QUALITY SOIL MANAGEMENT OR SOIL QUALITY MANAGEMENT: PERFORMANCE VERSUS SEMANTICS

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In the past 200 years, soil science has used reductionist research to develop agricultural technologies that have unlocked the hidden potential of earth's natural systems to feed, clothe, and provide raw materials to the human population of over six billion. The soil quality paradigm seeks to change that scientific approach, the nomenclature of soil science, and institutional priorities for soil management and research. The definition of soil quality is elusive and value-laden. Concerns exist for the paradigm's policy overtones, regional and taxonomic biases, failure to reconcile conceptual contradictions, as well as its ambiguous definitions that are confounded by countless circumstance-specific, function-dependent scenarios. The paradigm does not recognize or offer practical means to manage conflicting, and often contradictory soil management requirements for the multiple functions of

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soil that occur simultaneously. Implementation of the concept has delivered low index ratings for many of the most economically productive and least subsidized US soils and agricultural sectors, and high ratings for soils and regions with some of the lowest economic return and greatest subsidization. The paradigm's focus on arbitrarily selected function assessment has diverted research and management resources from efforts aimed directly at developing improved management capable of solving existing identified and prioritized problems. We attempt to articulate the dangers of shifting soil science 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. We submit that over-arching, philosophically driven indexing of soil status, as opposed to focused, specific soil status and property characterization, carries risks to the scientific assessment process, and to the scientist's role as a data interpreter and science mediator. Value intrusion in umbrella-style indices erodes the individual manager's access to objective data to make decisions. We suggest emphasizing quality soil management rather than soil quality management as a professional and scientific goal.

I. INTRODUCTION

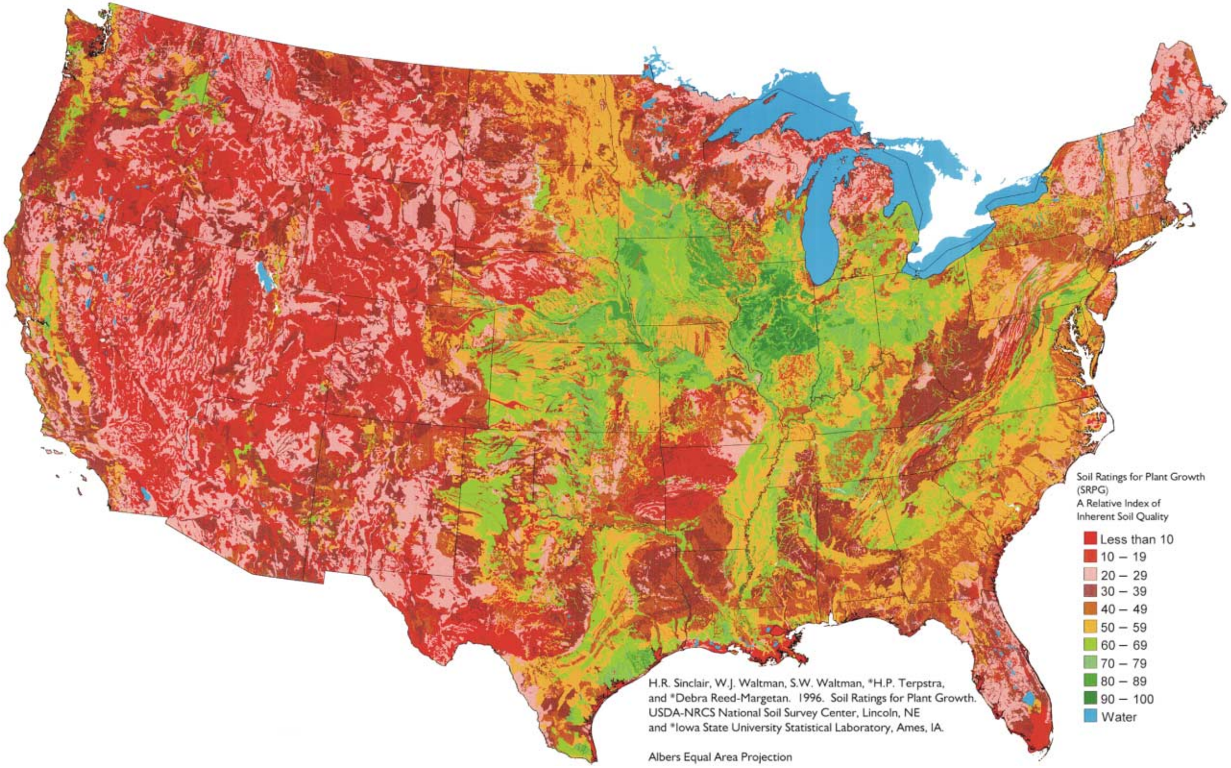
A good place to start this discussion is to share some background and reasons why this chapter was written. While we address many technical points, much of this chapter is philosophical. Scientists occasionally need to pause, reflect, and speculate about the direction they are taking and the underlying philosophy of their endeavors. Soil physicist John W. Gardner once said "The society which scorns excellence in plumbing, because plumbing is a humble activity and tolerates shoddiness in philosophy, because it is an exalted activity, will have neither good plumbing nor good philosophy. Neither its pipes nor its theories will hold water." We were invited to write this chapter and an earlier editorial (Sojka and Upchurch, 1999) as counterpoints to publications promoting the soil quality concept (Karlen *et al*., 1997, 2001). These documents arose because several editors overseeing Soil Science Society of America (SSSA) publications and past or current SSSA presidents recognized that the philosophy of soil science was in need of the same kind of critical examination that we are accustomed to focusing on our technical work (the plumbing). The issue examined in all four works is the soil quality paradigm.

The term soil quality has been in occasional and "casual" use for decades, going back at least to the 1970s (Alexander, 1971; Warkentin and Fletcher, 1977). The term and concept has gained popularity with members of the soil science community, especially among soil biologists and microbiologists

(Visser and Parkinson, 1992). Over the last decade, numerous papers (Allan *et al*., 1995; Doran *et al*., 1994; Doran and Jones, 1996; Karlen *et al*., 1997, 2001) have summarized technical studies and concepts underlying the soil quality perspective. We value these data and technical findings. Accompanying the reductionist technical output has been holistic analysis, philosophical synthesis, and institutionalization of interpretation aimed at restructuring public soil resource management policy and infrastructure (Allan *et al*., 1995; Cox, 1995; Mausbach and Tugel, 1995; National Research Council, 1993). The impact of these influences can be seen (Fig. 1) in the first institutional application of the soil quality concept (Sinclair *et al*., 1996). The index demonstrated a bias toward Mollisol and Alfisol soil properties and their regional farming conditions and cropping system choices. This can be seen from the correspondence of soil quality ratings in Fig. 1 with the distribution of soil orders (Fig. 2). These aspects, more than the technical findings, have shaped the emerging paradigm and largely define the philosophical crevasse that we and many other soil scientists find ourselves on the other side of and reluctant to cross.

The stewards of the SSSA and its publications, and the editor of this monograph, looked outside the community of soil quality proponents for a critical analysis. They and we regard the critical examination of theories and views as normal, appropriate and essential to the scientific method. It is, after all, exactly this approach that led the proponents of the soil quality paradigm to take critical aim at prevailing reductionist application of soil science principles. There is a deep literature of historical scientific controversies (Mendelsohn, 1987; Narasimhan, 2001; McMullin, 1987) and it is universally agreed that controversy is normal in a discipline that examines ideas, particularly given the structure of science which is based on the presentation and challenging of hypotheses. Nowotny (1975) stated “controversies are an integral part of the collective production of knowledge; disagreement on concepts, methods, interpretations and applications are the very lifeblood of science and one of the most productive factors in scientific development.”

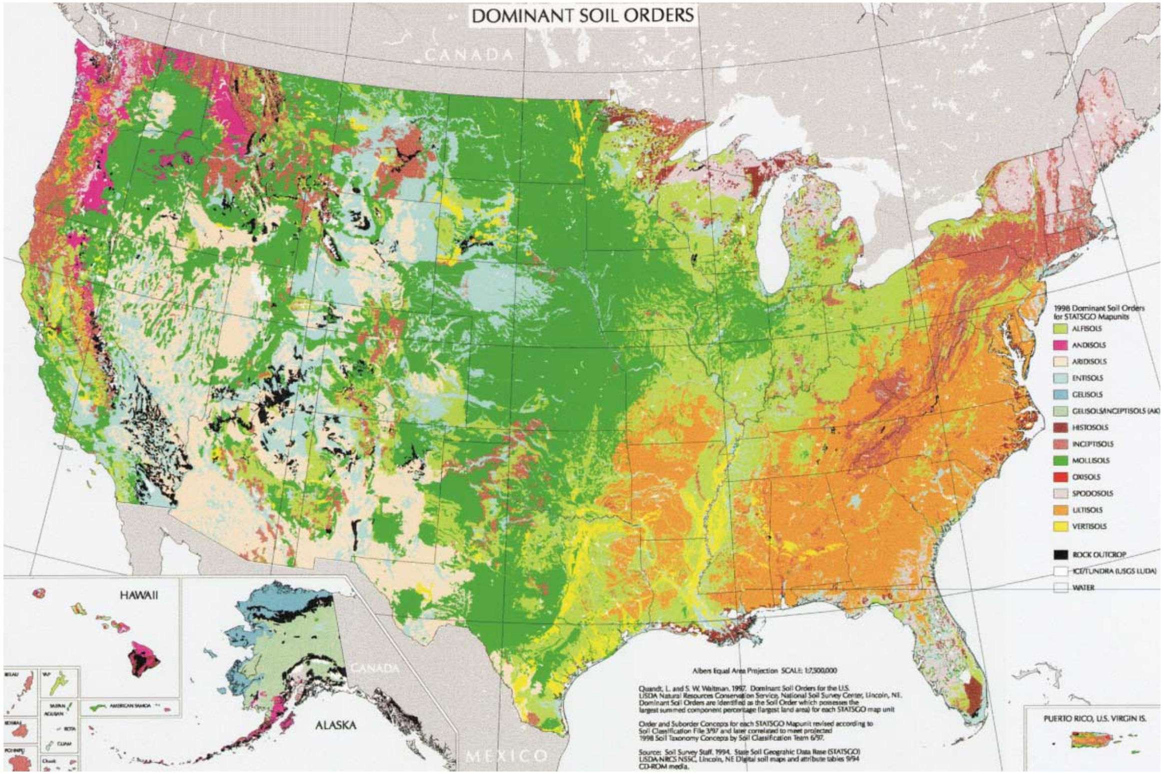
Ultimately it is the unfettered process of scientific skepticism that is important in this dialogue. Robert Merton said it well “Most institutions demand unqualified faith; but the institution of science makes skepticism a virtue” (Mackay, 1991). Skepticism of prevailing ideas and technology or of new ideas and approaches has equal validity in the house of science. However, it is understandable that the deeper the criticism of the *status quo* and the more sweeping the paradigm shift being entertained, the more skeptical the scientific community generally is and should be. In fact, it would be a curious brand of science that overthrows an existing paradigm without first examining and comparing the validity, consistency, and functionality of a proposed and untested substitute. The net effect, the fallout of the debate surrounding the soil quality concept, after all aspects of the paradigm are evaluated, pros and cons, may determine the direction and size of the next step for soil science.



H.R. Sinclair, W.J. Waltman, S.W. Waltman, *H.P. Terpstra,
and *Debra Reed-Margetan. 1996. Soil Ratings for Plant Growth.
USDA-NRCS National Soil Survey Center, Lincoln, NE
and *Iowa State University Statistical Laboratory, Ames, IA.

Albers Equal Area Projection

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



Quandt, L. and S. W. Waltman, 1997. Dominant Soil Orders for the U.S. USDA Natural Resources Conservation Service, National Soil Survey Center, Lincoln, NE. Dominant Soil Orders are identified as the Soil Order which possesses the largest summed component percentage (largest land area) for each STATSGO map unit

Order and Suborder Concepts for each STATSGO Mapunit revised according to Soil Classification File 3/97 and later correlated to meet projected 1998 Soil Taxonomy Concepts by Soil Classification Team 6/97.

Source: Soil Survey Staff. 1994. State Soil Geograhic Data Base (STATSGO) USDA-NRCS NSSC, Lincoln, NE Digital soil maps and attribute tables 9/94 CD-ROM media.

Figure 2 The dominant soil orders of the USA, adapted from Quandt and Waltman (1997).

The debate about the soil quality concept (and it is important to acknowledge that there is a debate and that it is far from resolved) stems from several noteworthy philosophical and scientific disagreements. Miller (1999) a past president of the SSSA, noted in editorial comment that the Sojka and Upchurch (1999) paper "made a compelling case to rethink the concept of soil quality." Price (2000), a recent President of the Australian Soil Science Society stated in an editorial on soil quality, "I hope we in Australia will not allow our science to be hijacked in such a way as to diminish the good scientific work, which has brought this country so much credit." Norcliff (2002) specifically called upon the International Standards Organization to address the fundamental concerns identified by Sojka and Upchurch (1999). World Food Prize winner Pedro Sanchez has referred to soil quality as misleading, a fad, lacking scientific rigor, fraught with social value intrusion, and a term which has become a code phrase required for project funding (Sanchez *et al*., 2003). Letey *et al*. (2003) noted that if soil quality indexing had been the prevailing preoccupation of the 1980s, vast tracks of productive land might have been withdrawn from farming because of poor ratings, rather than implementing the technological solutions to overcome problems via improved management.

One of the most fundamental concerns about the institutionalized soil quality paradigm relates to the nature of science, how it is conducted, and what level of scientific scrutiny is appropriate before adopting a paradigm as a basis for institutionalized public programs (Singer and Sojka, 2001). This point is, perhaps, especially relevant to applied natural resource sciences, where nuances of meaning and circumstance- or site-specific considerations are more complex and vastly more potent determiners of outcome and interpretation than in the basic sciences. As the late Nobel Laureate physicist, Henry Kendall said, "If you want to go into something simple, then it is physics. . .if you are looking for a challenge—then it is environment (Rapport, 2000)."

Karlen *et al*. (2001) imply that because numerous citations and research projects have used the term soil quality, it is universally accepted as a formal soil property concept, and that by extension any study of soil properties in relation to soil functionality is a tacit acceptance of the soil quality paradigm. Increased use of the term is recognition of one particular school of thought in a divided profession. It is recognition that scientists have identified an institutional funding source. It is an easy term for the philosophically uncommitted to add to keyword lists to casually convey that a collection of soil properties were measured in a study and hope for readership and citation by others interested in the term or the casual connotation of the term. The term soil quality is also cited and found in titles and keywords of papers and projects questioning or critical of the soil quality concept.

