A RESEARCH EDITORIAL BY CONSERVATION PROFESSIONALS

Deficiencies in the soil quality concept and its application

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ABSTRACT: Soil quality is a concept that has deeply divided the soil science community. It has been institutionalized and advocated without full consideration of concept weaknesses and contradictions. Our paper highlights its disfunctional definition, flawed approach to quantification, and failure to integrate simultaneous functions, which often require contradictory soil properties and/or management. While the concept arose from a call to protect the environment and sustain the soil resource, soil quality indexing as implemented may actually impair some soil functions, environmental quality, or other societal priorities. We offer the alternative view that emphasis on known principles of soil management is a better expenditure of limited resources for soil stewardship than developing and deploying subjective indices which fail to integrate across the necessary spectrum of management outcomes. If the soil quality concept is retained, we suggest precisely specifying soil use, not function or capacity, as the criteria for attribute evaluation. Emphasis should be directed toward using available technical information to motivate and educate farmers on management practices that optimize the combined goals of high crop production, low environmental degradation, and a sustained resource.

Keywords: Environment, land use, landscape, soil condition, soil fertility, soil health, soil organic matter, soil properties, soil quality index, water quality

The term "soil quality" came into vogue in the 1990's following a 1993 National Research Council Committee (NRCC) report on long-range soil and water conservation entitled "Soil and water quality: An agenda for agriculture" (National Research Council, 1993). The development of the concept and its application in land management has been highly controversial among soil scientists since its inception. Land, air, and water are the basic natural resources. Federal legislation in the 1970s aimed to protect air and water quality. The NRCC report proposed that protecting soil quality should also be a basic goal of environmental policy, emphasizing the connection between soils and water quality. The NRCC listed four strategies to prevent soil degradation and water pollution while sustaining profitable agriculture. "National policy should seek to: 1) conserve and enhance soil quality as a fundamental first step to environmental improvement; 2) increase nutrient, pesticide, and irrigation use efficiency in farming systems; 3) increase the resistance of farming systems to erosion and runoff; and 4) make greater use of field and landscape buffer zones." An effective policy to conserve and enhance soil quality would require a definition of and means to assess soil quality. Soils differ from air and water, which have a "pure" state that can be used as a standard. Air and water's chemical, physical, and biological composition can be quantified with relative ease to determine deviation from the pure state, enabling inferences for specific uses. Although the physical, chemical, and biological composition of soil varies widely, and none can be established as a standard state, scientists have attempted to define and quantify soil quality. The Soil Science Society of America (SSSA) noted the significance of the National Research Council Committee report and an ad hoc committee developed a statement on soil quality (Allan et al., 1995).

Many concepts proposed since the National Research Council Committee report are based on papers by Larson and Pierce (1991, 1994). They defined soil quality as "The capacity of a soil to function within the ecosystem boundaries and interact positively with the environment external to that ecosystem." The Soil Science Society of America definition deviates slightly: "The capacity of a specific kind of soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation." The Soil Science Society of America ad hoc committee statement was expanded in an editorial (Karlen et al., 1997) by a subset of the committee.

Our discussion will show that the terms and concepts of "capacity" and "function,"

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which are used or explicit in all the definitions, are the source of operational conflicts in execution of the soil quality concept. While the various published lists of soil function are conceptually similar, they are not identical. However, the difficulty of reconciling the different lists, or designating which list should be authoritative, is minor compared to another problem related to multiple functions. A soil that might be "good" for one function may be "poor" for a different function(s) that the soil performs simultaneously. Karlen et al. (1997) acknowledged this problem when reviewing Doran and Werner (1990), concluding "The organic system with a winter cover crop had higher levels of microbial biomass and potentially mineralizable nitrogen (N), but lower levels of nitrate nitrogen (NO_3-N) in early spring (April 10th). With regard to soil functioning to protect the environment by decreasing the potential for nitrate nitrogen leaching, this was interpreted to indicate an improved soil quality. However, the trade-off was that the higher residue cover and lower potential nitrogen leaching losses during the nongrowing season resulted in lower available nitrogen, which was a potential limitation with regard to the soil functioning for corn production." These statements clearly describe how soil management affected rating and performance of two functions. Karlen et al (1997) failed to note that a single quality rating cannot properly assess both functions simultaneously, since different weighting of input data is needed to indicate if soil was improved or degraded for each function.

