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EDITORIAL

Reservations Regarding the Soil Quality Concept[1]

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ABSTRACT

We consider the appropriateness of institutionalizing *soil quality* as a defined parameter in soil science. The soil management research of land grant universities and the Agricultural Research Service (ARS) and the mission and goals of state, federal, and private conservation agencies stand to be significantly affected. We feel that a non-advocative examination of this concept could provide a positive contribution. The definition of soil quality has proven elusive and value laden. There is concern by some that the concept has developed arbitrary policy overtones. Our reservations stem from concerns regarding premature acceptance and institutionalization of an incompletely formulated and largely untested paradigm, potential unintended negative outcomes, promotion of a narrowly defined environmental policy in a context normally associated with value-neutral science, and taxonomic and/or regional bias in establishing the paradigm. To date, soil quality assessments have drawn from a relatively narrow crop production and ecological perspective to positively or negatively weight soil quality assessment factors. Although the soil quality paradigm acknowledges *multi-defined* soil functions, it has yet to operationally recognize and integrate the *simultaneity* of diverse and often conflicting functions and soil property requirements. 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. Traditionally, it has been the soil science profession's role to perform the science to enable resource management policy and problem solving, not to establish relational-based value systems within the science. We suggest emphasizing quality soil management rather than soil quality management as a professional and scientific goal.

THE SOIL SCIENCE SOCIETY OF AMERICA (SSSA) has provided several written forums promoting the soil quality concept (Allan et al., 1995; Doran et al., 1994; Doran and Jones, 1996; Karlen et al., 1997). These and several non-SSSA publications have described a soil quality paradigm to assess the condition and sustainability of soil and to guide soil research and conservation policy. No comprehensive critical examination of the scientific basis of the concept or the paradigm shift's ramifications has been published.

There can be no argument with the high goals of improving our ability to assess soil condition and promote sustainability. However, many soil scientists fear that in the emerging soil quality paradigm, those high goals have led to advocating a value system as an end unto itself, supplanting otherwise value-neutral science and prematurely accepting interpretations and assertions of soil quality before the concept has been thoroughly and analytically challenged. Indexing of soil properties for specific outcomes is not new. In the past, however, the scope of the indices were limited and specific. Soil quality indexing, while perhaps originally focused on indexing and optimization of limited collections of specific attributes, has evolved to assessment of highly generalized, sometimes unspecific *overall* worth, value, or condition of soil. This approach risks certain pitfalls. As Lackey (1998a) noted, "quality" of managed natural systems is not an objective scientific attribute. Such quality definitions are contextual, subjective, value laden, outcome driven, and infinite in possibilities. While individuals (especially non-scientists) assessing soil quality may be familiar with the assessment parame-

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[1] In 1994 the Soil Science Society of America established ad hoc Committee S-581 to define and describe the emerging soil quality concept. Committee members solicited the SSSAJ Editor for an opportunity to present their views in a guest editorial for the express purpose of addressing what they acknowledged was a contentious and emotionally charged issue. Because of the solitary perspective presented by the committee in its editorial (SSSAJ 61:4-10), the SSSA Editor-in-Chief and SSSAJ Editor recognized a need for and solicited an alternative comment. This paper is that invited response, and is written in the spirit of scientific discourse called for in the 1997 editorial.

ters being measured, they often do not know the *value judgements* that were used or excluded in selecting or interpreting the parameters. Index scores are the only outcome delivered to most users, who often do not have the expertise to evaluate the validity of the indexing process relative to their own needs or values. Singer and Ewing (2000) stated:

> Useful evaluation of soil quality requires agreement about why soil quality is important, how it is defined, how it should be measured, and how to respond to measurements with management, restoration, or conservation practices. Because determining soil quality requires one or more value judgments and because we have much to learn about soil, these issues are not easily addressed.

In other words, assessing soil quality must balance a combination of value judgments, much like the ecological concept of multiple-use management. This implies that no unique *true* or *correct* soil quality determination can be arrived at strictly from scientific principles. Indeed, agreement on a definition this complex, with the diversity of values among special interests and affected stakeholders, is unlikely.

These formidable barriers notwithstanding, a key focus of soil quality essays and research has been development of soil quality assessment tools (Larson and Pierce, 1991, 1994; Pierce and Larson, 1993; Anonymous, 1996a; Arshad and Coen, 1992; Romig et al., 1995; Granatstein and Bezdicek, 1992; Gregorich et al., 1994; Warkentin, 1995; Liebig et al., 1996; Hortensius and Welling, 1996; Doran and Parkin, 1994; Halvorson et al., 1996; Turco et al., 1994; Harris et al., 1996; Sinclair et al., 1996). Most of these assessment tools stem from and are based on attempts to define parameters and functions linking crop performance with soil properties. Some include non-production empirical factors related to micro- and meso-faunal and -floral ecology and function. Some are based to varying degrees on non-empirical *perceptions*. As with many modeling efforts, the most comprehensive and science-based indices may be too complex to be practical at reasonable cost or timeliness, while some are too simplistic to be scientifically defensible. A major concern, however, is that none objectively and simultaneously consider both the potential positive and negative outcomes of all the indicators employed for all three major considerations of soil management—production, sustainability, and environmental impact (Sojka and Upchurch, 1999). Typically, only positive outcomes are recognized for certain touchstone parameters such as soil organic matter (SOM) contents and earthworm counts, and only negative outcomes for such parameters as salinity or compaction. These judgements are made largely on their relationship to crop productivity and microbial vigor. Each assessment index is not rigorously weighted separately and objectively for the simultaneous and concomitant effects on production, sustainability, and environmental impact in the context of each specific farming (or other land management) system's constraints. What has emerged is a soil quality paradigm that conforms to a narrow vision of an ideal, and some would even argue *politically correct* soil.

In the last decade, there has been a gradual evolution of the soil quality concept. Karlen et al. (1990) attempted to identify the specific soil properties within identical soil mapping units that were responsible for yield variation in an otherwise uniformly treated corn (*Zea mays*) crop. In broadening the goals to the definition of soil quality, the limited linkage to explaining crop performance ostensibly became less central to the concept. Larson and Pierce (1991) stated "In the past, Q [soil quality] has been defined in terms of productivity. However, Q is not limited to productivity and such a limited view of soil quality does not serve us well in addressing current problems." Thus, they suggested delinking the concept of soil quality from productivity with the rationale that "...productivity is determined by the efficiency in the use and management of resource inputs", whereas, they postulated that soil quality is related to a set of intrinsic soil properties. Further, they suggested establishing a set of standards for evaluating soil. Pierce and Larson (1993) suggested that the intuitive concept of soil quality be formalized and they identified efforts then under way (Larson and Pierce, 1992; USDA, 1992). They described (but did not specifically attempt) the use of mathematical functions involving minimum data sets and pedotransfer functions, applying statistical concepts from quality control theory to evaluation of soil quality.

Science strives to eliminate any doubt as to the facts determined. Interpretation of facts, setting goals, and establishing environmental indices are matters of policy or belief systems, with inherent capacity for ambiguity, confusion, disagreement, and even hostility (Lackey, 1998a,b; Zeide, 1998a,b; Callicott, 1998). Referring to communication dilemmas associated with the soil quality lexicon, Karlen et al. (1997) stated: "...what would seem to be a relatively simple choice of words, can result in very different messages when delivered to our clients." 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. *Value* can mean financial, spiritual, emotional, cultural, or strategic worth; or it can mean the quantified numerical measure of a statistically analyzable parameter. Such inherent ambiguities, while a common aspect of policy debate, have always been regarded as unacceptable in development of scientific vocabularies and tenets. They create the potential of unintended outcomes when use of formulaic interpretations are taken out of the hands of scientists and left to the discretion of end users who could range from farmers to agricultural scientists, legislators to environmentalists, bankers to realtors, or lawyers to government bureaucrats. Many concept users will not have the soil science training or acumen needed to understand the subtleties of the concept, its ambiguities, or its potential pitfalls if improperly interpreted. Worse still, some may have objectives or motivations that are counter to science and may exploit the conceptual conflicts and ambiguities.