The editorial by Sojka and Upchurch (1999) itemized and documented an extensive, but not exhaustive list of specific conceptual, technical and strategic reservations to the soil quality concept. We attempt in this chapter to strengthen our presentation of the most fundamental reservations, as well as present some additional points that complement our original thesis. We encourage those interested in this debate to read the 1999 editorial for in-depth documentation of some points that are either revisited here in less detail, or eliminated for brevity. Some 30 years have passed since inception of the soil quality concept in the 1970s and several years have passed since the 1997 and 1999 editorials. Insights can be drawn from the track record of soil quality concept-implementation or lack thereof. We use these to hone our presentation of fundamental concerns regarding the implications for the future direction of soil and crop research, education, extension, land management, natural resource policy, and meeting of the world's food and fiber production needs.

II. HISTORICAL BASIS OF QUALITY SOIL MANAGEMENT VERSUS SOIL QUALITY MANAGEMENT

Doran *et al.* (1996) summarized how ancient scholars identified land suited to crop production. Citing Cato, Varro, Vergil, and Columella, they noted that early farmers worked within the constraints of what they termed "natural fertility," and that sustained productivity was only possible when natural fertility was maintained through addition of organic matter, crop rotations, and incorporation of green- and animal-manure. The purpose was to maximize crop production efficiency. The insights of these early thinkers provided the basis for agricultural management systems for centuries.

The 19th century saw concern and debate about the ability of the then current farming systems to expand food production to feed the rapidly expanding population. That concern has grown exponentially in the present day, even though current food supply limitations are more the result of social or political problems than technological production limitations.

Doran *et al.* (1996) noted that during the 19th century, two theories emerged regarding the role of soil organic matter (SOM) and plant nutrition. One theory postulated that organic matter was the only source of nutrients and that plants were fed directly by soil humus. Justus von Liebig (1862), used the elemental analysis of plants to prove that elements removed when harvesting the crop, could be replaced by applying mineral fertilizers. While Liebig acknowledged the important role of organic matter in natural nutrient cycles, he also recognized that in production agriculture these cycles were disrupted by the removal (harvest) of all or part of the crop. This postulate led to the modern principles of agricultural nutrient management.

Liebig's concepts were not without detractors. Doran *et al.* (1996) identified Sir Albert Howard, J.I. Rodale, Lady Eve Balfour, and William Albrecht as representative of scientists and farmers who "regarded the soil as a living resource" rather than simply a repository for plant nutrients. Although the addition of mineral nutrients was encouraged, the value of organic material was recognized to extend beyond nutrients, to include other biological and physical benefits.

Soil productivity was linked to public health through the nutritional health of animals and humans (Albrecht, 1975). Soil management was seen to control the nutritional value of plants used for animal and human consumption. This rationale culminated in the early 1990s with a proposal to link soil quality definition with human health, on a par with crop productivity and environmental quality (Papendick and Parr, 1992; Rodale Institute, 1991).

A key point of contention in attempting this linkage has been the belief by some that food quality is impacted by the choice of organic versus conventional production methods. Doran *et al.* (1996) noted that no scientific evidence exists proving enhanced nutritional value of food grown in organic or "biodynamic" production systems. The USDA (1980) showed no improved nutritional value in organically grown food compared with conventional production. Warman and Havard (1996) showed that no consistent nutritional or quality differences can be detected in vegetables among various organic systems versus conventional if the nutrient, water and aeration requirements of the crops are adequately provided for. Condron *et al.* (2000) noted that some forms of organic farming may be unsustainable if the macronutrients removed at harvest are not replaced. Critical micronutrient deficiencies can often only be prevented by non-organic inputs.

Doran *et al.* (1996) concluded that "The failure to link food quality to actual soil health conditions, regardless of method of production, will continue to impede an informed discussion on the relationship between soil health and human nutrition." Avery (1995), addressing the linkage between food production systems and human health, suggested that improved diets made possible by cheap plentiful food supplies result in better overall health, while the health impacts of bioaccumulation from applied chemicals or their derivatives are yet to be quantified (Culliney *et al.*, 1992). In fact, the alleged health claims of organic systems, fall into serious question if one weighs the negative impacts on the environment and on human health and hygiene from animal manure applications, and crops grown without proper management (Avery, 1994; Comis, 1999).

When advising pioneer settlers, Hilgard (1914) linked soil productivity to the natural vegetation observed growing on the land as the prime indicator of the value of the land. However, he noted the need for a rigorous scientific evaluation of the physical and chemical properties of soils, particularly emphasizing the lack of previous investigations on arid soils. He also noted the potential for drawing erroneous conclusion when the full extent of factors affecting productivity are not known. "...mere physico-chemical analyses, unassisted by other data, will frequently lead to a wholly erroneous estimate of a soil's agricultural value, when applied to cultivated lands" (Hilgard, 1914). He also recognized the potential for combining complete soil analysis and enlightened management. He further stated, "...these factors once being known, we shall be justified in applying them to those cases in which guiding mark of native vegetation is absent, as the result of causes that have not materially altered the natural condition of the soil." This statement provided the guiding principle for the developing field of soil science.

Secretary of Agriculture, Wallace (1938), called for improved soil management in the 1938 Yearbook of Agriculture entitled "Soils and Man." Wallace is historically important, because he called for the application of rigorous scientific investigations and promotion of soil conservation principles. In this same volume, Albrecht (1938) cited the importance of evaluating soil management strategies across wide geographic regions, with varying soil. In another chapter, Wharburton *et al.* (1938) emphasized the need for appropriate management on the soil of interest, stating, "Certain soils may be inherently unproductive for particular plants under natural conditions but at the same time may be very responsive to management and offer possibilities for the development of a fine farm when properly managed." In our lexicon this is an expression of the sentiment that quality soil management is more important than arbitrary designation of inherent soil quality.

The preceding discussion of historical concepts, with some current thoughts interjected, establishes a pattern of thought that inextricably relates soil management to crop production for human benefit. It is this premise upon which the development of soil science was originally based. While the degree of current human impacts on the environment demands that all our efforts to develop improved management for production be tempered by safeguarding the environment, we cannot and should not forget that the primary purpose of agricultural soil management is to overcome nature's limits to better provide food and fiber. The primary purpose is not the management of soil properties as an end unto itself nor the acceptance of "natural" soil properties, with their intrinsic production limits, as optimal soil property management baselines.

We agree with the statements of Doran and Weinhold (2001) that "Our efforts as soil scientists should center on how soil can be managed to help meet the future challenges of sustaining earth and its people," and that, "Our major focus must be on how we as soil scientists can serve humanity and meet the unique economic, social, and environmental challenges we face in the future." Yet, while we agree on the goals, we have a very different vision of how those goals can be achieved. Put perhaps at its very simplest, erosion, runoff, low yield, pollution, compaction, poor plant nutrition, drought, poor stand establishment and dozens of other soil problems are clearly obvious to farmers and land managers. The problems do not need development of burdensomely complicated indices that attempt to integrate dozens of categories of analytical output to be diagnosed, to focus attention or research, or to evaluate solutions. The most important problems facing agriculture are simple to identify but usually frustratingly complex to solve. The difficulty arises for solutions to be viable within the context of management constraints faced by land managers and farmers, who live in a real world with limits determined by time, space, and money.

Where soil quality assessments tie their evaluation most closely to biodiversity, bioactivity, or matching soil chemical or physical attributes to levels believed to be reflective of "natural" benchmark conditions, there is a great danger of working at cross purposes with the *raison d'etre* of agriculture. Assessing soil properties to match dynamic responses to so-called natural benchmark soil conditions or to biotic indices divorced from utilitarian soil function, is to reverse the logical basis of modern agriculture. Agriculture, i.e., soil management, has been humankind's strategy for survival—by vastly exceeding the low production potential of soils in their natural unmanaged equilibrium (benchmark) state.

Where a paradigm is focused on soil quality rather than management outcomes, many questions arise. How much yield potential must be sacrificed by matching soil properties to natural benchmark status to satisfy soil quality criteria? What collection of modern production and soil management technologies shall we sacrifice to raise soil quality scores? Should we favor organic farming in order to achieve improved soil quality scores? Should we cease inorganic nitrogen fertilization to raise soil quality scores? In a recent millennium essay, Smil (1999a,b) stated "Without ammonia, there would be no inorganic fertilizers, and nearly half the world would go hungry. Of all the century's technological marvels, the Haber–Bosch process has made the most difference to our survival."

III. NOMENCLATURE: DEFINITION, PRECISION, APPLICATION, INTERPRETATION

We contend that the soil quality paradigm suffers from an insurmountable definition problem. An early definition 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).

Mausbach and Tugel (1995) developed a separate definition of soil quality and soil condition for use by the Natural Resource Conservation Service's Soil Quality Institute:

> *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.

We think it is extremely important to note that the institutional definition of soil quality lists at least six diverse simultaneous functions that must be optimized to achieve a high rating of soil quality, to sustain (1) plant and (2) animal productivity, maintain or enhance (3) water and (4) air quality, and support human (5) health and (6) habitation. We say "at least six" because the institutional literature has identified other critical functions. The Soil Survey Staff (1997) lists biodiversity and productivity, partitioning water and solute flow, filtering and buffering, nutrient cycling, and structural support as critical functions. We are unaware of any soil quality index that integrates these functions, and, as our discussion later will show, if these assessments were integrated, perceptions and ratings of soil quality would likely be very different from those currently being institutionally promoted. The institutional use of the concept defines soil condition or health separately.

> *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.

Whereas the original rationale for development of soil quality indicators was to keep track of changes in soil properties resulting from management, the institutional definitions appear to assign this task to the assessment of soil "condition." The institutional definition of "condition" equates the term with the alternate term "health." This co-definition seems at odds with the use of the term health in most of the soil literature that tends to equate the term health with biologically based soil functions, rather than the stated applicability of "function" to encompass non-biological aspects if so designated. Separation of the quality and condition (health) concepts have led to the development of an institutional soil quality index that ranks the intrinsic value of soils of different taxonomies or regions (Sinclair *et al.*, 1996).

The linking of soil quality (or condition) to distinct management and environmental scenarios, specific to a single soil, under explicit circumstances for a given use, creates almost unimaginable indexing complexity. In addition, implicit in the definition are social, economic, biological and other value judgments, all with great potential for disagreement. The resulting matrix of possible determinants is further multiplied by the over 20,000 soil series that occur in the US and by the number of crop or non-crop uses, crop species and cultivars, cropping systems, management, climate, and resource availability factors possible. Thus, the potential number of soil quality or condition indices required to adequately describe potential soil function is astronomical.

Andrews and Moorman (2002) defend the direction of soil quality index development by pointing to the development of several regional indices. However, they make no explanation of the role of the Sinclair *et al*. (1996) index, nor do they acknowledge the extent of indices needed to adequately cover the needs.

Soil performs several functions simultaneously, not separately. The problem of simultaneity was identified by Sojka and Upchurch (1999) as a major impediment to realization of soil quality indexing. Karlen *et al*. (2001) presented a conceptual diagram for indexing parallel soil functions but did not address any of the practical realities of resolving the indexing conflicts caused by simultaneity of function. Thus, we feel it is important that the presentation of the significance and magnitude of this issue be reiterated and expanded. It would be impossible to integrate the mixture of scientific and non-scientific judgments needed to "score" soil quality or condition, or to properly weight conflicting simultaneous functions, especially in soil systems that have high spatial variability (Parkin, 1993; Stenberg, 1998).

The attempt to make soil quality an all-encompassing concept has resulted in an open-ended definition that is confounded by countless circumstance-specific, function-dependent scenarios. Each individual scenario must itself be specified, limited, and compartmentalized in meticulous detail in order to render contextual meaning to assessment of soil quality. This leads to the logic corollary that *Anything that is infinitely defined is, ultimately, undefined and undefinable*. The concern that the soil quality concept is ultimately too complex to define has been articulated repeatedly in the literature (Bosch, 1991; Derbruck, 1981; Koepf, 1991).

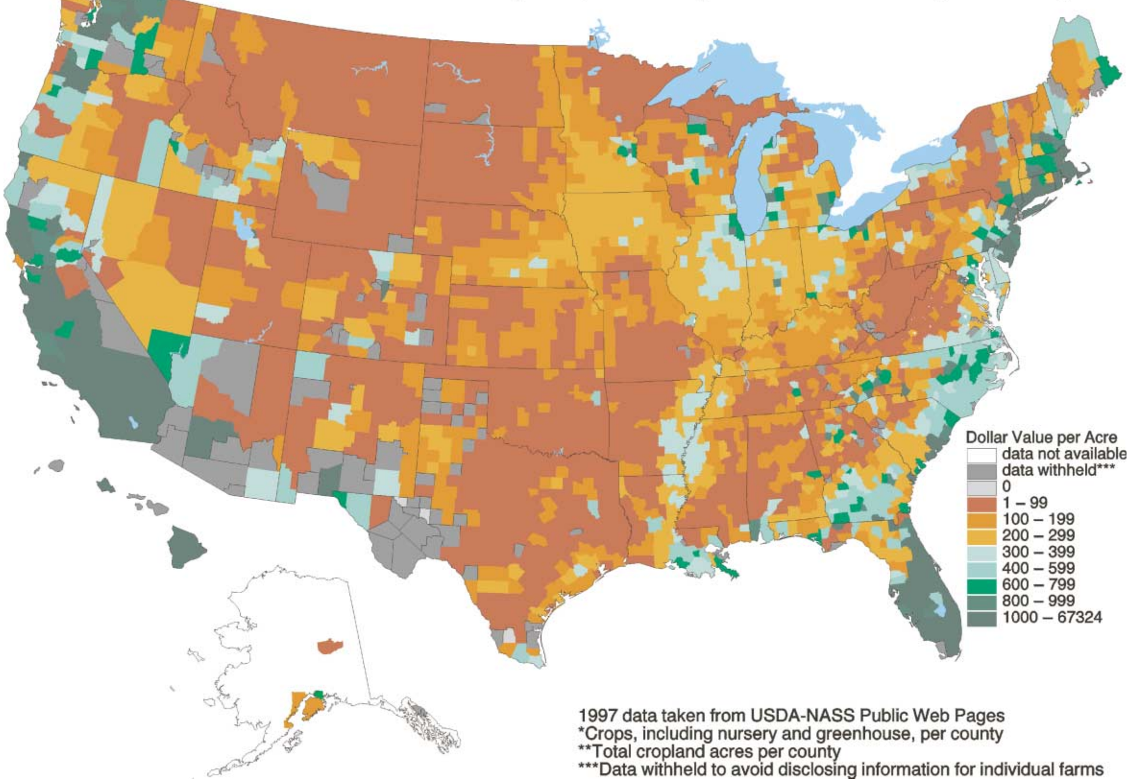
More than rendering soil quality undefinable, diverse user-specific definitions render the concept highly redundant in the existing vocabulary of soil science. The need to identify specific soil functions, considerations and scenarios for defining soil quality accomplishes little more than using new but less precise nomenclature to refer to existing established but less ambiguous production indices, drainage classes, erosion susceptibility indices, aeration indices, nutritional indices, compaction indices, etc. Singer and Ewing (2000) reviewed a variety of such indices with comment on their origins, uses and limitations.