Larson and Pierce (1991) likened soil assessment to medical diagnosis of human health. Doctors measure temperature, blood pressure, blood chemistry, etc. as indicators of health status. Analogously, key indicators were proposed to diagnose soil quality status. Although this analogy has some merit and for many is appealing, it also has major deficiencies. Doctors have standard norms representing healthy individuals for comparative purposes and the norms do not deviate substantially for an individual's "function," climate, neighborhood, etc. Standard norms for soil quality indicators are generally lacking. Furthermore, doctors do not use "health" indicators to establish a numerical rating of the patient's health, but instead determine what treatment (management) is required to sustain life as a "healthy" individual. Moreover, health care management must accommodate each patient's situation and personal value system. Treatment choices are affected by such considerations as economic resources (affordability and insurance coverage), goals (desire for independence, employment needs, or wish to continue certain activities) and personal values (pain tolerance, aversion to medication, or even ultimately, whether to extend life with all available measures versus allowing natural expiration).

Larson and Pierce (1991) proposed that soil quality (Q) can be expressed as a function of attributes of soil quality (q_i) defined as:

$$Q = f(q_{1 \ldots n}) \tag{1}$$

(More recent literature uses the term "indicators" rather than "attributes" and soil quality index [SQI] is used to represent Q). Examples of soil quality attributes (q_i) are soil organic matter (SOM) or carbon, texture, structure, pH, electrical conductivity (EC), etc. Equation 1 specifies that the magnitude of Q is the collective contribution of all q_i. Larson and Pierce (1991) suggest that conservation enhancement or soil degradation can be evaluated by measuring q_i at different times. They derive the equation:

$$\frac{dQ}{dt} = f\frac{\left(\frac{q_{it} - q_{it_o}}{q_{it_o}} \quad \cdots \quad \frac{q_{nt} - q_{nt_o}}{q_{nt_o}}\right)}{dt} \tag{2}$$

where:

dQ/dt = dynamic change
t_o = initial time
t = later time when q is measured

A positive value for dQ/dt represents improved soil quality and a negative value for dQ/dt represents decreased soil quality or soil degradation. Since Equations 1 and 2 are mathematical relationships between inherent or static soil quality (Q) or dynamic soil quality (dQ/dt) and soil attributes or indicators (q_i), the soil quality concept appears to be based on solid scientific principles. However, Equation 1 simply states that Q is a function of $q_{i..n}$ and is of no practical value without the quantitative functional relationship between Q and the several q_i values and their complex interactions. Furthermore, values for q_i vary with soil depth and the equations do not accommodate soil profile characteristics. Herein lies one of the fundamental scientific weaknesses of the soil quality concept as evolved in various forms from Larson and Pierce (1991).

Soils serve numerous functions, but to simplify discussion, we only consider the soil function as a crop growth medium. Neglecting all other functions, the highest quality soil might be regarded as one that produces the highest crop yield. Decades of effort by hundreds of empirical and mechanistic modelers notwithstanding, no unique functional relationship can be established through scientific principles between crop yield and soil texture, structure, strength, organic matter, and other soil attributes. The large number of independent variables in Equation 1 precludes empirical establishment of functional relationships. Thus, the approach is open to arbitrary value-laden judgments of individuals or groups of individuals.

Evolving Concepts

Doran and Parkin (1994) described a performance-based soil quality index consisting of six elements:

$$SQ = f(SQEI, SQE2, SQE3, SQE4, SQE5, SQE6) \tag{3}$$

where:

SQE1 = food and fiber production
SQE2 = erosivity
SQE3 = groundwater quality
SQE4 = surface water quality
SQE5 = air quality
SQE6 = food quality.

They reasoned that one of the highest research priorities should be to establish guidelines and thresholds for soil quality indicators to enable identification of relationships between measured attributes and functions. This would permit valid comparisons across variations in climate, soils, land use, and management systems. They recognized that, while conceptually valid, Equation 3 is useless without quantitative functional relationships. They also emphasized the importance of soil quality comparisons that account for variations in soils, climate, etc.

More recently, Karlen et al. (2001) attempted to differentiate between "inherent" and "dynamic" soil quality. They linked "inherent" quality with characteristics determined by soil formation factors stating, "Soils with differences due to their forming factors have different absolute capabilities." They also state that dynamic soil quality reflects "Changes associated with current or past land use and anthropogenic management decisions." Assuming that a reliable quantitative soil quality index value can be determined, it is specific to the time when the indicators were assessed. Using "inherent" to specify the time before human manipulation is reasonable. Using "dynamic" to specify soil quality index after human manipulation is unnecessary and confuses the issue.