Traditional soil assessments for crop production have always striven for clarity of interpretation and applicability. Karlen et al. (1997) proposed tying soil quality evaluation to the relational non-absolute environmental philosophy of Aldo Leopold. The logic, ethical consistency, and scientific credibility of Leopold's "Land Ethic" were critically examined by Zeide (1998a), who raised significant questions as to the term's technical validity and appropriateness as a cornerstone for soil science—a discipline in which Leopold, a forester and game manager, had little actual expertise. Perhaps more importantly, contrary to the premise of Karlen et al. (1997), we do not believe that most soil scientists fail to assign adequate intrinsic value to soil, nor do we believe that they feel any less of a "special relationship with the earth" than "naturalists". Rather, it is because of the soil science community's general high regard for the soil resource that assigning "low quality" ratings to broad categories of soil is disturbing to many soil scientists. Moreover, this aspect, as noted by Karlen et al. (1997), underscores the evolution of the term soil quality away from objective and empirical quantification of "soil attributes" as suggested by Larson and Pierce (1991) and Pierce and Larson (1993), toward a subjective (cultural, etc.) designation of *value per se*. This evolution is troubling because it injects an emotional aspect to the soil quality debate by pitting the vast possible range of conflicting personal, cultural, institutional, and economic value systems against one another. While this evolution is surely not the intent of scientists researching soil quality, the concept, unfortunately, attracts many adherents who cling specifically to such subjective interpretations. Therefore, we have reservations about institutionalizing soil quality. We are apprehensive of burdening soil science with ambiguous deviations from established, clear, objective, scientific principles of edaphology aimed at problem solving. We address these concerns: definitions, conceptual contradictions and dysfunctions, regional or taxonomic bias, advocacy and plausible ramifications, unintended outcomes, and premature institutionalization.

Definitions

The terms *air quality* and *water quality* are ingrained in the scientific community, general public, and environmental regulatory bureaucracy. *Soil quality* might seem a logical ecosystem concept extension. Indeed, the European soil quality literature has emphasized establishing limits on measurable pollution (Howard, 1993; Bouma, 1997; Hortensius and Welling, 1996). However, with minor exceptions, *quality* in the context of air or water, implies analysis of specific pollutants below set concentration thresholds. With limited exceptions, the standard is the pure state. Air and water quality assessments do not attempt to specify a complex integration of static and functionally dynamic chemical, physical, biological and ecological factors defining an ideal state for an infinite number of environmental or management scenarios. We do not attempt to define air quality in terms of species diversity of airborne pollens, molds, bacteria, viruses, seeds, flying insects, birds etc. or their metabolic processes representative of a *healthy* or *natural* air mass. Nor do we attempt to stipulate air quality for every conceivable use of air, such as microwave transmission, jet traffic, combustion, tire inflation etc. Rather, air and water quality are defined almost entirely in terms of restricting negative impacts of a finite number of biological, physical, and chemical pollutants in a limited number of specific environmental scenarios.

Sims et al. (1997) proposed a nonpolluted soil criterion for soil quality that they referred to as the "clean" state of soil. However, for other than a discrete list of xenobiotic substances, *pure soil* cannot be defined. Soil accumulates both naturally occurring and anthropogenic toxic substances. Indeed, naturally occurring toxins and heavy metals are common at detectable levels in soils and parent materials.

One of many uses and roles of soil is its function as a filter. Soils can sequester large amounts of pollutants before threatening biological organisms or the healthiness of food (Cook and Hendershot, 1996; Oliver, 1997). High soil quality as a filter media requires sink capacity for toxins, i.e., the ability to be *unclean*. Alternately, making a soil unclean by adding toxic herbicides and pesticides improves soil quality for crop production by suppressing target organisms while raising *pollutant* concentrations.

The conundrum of clean vs. unclean soil underscores the incompatibility of soil quality with the water and air quality paradigm. There is, after all, no all-encompassing *pedologic cycle* comparable to the hydrologic cycle or the O_2–CO_2 cycle, that regularly distills and replenishes soil in its entirety to a unique, pristine state. Thus, ultimately, there is little if any parallel between air or water quality and soil quality.

An early definition of soil quality, was offered by Larson and Pierce (1991), "Soil quality (Q) can thus be defined as the state of existence of soil relative to a standard, or in terms of a degree of excellence." SSSA ad hoc committee S-581 said of soil quality:

> By encompassing productivity, environmental quality, and health as major functions of soil, this definition requires that values be placed on specific soil functions as they relate to the overall sustainability of alternate land-use decisions. Although unstated, the definition presumes that soil quality can be expressed by a unique set of characteristics for every kind of soil. It recognizes the diversity among soils, and that a soil that has excellent quality for one function or product can have very poor quality for another (Allan et al., 1995).

With institutionalization through the establishment of the Natural Resources Conservation Service Soil Quality Institute, a new and difficult dimension was added to the definition of soil quality. Mausbach and Tugel (1995) defined soil quality and soil condition separately, as follows.

> *Soil Quality*—reflects 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.
>
> *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.

The imprecise meaning of the phrase "natural or managed ecosystem boundaries" coupled with the last sentence defining "condition" seems to contradict earlier stated rationales of using soil quality assessment per se to determine soil status at a point in time along its relative scale of potential function. Separation of the concepts sets up the potential use of soil quality indices to rate intrinsic value of regions or taxonomies.

Thus, soil quality must be defined in terms of distinct management and environmental considerations specific to one soil, under explicit circumstances for a given use. The considerations include social, economic, biological, and other value judgments. Aside from obvious potential for disagreement on these management determinants, as many as 20 000 soil series occur in the USA. Multiplying by the number of crop or non-crop uses, crop species and cultivars, cropping systems, management, climate, and resource availability factors raises the needed total of specific soil quality indexes to an astronomic number. Furthermore, soil performs several functions *simultaneously*, not several functions separately. Only a difficult mixture of scientific and nonscientific judgements could decide the balance of functions needed to *score* soil quality or properly weight conflicting simultaneous functions. Multiplicity of definition and simultaneity of function is exacerbated by spatial variability, another incompletely understood factor, whose quantification and interpretation are not completely developed or agreed upon and which are made more enigmatic in the dynamic complexity of soil quality (Parkin, 1993; Stenberg, 1998).

The soil quality literature repeatedly emphasizes the need for indexing to encompass the diversity of soil function (Larson and Pierce, 1991; Pierce and Larson, 1993; Allen et al., 1995; Soil Survey Staff, 1996). Yet, the indices formulated to date are narrow in scope, mainly emphasizing soil factors related to plant growth and crop productivity (Sinclair et al., 1996). Soil micro- and meso-biological vigor are also heavily emphasized. Realistically, this is probably appropriate, despite contradicting the stated vision, 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. It would greatly help focus the debate if soil quality paradigm proponents would concede that little soil property management (globally) has, or will ever have, as a primary goal any other focus. Engineering uses of soil rarely consider soil biological properties outside of filtration uses of soil, and the rank and file engineering community is largely unconcerned with and all but oblivious to the soil quality polemic (an exception is an activity of the International Standards Organization—addressed below).

Even in the productivity context, we feel quality (singular) is undefinable for complex systems as diverse as soils. *Anything that is infinitely defined is, ultimately, undefined and undefinable*. This principle of logic applies to soil quality, which is only definable in an infinitely branching tree of scenarios. Consider the following.

1. The definition must change for the same land and same use depending on weather—e.g., flood, drought, wind, heat, cold, etc.
2. The definition must change depending on the skill of each farmer. Some farmers consistently over or under apply inputs, improperly match tillage tools or tractors with production needs, ill time field operations etc. A manager's decision may be an error on one soil but less damaging or even beneficial on another.
3. The definition must change for every crop and cropping system, for every pest, etc., since the systematics for each scenario alter the definition.