In attempting to evaluate a particular critical soil attribute, there is a significant loss of specificity when delivering the evaluation under the generalized concept of soil quality. There is an added danger of projecting a misleading interpretation in the event that an overall soil quality "score" is favorable, as in the system of Liebig *et al*. (2001), while a specific critical component parameter might be unfavorable, leading to management problems. Furthermore, we disagree with the blanket contention of Karlen *et al*. (2001) and Warkentin and Fletcher (1977) that traditional soil indices focused on limitations, whereas the soil quality concept is based upon positive potential. Many of the most familiar soil management indices such as production- or yield-potential assessments, land capability class, yield-based fertility indices, etc. are aimed at identifying soil status with respect to an optimal positive outcome potential. These familiar examples consider soil limitations in the same way current soil quality indices do, but limit the interpretation to a specific outcome based on specific parameters. Many traditional indices are only positively or negatively based in the eye of the beholder or as targeted at a specific use. For example, drainage class, can have a score that is encouraging for rice production but not for peas or tomatoes—the key being the interpretation and judgment of the manager in coupling the index to the intended use and necessary management criteria.

A collection of soil physical properties important to crop production was presented by Letey (1985). It is noteworthy from today's perspective, some 17 years later, that long before the onset of the current debate, Letey specifically evaluated production relationships, where direct and indirect effects were considered as well as how the factors interrelated. But perhaps most important was that soil properties and their interrelationships and their effects on production were interpreted in terms of their impact on soil management. Somewhat prophetic to our discussion in this paper was Letey's concluding statement. He said, "Because management and weather are integral factors, no meaningful correlation between texture, bulk density, or structure and crop productivity is possible." Many farmers learn the painful lesson each year that no matter how good they think their farm or their soil is, it is entirely possible to fail at farming if they manage poorly. Similarly, there are over a million farming success stories on the soils designated by Sinclair *et al.* (1996) as having ratings of less than 50% "inherent soil quality for crop production." Indeed, as we pointed out earlier (Sojka and Upchurch, 1999), some of the highest earnings in American agriculture occur on supposedly low quality soils (Fig. 3).

Sojka and Upchurch (1999) noted that the terms air quality and water quality are popular and widely accepted among scientists, the general public, and environmental regulatory bureaucracy. Some see a logical extension to the concept of soil quality. This is especially true where the conceptual focus is on soil contamination (Howard, 1993; Bouma, 1997; Hortensius and Welling, 1996). We argue, however, that 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. There are human and other organismal health-based criteria, but they are still quantitatively referenced to a definable pure state.

Karlen *et al.* (2001) took exception to the argument that air quality and water quality are incompatible concept models for soil quality. They argued that distilled water will not support life, and that "For applications involving environmental and human interactions (e.g., allergy ratings, odors, suitability for swimming, fishing or drinking), air and water quality are defined based on current or intended use." Their argument, however, marginalizes that there is a simple



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

defined universal reference for pure air and pure water, and that even in the instances where water quality must deviate from purity, it is defined with clear reference back to a simple universal standard of purity. Thus, our original argument remains unrefuted. Namely that air and water quality assessments do not specify an ideal integration of complex 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 positive functional quality for air 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. It is impossible to define a single pure chemical formula for soil to use as a universal reference for pollution or even to stipulate ideal concentrations of necessary nutrients or osmotic levels.

Sims *et al*. (1997) proposed a non-polluted soil criteria for soil quality that they referred to as the clean state of soil. However, although we can make discrete lists of xenobiotic or naturally occurring contaminants, "pure soil" cannot be defined. There is no simple unique chemical equation for soil. Soil cannot be refined, distilled, or restored to a discrete pure substance. There is no 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. Soil accumulates both natural and synthetic contaminants, toxins and heavy metals. Indeed, naturally occurring toxins, nutrient contaminants and heavy metals are detectable in most soils and parent materials.

In functioning as a filter, soils can sequester large amounts of pollutants before threatening soil-borne organisms or the safety of food crops (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. On the other hand, making a soil unclean by adding "toxic" herbicides and pesticides improves soil quality for crop production by suppressing target organisms. The soil quality literature repeatedly emphasizes the need for indexing to encompass the diversity of soil function (Allan *et al*., 1995; Larson and Pierce, 1991; Mausbach and Tugel, 1995; Pierce and Larson, 1993; Soil Survey Staff, 1997). 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 is also often emphasized (Visser and Parkinson, 1992).

Figure 3 Total crop dollar value per county divided by the acres planted in each US county in 1997. Data are from the USDA-National Agricultural Statistics Service public web site (2.47 acre = 1.0 ha).

The definitions of soil quality offered to this point run counter to the philosophy that resulted in the formulation of the modern US comprehensive Soil Taxonomy (Soil Survey Staff, 1975). The fundamental advancement of the current taxonomy was elimination of the need for soil classifiers to attempt to infer soil developmental status along an assumed evolutionary path predetermined by parent material, climate, etc. Instead of guessing the potential evolutionary path and climax state of the soil in question, the new taxonomy bases classification simply on the state of the soil as found *in situ*. The compilers of the Soil Taxonomy drew special attention to this conceptual advance, stating:

> 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, on the other hand, uses various empirical and subjective measurements and perceptions to make a subjective "estimate" of how well soil attributes and dynamics match those presumed to be the potential for that soil (Karlen *et al*., 2001; Warkentin and Fletcher, 1977). These evaluations can include ratings derived from simplified guides and test kits (Anonymous, 1996a,b,c, 1998a,b; Liebig *et al*., 1996), score cards (Anonymous, 1998c; Soil Survey Staff, 1998), aroma (Anonymous, 1996b; Romig *et al*., 1995; Kennedy and Papendick, 1995), etc. (Ditzler and Tugel, 2002; Herrick *et al*., 2002; Wander *et al*., 2002). Singer and Ewing (2000) noted that while various other soil rating systems are also based on various simplified testing procedures, soil quality ratings offered to date have not been fashioned as highly specific determinations of suitability of a single soil property for a specific intended use—e.g., evaluation of a given soil's nutrient status for cotton versus tobacco or rice. Sojka and Upchurch (1999) noted that unlike traditional soil tests, soil quality assessments, in striving to be holistic, rely on generalized suites of attributes, including several highly dynamic properties that may not still exist at the previously measured status or rate when the soil must actually perform that function (e.g., soil respiration rate). Karlen *et al*. (2001) did not address how soil quality assessment can cope with the problem of status or rate changes of dynamic properties before the soil function occurs.

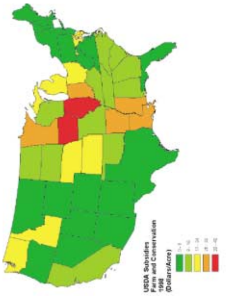
IV. SOIL QUALITY OR MANAGEMENT? THE INPUT ARGUMENT

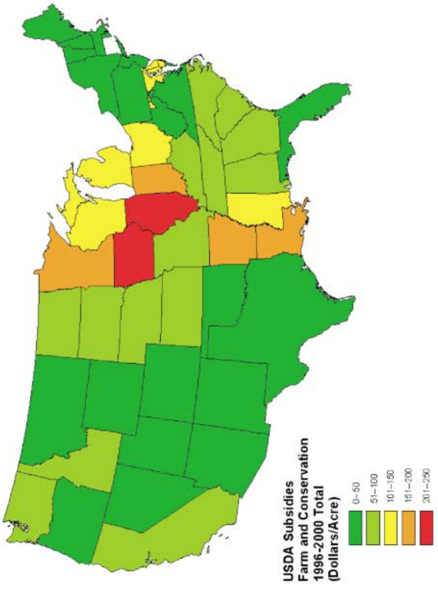
Most of the limited indices traditionally used in agriculture can point to specific management and inputs. These can be applied to soil to achieve a predictable adjustment in the soil index and response in a given crop grown on that soil at a specified site. To date, holistic soil quality indicators are incapable of directly providing either of these quantitative management recommendations or crop response recommendations. To arrive at recommendations the indexes must first be deconstructed to use individual reductionist predictive elements to achieve individual parameter responses. The inability to prescribe specific management measures to achieve desired soil quality index outcomes was recently underscored by a 20-year 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."

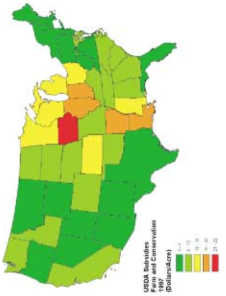
Crop production and farming are the end result of soil properties, climate, water, plant genetic potential, symbionts, pests, physical and chemical inputs, market economics, government regulations, subsidies and incentives, and, most of all, management. Furthermore, soil is not something that occurs in a bucket or a test sample. It is a dynamic entity that occurs in nature on a landscape, within a climate, affected by its physical, biological, social and governmental setting and by the dynamics of all processes, both *in situ* and across its boundaries, where off-site effects of neighboring factors affect and are affected by the soil in question.

It is our contention that no soil has 100% inherent soil quality for crop production. No production exists free of the factors for cropping itemized earlier, and any soil can produce a zero yield if the non-soil factors are improperly assembled, especially if the management component is inadequate. We therefore submit that the term inherent soil quality for crop production has no intrinsic meaning, since it cannot be defined without specifying all these other factors—many of which cannot be predicted for a given growing season. A simple example of the failure of the soil quality concept to fully integrate these concepts would be to compare the corn yield potential of a Coachella Valley farm grown on a salt-affected hyperthermic Aridisol versus a Cornbelt farm on a Mollisol, where the yield potential is measured from October through March rather than April through September. In the absence of massive inputs (heat, greenhouses, etc.) and determined management, frozen soil has zero yield potential, and thus zero inherent soil quality for crop production for six months of every year. Although an extreme, this example goes to the heart of the debate. Conversely, very few soils have inherently low quality for crop production when properly managed considering the above factors.

Karlen *et al.* (2001) defended the Sinclair *et al.* (1996) model stating it "...is an accurate reflection of the soil resource potential in the absence of human intervention and external input of energy resources (e.g., fossil fuel, water). Lack of correlation between inherent soil quality and economic value of the products produced is fully expected because the high productivity in areas with low inherent quality can only be achieved by creating a dynamic soil quality through external inputs and high-value crops." This statement is a *de facto* acknowledgment of our argument, namely that quality soil management and not inherent


USDA Subsidies
Farm and Conservation
1998
(Dollars/Acre)


USDA Subsidies
Farm and Conservation
1996-2000 Total
(Dollars/Acre)
0–50
51–100
101–150
151–200
201–250


USDA Subsidies
Farm and Conservation
1997
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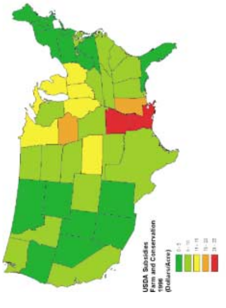
USDA Subsidies
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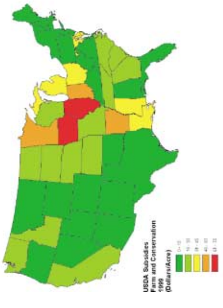
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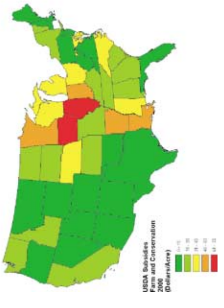
USDA Subsidies
Farm and Conservation
2000
(Dollars/Acre)

soil properties controls productivity. “In the absence of human intervention” Mollisols and Alfisols would be canopied in tall grass or forests and have fertility and productivity far lower than the currently managed manifestations of these soil orders interpreted by the Sinclair *et al.* (1996) model. Furthermore, the earlier statement is at odds with previously published statements of the soil quality concept (Mausbach and Tugel, 1995; Allan *et al*., 1995; Larson and Pierce, 1991, 1993, 1994). The Sinclair “relative index of inherent soil quality” is a direct contradiction to contention of Karlen *et al.* (2001) that “There never was nor can be a single value for rating all soils or land uses.” Also, the Karlen *et al.* (2001) statement defending the Sinclair *et al.* (1996) model ignores the enormous historical and ongoing inputs (such as logging, drainage, and fertilization) that were/are required to render the Sinclair *et al.* (1996) 100% soils farmable.

If the stated function of the soil is: to produce multiple high value cash crops per year, for fresh market sales, under appropriate management; why should a model penalize that potential by using assessment criteria that favor a high score for soils that produce a single, annual crop, of subsidized, low-value grains or other staples? Furthermore, if the failure of the model to correlate soil quality with economic outcome is the result of matching soil properties to arbitrary choices of crops and cropping systems rather than other crops of potential or demonstrated greater economic return, this again is *de facto* acknowledgment that the model is judging cropping system choices, and not soil properties. The structure of the Sinclair *et al.* (1996) model fails to recognize the economic realities of US agriculture in a way that tacitly favors corn, soybean and small grain production over other higher value crops nationwide. Karlen *et al.* (2001) state “With regard to soil quality assessment or indexing, the most important fact is that since both inherent and dynamic properties are involved, there are no magic scores or perfect ratings. Soil quality index scores are always relative, not absolute.” Yet, it is apparent that in the Sinclair *et al.* (1996) model, that all soils are referenced to a single standard. This standard is arbitrarily associated with the properties of soils concentrated in a region producing low-return, highly subsidized, staple grains.