Differentiation between "inherent" and "dynamic" soil quality was apparently prompted by concern raised (Sojka and Upchurch, 1999) over comparing soil quality index values for different soils. Karlen et al. (2001) stated, "Soil quality index scores are always relative, not absolute. To be meaningful and useful, the comparisons must be logical (e.g., temporal changes or comparisons of practices on soils having the same inherent soil quality characteristics) and defendable." Thus, according to these authors, the only "logical" use of soil quality index scores is for comparisons with time or different management on the same soil. This conclusion is inconsistent with the very concept of " inherent" quality that they articulated and with other reports by soil quality proponents.

Claiming that the only "logical" use of soil quality index scores is for comparisons on the same soil is contradicted by Karlen et al. (2001) who defended Sinclair et al. (1996) for producing a map of inherent soil quality for crop production for mainland U.S. soils. They claim that the map accurately reflects soil resource potential for agricultural production in the absence of human intervention. That is a particularly moot point because there can be no agricultural production without human intervention. The truly important information is the soil potential to produce crops "with management."

A major disagreement among advocates and opponents of the soil quality concept is whether reliable quantitative soil quality index values are achievable, and if so, their comparison among different soils can identify relative qualities of the soils. Although the specific number may be meaningless, comparison among numbers is valid in certain contexts. If reliable soil quality index values are not possible (as we contend), evaluating temporal changes or comparing practices on the same soil can lead to seriously erroneous conclusions.

Application of the Soil Quality Concept

To illustrate difficulties in the application of the soil quality concept, we review two examples of how it has been applied. The first example is the set of published guidelines for soil quality index preparation and use. The second is the application of a soil quality index in a recent scientific journal article.

The guidelines. In 1994 the Soil Quality Institute published, "Guidelines for soil quality assessment in conservation planning," prescribing its approach for application of the soil quality concept. They emphasize "dynamic" soil quality as the change of soil properties with time. "Dynamic" in this sense differs from traditional soil science reference to dynamic processes (ones with measurable fluxes) that simultaneously occur in soil at any given time. The Institute's guidelines explicitly state, "The soil quality assessment procedures outlined in this guide should not be used to compare soil quality among different soil map units (soil types)."

The guide notes that assessments should employ indicators that represent physical, chemical, and biological properties of soils. It also states that indicators can be qualitative and / or quantitative, specifically acknowledging that qualitative assessments are subjective and are best done by the same person to minimize variability. The guide fails to point out that indicator variability across a field is often greater than changes occurring with time, particularly if observed qualitatively.

Since it is impractical to measure every soil property over space and time, the guidelines specify that minimum data sets and indicators must be established. Once indicators are selected, they are incorporated into a "soil health card." The guidelines include an example health card template. It rates health by smell, earthworm number, compaction, soil aggregation, drainage, and various other properties. Many of these indicators vary with soil depth, but depth is not considered in the health card template. Each indicator is ranked low, medium, or high. It is suggested that health cards should be established at the state or local level, using farmer-selected soil quality indicators and ranking descriptions. Some states have established such cards. All cards have a scoring system that usually includes either a range of poor to good or a numerical scale from 1 to 10 for each indicator. The guidelines specify that individual indicator scores are generally not combined or totaled, meaning that soils do not have a numerical soil quality value. In other words, no soil quality index value can or should be computed.

The positive aspects of the guidelines are that they emphasize the qualitative nature of assessment—that soils should not be compared, and that indicator scores should not be added to get a soil quality index value. This approach, which stimulates farmers' interest in their soil and motivates them to observe soil characteristics, is positive. Some indicators and ranking techniques, however, are questionable. More is not always better, particularly in the absence of expert interpretation or management recommendations, or for "other" soil functions. For example, soil organic matter has many positive effects on productivity but also has negative impacts. All scorecards raise rankings with increased soil organic matter. This could lead the uninformed to over apply manure, urban biosolids, or green waste, which could overload soil with salts, nutrients, trace metals, or other harmful constituents. Increases in soil organic matter can also increase soil porosity and improve aeration, but may lower waterholding capacity and promote preferential flow. Preferential flow risks loss of costly applications by increased transport of chemicals or pathogens to groundwater.