Gersmehl and Brown's work (1990) underscored the problem of relational definitions. They tried to relate large integrated yield data bases of specific crops to each other. They segregated the data by soil mapping units to allow interchangeable predictions of crop performance for a given soil classification. In Union County, IA, soybean [*Glycine max* (L.) Merr.] yield easily predicted corn yield across taxonomies ($R^2 > 0.9$). However, in Dillon County, SC, soybean yields were unrelated to cotton (*Gossypium hirsutum* L.) yields. One can assume that *average soil quality* varied randomly among data pairs for either county. The predictive capability of crop response was affected more by the unique needs of specific crops than by the range of soil properties encountered within each soil taxa. It is hard to conceive of score cards, conceptual assessment frameworks, test kits, aroma, and quality pamphlets better assessing soil quality if another well-suited rotation crop cannot provide adequate prediction.

Multiplicity of definition is rationalized as providing flexibility to accommodate the manifold uses of soil demanded by production, sustainability, environmental, economic, and social imperatives. However, this rationale is inconsistent with activities that have focused on development of kits, scorecards, and pamphlets to diagnose and rate soil quality from sparse collections of measurements (Minimum Data Sets) without providing adequate interpretive guidance, leaving the impression that, in fact, one size fits all. Activities of the International Standards Organization (ISO) Technical Committee 190, which has begun to codify soil quality standards and soil quality determination methodology standards, indicate a different potential problem (Hortensius and Welling, 1996). The extent of the ISO 190 actions and their expressed intent does not seem to recognize a committee's practical limits, the enormity of such an undertaking, and the actual frontiers of science's understanding of soil. Committee 190 stated "Therefore, ISO/TC 190 established various subcommittees to cover *all aspects of soil quality* [emphasis added].”

The attempts to define soil quality to date are at odds with the evolution of the modern U.S. comprehensive Soil Taxonomy (Soil Survey Staff, 1975). Its fundamental advancement was the movement away from interpretation of how classifiers thought a soil *ought to be* to simply describing what was found. To emphasize the non-judgmentalism of the new Soil Taxonomy, it’s authors stated:

> This was a revolutionary concept. The soil scientist did not need to depend wholly on inferences from the underlying rocks, the climate, or other environmental factors, considered singly or collectively; rather, he could go directly to the soil itself and see the integrated expression of all these in its morphology.

Soil quality evaluation employs a variety of empirical and subjective measurements and perceptions from test kits, score cards, aroma etc. to make a subjective *estimate* of how well soil attributes and dynamics match those presumed to be the *potential* for that soil. This must not be dismissed as analogous to a variety of other land use classification schemes (Singer and Ewing, 2000). The evaluation is not based on a highly specific determination of suitability for a single intended use—e.g., as in the case of a nutrient analysis for soybean vs rice (*Oryza sativa* L.). Unlike traditional soil tests, the assessments rely greatly on highly dynamic properties that may not still exist at the previously measured rate when the soil must actually perform that function (e.g., soil respiration rate). Furthermore, few if any soil quality assessment indicators have reliably quantified calibrations capable of predicting actual outcomes for the full range of possible soil functions, particularly crop performance. These problems were recognized by Wagenet and Hutson (1997). They were optimistic of producing management decision aids for soil quality improvement through dynamic process modeling. This may point toward promising research of an academic interest for some soil scientists. However, the difficulty, time, and cost of providing sufficient assessment inputs, needed for meaningful site-specific soil quality management recommendations, does not appear achievable for practical, affordable, and timely use by farmers. Furthermore, optimizing crop (and forest, range, or habitat) production remains a concomitant need to the goal of soil quality improvement. While correlations and calibrations exist for input prescriptions for crop production based on soil test results, virtually no such precise predictive management recommendations exist for prescribed improvements in soil quality. By contrast with traditional edaphic management for crop production, a farmer usually has a clear decision path to follow, guided by quantifiable cost and income parameters, lacking with soil quality considerations in the absence of regulatory incentives or disincentives. The inability to prescribe specific management measures to achieve desired soil quality index outcomes was recently underscored by a 20-yr management comparison conducted by Waldon et al. (1998) who concluded “Efforts to change whole soil ecosystems to achieve an arbitrary standard may not be practical or economically possible.”

Conceptual Contradictions and Dysfunctions

Despite suggestions for rigorous approaches to soil attribute quantification (Larson and Pierce, 1991; Pierce and Larson, 1993), soil quality assessment has gravitated, instead, to use of subjective perceptions, and unquantifiable, even unresearched “measurements”—e.g., aroma (Romig et al., 1995; Anonymous, 1996b). Several important soil quality index components project outcomes based on a limited conceptual base, principally associated with Mollisols or close taxons such as Alfisols. This bias has led to maxims that, while environmentally popular, do not adequately recognize negative consequences of some aspects of the paradigm. Examples follow.

Certainly, SOM provides many benefits; however, it can also have negative environmental and crop production impacts. These negative impacts are rarely considered or significantly weighted in soil quality assessments. Consideration of negatives related to SOM content has not appeared in any soil quality promotional materials (Anonymous, 1996a,b,c,d, 1997b, 1998a,b,c).

Increasing SOM content increases the application requirements of many soil-incorporated pesticides (Stevenson, 1972; Ross and Lembi, 1985; Anonymous, 1997a; Gaston et al., 1997). As SOM increases from about the 1 to 3% range to the 3 to 5% range, soil incorporated pesticide application rates needed for efficacy commonly rise 20 to 100%. Soil sample clay fractions with 11% SOM, had 68% of the atrazine sorption affinity in the organic fraction (Laird et al., 1992; 1994; Barriuso et al., 1994). Clancy (1986) and Hallberg (1987) noted that increased use of synthetic insecticides, fungicides and herbicides increases the probability of people being exposed to toxic hazards. Economics of crop production, environmental quality, and human exposure to pesticides are all negatively affected by the increased pesticide loading and human exposure necessitated by higher SOM.

Negative impacts of increased pesticide loading are compounded by SOM’s role in aggregation and macropore formation, bypass flow, and rapid transmittal of dissolved or soluble organically complexed surface-applied contaminants to groundwater (Barriuso et al., 1992; Hassett and Anderson, 1982; Muszkat et al., 1993; Vinten et al., 1983; Flury, 1996; Ghodrati and Jury, 1992; Grochulska and Kladivko, 1994; Shuford et al., 1977, Simpson and Cunnigham, 1982; Vervoorst et al., 1999). Increased DDT (dichlorodiphenyltrichloroethane) and PCBs (polychlorinated biphenyls) solubility was attributed to complexing with soluble SOM (Chiou et al., 1987). Complexing with soil humic fractions accelerated atrazine transport through soil (Graber et al., 1995; Hayes, 1970; Senesi, 1992; Sposito et al., 1996). Mudhun et al. (1986) found similar complexing and enhanced transport for six herbicides. Complexing with dissolved SOM promoted rapid transport of napropamide through soil (Nelson et al., 1998).

High SOM and manure were linked to greater P solubility (Robinson and Sharpley, 1995; Meek et al., 1974, 1979, 1982; Sharpley and Smith, 1995). This facilitates loss to groundwater, as well as surface waters fed by runoff or springs (Beauchemin et al., 1998; Heckrath et al., 1995; Stamm et al., 1998).

Organic matter darkens soils. Summer soil temperature is higher in darker soils. This benefits crop emergence and early growth in temperate regions. Higher midseason soil temperature, however, is detrimental to production and quality of many field and vegetable crops, especially in hot climates.

Few, if any, studies have explored the potential negative role of SOM in environmental or on-farm soil management. For example, does higher SOM content increase weed seed viability or seed bank size? Both are plausible hypotheses, given the effects of SOM level on efficacy of soil incorporated herbicides. Colonization and performance of vesicular arbuscular mycorrhiza have been increased by addition of manure or green manure on low organic matter soils, but suppressed by additions to soils with moderate to high SOM contents (Ellis et al., 1992; Baltruschat and Dehne, 1988; Harinikumar and Bagyaraj, 1989; Brechelt, 1987, 1989; Lambert and Weidensaul, 1991). What negative weighting should be assigned to SOM for its role in THM (trihalomethane) contamination of chlorinated drinking water sources (Milnear and Amy, 1996)? Higher SOM has numerous benefits for plant growth, but responsible science requires that these be assessed against known environmental and production negatives.