Beyond the definitional inconsistencies, comments of Karlen *et al.* (2001) about the Sinclair *et al.* (1996) model reflecting the need for external inputs, clearly ignores historical and ongoing inputs to the soils with the highest ratings. This is particularly true if crop subsidies and conservation incentives are considered (Fig. 4). An objective evaluation of external inputs and subsidies needs to be uniformly applied. In the case of the high scoring Mollisols and Alfisols across the north central states, this would have to include consideration

Figure 4 Total crop and conservation subsidies by planted acres for each state in the US for 1996–2000. Data are from the USDA-National Agricultural Statistics Service public web site (2.47 acre = 1.0 ha).

of the deforestation, prairie elimination, wildlife loss, tile drainage, fertilization, terracing, windbreaks, seasonal limitations, perennial flood compensation costs, contributions to Gulf hypoxia and heavy direct crop subsidies that are necessary to enable soil functionality for cropping on the landscape *in situ*.

Karlen *et al.* (2001) take no account of the lost value of forest or grassland habitat, hardwood forest products production, wildlife, or >50% loss of sequestered carbon in the soils of these Mollisolic and Alfisolic areas, nor their vast store of above-ground vegetatively sequestered carbon (Entry *et al.*, 2002). They make no tally of the energy expended or financial costs of clearing, terracing, windbreak establishment, surface and tile drainage, or institution of conservation tillage practices across the region, all of which have been heavily government-subsidized. These are ecosystems that were nearly completely destroyed to institute heavily subsidized production of corn, soybean and small grains. The Swamp Lands Act of the mid-19th century initiated one of, if not the largest, subsurface drainage campaigns ever conducted on earth. In the north central region of the US, over 17 million ha were tile drained by 1987, and expansion continues (USDA, 1987; Zucker and Brown, 1998), largely under various government subsidies.

Perhaps other production attributes account for the high scores that predominate in the north central region of the US in the Sinclair *et al.* (1996) model. Let us look at soil fertility, perennially one of the largest production inputs in most farms. This region accounts for 53% of the commercial nitrogen fertilizer use (Watts *et al.*, 2000) on 54% of the nation's cropped land, but produces only 41% of the US market value of crops. This is a surprising lack of N-fertility advantage and low market value of crop production for such supposedly high quality soils. The ecosystem, landscape, and field-scale inputs of the north central region are an interesting collection of anomalies for a region supposedly dominated by superior inherent soil quality.

Likewise, for the low rated soils of the model of Sinclair *et al.* (1996), if water delivery to a crop is accompanied by infrastructure that results in power generation rather than energy consumption (as is the case in many irrigated areas), expanded wildlife habitat, recreation, etc. then that should be recognized as an advantage and not offhandedly ignored in rationalizing the failure of the model and soil quality paradigm to explain reality. The model fails, because it attempts to explain the full complexity of American crop production through the indexing of a single parameter, soil.

V. SOIL QUALITY OR SOIL PRODUCTIVITY? IMPORTANCE OF INDEX SPECIFICITY

A key focus of the soil quality movement has been development of soil quality assessment tools (Larson and Pierce, 1991, 1994; Pierce and Larson, 1993; Anonymous, 1996a,b,c; 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 upon attempts to define parameters, functions or "perceptions" linking crop performance with soil properties.

As Karlen *et al.* (2001) concede, to date most soil quality indices presented are simply yield or productivity indices. A few publications have identified critical limits for specific soil contaminants. A few are primarily bio-diversity or bioactivity indices, sometimes not empirically linked to any assessment of soil functionality for economic crop production. Sometimes, following a rationale that we do not feel has been adequately (quantitatively) explained technically or documented, one or more of these perspectives are also presented as indicators of "sustainability." If a yield or production function is the only intent of a soil quality index, then science, soil management and public resource stewardship programs are better served by avoiding ambiguity and specifically designating the parameter as a yield or production index. This avoids the risk of implying "high quality" for other functions (particularly environmental functions), merely because of a favorable production index. In other words, the current direction of soil quality indexing emphasizes the opposite conceptual development of that suggested by Larson and Pierce (1991, 1994) and Pierce and Larson (1993).

High soil quality for crop production does not guarantee high quality for environmental protection or for biodiversity or bioactivity or sustainability—regardless of its definition. High soil quality for environmental protection does not guarantee high quality for crop production or biodiversity or bioactivity or sustainability. High soil quality for biodiversity or bioactivity or sustainability does not guarantee high quality for environmental protection or for crop production. In fact, high quality for one function often predisposes poor (or at least reduced) soil quality for other simultaneous functions. This is particularly the case for high soil quality for production adversely impacting high quality for environmental protection if adequate management measures are not taken to specifically prevent negative consequences across other functions.

The problem of antagonistic functions is compounded by the fact that these functions occur simultaneously. Quality soil management demands the integration and balanced simultaneous optimization of all these considerations through enlightened management interventions to meet the combined needs of real world soil stewardship. Stenberg (1999) acknowledged this dilemma, stating, "To extend the quality concept of agricultural soils to a range of functions not directly coupled to agriculture, as proposed by the "multifunctionality" approach (Blum, 1993; Nortcliff, 1997), would severely complicate the interpretation of soil-quality indicators." He further stated, "Overall, it can be concluded that the soil-quality concept can only be useful for specified purposes and focused problems.

Otherwise, any kind of soil-quality index or threshold value would be very ineffectual as a result of opposing functions." In other words, when soil is assessed for limited narrow functions (the traditional reductionist science approach to indices) predictability is good, but when generalizing to an "umbrella" holistic assessment of overall "quality" the concept does not work. We cannot help asking, then, what is new besides the term soil quality? And does it not follow that the generalized term risks an erroneous assumption of general quality?

Important non-production functions of soil can be impaired by, or bear little or no relationship to suitability for yield. This seminal concept (Larson and Pierce, 1991, 1994; Pierce and Larson, 1993), recognized in the institutional definition (Mausbach and Tugel, 1995) has been all but forgotten by the predominately yield-focused soil quality movement of the last decade. This is much to the detriment of the concept itself. We submit that this failure points to denial of the practical impossibility of evaluating soil quality integratively across all simultaneous functions. A simple and obvious example is that nutrient contamination of groundwater or surface waters occurs more easily from water draining through or running off a highly fertile soil than an infertile soil. High fertility (nutrient availability) is a strongly positive production attribute, but can be a serious environmental detriment to surface and groundwater if proper management interventions are not implemented.

We are unaware of any published work that has kept the paradigm's promise of assessing soil quality as an optimized integration of simultaneous and diverse (even contradictory) functions. Rather, soil properties have merely been correlated solely with yield or with *in situ* micro- or meso-biological robustness.

Nelson (1994), a former President of the SSSA, stated "The concept of soil quality will not be in the mainstream of soil or environmental science programs until there is wide acceptance of the definition for the term and quantitative indicators of soil quality are developed. Air and water quality are well-recognized concepts that have standards established by law and regulation. A great deal of study and education will be necessary before soil quality becomes an important national natural resources issue." We agree and, indeed, feel that a predictive capability for assigning specific management to achieve a given soil quality that will result in a given yield has yet to be demonstrated for any but existing standard soil analytical parameters. Even the quantitative scoring proposed by Liebig *et al.* (1996, 2001) provides no predictive capability linked to recommended management. Even though Liebig *et al.* (2001) identified and scored more than one function, the functionalities were limited in scope and not integrated to accommodate their simultaneity.

Karlen *et al.* (2001) presented a schematic of soil function assessment that indicates parallel and simultaneous functionality. But, as with all previous soil quality conceptual papers, no procedural approach to quantitatively perform the integration was described or attempted. While presenting conceptual schematics for process integration is possible, the complexity and conflict of values that surround the realization of the next step are probably insurmountable, if approached quantitatively and eclectically. Sparrow *et al.* (2000) recognized that development of soil quality assessment is a long way from implementable functionality. In considering both soil and water quality indicators they stated that "...better guidelines for indicators are needed if these guidelines are to be defensible. More work also needs to be done to decrease the cost of appropriate monitoring..."

VI. HOLISM AND THE META-ORGANISM ANALOGY

The soil quality paradigm has drawn attention to use of collections of soil parameters for soil evaluation (so-called "minimum data sets") rather than single soil properties or targeted collections of properties (e.g., nutrient status for fertilizer application, or bulk density for tillage recommendations). The soil quality paradigm has also increased consideration of micro- and meso-biological properties often neglected in the past. We feel that broad collections of data for soil characterization are always appropriate and desirable when practical and affordable, especially for harder-to-diagnose soil problems. This approach, however, is hardly new in soil science, and certainly not a paradigm shift in itself. It is and has always been the established approach to diagnosing specific production limitations in a given field. The soil science literature confirms that detailed field experimentation has always used extensive collections of data to interpret crop responses from experiments. Furthermore, there is certainly nothing wrong with holistic analysis *per se*, but holistic analysis still does not provide the critical information, which is the specific management recommendation needed to achieve a desired outcome.

What is new is the unproven assertion that comprehensive, holistic characterization can be routinely done quickly, affordably, at adequate spatial intensity by minimally trained (or even untrained) individuals using simple soil quality test kits and interpretive guides (Anonymous, 1998a,b; Liebig *et al.*, 1996; Anonymous, 1998c; Soil Survey Staff, 1998; Anonymous, 1996a,b,c; Ditzler and Tugel, 2002; Herrick *et al.*, 2002; Wander *et al.*, 2002). Assessment of such comprehensive data collections cannot be properly and meaningfully interpreted for timely practical use by today's mainstream farmers, managing thousands of acres each season, without consulting a team of cooperating scientists researching the topic.

Twenty-seven categories of parameters for point-scale assessment of soil quality and 15 categories for field or farm scale assessment were listed by Karlen *et al.* (2001). Each category, in turn, consists of several measurements or choices of measurements and/or requires several multiparametric analyses to adequately assess the individual category of soil property. This is all feasible for PhD dissertation research or other in-depth investigations, but is completely unrealistic for practical wide-scale assessment of soil status for use by actual soil managers. In production agriculture, forest management, or wetland management, how many microorganism biodiversity samples would adequately characterize soil condition under a half-mile center pivot, in a single timber stand, or for a coastal wetland? Is one characterization per hectare sufficient? How do you decide where, when, how, etc. to take the sample? Which of a dozen analytical approaches should be used and who will adjudicate the choice of analysis? How long will this take? What will the assessment cost? Most of the above questions can be repeated for each category and choice of measurement.

The needs of modern US farmers, the needs of foresters, the needs of habitat managers and others, are pushing them to remotely sensed, and other large scale automated integrative data collection approaches. This is true for parameters such as real time soil water status assessment, yield monitoring, foliage vigor, salinity mapping, and many others. Attempting to make an adequate spatial assessment of a dozen or more time-consuming individually hand-acquired data categories is possible for small plot monitoring and intensive scientific studies, but is an unrealistic expectation for routine on-farm use, or forest or habitat evaluation. If only a few assessment sites are sampled, significant danger exists that improper spatial representation will misdiagnose the overall status of the field (and by extension, watershed or region). This could potentially result in costly or environmentally harmful management recommendations. These could take the form of over- or under-recommendation of chemicals, irrigation, tillage, etc. in crop management or other interventions in rangeland, forests, wetlands, etc.

Karlen *et al.* (2001) argue that one of the rationales for soil quality assessment (and a way to keep down cost of assessment) is to use existing soil property databases to make large scale assessments of soil quality and soil condition as was done by Sinclair *et al.* (1996). This would seem to contradict the stated goal of using dynamic soil properties closely linked in time to management interventions, to assess soil quality (or condition). National and regional soil property databases are notoriously dated and poorly linked to the kind of site documentation or baseline establishment that the current soil quality concepts supposedly rely upon. Assessments using such databases could hardly be seen as a new approach unique to the soil quality paradigm, and in fact may represent a threat to the paradigm because the lack of temporal integrity of the data could undermine its accuracy of interpretation and application for current management of certain dynamic functions.

Another point that we feel needs to be internalized by proponents of holistic approaches is that holism does not merely mean making larger collections of parameters that support one analytical or philosophical view, but also means integrating data and interpretations that point toward alternative views. We remind the reader that the institutionalized definition of soil quality includes at least six simultaneous soil functions. Holism means adding all the positives and all the negatives to determine the net, not merely adding some of each, or only the positives or only the negatives. As the institutional definition of soil quality would imply, one ideally should not look only at production effects and ignore environmental impacts and claim to have made an adequate analysis of soil quality. We would add that one cannot look only at production effects and environmental effects that support a paradigm or a politically correct philosophy of farming while ignoring data or analyses that detract from the paradigm, and then claim to have made an objective scientific analysis of soil quality. One cannot look only at production benefits of individual soil properties, such as macro-porosity, worms, or organic matter, and ignore negative effects on production such as leaching, disease vectoring, or increased pesticide application requirements, or ignore negative environmental impacts such as groundwater chemical or biological contamination, or contributions to surface water anoxia or harmful water treatment by-products. One cannot use selective reasoning and analysis and claim to be holistic. Indeed, most professional associations, societies, universities and government agencies have codes of ethics that stipulate full disclosure of "all relevant and pertinent information" (or equivalent language) when discussing and reporting technical matters (Thompson, 1999). Edward Teller, the world-renowned physicist, explained that truth in science is the simplest explanation that includes all known facts—no more and no less. If holistic science is to strive for scientific truth it must meet these criteria.

Soil can be viewed as an ecosystem unto itself, or as a key component in a more broadly delineated ecosystem. The debate surrounding scientifically defining and assessing subjective concepts such as "quality" or "health" is not unique to soil science. It is, in fact, occurring across a wide spectrum of natural sciences and ecological management (Lackey, 2001). The arguments that divide the holistic quality/health assessors from the parametric reductionists are remarkably similar across a wide spectrum of disciplines. Soil science's debate may deserve compliment for being less shrill than in other disciplines. However, it may warrant criticism for being less energetic and comprehensive than the importance of the subject warrants.

Lancaster (2000) an advocate of ecosystem-level analysis, nonetheless had this to say about the meta-organism/health approach, "Value judgments are inappropriate as a scientific basis for monitoring, managing or protecting the environment. Cynically, I would venture that definitions and measures of ecosystem health are open to so much abuse and misuse that they represent a threat to the environment." She concluded with an even stronger indictment of the subjectivity of these approaches, saying, "Ecological health (and its synonyms) cannot be defined or measured objectively and claims to the contrary are essentially fraudulent."