Historically, extensive soil survey information has been used to develop conservation plans. Hopefully, conservationists developing soil quality or soil health indices note the admonition in the soil quality guidelines, "Local soil health cards are do-it-yourself farmer tools and are not meant to be used as an official document in a conservation plan."

The journal paper. Andrews et al. (2002) is an example of the application of the soil quality concept in crop production research. This paper reported results from on-farm trials in California's Central Valley. Farmers who were willing to use a cover crop, compost, or manure amendments on alternate fields, for comparison to a conventional treatment that did not receive organic supplements, were selected for the study. As Andrews et al. (2002) explained, the farmers on all but one farm were unwilling to risk possible revenue loss from reducing synthetic fertilizer applications on the alternate fields receiving organic nitrogen (N). Synthetic and organic fertilizers were applied in the alternative treatment, which was reported as a "C supplement" rather than N fertilizer. Thus, fields receiving "C supplements" also had higher total N applied, creating two experimental variables (organic C and total N), confounding the effect of the two variables.

A quantitative relationship between indicator score and indicator level had to be established (i.e.; a score between 0 and 1 associated with the level of each soil indicator such as soil organic matter, bulk density, etc.). This relationship "was determined by consensus of the researchers involved and literature values quantifying the relationships between indicators and soil functions." There is a direct effect of electrical conductivity (EC), pH, and Zn on plant growth, whose functional relationships can be based on data. Neglected in the discussion, however, was that each relationship is crop-specific. For example, the EC function depends on each crop's particular salt sensitivity. Soil organic matter (SOM) and water stable aggregates have no direct effect on plant growth. The investigators chose a sigmoidal relationship with a zero indicator score for zero SOM or zero aggregates and a top score of 1 when the SOM was 40,000 kg ha^{-1} (35720 lb ac^{-1}) and aggregates were 100% stable.

The authors do not identify the specific soil function being indexed, but clearly the only function indexed was crop production. The relationship between indicator score and magnitude of the indicator should represent the functional relationship between the indicator amount and crop production, assuming all else is equal. Zero or very low yield, attributed to low soil organic matter or water stable aggregates, is unrealistic. In other words, these relationships were dependent upon the perceptions, values, knowledge, and/or lack of knowledge of those creating the scale. Thus, they are highly subjective and scores could be highly misleading.

The calculated soil quality index was not reported for the six farms using a combination of organic and commercial fertilizers. The soil quality index was reported for a farm with a history of applying only organic matter. Organic applications in 1996, 1997, and 1998 were 11.2 mg ha^{-1} (5 tn ac^{-1}) of poultry manure. Manure nitrogen content was not given, but assuming a typical range of 3% to 6%, 330 to 660 kg ha^{-1} (295 to 590 lb ac^{-1}) of nitrogen would have been applied. This range probably exceeds nitrogen removal by the crop and represents a potential for nitrate degradation of groundwater. Fly and odor problems from manure, or potential bio-contamination of surface or groundwater, were neither monitored nor considered.

A soil quality index was calculated by multiplying the individual indicator value by its weighting factor and adding the values for all indicators at that site. The highest weighting factors were for soil organic matter and electrical conductivity. Since all treatment electrical conductivities were low and nonlimiting, the soil quality index values among treatments depended entirely upon soil organic matter. Thus, the organic system received the highest soil quality index values—a quite predictable result. If one provides a high positive weighting factor for an applied input, then soil receiving that input will have higher soil quality index values. Potential failures or abuses of such a system are obvious.

On the other six farms, three had reduced soil organic matter from organic additions over three years, and presumably reduced soil quality index. The authors explained that on those farms soil organic matter was lost by tillage. This explanation emphasizes precisely the objection to indexing that we have pointed out—namely, management is the key to system function. Only results supporting the hypothesis that organic farming is necessary to sustain or enhance soil quality were highlighted in the *Agronomy Journal* article, when, in fact, soil organic matter actually increased on three of the conventionally managed farms over the three-year period. In their analysis of conventional versus organic systems, Andrews et al. (2002) ignored risks to groundwater or other possible negatives from high manure rates needed to produce high soil quality index scores, as well as application economics, logistics, and inadequacy of manure supply to provide nutrients to more than a small fraction of agriculture.