The soil quality paradigm also affords great positive weight to earthworms. They too can greatly benefit crop production. However, they also produce negative effects, acknowledged by a few researchers, but ignored by most. Earthworm burrows increase bypass flow and rapid movement of surface-applied contaminants to groundwater (Cohen, 1997; Edwards et al., 1989, 1992, 1993; Ehlers, 1975; Hall et al., 1989, 1991; Isensee et al., 1990; Tyler and Thomas, 1977; Shipitalo et al., 1994; Steenhuis et al., 1990; Trojan and Linden, 1992; Zachmann et al., 1987; Zachmann and Linden, 1989). In rainfed agriculture, earthworms help reduce runoff and erosion. In furrow irrigation, however, they cause a serious water management problem that irrigators call *backing up*—a sudden infiltration increase as earthworms surface to escape flooding. The result is severe nonuniformity of water application, affecting leaching, fertility, and crop water stress (Kemper et al., 1987; Trout et al., 1987; Trout and Johnson, 1989).

When earthworms digest organic-matter-rich soil the solubility of plant nutrients increases. While this can benefit crops, it can also contribute to runoff water quality degradation (Sharpley and Syers, 1976, 1977; Broussard et al., 1996). Earthworms also stimulate and accelerate soil nitrogen mineralization (Parkin and Berry, 1994). Earthworm activity increased extractable nitrate N in field and soil core studies (Blair et al., 1996; Willems et al., 1996). Their role in stimulating and accelerating mineralization of various N forms to nitrate, coupled with their role in macropore creation, is an obvious dichotomy in the ecological and soil quality value of earthworms related to groundwater nitrate management. Earthworm activity contributes to the need to use nitrification inhibitors for N conservation and groundwater protection (more use and human exposure to agrichemicals—and increased costs). Ironically, earthworm populations are higher on more fertile, higher SOM content soils. Thus, the negative environmental impacts related to nutrient solubilization are greatest where existing indices credit them most for their contribution to soil quality.

Earthworms are vectors of soil-borne plant diseases (Edwards and Lofty, 1977; Hampson and Coombes, 1989; Hoffman and Purdy, 1964; Khambata and Bhat, 1957; Thornton, 1970; Toyota and Kimura, 1994; Marialigati, 1979; Hutchinson and Kamel, 1956). This vectoring is direct at short range, via ingestion in and through the gut followed by supra- and/or sub-terranean transport, and indirect over long range, via birds feeding upon and dropping earthworms and earthworm fragments in flight.

Earthworm effects on soil properties are not always positive, varying with species and geographic adaptation. Bulk density increase and reduced porosity have resulted from earthworms (Alegre et al., 1996; Gilot, 1994; Rose and Wood, 1980). Shrader and Zhang (1997) measured lower stability of earthworm casts compared with non-digested aggregates. Earthworms reduced water retention and sorptivity, which impaired soil–plant water relations, increased crop water stress and reduced rice yield by 43% (Pashanasi et al., 1996). Earthworms provide numerous benefits for plant growth, but responsible science requires that these be assessed against known environmental and production negatives.

Compaction, is generally regarded as a negative attribute. However, again, it must be evaluated in terms of specific processes and contexts. Traffic lane soil compaction reduces wheel slippage and increases traction, lowering horsepower and weight requirements for tillage and other field operations, conserving fuel and reducing atmospheric CO_2 emission. Seed germination and emergence generally improve with soil firming until compaction is excessive. Compaction can also reduce bypass flow by restricting macropores (Starett et al., 1996).

Appropriately, the soil quality concept has focused increased interest on integrating soil microbiological assessments into soil evaluation and better understanding the functioning and makeup of soil microbial communities (Kennedy and Smith, 1995; Yakovchenko et al., 1996; Turco et al., 1994). Kennedy and Papendick (1995) stated "size and composition of soil microbial populations could be useful indicators of soil quality *once they are fully understood* [emphasis added]." The extensive focus of soil quality indices on microbial ecology and dynamics, is disturbing given that microbiologists acknowledge that critical roles and functions of soil microorganisms are yet to be fully explained. We are not suggesting that because a concept is difficult, its pursuit should be abandoned, but rather it is imprudent and premature to promote and institutionalize an index based on inadequately understood components.

Because the specific functions of most soil microorganisms are unknown or poorly understood, it seems unreasonable to interpret increased microbial biomass and activity entirely as a positive indicator. Clearly, if specific microorganisms are pathogenic or otherwise deleterious to the crop, their contribution to community biomass and function must be weighed negatively. Microorganisms can even exacerbate otherwise largely physically mediated phenomena. Lindqvist and Enfield (1992) found an 8-fold increase in DDT movement through sand when bacteria were present. In wet or flooded soils, particularly upon incorporation of fresh organic matter, or coupled with high temperature, surface sealing, or compaction, microorganisms compete fiercely with roots of higher plants for remaining available oxygen and accelerate the onset of soil hypoxia or anoxia. As redox potentials shift, facultative and obligate anaerobes can produce toxic metabolic byproducts that further impair crop performance or survivability.

Important microbially mediated soil quality indicators are highly spatially variable (Parkin, 1993). Soil respiration varies greatly in short time periods. Influencing factors include soil disturbance, season, substrate introduction, forage mowing, temperature and soil water (and aeration) fluctuation, radiation shifts (solar/UV), fumigation, agrichemical application, certain xenobiotics, and heavy metals (Bremer et al., 1998; Grahammer et al., 1991; Lloyd and Taylor, 1994; Fitter et al., 1994; Garcia and Rice, 1994). It is unclear which of these highly complex and transient states should be the benchmark condition for soil quality respiration assessment. Respiration status changes diametrically on rotation between soybean and rice, or before and after tillage, and with weather or a preceding crop's residue type and amount (Alvarez et al., 1995a,b; Reicosky et al., 1993). Such perturbations have always defied simple extrapolation of respiration to a general assessment of soil status and will not likely soon be better calibrated.

A major rationale for soil quality assessment and management is to ensure soil sustainability and ecological balance. Since SOM concentration is used as a prime indicator of soil quality and sustainability, high soil respiration bears an element of self-contradiction as an index component. Global environmental research has sought for decades to sequester atmospheric CO_2. Also, overly valuing SOM encourages greater exploitation of soils having high potential for SOM oxidation and CO_2 release to the atmosphere.

Arid zone agriculturalists and irrigators recognize the double *Catch 22* of an SOM-dominated perspective. Many low SOM irrigated soils that are moderately saline are routinely managed for high productivity (Sojka, 1996, 1998; Bucks et al., 1990). Certain low salinity, high SOM soils such as Natrustolls and other soils with natric horizons (formerly called Solonetzic soils) are nearly incapable of supporting higher plant life. The first institutional use of a soil quality index devalued most U.S. arid-zone soils (Sinclair et al., 1996). Yet, on average, arid zone irrigated agriculture produces over twice the yield and three times the crop value per acre of rainfed agriculture (Kendall and Pimentel, 1994; Bucks et al., 1990). The key is water management. Aggregate stability, porosity, hydraulic conductivity, and aeration of low SOM irrigated soils are negatively affected by distilled water but are improved if irrigation balances divalent cation delivery (adding calcium salts with irrigation water) and leaching (Rhoades, 1972, 1998). In fact, high yields can be achieved with only mineral salts and water and no soil (hydroponically). Salinity alone is an unreliable productivity index without knowing the crop to be grown, the nature of the salinity (exchangeable sodium percentage—ESP, boron content, etc.) and the nature (sodium adsorption ratio—SAR and electrical conductivity—EC), amount, timing and evaporation path of irrigation water (positional salt deposition on irrigated beds), and the leaching fraction. These management factors can govern the ability of salt-threatened soil to function more than intrinsic soil properties themselves (Rhoades, 1972, 1998).