A significant problem in transferring the health analogy to ecosystems is that while it is easy to transfer the notion of individual health from the intuitive understanding gained from personal medical experience (Ryder, 1990), ecosystems focus on health of an aggregate population (Schaeffer *et al*., 1988). In fact, the situation is even far more complicated than that. The aggregate population in an ecological context includes the performance of both individuals and populations of highly diverse distinctly different organisms. However, "natural healthy" ecosystems, balanced in all their components, by definition must include individuals, and, sometimes, even groups of individuals, that are identifiably "unhealthy." This allows normal cycles of population dynamics to proceed effectively and naturally.

Human-managed ecosystems are even more unusual, in that they are entirely artificial systems (e.g., a farm field on land cleared from forest) established by man for distinct purposes of production or other resource management needs. These ecosystems, managed for their specific outputs are often further distorted in order to meet intangible societal aesthetics, political agendas, etc. It is this latter set of complications that lead Lackey (2001) to draw distinctions between pristine, wild, and managed ecosystems. It is at this point where value weighting occurs, as scientists, managers and policy makers/enforcers attempt to assign and assess so-called ecosystem "integrity."

Numerous environmental scientists have noted that "health" is a frequently abused term used to interject social, aesthetic, economic and cultural values, and political correctness into environmental technical arguments to disguise advocacy as science (Lackey, 1998a, 2001; Anderson, 1991; Lele and Nogaard, 1996; Gaudet *et al*., 1997; Lancaster, 2000; Sagoff, 1995; Jamieson, 1995; Kapusta and Landis, 1998).

Nielsen (1999) dealt with the difficulties of defining health, even in the human medical community. He stated, "In the final analysis what is considered healthy must be reasonable from biological, physical, ethical, and aesthetic points of view as determined by people. Therefore, health is not a science *per se*. It is then a social construct and its defining characteristics will evolve with time and circumstance."

In a lively exchange on the concept of ecosystem health Calow (1995), a critic of the concept, favored defining ecosystem health in terms of management goals serving human needs. He stated "This moves away from the definition of ecosystem health in terms of naturally defined norms, to anthropocentric ones—and there is then a direct relationship between human and ecosystem health. Moreover, we can view the services as goal states, and aim to achieve them through active monitoring and management." Calow (2000) expanded this stating "...we should remain skeptical about the ecosystem health concept, except insofar as it is clearly intended pragmatically, to refer to the extent ecosystems can deliver services to humanity." Rapport *et al*. (2000), Calow's critics and proponents of the health concept, seem to agree that ecosystem health is really a subjective, if utilitarian management-oriented, concept. They stated "..."health," whether at the individual, population, or ecosystem level, necessarily involves value judgments and therefore we agree with Nielsen (1999, p. 65) that (quoted above).”

These quotes parallel the debate regarding soil quality and soil health. They also reasonably express some of our objections to the terms. For many decades, soil science has used analysis and quantification of specific attributes and parameters to guide management for specific outcomes. The soil quality and soil health paradigms undermine this precise and specific management capability by homogenously blending collections of attributes and parameters to arrive at a vague diagnosis of overall quality or health (Haberern, 1992) which cannot be used to recommend specific production, maintenance or remedial management needs without first going back to see which index components affected the overall evaluation in the first place.

VII. REGIONAL EVIDENCE OF PARADIGM FAILURES

Karlen *et al.* (2001) acknowledged that to date the soil quality concept has focused nearly exclusively on yield. They predict that alternate function indices are coming. We wonder why the active development of the soil quality paradigm has spent the first 10 years producing more yield indices, when the seminal soil quality literature emphatically stated that soil quality assessment must move away from merely indexing productivity (Alexander, 1971; Larson and Pierce, 1991, 1994; Pierce and Larson, 1993; Warkentin and Fletcher, 1977). Why not first attempt to define and produce the alternative functional indices said to embody the concept innovation and identified as most lacking and most needed?

Karlen *et al.* (2001) criticized the presentation of Sojka and Upchurch (1999) of regional production value which resulted from several factors not adequately considered by the Sinclair *et al.* (1996) model which they defended on the assertion of cropping inputs. We have noted the failure of an input-based argument. If soil quality is more than mere soil productivity, then the danger of over-emphasizing productivity over other functions also deserves specific attention, particularly given the stated rationale of the soil quality concept originators.

As institutionally defined, a true assessment of soil quality must “sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation.” This echoes the rationale of the concept originators. Notably, 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.” Let us consider some other simultaneous soil functions, beginning with “maintain or enhance water and air quality.”

Watts *et al*. (2000) noted that nitrate contamination of water resources is a major concern in the north central region. Nitrogen compounds that move through the primary river systems of the upper midwest to the Gulf of Mexico, mainly nitrate (Goolsby *et al*., 1999) are a major cause of hypoxic conditions leading to the so-called "dead zone" in the once rich fisheries of the Gulf of Mexico (Annin, 1999; CENR, 2000; Rabalais *et al*., 1994). The extensive tile drainage of this area and extensive distribution of soils with abundant macropores rapidly transport nitrate leached from applied fertilizer and mineralized SOM to contaminate surface waters at rates ranging from 17 to 70 kg N/ha, even when applying fertilizer at recommended rates (Fausey *et al*., 1995; Kladivko *et al*., 1991; Mitchell *et al*., 1997; Mulla *et al*., 1998; Quade, 1985; Schwab *et al*., 1985). Several studies (Burkart and James, 1999; David *et al*., 1997; Randall *et al*., 1997; Keeney and De Luca, 1993) concluded that, in this region, nitrate losses from SOM mineralization may be a larger contributor to tile drains and ultimately contributing to Gulf hypoxia than applied fertilizer and manure. Most of the 25–135 kg N/ha annual mineralization occurs during winter months when frozen soils cannot grow crops (Bjorneberg *et al*., 1996; Burkart and James, 1999; Keeney and De Luca, 1993). Surface water nitrate levels in the region are strongly correlated to losses from tile drainage (Fenelon and Moore, 1998; Mulla *et al*., 1998). The lost N contributing to Gulf hypoxia was estimated to have annual fertilizer value of $410 million (CAST, 1999). No price tag has been estimated for the full extent of negative impacts of this lost N nor for the potential mitigation cost. A single industry severely threatened by Gulf hypoxia, the Gulf fishing industry is valued at $2.8 billion annually (CAST, 1999).

The fate of all this nitrogen results in cascading environmental, commercial and hygiene consequences and costs. Denitrification of river-borne nitrates occurs under anaerobic conditions (Bradley *et al*., 1995; Howarth *et al*., 1996; Kellman and Hillaire-Marcel, 1998; McMahon and Böhlke, 1996; Smith *et al*., 1997) releasing nitrous and nitric oxides, which contribute to global warming, at a relative impact up to 310 times the effect of equal molar portions of CO_2. CAST (1999) stated "Hypoxic zones are now one of the most widespread, accelerating, human-induced deleterious impacts in the world's marine environments."

Recent studies have shown that nitrate contamination of drinking water, which is very costly to remove, is linked to increased bladder cancers at levels as low as 2.5 ppm (Weyer *et al*., 2001). A recent survey found that 30–40% of public drinking water sources in Iowa had nitrate nitrogen concentrations in excess of 5 mg/l. Medical science has begun to recognize that ingested nitrate can be endogenously reduced to nitrite, which can then undergo nitrosation in the stomach, intestine, and bladder to form highly carcinogenic N-nitroso compounds. Thus, new attention is being paid to drinking water nitrate levels, well below the 10 ppm limits originally established out of concern for infant methemoglobinemia, a syndrome rare in the US. Numerous cancers linked to drinking water nitrate are now implicated, but await new epidemiological studies structured to identify specific risk from long-term nitrate ingestion (Weyer *et al.*, 2001).

This discussion is included to draw attention to the now realized ramifications of soil quality indexing. This is not a condemnation of agricultural systems in the north central US. This analysis calls attention to the severity of potential index misuse from structuring and implementing a flawed index or indexing philosophy that does not adequately consider or account for all six of the simultaneous soil functions institutionally definitive of soil quality. We conclude that if quality were assessed in a non-regionally biased appraisal of the role of soils in producing commercially successful agriculturally relevant crops, not skewed to temperate climate cropping patterns, not skewed to heavily subsidized low value staple grain crops, not dependent on heavily subsidized annual soil management programs and that accounted for a full spectrum of the six institutional criteria for soil quality, the concepts, criteria, assessments and interpretations of soil quality would be vastly different from any of those published to date.

VIII. INDEX COMPONENT BIASES

We need not look at the national assessment of soil quality to make our case about the paradigm's failure to adhere to its own tenets regarding non-production functions. This can be seen by looking at individual soil properties promoted, without qualification, as essential to soil quality, but which are often detrimental to one or more production or non-production functions. Some of the promoted soil properties only favor production in limited circumstances, and have negative production consequences never fully considered outside the narrow bias of the paradigm. Examples follow.

Certainly, SOM provides many production benefits. In the absence of specific management, however, it can also have negative environmental and crop production impacts. We have yet to see any soil-quality-construct even entertain the possibility that SOM can have negative production or environmental impacts. Sojka and Upchurch (1999) addressed this concern in some detail, but Karlen *et al.* (2001) did not address the issue. Thus, we feel it is important to restate the concern and provide additional evidence for its relevance.

Increasing SOM content increases the application requirements of many soil-incorporated pesticides (Stevenson, 1972; Ross and Lembi, 1985; Anonymous, 1997; Gaston *et al.*, 2001). As SOM increases from about 1–3% range to 3–5% range, soil incorporated pesticide application rates needed for efficacy can rise 20–100%. Soil sample clay fractions with 11% SOM, had 68% of the attrazine 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 human exposure to toxic hazards. Crop production cost, environmental quality, and human exposure to pesticides are all negatively impacted by the increased pesticide use necessitated by higher SOM.

Negative impacts of increased pesticide loading are compounded by SOM's role in aggregation and interaggregate macropore formation, often accompanied by increased earthworm burrowing. The resulting continuous macropores promote bypass flow, and rapid transmittal to ground water of dissolved or soluble organically complexed surface-applied pesticides and nutrients (Barriuso *et al*., 1992; Hassett and Anderson, 1982; Muszkat *et al*., 1993; Vinten *et al*., 1983; Flury, 1996; Flury *et al*., 1994; Ghodrati and Jury, 1992; Grolchulska and Kladivko, 1994; Shuford *et al*., 1977; Simpson and Cunningham, 1982; Stagnitti *et al*., 1995; Stamm *et al*., 1998; Vervoort *et al*., 1999). Increased DDT and PCB 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 napropamide transport through soil (Nelson *et al*., 1998).

Preferential flow via macropores contributes to rapid flow of pesticides and nutrients from the soil surface or as internal drainage to tile drains (Magesan *et al*., 1995; Kladivko *et al*., 1999; Stamm *et al*., 1998). While some have noted that SOM or clay can slow movement of some pesticides and complex certain organic and inorganic components of runoff or leachate, the effect, for a variety of reasons, is not always simple and does not always favor sequestration. Shipitalo *et al*. (2000) noted that "If a heavy, intense storm occurs shortly after surface application of an agricultural chemical to soils with well-developed macroporosity, the water transmitted to the subsoil by the macropores may contain significant amounts of applied chemical, up to a few percent, regardless of the affinity of the chemical for the soil." Temminghoff *et al*. (1998) found that dissolved organic matter enhanced Cu mobility. Several researchers have shown that increased microbial activity along and in proximity to macropores accelerates nitrogen mineralization and degradation and remobilization of organic pesticides and organically complexed minerals at these sites. This ultimately results in mobilization of nitrogen and other chemicals and nutrients into macropores (Hagedorn *et al*., 1999; Pivetz and Steenhuis, 1995; Mallawatantri *et al*., 1996).

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, and to surface water fed by runoff or springs (Beauchemin *et al*., 1998; Heckrath *et al*., 1995; Stamm *et al*., 1998).

Organic matter darkens soils. During early spring soil temperature is higher in darker soils improving crop emergence and early growth in temperate regions.

Higher mid-season soil temperature, however, is detrimental to production and quality of many field and vegetable crops, especially in hot climates.

Deileman *et al.* (1997) reported that broadleaf weeds typically infested areas with higher SOM. Medlin *et al.* (2001) saw increased infestation of sickelpod in soybean in areas higher in SOM and, in 1 year of their 2-year study, SOM was the highest correlating factor for morning-glory infestation. Benoit *et al.* (1992) noted that organic soils, either cultivated or under grassland had significantly larger total weed seedbanks than mineral soils. Other studies of soil property correlations with weed seedbank size have shown significant correlations of SOM (measured as loss on ignition) with seed content for some weed species (Andreasen *et al.*, 1991; Heisel *et al.*, 1999). In a study of spatial distribution of weed emergence in cotton (*Gossypium hirsutum* L.), Gaston *et al.* (2001) reported that weed densities were significantly greater both in herbicide treated and untreated sampling areas where soils had higher organic C and finer texture, whereas areas of low organic C and coarse soil often had no weeds, sometimes for 2 years after an initial herbicide treatment. This finding is particularly noteworthy since clay content and organic carbon content increase the amount of soil-incorporated pesticide application needed to achieve efficacy. Therefore, soil organic carbon both favored weed occurrence as well as interfered with weed control while also increasing human pesticide exposure and environmental loading.

Banks *et al.* (1976) reported higher weed infestations in areas that received regular fertilizer and lime application. Rew and Cousens (2001) and Medlin *et al.* (2001) reviewed studies linking soil properties and weed populations and/or weed seedbank size for a number of weed species and soils. Their reviews noted that in most instances soil properties favoring crop growth also favored weed growth and/or weed seed accumulation, but not always. Low fertility, extreme pH, coarse texture, and other factors sometimes favored specific weed species, even further complicating the positive or negative scoring of given traits for soil quality where a weed competition and herbicide requirement component is properly integrated into the evaluation.

Addition of manure or green manure to low organic matter soils increased colonization and performance of vesicular arbuscular mycorrhiza, whereas they were suppressed by manure 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).

Sojka and Upchurch (1999) asked, in light of publication of Milnear and Amy (1996), what negative weighting should be assigned to SOM for its role in trihalomethane (THM) contamination of chlorinated drinking water sources? Karlen *et al.* (2001) did not respond to this question. Thus, we feel it is important to restate the concern and provide additional evidence for its relevance.