Limitations of the Soil Quality Concept

The ingenuity of farmers, the exigencies of specific circumstances, innovative new technology, and even the vast extent of existing management options cannot be anticipated or fully accounted for by an index. Many examples can be offered of soils that would produce poor soil quality index ratings, but

Figure 1
Alternate-furrow-irrigated cotton in California on an Imperial-Glenbar silty clay loam soil. The irrigated furrow (left) supplies water, which sweeps salt from the root area under the row of plants, depositing the salt upon evaporation in the nonirrigated inter-row area (right).
Photo by Herman Meister.

Figure 2

Positioning of banded N (N_{ba}), sidedressed N (N_{sd}), and broadcast N (N_{bc}), where furrow (A) was irrigated all season and furrow B remained dry. Equipotential isopleths and soil-water flow lines are conceptually shown for 0.76 m rows (adapted from Sojka et al., 1994). Banding on the dry side of the furrow greatly reduces loss of N to groundwater but does not impair yield.

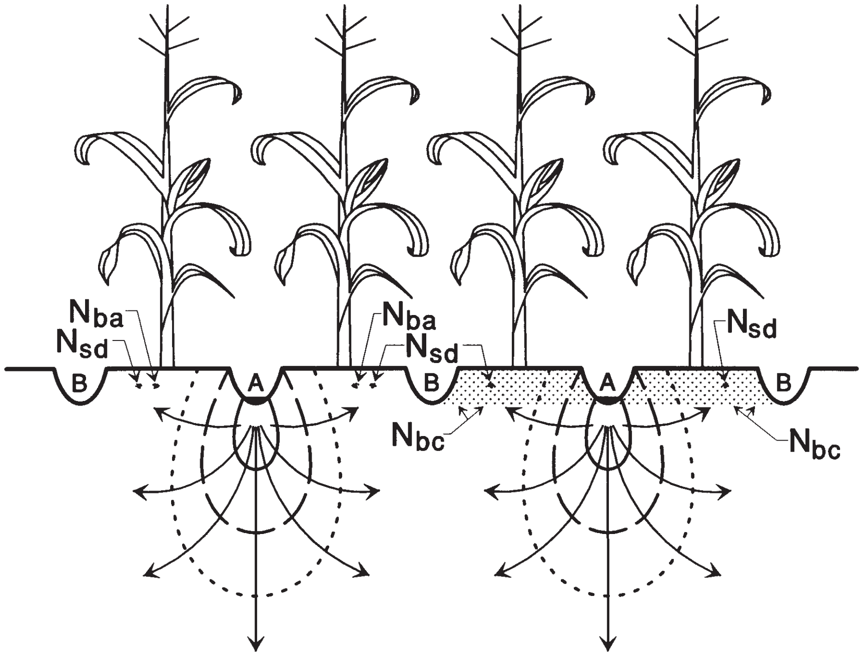

Figure 3

Cropping of corn and soybean on steep slopes in Mississippi using no-till and vegetative surface mulching. No-till improved infiltration, overcoming soil-depth-related water supply problems on the slopes, while also reducing erosion and runoff. The result was improved crop productivity of the soil and protection of surface water quality, by elimination of erosion and transport of soil and agrichemicals to surface waters. Photo by G.B. Triplett.

which, in practice, actually pose negligible soil-use limitation to astute managers, often with mitigating management that carries no additional cost.

Figure 1 shows irrigated cotton *(Gossypium hirsutum)* grown on a salt-affected California soil. Soil salinity limitation is overcome by soil and irrigation management. Only alternate furrows are irrigated, in order to "sweep" salts away from planted rows by capillarity. As water evaporates, salts are carried to the dry inter-row area (which is tilled in this field, and not shaped to carry water). Indexing of salt-affected soils based on undifferentiated soil samples may indicate high electrical conductivity or specific ion contents that impair quality for cropping. Indexing cannot anticipate soil properties in the root zone of a cleverly managed soil. Soil quality determined from broadcast sampling before cropping would indicate poor soil quality. But, without changing inputs or operational costs, alternate furrow irrigation prevents salt stress—a purely soil management result affecting crop productivity that cannot be predicted by soil quality indexing.