Regional and Taxonomic Bias

The soil quality paradigm firmly links quality to increases in SOM content, aggregation, porosity, earthworm populations and microbial biomass and activity (Anonymous, 1996a; Arshad and Coen, 1992; Romig et al., 1995; Granatstein and Bezdicek, 1992; Gregorich et al., 1994; Warkentin, 1995; Liebig et al., 1996; Hortensius and Welling, 1996; Karlen et al., 1997; Kennedy and Papendick, 1995; Doran and Parkin, 1994; Halvorson et al., 1996; Turco et al., 1994; Harris et al., 1996; Sinclair et al., 1996). As these references and their cited research suggest, the tenets of the soil quality concept evolved from a predominately *Mollisol-centric* and temperate climate and cropping system outlook. While certainly unintended, negative political, economic, and conservation consequences could result for physiographic areas not dominated by Mollisols or close taxons, such as Alfisols. Although many soil quality researchers stress specificity of soil quality evaluation, there is concern that this subtlety will be lost on untrained practitioners and policy makers using an index. No single soil paradigm or index is intended, or regarded by most soil quality researchers as appropriate, or feasible nationally. Yet, the soil quality literature has not been forthcoming in identifying the needed host of specific indices or specific regional criteria. Criteria published to date, as well as promotional literature, are strikingly similar, clearly adhering to a Mollisol-centric ideal. Even if suitable individual indices emerge for the multitude of needs, we wonder with great concern, how non-scientists will know which indices are appropriate to which needs or what institutional framework could assure their appropriate designation and use. The fact is, soil quality definition has been institutionalized and applied nationally (Mausbach and Tugel, 1995; Sinclair et al., 1996).

To date soil quality assessment has generally focused on soil attributes most commonly associated with Mollisols (Anonymous, 1996a, b, c, d, e, f, g, h; 1998a, b, c). If readers are not convinced of a soil quality paradigm taxonomic bias from the collection of soil attributes described in these assessment documents and pamphlets, we refer them to Fig. 1 and 2. These figures,

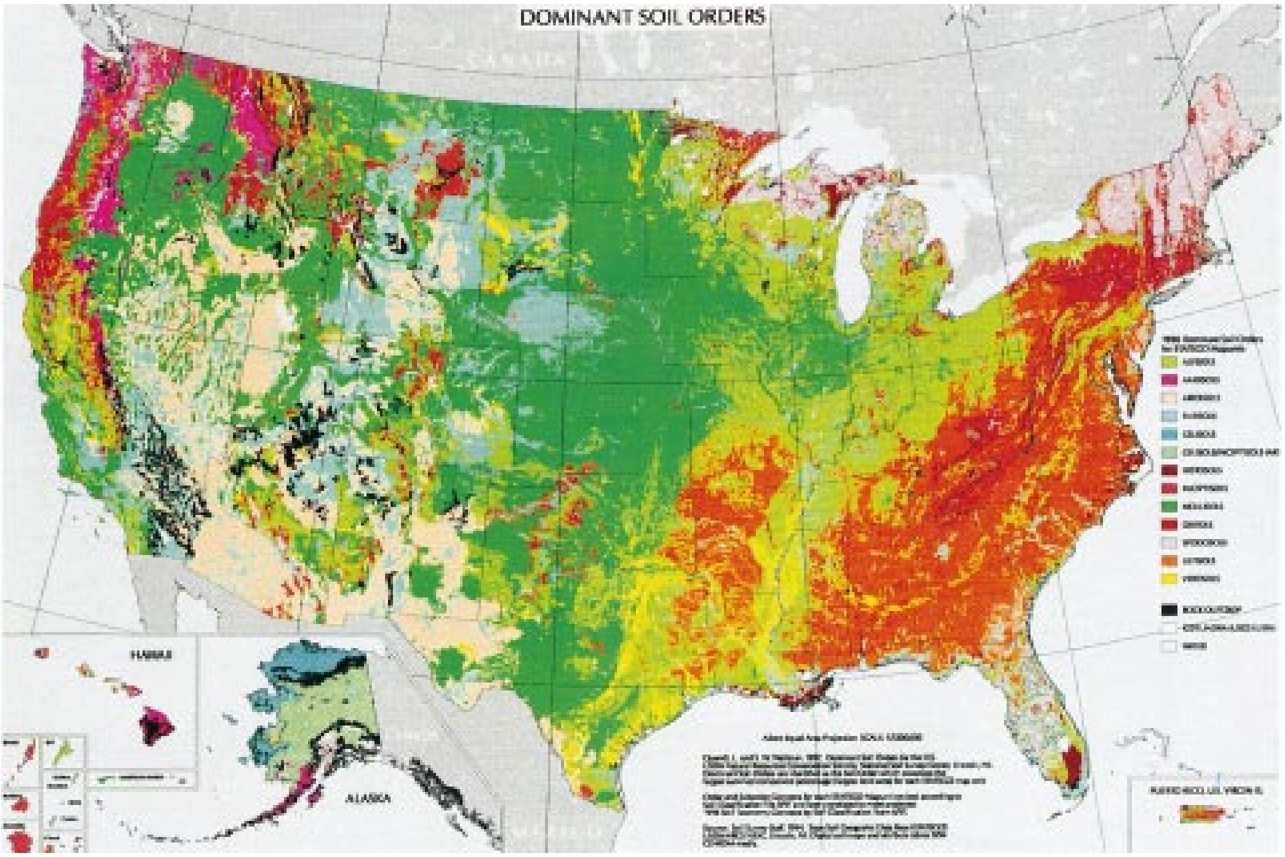


Fig. 1. The dominant soil orders of the USA, adapted from Quandt and Waltman (1997).

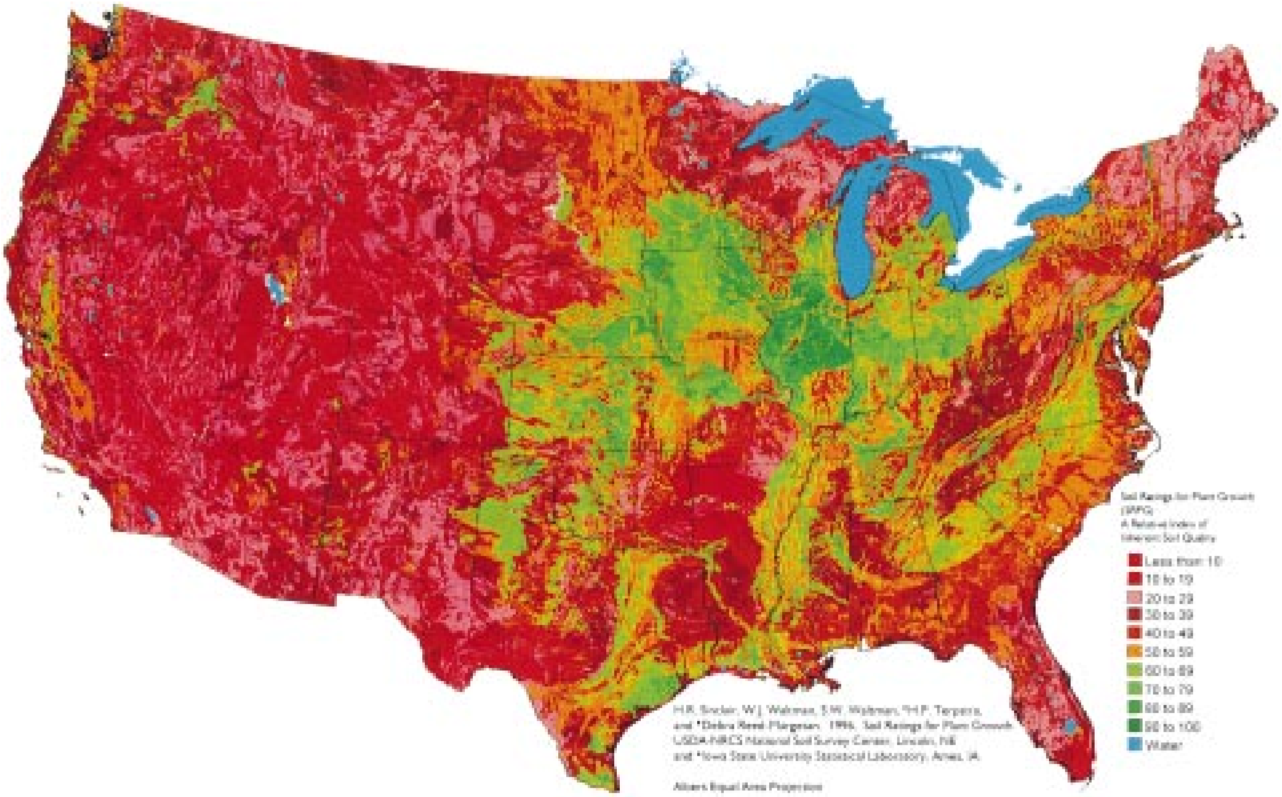


Fig. 2. A relative index of inherent soil quality for the USA, adapted from Sinclair et al. (1996).

present the dominant soil orders of the USA (Fig. 1) and the result of the Natural Resource Conservation Service's use of soil property data, crop performance and evaluator perceptions to model and map (Fig. 2) "a relative index of inherent soil quality" for the USA (Sinclair et al., 1996). The correspondence between locales with high soil quality rating and Mollisol- or Alfisol-dominated taxonomies is inescapably obvious. Conversely, the lowest soil quality ratings strongly correspond to the remaining soil orders. There are only isolated areas where Mollisols and Alfisols receive low soil quality ratings, largely confined to areas of low precipitation.