A vast array of halogenated organic compounds known as disinfection by-products (DPBs), that result from treatment of drinking water, have been linked to or implicated in increased risk of bladder and colo-rectal cancers, increased mutagenic effects and reproductive interference, developmental problems and immuno/neuro-toxicities (Boorman *et al*., 1999; Clark *et al*., 1986; Morris *et al*., 1992; Doyle *et al*., 1997; Hildesheim *et al*., 1998; Cantor *et al*., 1998; Milnear and Amy, 1996; Waller *et al*., 1998). In 1979, under the "Safe Drinking Water Act," the USEPA required that THMs not exceed 100 μg/l. Under stage 1 of the "Disinfectant/Disisnfection By-Product (D/DBP) Rule" the limit was lowered to 80 μg/l, with a sum of 60 μg/l for the sum of five haloacetic acids and a limit of 10 μg/l for bromate (USEPA, 1993). Furthermore, strict pretreatment requirements are in place to reduce DPB precursors in surface waters. In general, regulation of THMs is stricter in the European Community but laxer throughout the rest of the world. Simpson and Hayes (1998) noted that the occurrence of DBPs and THMs are attributed to treatment of waters generally high in organics and with high levels of DOC; they stated "The removal of natural organics prior to disinfection represents the best option for DBP reduction as new technologies aimed at improving the effectiveness of this process would be well received by the water industry internationally." Fujii *et al*. (1998) identified the DOC contribution to public waters from organic soils as a significant problem because of the occurrence of THM precursors in the DOC and the increased risk and cost associated with water treatment. Black *et al*. (1996) also identified the strategy of removing organic carbon from water prior to treatment in order to reduce cancer risk and Boorman *et al*. (1999) called for more research into the link between the toxicity of DBPs and source water variables related to "natural organic matter" in the treated water. Bergamaschi *et al*. (1999) found that leachates of agricultural fields planted to corn were prone to formation of DOC precursors to THMs. Ludwig *et al*. (2000) noted that dissolved organic carbon (DOC) in seepage water can combine with organic pollutants, with Al and heavy metal ions and transport them through the soil profile with a potential to contaminate groundwater.

Freeman *et al*. (2001) reported a 65% increase in DOC concentration in water draining from upland catchments in the UK, in the past 12 years. Their research suggests that further increases in the release of DOC from peatlands are likely if global temperatures rise. They showed that a key terrestrial carbon store could be in the process of being relocated to the ocean, and call for investigation of the impact on the recipient ecosystems. The DOC being released is selectively enriched with phenolic compounds, which are noteworthy in their metabolic inhibitory character.

Higher SOM has numerous production benefits. However, there are also production negatives. But, more importantly, responsible science and the institutional definition of soil quality (Mausbach and Tugel, 1995) requires that these be assessed against simultaneous environmental and human health impacts. If the institutional deployment of the paradigm is true to its stated definition and principles, the unqualified endorsement of increasing SOM without seriously looking at case-by-case cost benefit analysis and risk assessment cannot be justified.

Sojka and Upchurch (1999) noted that the soil quality paradigm affords great positive weight to earthworms in its assessment indices. Earthworms can benefit crop production. However, they can also produce negative effects. Karlen *et al.* (2001) did not respond to the concerns noted regarding this indicator. Thus, we restate the concern and provide additional evidence for its relevance.

Earthworm burrows increase by-pass 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 non-uniformity of water application, impacting 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 (Helling and Larink, 1998; 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, present an obvious ecological risk related to groundwater nitrate management. These effects of earthworm activity contribute to the need to use nitrification inhibitors for N conservation and groundwater protection (more agrochemical use, human exposure and costs). Earthworm populations are higher on more fertile, higher SOM content soils. Thus, negative environmental impacts related to nutrient solubilization, transport and ancillary chemical use 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; Marialigeti, 1979; Hutchison and Kamel, 1956). This vectoring is direct at short range, via ingestion in and through the gut followed by supra/subterranean 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 unidirectional; they vary with species and geographic adaptation. Increased bulk density 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 to non-digested aggregates. Earthworms reduced water retention and sorptivity, which impaired soil–plant water relations, increased crop water stress and reduced rice yield 43% (Pashanasi *et al*., 1996).

Le Bayon and Binet (1999) pointed to the need for specific analysis of individual scenarios when ascribing benefit or detriment to earthworm activity. Their study concluded "earthworms greatly contribute to soil erosion, especially from compacted soils, by their casting activity." They also noted the link between phosphorous enrichment of surface runoff waters and worm cast disintegration. Similarly, Borken *et al.* (2000) noted that whether earthworms reduced or increased the production of the highly potent greenhouse gases, methane and nitrous oxide, depended upon several aspects of soil management. In a study of earthworm and soil moisture effects on the productivity and structure of grassland communities, Zaller and Arnone (1999) found that earthworm activity had no effect on aboveground biomass production of the plant community or on any plant functionality.

Shipitalo and Gibbs (2000) studied the flow paths of macropores caused by earthworms and concluded that "earthworm burrows in close proximity to tile lines may expedite transmission of injected wastes offsite." Their work was prompted by numerous reports in Ohio of animal wastes detected in tile outlets shortly after injection into farm fields. The problem seemed more prevalent when application was in no-till fields, drawing suspicion that the greater worm population associated with no-till management caused the increased transmission of animal-waste-derived contaminants (Widman, 1998). Management to achieve improved soil properties (synonymous with soil quality) through organic slurry application caused a negative synergism for this problem, since the wastes increase the food available to the earthworms, increasing their populations up to 53% (Curry, 1976), and exacerbating the prevalence of conducting macropores (Haraldsen *et al*., 1994). Use of no-till worsened the scenario by increasing the persistence of burrows in the absence of tillage disturbance. To make matters worse, the improved soil aeration associated with tiling fields for improved crop production further stimulated earthworm populations (Carter *et al*., 1982). As Shipitalo and Gibbs (2000) noted, earthworm burrows, unlike cracks, remain open even when soil water contents increase (Friend and Chan, 1995). There is also a tendency for burrows to be directly hydraulically linked to tile drain back fill areas. These burrows can be as deep as 2.4 m and as large as 12 mm in diameter (Urbánek and Doležal, 1992; Edwards and Bohlen, 1996). Infiltration rates for a single burrow were reported to range from 41 to 1005 ml/min by Shipitalo and Butt (1999) and from 37 to 284 ml/min by Wang *et al*. (1994). Such drastic impacts on transport, residence time, and nutrient or pesticide transformation opportunity time clearly demonstrate that earthworm activities can have both positive and negative consequences to the environment, to human health and hygiene, and to agronomic management.

Higher earthworm populations can have production benefits. However, there are also production negatives. More importantly, responsible science and the institutional definition of soil quality (Mausbach and Tugel, 1995) require that these be assessed against simultaneous environmental and human health impacts. If institutional deployment of the paradigm is true to its stated definition and principles, unqualified endorsement of increasing earthworms without seriously looking at case-by-case cost benefit analysis and risk assessment cannot be justified.

Sojka and Upchurch (1999) noted that the soil quality paradigm affords positive weight to enhanced macroporosity and low bulk density in its assessment indices. These attributes can benefit crop production. However, they can also produce negative effects. Some of the negative effects of high macroporosity were addressed in the sections above. Karlen *et al.* (2001) did not respond to the concerns listed regarding these issues. Thus, we restate them and provide additional evidence for their relevance.

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 also reduced by-pass flow by restricting macropores (Starett *et al.*, 1996).

Silva *et al.* (2000) found that transport through soil macropores >600 μm was responsible for 98% of the N leaching in their study of cow urine movement in soil profiles. The rapid transport of water and solute through macropores decreased soil residence time of N, leaching urea-N or NH_4-N before it could be converted to NO_3-N. When macropores were prevented from conducting, by applying a 0.5 kPa suction, the urine N remained in the profile longer, allowing N to be transformed from urea-N to NO_3-N, which was then denitrified or immobilized. The implications for managers are clear: take stock off pastures before irrigating. The implication for inherent soil quality scoring sans management is also clear. Macropores are not always good. They can be bad, especially if you are not in a position to manage water application, but are forced to deal with the conjunction of stocking presence and rainfall.

Low bulk density and high porosity have production benefits. There are also production negatives. More importantly, responsible science and the institutional definition of soil quality (Mausbach and Tugel, 1995) require that these be assessed against simultaneous environmental and human health impacts. If institutional deployment of the paradigm is true to its stated definition and principles, unqualified endorsement of low bulk density and high porosity, without seriously looking at case-by-case cost benefit analysis and risk assessment, cannot be justified.

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)." Microbiologists acknowledge that critical roles and functions of most soil microorganisms are yet to be fully explained. Because the specific functions of most soil microorganisms are unknown or poorly understood it seems unreasonable to interpret increased microbial biomass and activity unequivocally as positive indicators. If specific microorganisms are pathogenic or otherwise deleterious to production, the environment or human health, their contribution to community biomass and function must be weighed negatively.

Microorganisms can affect physical processes. Lindqvist and Enfield (1992) saw an eightfold increase in DDT transport 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 plant roots for oxygen, accelerating onset of soil hypoxia or anoxia. As redox potentials shift, facultative and obligate anaerobes can produce toxic metabolic by-products that further impair crops.

Vaudaux (1998) noted that distinction between environment and public health is arbitrary when dealing with pollutants. He called for better recognition of the environmental health hazards of "microbiological pollution." He stated "a strategy to combat microbiological pollution must be based on reduction of the microbiological load of the environment for pathogenic agents." He further noted "Data from various health agencies indicate that microbiological pollution is considerably more responsible for human suffering than chemical and radiological agents combined." Soil quality assessments of biodiversity or bioactivity need to include specific analysis for presence and rating impact of plant, animal and human pathogens to meet the criteria of the institutional soil quality definition (Mausbach and Tugel, 1995). The potential seriousness of failure to objectively consider pathogens as a component of biodiversity is exemplified by recent reports in which common soil microorganisms were implicated as possibly linked to onset of multiple sclerosis (MS) and bovine spongiform encephalitis (BSE). In humans BSE is known as variant Creuzfeldt Jacobs disease or vCJD (Coghlan, 2001).

Management for the explicit goal of elevating organic matter and bioactivity to improve soil quality ratings often uses a strategy of manure and biosolids additions to soil. Without testing for specific microorganisms, Vaudaux's concerns apply to pursuit of the soil quality paradigm. This concern could have particular validity to underdeveloped settings where raw animal and human wastes are the most common source of nutrients and OM, and where promotion of soil quality standards without adequate coupling to hygiene education and cautionary management measures could endanger human health. Even the developed world is not immune to this potential pitfall of a SOM-based soil quality management strategy as we grapple with ways to improve our ability to dispose of sewage sludge and animal wastes from Confined Animal Feeding Operations (CAFOs). Recent epidemics of coliform contamination in North America bear this out. If one were to ask citizens of Walkerton, Ontario, Canada to weight soil quality index components, knowing that extent of animal waste utilization might be affected by the index structure, they might recommend a negative weighting for SOM. It has only been a few years since Walkerton gained prominence in the environmental news, when seven of its citizens died and thousands were made seriously ill by agricultural runoff containing *Escherichia coli* (O157:H7). Their concerns for human health and hygiene might demand assurance that dangerous organisms never have another opportunity to contaminate their water supply, regardless of whether SOM levels declined as a result.

The work of Gagliardi and Karns (2000) points to another difficulty of assigning a quality rating to soils, where the quality assessment involves an environmental or human hygiene function. They tracked the movement of *E. coli* O157:H7 strain B6914 from treated soils and showed that the amount and mode of loss of the organism depended both on soil properties and management. Finer textured soils showed runoff losses, whereas coarser textured soils showed leachate losses. The amount and timing of losses were affected by tillage and soil nitrogen status. Addition of manure and nitrogen, which are practices often aimed at improving soil quality ratings for production, or for bioactivity or biodiversity, increased O157:H7 reproduction and transport. Similar dangers exist for the spread of *Cryptosporidium parvum*. *C. parvum* sickened over 400,000 residents of Milwaukee, Wisconsin in 1993 (Comis, 1999). Manure application to improve soil quality ratings for production-potential or for bioactivity/diversity carries significant environmental and human hygiene risks in the absence of additional well-rounded management guidelines. Depending on the soil texture, the mode of risk expression is shifted from surface water contamination to groundwater contamination.

Important microbially mediated soil quality indicators are highly spatially variable (Parkin, 1993; Rochette *et al*., 1991). Numerous studies have shown that microbial activity, populations and diversity near macropores is vastly different than within the soil matrix (Bundt *et al*., 2001; Mallawatantri *et al*., 1996; Pivetz and Steenhuis, 1995; Vinther *et al*., 1999). Various other sources of soil heterogeneity contribute to irregular occurrences of microbial “hot spots” including variations in aggregate properties (Cambardella and Elliott, 1993; Chotte *et al*., 1998; Tiedje *et al*., 1984; Sextone *et al*., 1985), variations in pore sizes (Juma, 1993), accumulated particulate organic matter (Parkin, 1987; van Noorwijk *et al*., 1993), animal manure (Nielsen and Revsbech, 1998; Petersen *et al*., 1996) and rhizosphere influences (Joergensen, 2000). All these sources of variability greatly complicate the sampling strategy and intensity necessary to get an adequate and accurate picture of field, farm, landscape, or regional soil microbial status.

Soil respiration varies greatly in short time periods. Influencing factors include soil disturbance, season, substrate introduction and current vegetation photosynthesis, vegetation and/or plant community shifts, above- and below-ground macro- and meso-faunal activities, grazing or mowing, as well as fluctuating temperature, soil water, aeration, and radiation (solar/UV), plus fumigation, fire, exposure to smoke, agrochemical application, certain xenobiotics and heavy metals (Akinremi *et al*., 1999; Boone *et al*., 1998; Bremer *et al*., 1998; Davidson *et al*., 1998; Edwards, 1975; Ewel *et al*., 1987; Fitter *et al*., 1998; Focht, 1999; Garcia and Rice, 1994; Gordon *et al*., 1987; Grahammer *et al*., 1991; Högberg *et al*., 2001; Howard and Howard, 1979; Kirschbaum, 1995; Lloyd and Taylor, 1994; Peterjohn *et al*., 1993; Raich and Potter, 1995; Raich and Schlesinger, 1992; Rustad and Fernandez, 1998; Rustad *et al*., 2000; Schlenter and Van Cleve, 1985; Schleser, 1982; Singh and Gupta, 1977; Tewary *et al*., 1982; Weber, 1990; Winkler *et al*., 1996; Witkamp, 1969). It is unclear which of these highly complex and transient states should be the benchmark condition for soil quality respiration assessment. Respiration status changes radically 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 and Lindstrom, 1993). Such perturbations have always defied simple extrapolation of *in situ* respiration to a general assessment of soil status and will not likely soon be resolved.