Figure 2 is a schematic adapted from Sojka et al. (1994). It shows planting, banding, and irrigation water placement for three management strategies affecting nitrogen leaching. Banding, instead of broadcast fertilizing, is a first step to reduce nitrogen leaching. Placing the band in the planted bed opposite the season-long irrigation flow moistens soil enough by upward capillarity to allow efficient root uptake of nutrients for optimal production. However, with this "dry-side banding" management strategy, soil water content near the band is never wet enough to enable downward nitrogen movement toward ground-water. No soil attribute changes among the standard broadcast fertilizer placement, wet-side band placement, or the dry-side banding. Operational costs and inputs are identical. But with identical soil quality, dry-side banding reduces the potential for groundwater contamination—a purely soil management result affecting environmental quality that cannot be predicted by soil quality indexing.

Figure 3 shows successful, environmentally friendly no-till corn *(Zea mays)* cropping on very steep slopes in Mississippi. Where soil erodibility and infiltration (and by default its inverse runoff) is heavily weighted by soil quality indexing (either for their relationship to cropping or for their relationship to environmental protection), this soil would receive a poor rating. Such a rating system might discourage any row cropping at all. How-ever, with no-till cropping and vegetative mulching, management allows sustainable and profitable production without harming the environment through erosion or contamination of surface waters with runoff. This is a management result affecting both crop production and environmental quality that cannot be predicted by indexing.

Summary of the Deficiencies of the Present Soil Quality Concept

The problems with the current soil quality paradigm are numerous, but we have tried to emphasize several of the important ones using examples from the soil quality literature. There is no standard to which soil quality indicators can be compared, but higher soil quality index numbers are interpreted as higher soil quality. Critical to establishing a soil quality index is the functional relationship between soil quality (Q) and soil quality indicators (q_i). These functional relationships cannot always be established empirically. This is particularly true for indicators with only indirect effects on plant growth. For example, the relationship between Q and q_i for soil organic matter and water stable aggregates used by Andrews et al. (2002) differs dramatically from what we would propose. The significant point is that there can be substantial scientific disagreement in selecting relationships or even whether a scientifically valid relationship exists. Potential subjectivity and opportunity for value-laden biases to skew analyses are obvious. Furthermore, it is not clear what weighting factors should be given to individual q_i values, or even if it is appropriate to sum the q_i indicator values. The situation is even more complex if one considers that soil simultaneously serves many diverse functions with a different relationship between Q and q_i for each one. Even soil quality advocates have recognized the substantial operational predicament that results when individual indicators show conflicting trends or favor opposing functions (Herdt and Steiner, 1995; Carter et al., 1997). Combining all of these functions into one soil quality index number is prohibitive. There is confusion and contradiction as to which soil quality index values can be compared (assuming a reliable soil quality index can be determined). Possibilities range from comparing all soils, to only comparing temporal or spatial variation, or treatment or management-induced changes on a single soil.

The soil quality paradigm does not address water quality issues. Indeed, some soil properties promoted as positive for soil quality can greatly increase the probability of surface and groundwater degradation. Karlen et al. (2001) illustrate a hierarchy of agricultural indices, representing soil, water, and air quality indices as separate and independent. We contend that they are highly interdependent. No consideration is given to crop specificity although crops differ in their response to many soil attributes. Thus, a soil of high quality for one crop may be low quality for another.

Health cards, if used within the limitations specified in the "Guidelines for soil quality assessment in conservation planning," might be useful inducements for some farmers to become more aware of their soil's status, although it is hard to believe that astute modern managers are not already performing more organized and targeted monitoring than those possible with soil quality health cards and kits. The guidelines specified that: 1) no combined score for the various indicators should be computed, 2) results should not be compared to target levels for soil properties, and 3) results should not be compared among different users, farms, or map units. Yet, soil quality research publications have repeatedly disregarded all of these conceptual limitations. We worry that health cards promote oversimplification of the complex, dynamic interactions occurring in soil. The cards do not provide the kind of specific technical data, analysis, or response calibrations, nor do they evaluate information at appropriate spatial or temporal scales, or in a user format that modern farmers routinely rely upon, to enable economic or logistical management decisions for crop production or environmental protection.

An Alternative

Having found fault with the existing soil quality approach, some would argue we have an obligation to recommend a better one. We feel that a better definition would be a starting point, and that application of a new edaphic concept should be management outcome-based rather than soil resource indexing-based.