If the paradigm's basis is not taxonomic, then perhaps, because the soil quality concept arose largely from Midwestern research, one might contemplate that the paradigm is based on an analysis of regional agricultural productivity. Midwestern farmers and scientists take great pride in their region's corn production. However, since 1980, county-wide average corn yields of Iowa, Nebraska, and Illinois have been erratic and 20 to 50% less than Washington state's steadily increasing yields (Fig. 3).

Readers might note that the Midwest has had several poor growing seasons since 1980 and that Washington corn is entirely irrigated. Management strategies and inputs reflect different production constraints, such as Midwestern fertilizer use reduction to reduce groundwater contamination. Disease and insects are less a factor for corn production in the Columbia Basin than in the Midwest. Government programs, fertilizer taxes and production incentives apply differently to the areas. Basically, yields are affected by many factors unrelated to soil quality. And that, of course, is our point. It is hard to reconcile a Mollisol-centric paradigm for soil quality when the productivity of Mollisols, for the crop perhaps best suited to its edaphic nature, is affected more by nonsoil factors than soil factors. The irony is deepened, given the disproportionate contribution of Iowa and Illinois to Gulf Hypoxia (Burkart and James, 1998).

Mollisols develop, in great part, as a response to temperature and soil water. The cold wet winter months of temperate climates promote accumulation of SOM. The cold winter (Mesic, Frigid, Boric) and wet (Udic) soil conditions also restrict temperate Mollisols to a growing season of only about 6 mo. Contrast a cold Mollisol to the hot Aridisols, Entisols, and Inceptisols of places like the California Imperial and Coachella Valleys or the Nile Valley of Egypt. A Mollisol-centric soil quality paradigm offers a poor conceptual framework for explaining high-yield production of two or even three high-value crops per year on hyperthermic and often salt-affected arid-zone soils. Meek et al. (1982) showed that Holtville sc (Typic Torrifluvents) in Brawley, CA, retained only a mean of 0.6% increase in SOM over the unamended 1.0% OM control, five years after a 3-yr accumulated application of 360 to 540 Mg/ha manure.

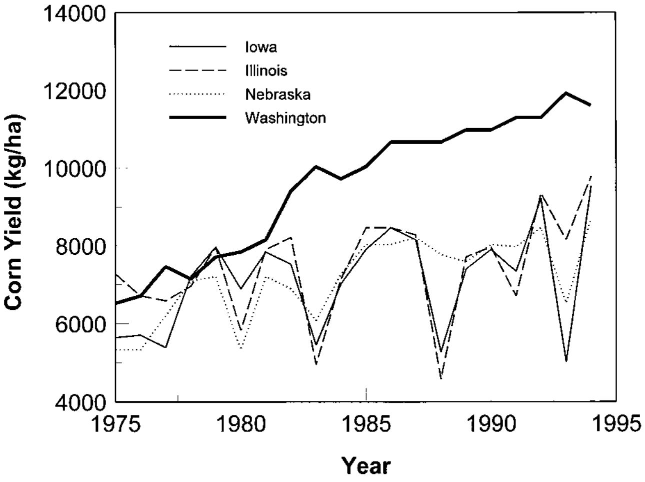


Fig. 3. Statewide annual average corn yield. Data are from the USDA-National Agricultural Statistics Service public web site.

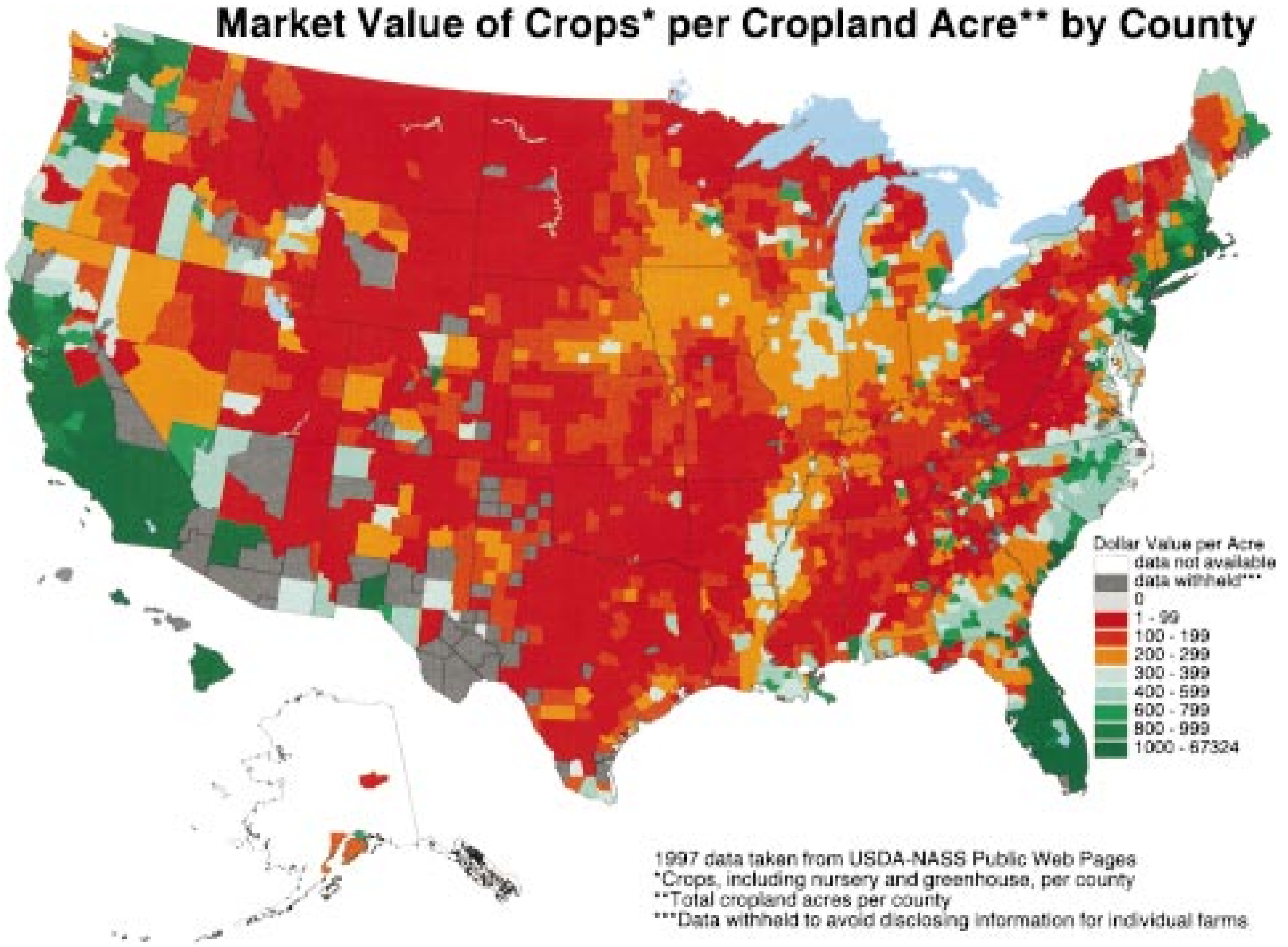
The unreliability of soil quality for predicting one of the most important corollaries of soil and crop performance is evident in Fig. 2 and 4. There is a very poor correspondence between high soil quality rating (Fig. 2) and market value of crops per cropland acre (Fig. 4). Conversely, most of the highest market values per cropland acre correspond to some of the lowest rated soil quality regions. We should emphasize that the soil quality map uses a linear color scale; the market value of crops per cropland acre uses a scale of ascending incremental values for the higher value categories. Thus, the failure of the soil quality index to predict high market value is worse than immediately obvious from color distribution per se.