A major rationale for soil quality assessment and management is to insure 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. Overly valuing SOM as an indicator of production potential also encourages exploitation of soils having high potential for SOM oxidation and CO_2 release to the atmosphere.

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) barely support plant life. The first institutional use of a soil quality index devalued US 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 management. Aggregate stability, porosity, hydraulic conductivity, and aeration of low SOM irrigated soils are negatively impacted by distilled water but are improved if irrigation balances divalent cation delivery (adding calcium salts with irrigation water) and leaching (Rhoades, 1972, 1998). Soil salinity alone is an unreliable productivity index without knowing the crop to be grown, the nature of the soil salinity (exchangeable sodium percentage—ESP, boron content, etc.), the quality of the water (sodium adsorption ratio—SAR and electrical conductivity—EC), and the amount, timing, leaching fraction and evaporation path of irrigation water at the soil surface affecting salt deposition relative to plant rows. These management factors govern the ability of salt-threatened soil to function more than intrinsic soil properties (Rhoades, 1972, 1998).

IX. FOCUS THE MESSAGE AND PRIORITIZE THE EFFORTS

Pimentel (2000) listed three reasons why erosion control has not received the research and mitigation support it deserves, given the magnitude of its threat to humanity. The reasons were erosion's insidious nature, its slowness relative to human perception, and the public's lack of regard for the value of soil. He reasons, therefore, that "the soil erosion issue is out-competed by many other more dramatic events requiring public attention." We submit that there are other reasons why erosion abatement does not receive the research or conservation support it deserves—reasons for which we, the soil science community, share culpability. They are our failure to prioritize, communicate unambiguously, and, as communicators say, "stay on message."

We believe that holistic lumping together sets of problems, focusing on whole-system assessments of what Leopold (1941) termed "sickness," rather than using reductionist diagnostics, prioritized problem identification and amelioration, is a mistake. The environmental "health" philosophy is hotly debated across the environmental and resource sciences. As stated earlier, we recognize the value of collections of measures to characterize soils or other ecosystems or ecosystem components. It has been a routine approach to the science for decades. But, even health assessments rely on "triage" to prioritize action.

In the emergency room, the chest wound takes priority over the blistered foot. In the doctor's office, cancer is controlled before prescribing an exercise regime for muscle tone. Charities raise funds to battle specific maladies such as muscular dystrophy, heart disease and leukemia, not to defeat "poor health" nor to promote "good health." Similarly, we believe that environmental stewardship and soil conservation, are better served by staying on message. To be effective, we need to cogently communicate specific prioritized problems. We need to focus attention on research and action toward prioritized, clearly identifiable, important and achievable solutions. We should avoid confusing the pedologically uninformed public and its funding agencies with unspecific concepts that we as scientists do not agree upon. Failing to stay on message, to be specific and to categorically prioritize, risks leaving a poorly informed public the option to overemphasize popular, but less critical issues while underemphasizing more critical but less well recognized or less politically correct issues. If we want to control erosion, we need to identify erosion as the problem, not poor soil quality. Erosion imparts a specific image and target for conservation activists. Soil quality means different things to different audiences, in different places and even on different days.

How soil quality takes on different meaning and policy implications in different settings can be better understood by comparing European and US agro-environmental perspectives. Potter (1998) explored the basis for different expressions of agro-environmental reform policies in the USA, UK and EU. He postulated that in the US, erosion abatement and production management dominate the influences that have shaped policy, whereas in Europe chemical pollution abatement and concern for cultural integration of agriculture as manifest through landscape management are driving influences. In this context, soil quality assessment as a soil profile contamination-fighting tool is a conceptually discreet approach that fits and serves the European outlook reasonably well. In Europe, continental erosion is less dramatic than in the US and agricultural production is more highly subsidized and seen as essential to strategic and cultural independence, rather than as a spark plug of the economic engine. Institutionalization of soil quality in the US has been far less tentative than in Europe, despite a much more complex US definition and potentially expansive implementation and ramifications.

Thus, international gatherings addressing soil quality must translate what each group means by soil quality. A largely production/erosion-driven soil conservation paradigm has shaped the soil quality movement to suit the US focus, whereas a pollution-driven paradigm suits Europe. Does it not make much more sense to address erosion, pollution, etc. in the first place?

Karlen *et al.* (2001) chronicled development of the soil quality concept, listing the scientific disciplines and agencies that contributed to and influenced its direction and principles. However, we note that while calls for indices and institutional frameworks by scientists and government agencies are documented, no public call for the resulting indexing approach and institutionalization is documented. In their discussion of soil quality indexing they state "The expert opinion process functions best when a multidisciplinary team of scientists representing agronomy, ecology, economics, engineering, entomology, pathology, soil science, social science, or any other discipline deemed critical for the assessment being made can be assembled with land owners, operators, and other stakeholders." This statement points to the complexity of indexing soil quality. However, it also removes any allusion to the base problems of managers that would explain the need for institutionalized indexing as an outcome.

Lackey (2001) pointed to the same problem of balancing ecosystem assessment or indexing needs, versus the agenda of scientists or bureaucrats with vested interests in concept development. He stated:

> Understanding the values and preferences of society is crucial to appropriately implementing concepts of ecosystem health, but obtaining such understanding

> credibly is difficult. To assert, however, that concepts of ecosystem health are merely scientific constructs is incorrect. As Russow (1995) concludes, “The claim that scientific descriptions in general or measures of ecosystem health in particular are value neutral is simply false.” The likely alternative to public involvement is that the values of scientists and other technocrats will be used as surrogates for societal values and preferences.

We think implicit in Lackey’s statement is also the responsibility of public institutions promoting such arbitrary concepts to acknowledge, respond to and affect change based on criticism and dissent from within the scientific community.

X. ADVOCACY VERSUS SCIENCE

Karlen *et al.* (2001) defend advocacy and incorporation of external values in soil quality assessment. They state “. . .all decisions are value-laden and dominated by personal experiences and expectations (Keeney and Raiffa, 1976; Mayhew and Alessi, 1998). Even seemingly objective decisions, such as which grant proposals to fund, are driven by personal social values and preferences (Keeney, 1992). Given that all decisions are biased, who is better qualified to interpret scientific indicators than the scientists who developed them.” We take exception to every tenet in the above quote. We question the validity of value-laden indicators to begin with, and see advocation of them as a compounded problem. Index developers have an obvious conflict of interest regarding interpretation of validity and scientific merit of the index they developed.

Those steeped in the debate about value intrusion in sciences (especially applied sciences) are quick to emphasize that this debate is complex and arguments favoring detachment versus involvement cannot be set aside trivially. As Rykiel (2001a) stated “Scientists should be both objective and concerned. However, they bear a special responsibility to make a distinction between scientific statements and the values they associate with those statements.” Elsewhere Rykiel (2001b) notes that “Policy, which is our attempt to implement what ought to be, is based on values, not science.” Whereas he states “The work of science is to understand what is and how what is can lead to what might be. The work of policymakers is to wrestle what is and what might be into what ought to be.”

Government decisions and public policy may contain bias, they may be forced to. We contend, however, that the science that serves as the information base for making decisions should strive to be as free as possible of bias and values. The Karlen *et al.* (2001) quote above is insensitive to the soil quality paradigm’s and institutional infrastructure’s consistent failure to even inform users that there is scientific debate about the concept, its use, and the interpretation of soil quality indices—a debate which advocates have only acknowledged when forced to do so. That itself is one problem of advocacy within science.

Who is better to interpret? In the case of soil quality, the existence of criticism within the science implies that not everyone agrees on whose interpretation is or should be regarded as authoritative. This is particularly noteworthy where interpretation leads to institutionalization and public policy implications or even recommendation of enforced policy (National Research Council, 1993). If nothing else, the existence of credible critics implies that any given interpretation is not unilaterally and doctrinally authoritative and would seem to demand care to at least note and cite counterarguments if not indeed present and consider them in detail.

The difficulty of taking an advocative stance, that is, promoting a set of arbitrarily assigned values and policies within the construct of a supposedly empirical analytical index, is that the scientist ceases to be a scientific mediator among information users (managers), other stakeholders, and policy formulators. Instead, the scientist becomes one of the biased factions with vested interests in the outcome. Mackey (1999) explained the danger of scientists as advocates, "...the critical role scientists should be playing is that of mediators rather than advocates. The Oxford Dictionary defines an advocate as one who pleads the cause of another, or one who pleads, intercedes, or speaks for another. By practice, an advocate does not take an objective look at a situation and weigh the pros and cons to arrive at a reasoned position. The classical behavior of a lawyer in a court is therefore anathema to a good scientist." He goes on to say that in contrast to an advocate, a mediator, "...uses the skills and knowledge at their disposal to help resolve a situation. The role of a mediator is neither neutral nor weak. On the contrary, it implies there is a concrete goal to be achieved, and that there are feuding advocates who need the wisdom of the mediator to help achieve a satisfactory solution. There are plenty of activists but precious few mediators."

We might even go further than this and argue that mediation is not the right construct either, but that as scientists our role is to reliably and without bias inform the debate. Pouyat (1999) said much the same thing, "if biologists and ecologists wish to be taken seriously in the policymaking process, they must work at being viewed as members of the scientific community rather than as part of the advocacy community." As Rykiel (2001a) commented on this quote, "policy-makers want the truth from scientists, not their personal opinions."

Truly scientific decisions are not biased and they do not depend on personal values or the beliefs of the person making or interpreting the measurements. Deciding if one object is hotter or colder than another does not require personal values, it requires temperature measurement. Deciding how much of chemical A must be added to chemical B for a complete reaction depends on knowledge of the system's chemistry and physics, not personal values. Deciding if it is reasonable to expect a soil to support nitrogen fixation depends on presence of symbiotic bacteria, not personal values or opinions or even the output of a soil quality model. Deciding if it is likely that a seed will germinate is determined by the critical soil water content for seed germination, the seed response to water, bulk density, temperature, soil chemistry, salinity and aeration, not personal opinion, economics or social values. Deciding on whether a given soil has a 100% rating for crop productivity is entirely dependent on the subjective social, economic, and philosophical parameters and perceptions that affect the choice of and interpretation of cropping system and arbitrarily acceptable or unacceptable system inputs. To argue, as do Karlen *et al.* (2001), that soil quality assessment is scientific, and in the same breath state it is justifiably as socially biased as grant proposal evaluation, is a contradiction in terms.

If the rationale is that soil quality assessment is as humanly biased as grant proposal evaluation, then we argue for abandonment of the soil quality paradigm based on that presumption alone. A scientific index does not hinge on quixotic social, cultural, political, economic, programmatic, or topical values. A scientific index is accurate whether employed by a scientist or a non-scientist, under any circumstance by simple virtue of its adherence to universal scientific principles and physical reality.

All decisions are not biased. Decisions depending on personal, cultural, economic, political, programmatic, or topical factors are inherently biased, but they should be forthrightly recognized as non-scientific decisions. And if it is these kinds of decisions that support or determine an index, then the index must be recognized as other than an objective scientific index. Objectivity is the purpose of science. Subjectivity is the purpose of values and belief systems. Science is evidence-driven. Values and belief systems are faith or conviction-driven.

Karlen *et al.* (1997) noted in their conclusions that the concept of soil quality is “emotional and evolving.” We think it is fair to ask why that is so and what the implications of that statement are for a scientific concept, especially one already being institutionalized and suggested as a basis for government policy formulation. What issues have made the soil quality concept emotional? Karlen *et al.* (1997) attributed the emotionalism to different cultural views of soil. We submit that the reasons for the debate being emotional go far beyond that. Sources of emotion include concerns stemming from scientific, social and cultural value differences, problems and/or perceptions of unfairness and/or exclusivity, regional or taxonomic bias, unobjective data and parameter evaluation, premature institutionalization, concept redundancy, concept ambiguity, devaluing/renaming previously established functional concepts, disagreements about scientific approach, excessive emphasis on organic matter and organically oriented agricultural approaches, and concern for policy implications and intrusion of political correctness into the management philosophy of the soil resource.

Acknowledging that the concept is still evolving, while already institutionalizing it, troubles many scientists’ sense of system logic. This concern is compounded by the fact that many are unconvinced that the new paradigm has fully met the challenge of the scientific method. In 1984, Stephen Gould stated that "Science is all those things which are confirmed to such a degree that it would be unreasonable to withhold one's provisional consent (Mackay, 1991)." Consensus does not exist in the community of soil scientists regarding soil quality, despite institutionalization.

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). A number of scientists have noted the potential pitfalls of the soil quality concept because of its heavy reliance upon numerous subjective concepts and value judgments (Linser, 1965; Letey *et al*., 2003; Schönberger and Wiese, 1991; Singer and Ewing, 2000; Singer and Sojka, 2001; Sojka and Upchurch, 1999).

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), raising significant questions as to its 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.

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 be interpreted as degree of excellence, as in the conformance to a measurable standard; or it can refer to a categorical attribute or characteristic; in the environmental context, it has come to mean freedom from pollution. "Value" can mean financial, spiritual, emotional, cultural, or strategic worth; or it can mean the quantified numerical measure of a statistically analyzable parameter.

Doran *et al*. (1996) also noted communication problems among various interested constituents concerning the term soil health. He noted that the dictionary defines health as the condition of an organism or one of its parts in which it performs its vital functions normally or properly. However, he also pointed out that this was by no means a satisfying definition for all scientists or stewards of the land, stating that the term has factionalized academics, environmentalists, farmers and public land managers, with the end result that "The producers, and therefore society's management of the soil, are caught in the middle of these opposing views and the communication failures that result." Nonetheless, Doran *et al.* (1996) chose to use the term soil health as one completely interchangeable, and even preferable to soil quality. We see this as adding to the confusion of the US soil quality lexicon, which has an institutional definition that reserves the specific term soil quality to indicate the absolute potential of a given soil compared to other soils, and refers to the present state of the soil as its condition or health (Mausbach and Tugel, 1995).