Agriculture is an enterprise whose goal is to provide sustenance and profitability. Soil can be likened to a production endeavor where managers provide inputs to produce output of economic value. Prior to concern for environmental quality, enterprises maximized profits without consideration of environmental degradation. Today, managers must limit waste product discharges (point sources) and meet various other environmental, safety, and health needs. They also maintain their enterprise to continue efficient operation in the future. Analogously, farmers provide and manage inputs to produce crops. They, too, must not only produce crops, but also limit the chemicals and water discharged below the root zone or otherwise lost from the farm (nonpoint sources), to safeguard the environment, human health, and soil productivity.

The present soil quality definition, "The capacity of a specific kind of soil to function," specifies that soils serve functions. We propose emphasizing the "use" rather than "function" of soil. The distinction is subtle but very significant. The dictionary defines function as "assigned duty." In a sense, "function" implies a responsibility assigned to the soil. When one "uses" soil, responsibility is on the user, which distinctly shapes the concept in a management context. In Australia and New Zealand, despite a commitment to the concept, soil quality researchers have repeatedly noted real world constraints on its use, including the need for better implementation guidelines (Sparrow et al., 2000) and the need to move to a paradigm directly tied to highly specific designation of land use (Sparling and Schipper, 2002; Lilburne et al., 2002).

Water quality is defined as, "The chemical, physical, and biological properties of water, which affect its use." Whether it is high or low cannot be determined until use is specified. Salty water is high quality for marine fish, but low quality for fresh water fish. A comparable soil quality definition would be, "The chemical, physical, and biological properties of soil that affect its use." This definition requires that use be specified and that simultaneous uses and impacts be managed simultaneously. Since managers direct soil use, there is a clear tie-in to management. Management can alter water quality to match intended use. Likewise, farmers can manage soil to achieve intended outcomes.

We are not suggesting that a new definition lead to a numerical index and caution against it. However, a use-based definition would be in better harmony with the approach used for water and air quality, which have standards of limited parameters for intended use—not all-encompassing numerical "indices" or scoring systems.

Our proposed definition also eliminates the term "capacity," which is a quantitative term. While a soil quality index may quantify various capacity parameters, it is not possible to quantify "capacity to function." Capacity to function depends not only on the resource properties, but also (and perhaps most importantly) on management—particularly management of process demand or size in relation to capacity size. In the case of environmental filtering, which is one soil function, high application of nitrate or pesticides does not change soil filter capacity, but may exceed capacity by over-application. Thus, the definition does not lend itself well to protecting groundwater and can, in fact, harm water quality. For example, Andrews et al. (2002) reported that adding poultry manure raised the soil quality index. Adding more manure could have further raised the soil quality index they devised, but as noted earlier, would also have further imperiled water quality. Consequently, there is a severe disconnect between the existing approach and environmental protection, especially groundwater degradation.

In our proposed redefinition, specifying soil use to grow a crop is not sufficient unless the crop is specified. For example, a smectitic clay soil with high shrink-swell properties is poor for growing shallow-rooted vegetables such as lettuce *(Lactuca sativa)*, reasonably good for cotton or alfalfa *(Medicago sativa)*, and excellent for rice *(Oryza sativa)*. Within this framework, one should also consider whether the crop is rain-fed or irrigated. High infiltration rate and high water holding capacity are desirable for rain-fed agriculture, but less important for irrigated agriculture. High infiltration rate is undesirable for furrow irrigation because excessive water percolation prevents water from advancing across the field. Finally, critical environmental constraints must be quantified and monitored with all uses.

Good managers utilize all available technical information to target soil management for each crop. Management enabling high yield must also be astute enough to prevent environmental degradation and soil deterioration. Farmers are generally aware of the soil properties that affect productivity on their fields, but they are less aware, and sometimes unaware, of soil property and management implications for groundwater or atmospheric degradation. Since erosion and runoff are visible, farmers are more aware of these aspects of surface water quality, soil degradation, and resource conservation than in unseen changes in groundwater or atmospheric chemistry.

In the current world of farm production and environmental protection, farmers need to clearly understand and effectively manage the vulnerability of their soils and specific farm operation to water quality degradation. This implies they must have specific knowledge of the hazards or threats to the environment, such as water degradation by nitrate.

Nitrate moves with water and is subject to denitrification. Soils having textural or profile characteristics that inhibit water flow or create an environment conducive to denitrification, are less vulnerable than those having high infiltration rates, high profile water-transmission rates, and low denitrification potential. These characteristics can be estimated from soil series descriptions, giving farmers critically important insights for management to mitigate water degradation by nitrate on a specific soil.