Advocacy vs. Science

Scientists, their professional societies, journals, and public infrastructure have a vested interest and responsibility in keeping science balanced, objective, challenging, and even skeptical. Certainly, the motivation of scientists doing soil quality research is the advancement of soil science. Nonetheless, the validity of any scientific concept must ultimately survive the assessment of science at large. While we do not embrace the soil quality concept, we welcome its consideration in the literature as we would any concept. However, we have serious concerns that the soil quality paradigm has been institutionalized before core concepts have been thoroughly and objectively evaluated by the soil science community.

We note that the often-cited SSSA ad hoc committee (Allan et al., 1995) and National Research Council (1993) statements on soil quality presented no dissenting arguments or alternative viewpoints. This unfortunate lack of balance seriously undermines the credibility of those statements, particularly given the acknowledged dissension surrounding this nascent paradigm in the soil science community (Karlen et al., 1997). Institutional policy is sometimes forced to ignore credible disagreement, but science should not.

We are concerned that the zeal to popularize and elevate the concept has compromised scientific accuracy in soil quality promotional literature. In defining soil organic matter, one "Soil Quality Information Sheet" (Anonymous, 1996b) states "soil organic matter is that fraction of the soil composed of anything that once



Market Value of Crops* per Cropland Acre** by County

1997 data taken from USDA-NASS Public Web Pages
*Crops, including nursery and greenhouse, per county
**Total cropland acres per county
***Data withheld to avoid disclosing information for individual farms

Fig. 4. Total crop dollar value per county divided by the acres planted in each U.S. county in 1997. Data are from the USDA-National Agricultural Statistics Service public web site. [2.47 acre = 1.0 ha].

lived." Presumably the document did not intend to include bones, shells, coral, or water, which all once lived, but none of which are included in analysis of SOM or soil organic carbon.

The same document states, "Well-decomposed organic matter...has a pleasant, earthy smell." Romig et al. (1995) and Kennedy and Papendick (1995) implied that there is merit in the folk wisdom suggesting one can detect poor soil quality by the "off" or "sour chemical smell." There has been limited research into the aromatic compounds that emanate from soil (Stahl and Parkin, 1996). However, the existing body of research falls far short of validating serious consideration of aroma as a quantifiable evaluator of soil status or determiner of soil management. Research identifying compounds or concentration levels generating soil aroma are sparse, with insufficient correlation with soil properties and human olfactory pleasure or discomfort to warrant promoting aroma as a soil status indicator or management decision aid. Lastly, we offer some quotes from Soil Quality-Agronomy Technical Note No. 4 (Anonymous, 1997b), without comment, for our soil scientist colleagues to ponder: "In a healthy soil, nutrients become available when the plants need them." "Compaction... restricts the diffusion and flow of nutrients in the soil." "... weed residue may not decompose and recycle plant nutrients for the subsequent crops."

Advocacy of high environmental goals is understandable and even laudable; however, taking an advocacy approach to soil quality has created confrontation rather than scientific consensus. There are several reasons for this. One is simply because, for many, the concept is not regarded as proven, yet it is already being institutionalized. At a technical level, in the soil quality paradigm, the structure of the index is determined by the value assumptions that make up the index. That is, *quality* implies value assumptions—ones that are not universal and that are being arbitrarily assigned by only one school of thought within a scientific discipline having diverse and eclectic perspectives. Soil quality assessment, in other words, is a distinct philosophical advocacy which represents itself as objective scientific analysis. Advocacy may have its place in public resource policy formulation, but not in the science drawn upon as a basis for decisions.

Those unconcerned about mixing policy with science might still ponder what benefit a soil quality infrastructure provides. Is it perceived that soil science cannot otherwise identify the ecological role of soil in the environment? Is it that soil science cannot otherwise identify the presence and impact of pollution in soil? Is it that soil science cannot otherwise identify or address resource conservation or sustainability? Is soil quality meant to become a classification or taxonomy adjunct? We fail to see what new knowledge a soil quality index gives or what problems soil quality indices identify that have not already been identified via existing edaphology and management concepts. Many scientists question how the high investment in what they view as a redundant technology and infrastructure benefits research and solution of specific soils-related problems better than traditionally focused and targeted management research. Lastly, what specific problems of farmers, the environment, or agribusiness are/were only solvable by a soil quality paradigm?

Plausible Ramifications and Unintended Outcomes

SSSA president Lee Sommers (1998) itemized factors that have led a large portion of SSSA membership to consider seeking a new identity, separate from agronomy and crop science. A prominently cited factor was desire for a stronger hard science identity—on a par with physics, chemistry, or astronomy. Others have commented in detail about this issue (Simonson, 1991; Gardner, 1991; Greenland, 1991; White, 1993; Basher, 1997). We are concerned that a soil assessment paradigm that promotes kits, scorecards, perception surveys, and soil smelling to guide global soil management and ecosystem research and policy, risks diminishing the stature of soil science in the scheme of science at large.

Soil science has expended great effort to develop credible measures of soil properties and crop response to evaluate fertilizers and soil amendments. The lack of specificity of soil quality definition could encourage promotion of *wonder products* and questionable practices touting claims of improved soil quality. Exploiters need only point to the definition discrepancies in the literature, making debunking of product or practice claims more difficult.

Once a paradigm is established that associates superior quality with a narrow soil taxonomic concept, it will almost certainly have negative policy effects on locations dominated by “lesser” soil orders. A hint of taxonomically based policy bias emerged in a 1995 editorial entitled “Soil Quality: Goals for National Policy;” it stated:

> A soil quality policy should focus attention on our highest quality lands; that is, on those lands where we have the most to lose from soil degradation or where we have the most to gain from better soil (Cox, 1995).

We cannot help wondering how non-scientist politicians would interpret such a statement. Will a congressionally or bureaucratically mandated national Mollisol-centric soil quality paradigm recognize the two or three crop-per-year advantage of irrigated Southwestern hyperthermic Aridisols, Entisols, and Inceptisols? Or what of their two-fold yield advantage, or three-fold crop value advantage? What impact will their interpretation have on regional research and conservation funding? There could be big winners and losers based on taxonomically biased soil quality assessments. Figure 2 could be the first step toward implementation of taxonomically biased policy.

Clearly, a significant thrust of the soil quality movement is directed at bringing soil management into the environmental regulatory framework, both in the USA and internationally. Beck et al. (1995) reviewed Dutch and Canadian regulatory approaches and allowable limits for various organic contaminants. Singer and Ewing (2000) emphasized the strong environmental motivation of the soil quality movement, stating: “Perhaps more importantly, biological or ecological significance should hold greater weight than statistical differences among management systems.” Haberern (1992) stated “...losses of species at the far end of the chain, large, warm-blooded animals, for example, are likely to be less important to the world’s ecosystem than losses of those at the start of the living chain, those found in the living soil.” He goes on to state that his proposed soil quality index should be used to “...target more focused agricultural research... [and] aid agricultural scientists in determining research goals.’’ In listing what soil quality policy should achieve, Cox, (1995) suggested the first goal should be to ‘‘Establish soil-air-water quality parity.’’ Some may take this as a sign that soil science has finally *arrived*. But what are the implications? Will the environmental objectives of the soil quality movement have priority over production and profit? Will there be mandatory soil testing for designated pollutants? Will earthworms, soil microbes, or even soil-borne pests come under scrutiny of the endangered species act (Hågvar, 1998)?

