be measured/tested.	☐	☐	☐	☐	☐
I am willing to measure/test my soil health/soil quality.	☐	☐	☐	☐	☐
Even if I knew how, I would not measure/test my soil health/soil quality.	☐	☐	☐	☐	☐
There are reliable resources available to approximate my soil health/soil quality.	☐	☐	☐	☐	☐
If I wanted to measure/test my soil health, I would approach my university extension representative to inquire how.	☐	☐	☐	☐	☐
If I wanted to measure/test my soil health, I would approach professional agronomist to inquire how.	☐	☐	☐	☐	☐
If I wanted to measure/test my soil health, I would approach the USDA-NRCS to inquire how.	☐	☐	☐	☐	☐

When assessing your soil health/soil quality, please indicate the frequency with which you measure/test soil health/soil quality parameters below in the following classifications.

	Once a year	Every other year	Every five years	Never	I don't know
Fertility/chemical soil parameters	☐	☐	☐	☐	☐
Physical soil parameters	☐	☐	☐	☐	☐
Biological soil parameters	☐	☐	☐	☐	☐

Questions concerning the communication of soil quality/soil health

The following statements are asking about the frequency with which the terms soil quality/soil health are used to sell you an agronomic product.

	Very Frequently	Frequently	Little Frequency	Never
When purchasing an pesticide (insecticide, herbicide, fungicide, etc.), the terms soil quality/soil health are used	☐	☐	☐	☐
When purchasing farm equipment, the terms soil quality/soil health are used	☐	☐	☐	☐
When purchasing a soil additive/stimulant, the terms soil quality/soil health are used	☐	☐	☐	☐
When purchasing seed, the terms soil quality/soil health are used	☐	☐	☐	☐

The following statements are asking about the frequency with which the terms soil quality/soil health are expressed in a conversation with the following people:

	Very Frequently	Frequently	Little Frequency	Never
When I communicate with an extension specialist, the extension specialist uses the terms soil health/soil quality	☐	☐	☐	☐
When I communicate with a chemical company representative, the representative uses the terms soil health/soil quality	☐	☐	☐	☐
When I communicate with a fellow farmer, the farmer uses the terms soil health/soil quality	☐	☐	☐	☐
When I communicate with an independent crop consultant, the independent crop consultant uses the terms soil health/soil quality	☐	☐	☐	☐
When I communicate with my crop insurance provider, the provider uses the terms soil health/ soil quality	☐	☐	☐	☐

Questions concerning soil health/soil quality in relation to decision making and management strategies

Please indicate the importance you place on soil quality/soil health when making any of the following management decisions.

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
When deciding to perform any tillage practice, it's important to consider soil health/soil quality.	☐	☐	☐	☐	☐
Increasing crop diversity in a crop rotation improves soil health/quality.	☐	☐	☐	☐	☐
I believe that rotating multiple crops could improve soil health/quality.	☐	☐	☐	☐	☐
The economic risk of rotating multiple crops is too great.	☐	☐	☐	☐	☐
Using cover crops improves soil health/soil quality.	☐	☐	☐	☐	☐
The economic risk of using cover crops is too great.	☐	☐	☐	☐	☐
Using diverse cover crop mixtures are better for improving soil health/soil quality than using a single species cover crop.	☐	☐	☐	☐	☐
I believe planting cover crops may improve soil health/soil quality, but the economic risk is too great.	☐	☐	☐	☐	☐

Defining soil health/soil quality

How would you define soil health/soil quality?

Is there anything else you want to add about soil health/soil quality that we should know about in understanding your use of these concepts?