From a total farm operation perspective, the vulnerability to water degradation by nitrate is also related to the crop and irrigation system in irrigated agriculture, and rainfall amount and intensity, in rain-fed agriculture. Irrigation systems that allow precise control of the amount and uniformity of irrigation have the lowest potential for water degradation. Nitrogen (N) requirement, N fixation capacity, etc., are factors that influence crop system vulnerability and cause groundwater degradation from nitrate. Significantly, both production and environmental needs must be systematically integrated to receive equal and simultaneous quantitative attention. This precise approach was implicit in the 1993 National Research Council Committee (NRCC) statement on soil and water quality.

The soil quality "movement" was triggered by a 1993 NRCC report on long-range soil and water conservation. It emphasized improving farming "management systems" by "developing and implementing cost-effective diagnostic and monitoring methods to refine the 'management' of soils, nutrients, pesticides, and irrigation water should be a high priority of U.S. Department of Agriculture (USDA) and the Environmental Protection Agency (EPA) research and technology transfer programs." The report also suggested that "two types of research should be high priorities for USDA and EPA research programs: 1) research directed at identifying the nature and magnitude of factors influencing producers' "management" of cropping and livestock production systems, and 2) research leading to the development and implementation of the technologies, cropping systems, and methods to manage farming systems that are profitable and protect soil and water quality."

Consistent with the approach of developing what might be termed a hazard index, the NRCC report stated "Soil and water quality programs should be targeted at problem farms that, because of their location, production practices, or management, have greater potential to cause soil degradation or water pollution." Singer and Ewing (2000) stated "In an agricultural context, soil quality may be 'managed' to maximize production without adverse environmental effect, while in a natural ecosystem, soil quality may be 'observed' as a baseline value or set of values against which future changes in the system may be compared" The major thesis of Sojka and Upchurch (1999) and Sojka et al. (2003) is that "quality soil management rather than soil quality management" should be our professional and scientific goal.

Summary and Conclusion

The many shortcomings of the soil quality concept have been repeatedly articulated (Bosch, 1991; Derbruck, 1981; Koepf, 1991; Linser, 1965; Price, 2000; Schönberger and Wiese, 1991; Singer and Ewing, 2000; Singer and Sojka, 2001; Sojka and Upchurch, 1999; and Sojka et al., 2003). Several of these are in-depth critiques with extensive literature references, including one co-written by Nobel Laureate and "father of the green revolution" Norman Borlaug (Sojka et al., 2003). Recently, Pedro Sanchez, 2002 World Food Prize recipient, and coauthors (Sanchez et al., 2003) criticized the soil quality paradigm as a misleading "fad" lacking in scientific rigor, fraught with societal value intrusion, and conceptually incompatible to air and water quality. They stated "The tropics are awash in such value-laden philosophies, which are intuitively pleasing to many stakeholders, becoming 'code phrases' that must be included in proposals to many donors if they are to have a chance of being funded."

This editorial allowed only brief consideration of a few points. We encourage members of the Soil and Water Conservation Society to read the above papers. We should note that in the international community, even among advocates of the soil quality concept, a far more cautious and informal approach has been taken than in the United States (Sparrow et al., 2000; Stenberg, 1999; Nortcliff, 2002), where emphasis has been on narrowly indexing to specific use, just as we have proposed, with a dominant concern focused on limiting contamination of soil with heavy metals and xenobiotic chemicals. This more limited "pollution prevention" perspective is far more compatible with existing air and water quality concepts than the current American thrust. Nortcliff (2002), in addressing the International Standardization Organization's interest in soil quality, specifically recognized the need to address several fundamental concerns about the soil quality paradigm articulated by Sojka and Upchurch (1999).

We strongly recommend moving away from current, highly subjective efforts to develop soil quality indexing, towards using available technical information to motivate and educate farmers on management practices that optimize the combined goals of high crop production, low environmental degradation, and a sustained soil resource. If soil science indexing had been the focus in the past, instead of management innovation, millions of today's sustainable, productive hectares might have been abandoned to farming because a soil quality index suggested vulnerability to erosion, acidification, leaching, poor drainage, salinity, structure loss etc.—problems overcome by modern management innovations. Indices cannot foresee new technology or the ingenious adaptability of farmers to improve land use management. The term "soil quality" will probably not "go away." If not, a far more rigorous technical definition and implementation is needed.

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