It was further suggested that soil conservation should shift focus from soil loss, as the primary benchmark of mission accomplishment, to emphasis on the quality of retained soil:

> Soil management, that is, manipulation of the soil to achieve certain properties, infiltration, porosity, nutrient holding capacity, for example, should become an explicit objective of farm and ranch conservation plans rather than an indirect effect of erosion control Cox, (1995).

An interesting priority shift that is, perhaps, appropriate for deep resilient Midwestern soils. But what of the fragile, yet more highly productive soils of other regions, that measure epipedons in centimeters not meters? Erosion aside, who will do and pay for the monitoring? Who will judge compliance? How and at what spatial scale will compliance be assessed? What will be the consequences of degrading soil quality, and who will determine or assign blame? More important conceptually, how will highly kaolinitic soils ever attain adequate “nutrient holding capacity” if soils dominated by 2:1 clays are the conceptual basis of regulation?

Readers who feel they could stand to gain from *good* taxonomy through potential research and conservation funding increases, might ponder other potential consequences of the regulatory approach to management. If a soil is initially judged to have low quality, its management might undergo less regulatory scrutiny for decline in soil quality than a high quality soil that failed to maintain an arbitrary standard.

These editorial quotes were likely meant as an endorsement of sustainability. However, if so, we ask again—what is the basis for a Mollisol-centric soil quality paradigm? The Ultisols of the southeastern USA have been continuously farmed for 350 to 400 yr. Few U.S. Mollisols have been farmed longer than 150 yr—most barely 100 yr. Internationally, the ancient breadbaskets of civilization—Egypt, the Middle East, and China—have been farmed thousands of years; these are areas dominated by non-Mollisol soils.

The National Research Council (1993) discussed regulatory enforcement of soil quality policy. "The Secretary of the U.S. Department of Agriculture (USDA), the Administrator of the Environmental Protection Agency (EPA), and the U.S. Congress should undertake a coordinated effort to identify regions or watersheds that should be highest priority for federal, state, and local programs to improve soil and water quality." And "The development and implementation of approved integrated farming system plans should be the basis for delivery of education and technical assistance, should be the condition under which producers become eligible for financial assistance, and should be the basis for determining whether producers are complying with soil and water quality programs."

However, the NRC explicitly noted that freedom from oversight of these policies and programs might not be as simple as farmer non-participation, stating, "...policies are needed that target problem areas and problem farms, regardless of participation in federal commodity support programs." And, "Nonvoluntary approaches may be needed in problem areas where soil and water quality degradation is severe and where there are problem farms unacceptably slow in implementing improved farming systems." And, "The legal responsibilities of landowners and land users to manage land in ways that do not degrade soil and water quality should be clarified in state and federal laws." Such policies could make soil quality definition part of rural America's bitter property rights debate.

Conclusions

Soil science has struggled for over 200 yr to dispel the image of a second-class technology derived from folk wisdom and superstition. We are concerned that the ascendence of soil science to encompass crystallography, advanced physical and organic chemistry, biochemistry, numerical modeling, hydrology, artificial intelligence-based decision aids, remote sensing, global positioning, and geographical information systems, and more, is severely diminished by photos in our journals of farmers smelling a handful of soil, implying that this is the technical legacy of 200 yr.

We caution against the premature institutionalizing of a concept for which there remains significant questions and criticisms. Soil science cannot afford to deviate from the scientific method by assuming understanding that leads to policy implementation before completing objective research.

We are concerned that a single, affordable, workable, soil quality index is unattainable and that having individual indices for all soils and circumstances is unachievably complex technically, and would be unthinkably confusing upon lay implementation. This is not to say that a task should be avoided because it is difficult, but rather that the more complex a concept, the greater the danger of popularizing or prematurely institutionalizing it.

There is undoubtedly merit in seeking to manage soil well, in terms of production potential, sustainability, and environmental impact. However, none of these goals require a reinvention of soil science, or replacement of the value-neutral reductionist scientific basis of edaphology with an undefinable value-laden *holism*. We should be wary of a paradigm that is more committed to producing a passing score from a simplified battery of kit assays, than identifying (let alone solving) specific critical problems.

It is our experience that adept soil scientists or field practitioners of soil science have no difficulty identifying when a soil is in trouble. What they usually find preciously scarce are focused insightful management solutions to what, all too often, are lamentably easily recognizable problems that have degraded soil productivity. It is a fundamental concept of agriculture that management per se can have more impact on a soil's ability to function than intrinsic soil properties per se. We feel that far more environmental and agricultural benefit will come from developing quality soil management capability than institutionalizing soil quality management. Assessing and improving the quality of soil managers would likely have a far more immediate and profound affect on productivity, sustainability, and environmental impacts of soil management than decades of research on soil quality per se.

Our responsibility as scientists is not to attempt to establish the value system parameters that are acceptable for soil science. Our debate on this issue strongly parallels the acrimonious debates raging in all facets of ecosystem management. Soil, after all, is yet another identifiable multiple-use ecosystem. In agriculture, this also means a human-made ecosystem, since to manage in order to achieve any kind of *natural* soil ecosystem *health* would require reforestation and resodding of every hectare of America's farmland. In fact, this rationale cannot even be defended from a non-anthropogenic perspective, since, as Robert Lackey (1998) asked, "What is the natural state of Mount St. Helens?" Putting an emphasis on soil *quality* as opposed to our traditional science-based role of determining value-neutral *parameters* undermines our credibility as scientists with activity better left to metaphysicians and politicians. Even if we could agree on a universal value system to rate and assess soil quality, it is a mistake to elevate soil quality to an over-arching good unto itself.

As altruistic as we care to be in attempting to elevate soil quality as a priority above outcome, we will only fail with that approach. Soil use will always have as a first priority the accomplishment of the goal or desired outcome of that use, be it building highways, water purification, or growing a crop. The overwhelming emphasis of soil science and the primary rationalization of a soil quality concept must be conceded to be the improvement of plant growth using environmentally responsible technologies. Attempting to rationalize the weaknesses of a soil quality paradigm by saying quality will be tailored to all conceivable soil uses, belies both the entirety of the published body of soil quality research and the dominant focus of the soil science profession. We reiterate that soil performs a multitude of functions *simultaneously*.

If there is to be institutionalized soil quality assessment, it must employ soil- and utilization-specific indices and models that simultaneously account for all functions, properly weighting all inputs for all positive and all negative impacts of all productivity, sustainability, environmental, economic, social, strategic, and cultural components of the assessment. Physical, chemical, and biological index components should have zero reliance on subjective perceptions. Because of the potential impacts of this paradigm shift, program, policy, and regulatory status of institutionalized soil quality assessment seems premature before it has been comprehensively developed and exhaustively tested under impartial and balanced scientific peer review.

Better, we feel, that understanding, rather than rating the soil resource, be the primary goal of soil science. And understanding it cannot be justified to society except in targeting our effort to understand toward solution of recognized problems and better management of soil for all uses, in spite of the system constraints faced by individual land managers. We are troubled that rating soil and debating rating indices can be perceived as legitimate research in a time of severely limited funding, when working to solve well-known problems affecting the soil resource and maximizing its productivity are inadequately supported.

Within the life spans of our younger soil scientists, global agricultural production must rise more than 2% per year to meet rising population needs (Waggoner, 1994). This assumes we preserve most of our natural lands and provide our needs mainly from existing farmland. By one estimate, more food must be grown by man in the first generation of the new millennium than was grown in the preceding 10 000 yr of farming (Paarlberg, 1994). The threat of all forms of soil degradation (impaired soil quality?) to meeting world production needs is non-existent on 77% of managed world soils (Crosson, 1997). Weighting Crosson's area estimates by impairment level, suggests that 95% of global soil productivity remains intact. He concluded that the challenge in most urgent need of focused attention is continued development of new technology to raise soil productivity and yields while minimizing negative environmental impacts.

We, as soil scientists, can already identify the major problems facing soil management. We know where erosion is. We know where compaction is. We understand the logic of minimizing dependence on chemicals while maximizing the environmental benefit of their use through efficiency gains. More often, we don't know the answers to the problems, or when we do, how to enable their adoption. Preoccupation with diagnostics, definitions and trying to quantify something as illusive as soil quality does nothing to solve problems that are already clearly evident. 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-yr warning.

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