If the reader is not convinced that the soil quality paradigm and its various academic and institutionalized definitions and nomenclature have detrimentally impacted the technical lexicon of soil science, we would refer them to Patzel *et al.* (2000) who attempts to derive the etymology and epistemological basis of the terms soil fertility and soil quality. You may share our surprise at their conclusion that soil quality is a more precise and functionally specific term than soil fertility, stating "the concept of soil fertility has an almost infinite number of definitions." They further assert "Firstly, the term "soil fertility" cannot be shaped as a technical term of natural sciences… Secondly, the term "soil fertility" is considered to be a qualitative dispositional term, which is not completely operationalizable in natural sciences, as its actual value can never be verified." The paper by Patzel *et al.* (2000) ignores 100 years of clear communication by soil fertility experts and texts and attempts to convince us the last decade of disagreement about the meaning of soil quality is preferable. The Soil Science Society of America Glossary of Soil Science Terms clearly defines soil fertility as "The relative ability of a soil to supply the nutrients essential to plant growth," (Soil Science Society of America, 1998). Lamentably Patzel *et al.* took no account of the mounting specific arguments in the literature (of which they were eminently aware) criticizing the term soil quality for having etymological attributes precisely the opposite of those that they assert. Meanwhile, to date, the literature uses the term soil quality ubiquitously and almost exclusively to mean productivity. This is despite an elaborate and repeated recitation of the mantra that soil quality refers to current status of the soil for a given function, based on the seminal rationale of Larson and Pierce (1991, 1994) and Pierce and Larson (1993) who proposed the term as a means of assessing transient soil status and expressly advocated movement away from a dominant application of the term to be productivity. To date the only application of soil quality has been as a substitute term for the given function of soil productivity.

The preference of Doran *et al.* (1996) for the term soil health as a substitute hardly helps reduce the confusion deepened by Patzel *et al.* (2000). Most soil biologists and microbiologists, meanwhile, weight the term soil health to connote the diversity and/or activity of the spectrum of soil biota. Whereas, institutionally, transient soil status is defined interchangeably (for any specified use) as soil condition or soil health, even if that use is to support structures, provide insulation, or any other engineering use, which often prefers soil sterility over biotic activity, or even SOM enrichment.

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.

Management does legitimately utilize scientific input to make decisions, where the objective inputs are coupled with values to determine an outcome. However, if the inputs are already biased by values, the manager will unwittingly be at the mercy of someone else's judgment. This may be tolerable if the manager understands and agrees with the pre-existing bias. But where most index users are oblivious to the scientific debate or left uninformed of the debate surrounding an index, it makes managers using an index pawns to someone else's value system, possibly even supporting a paradigm that the manager would otherwise choose to oppose if better informed.

In a recent essay, Deichmann (2000) discussed the spectrum of implications and potential consequences for linking science to expedient policy, even if defined by proponents as being for the public good. He stated "...the call for politically responsible science, and hence more power for scientists, does not guarantee an ethical stance." Environmentalists' attempts in the 1980s to create a "political ecology" as the "guiding science of post-modernism" is a case in point. The intellectual origins of their criticisms of "causal reductionist" science lie in the 1920s when German ecologists, among them Karl Friedrich, proclaimed ecology as a path to "a view of the world, in which everything is related to everything else, everything directly or indirectly affects everything else." Friedrich expanded this view of biology as a doctrine aimed at serving "the benefit of the people," which was quickly subverted by the emerging political regime under the "doctrine of blood and soil." We might add: when values are mixed with science, science can lose control over which values and agendas are ultimately served and whose interpretations will ultimately be empowered or for what motivations.

We feel there needs to be clear separation between scientific analysis and formation or enforcement of public policy. Furthermore, between the two must be a scientist-mediator, knowledgeable about specific data, communicating with an information user who is knowledgeable about specific systems needs, limits and potentials. Substituting formulaic indices and simple analytical kits so that the uninformed in science or policy can make oversimplified do-it-yourself decisions seems an imprudent course for agronomic farm management, for environmental management, and for regional or national stewardship of farms, farmers, the environment or the general public. We concur with the sentiment of Butler (2000) that "the role of science is to illuminate political choices, not enforce them." And we share his concern for movement toward institutionalization of a non-universal scientific interpretation when "the most outspoken scientists on the matter tend to be those with interests in seeing the technology progress." When there is debate, and particularly when there is sharp debate, Butler notes it is important that the institutions of science (not government or policy) should step to the forefront to guarantee balanced investigation and analysis of issues. Among his suggestions is the need to broaden the expertise of advisory committees. In his editorial he speaks of broadening into the community, but we submit it should also mean broadening to insure that opposing scientific views are aired openly and with equanimity. Singing to the choir does not make for harmonious science. He further suggests that scientists and their professional societies will need to be more active in carving out a role as honest brokers who can help clarify the issues and ensure impartial information. We feel these sentiments apply to the formulation of and institutionalization of the soil quality paradigm.

Given the polarization among the soil science community regarding the soil quality concept, it is surprising the lack of acknowledgment and consideration of the counter arguments that appear in soil quality philosophical and promotional literature, bordering on what Sommer (2001) termed "bahramdipity" which he defines as roughly the opposite of serendipity. Where serendipity might be termed recognition of lucky discovery, bahramdipity might be thought of as intellectual "denial," or sublimation. Bahramdipity can include insistence upon the correctness of an interpretation even in the face of facts presented that undermine or disprove it, and an unwillingness to even consider modifications that correct the disparities. We certainly hope that soil science has not adopted the Red Queen's philosophy that "It's too late to correct it. When you've said a thing that fixes it, and you must take the consequences."

Sojka and Upchurch (1999) included a section discussing "Plausible Ramifications and Unintended Outcomes." That section dealt with plausible impacts of the soil quality concept and the manner of its advocacy on the soil science profession itself and with conceivable broad public policy implications based upon the published statements of soil quality advocates and institutional literature. Rather than repeat that discussion, which is somewhat removed from the concept and philosophy discussion we have assembled in this chapter and which has been alluded to in several of the preceding sections, we direct the interested reader to the previous publication for full consideration of those issues.

XI. GLOBAL PERSPECTIVE

The environmental movement that began in the 1960s brought a unique, and appropriate new view to agricultural production and land management, globally.

However, in recent years, the movement has been captured by elitists, and has evolved more and more toward an anti-science, anti-technology reactionary force. Many of its leaders oppose high-yield crop production technology, including chemical fertilizers, herbicides, insecticides, fungicides, and now genetically modified high-yielding varieties. Critics of modern agricultural technologies should consider the impact on the environment had these technologies not been adopted over the past 40 years. An additional 67 million ha would have been required to provide the same wheat production in India, had farmers continued the use of the low-yielding pre-Green Revolution technology. This is but one example of the positive environmental impact of adoption of high-yield production techniques, including both improved varieties and improved soil management. To put this in perspective, on a global scale, world cereal production increased from 650 million tons in 1950 to 1887 million tons in 1998. Using 1950's technology, it would have required an additional 1150 million ha of cultivated land to produce this yield, while only 650 million ha were actually cultivated.

While we agree that farmers should strive to return organic matter to the soil, through appropriate crop rotations, green manure crops, and animal manures, this does not address the full nutrient needs of the crop nor the environmental consequences discussed earlier in the chapter. Only 60% of our current world population can be supported without the use of chemical nitrogenous fertilizer (Smil, 1999a,b). The Sasakawa-Global 2000 (SG2000) program sponsored by the Nippon Foundation is aimed at food crop production technology transfer projects in sub-Saharan Africa. SG2000 and the Ministry of Agriculture jointly developed a package of improved crop production technologies for increasing food crop production. These include: (1) the use of the best available commercial varieties or hybrids, (2) proper land preparation and seeding to achieve good stand establishment, (3) proper application of the appropriate fertilizers and, when needed, crop protection chemicals, (4) timely weed control, and (5) moisture conservation and/or better water use if under irrigation (Borlaug and Dowswell, 2002). Local farmers using these practices have achieved crop yields two to four times higher than is typical with traditional production methods.

It is generally agreed that world population will increase from the current 6 billion to around 7.6 billion people by the year 2020. It is likely that the demand for cereals, which accounts for 70% of our food supply, will increase by 40–50%. The global arable land area potential for further expansion is limited. Therefore, most increases in global food supply must come from agricultural land already in production. It is estimated that 85% of the total growth in food supply must come from increased yield on land currently under cultivation (Pinstrup-Anderson and Pandya-Lorch, 2000). Formidable challenges exist for bringing unexploited, potentially arable, land into agricultural production. The Brazilian Cerrado, or savanna is a good case in point. The central Cerrado, with 175 million ha in one contiguous block, forms the bulk of the savanna lands. The soils of this area are mostly various types of deep loam to clay-loam latosols (oxisols, ultisols), with good physical properties, but highly leached of nutrients. Thanks to targeted soil and agronomic research, today there is an agricultural revolution underway in the Cerrado. A new generation of improved crop varieties are moving on to farmers field's. Improved crop management systems, built around crop rotations and minimum tillage, that facilitate infiltration and reduce runoff and erosion have been adopted. However, as in all of agriculture, further research is needed to solve specific, identifiable problems. Research is needed to define more exact fertilizer recommendations for various crops grown in the area. Since zero tillage is in widespread use, it is absolutely essential to develop crop rotations to minimize foliar infection with diseases that result from inoculum left in the soil or in crop residue from the previous season. The opening of the Cerrado will help assure an adequate world food supply, assuming wise policies are used to stimulate production.

From a global perspective what is discussed in this chapter is only a portion of a broader issue. The current backlash against agricultural science and technology evident in some industrialized countries is difficult to comprehend. The world has the technology, either available or well advanced in the research pipeline, to feed on a sustainable basis a population of 10 billion people. The more pertinent question is whether farmers and ranchers will be permitted access to the continuing stream of new technologies to meet the challenges ahead. We are not short of new theories, we need people who understand land management.

XII. CONCLUSIONS

Lal and Pierce (1991) stated, regarding stewardship of the soil resource, that "mismanagement and neglect can ruin the fragile resource and become a threat to human survival." Evidence continues to mount that the survival of civilizations has been far less related to the "inherent soil quality" of their lands than to their ability to manage the lands. Indeed, some of the longest continually occupied population centers of the world exist in settings and on soils that the Sinclair *et al.* (1996) model would rate as low quality. While, soil properties certainly played a role, and the management's success was related to the effect of agriculture on soil properties, the scenario was not the opposite. Namely, soil properties did not determine the success and longevity of the civilizations, independent of the management (Mann, 2000).

The needed outputs from soil science to meet the requirements of a sustainable civilization are highly specific and easily identifiable research products and management goals. Their attainment is poorly served by obscuring them in vague quality, condition or health assessments that require deconstruction for interpretation, are not even universally agreed upon by advocates of the approach and which, still worse, divides the scientific community rather than uniting it to achieve specific goals.

Gomes (2000) noted that at present, about 80% of the world's population lives in the poor, developing world. At current rates, in one lifetime of 75 or 80 years, poor countries will increase by 400% while the rich countries will grow by only about 8%. Today 47% of the global population lives in cities, and with virtually all of current growth happening in urban settings, this will be the last generation of humans to live mostly in rural areas. Despite this growth, the land under cultivation, which doubled from 1900 to 1960, has been nearly constant since then.

The miracle of that last sentence deserves some comment. The Green Revolution, which began in the 1960s, marked the triumph of a philosophy that human ingenuity, turned to the management of natural resources and genetic potential (pronounce that agriculture) could end starvation and assure the survival of the species, while simultaneously halting the relentless advance of agriculture onto more and more of nature's domain. Humans continue to expand their presence on the landscape, but the expansion is predominately for non-agricultural purposes. This was accomplished by focusing agricultural research on improving management to enhance production on existing lands. Along with this, again since about the 1960s, there has been an ever-increasing emphasis on achieving production goals while avoiding environmental degradation. This planetary accomplishment was achieved not by meta-scale analysis and meta-scale indexing, but by tackling individual discreet obstacles to production and environmental protection, one at a time, specifically, systematically, relentlessly, using the established and proven reductionist approach to science.

As a result of the soil science and agronomic research that preceded the current institutionalized soil quality paradigm, each American farmer now feeds 143 people (Burton, 2000), more than a doubling since World War II. In the US, barely 2% of the population is engaged in farming and the average urban family spends less than 7% of its annual income on food (Abelson, 1995). Life expectancies in the US and worldwide have increased markedly over the last few generations because of improved food supplies and quality.

Over the same time 25–30 million km^2 (the area of North America or Africa) have been spared from the plow because of improved agronomic and soil management technologies. This one fact is the greatest act of environmental protection achieved in the history of humankind. It has prevented billions of tons of erosion annually, staved off destruction of continental tracks of habitat, and avoided annual introduction of billions of pounds of additional agrochemicals and fertilizers on the lands spared. At the same time, in the last two to three decades, we have greatly reduced dependency on agrochemicals, nutrients, and destructive practices on lands we manage for agriculture. These achievements did not come from devoting the creative engine of agricultural research to renaming existing productivity indices and concepts. They resulted from working to solve pressing and obvious production and environmental problems. These feats point to both the success of the American agricultural research system to provide relevant solutions to the American farmer and to the need to maintain our efforts.

The need to remain focused and to solve problems has not changed. In the next generation, global agricultural production must rise more than 2% per year to meet rising population needs (Waggoner, 1994). This assumes we do not expand agriculture into new lands but, instead, provide our needs from existing farmland. By one estimate, more food must be grown in the first generation of the new millennium than was grown in the preceding 10,000 years of farming (Paarlberg, 1994). Patrick Moore, President of Greenspirit, a non-profit organization devoted to environmentalism, and one of the original founders of Greenpeace, has joined a group of world-renowned environmentalist, political leaders, and scientists (including three Nobel Prize winners) in signing the Declaration in Support of Protecting Nature with High-Yield Farming and Forestry. This group has recognized that the greatest protection to our global environment will come from supplying this increased food demand using currently cultivated land.

Why have we been so outspoken about our concerns for the soil quality paradigm? As this chapter and the Sojka and Upchurch (1999) editorial should make clear, there are a variety of reasons. They can probably be summarized in a few categories.

There are an extensive number of technical problems with the concept. To date, soil quality research has not addressed the important problems pointed out to them by scientists critical of the concept. By its own definition soil quality must function in several ways simultaneously. Many of the functions have contradictory requirements. Optimizing for one requirement can seriously impair others. No effort has been made to attempt integrated assessments. Many individual index components do not objectively weigh the full range of negative and positive impacts on all functions, including the production function. As with any broad index, a negative score must be deconstructed back to original component inputs to guide management. Managers prefer a full range of specific readouts over a red/green warning light.

An index scale must have a threshold for reaction. If we continue to implement soil condition indexes that are little more than red/green indicators, how will we determine either the threshold value for reaction or what the reaction should be? How does one practically integrate this concept to cope with simultaneous conflicting functions? Who will determine the threshold and what are the policy implications for triggering an institutionalized regulatory reaction? Such triggering is determined by weighting of inputs to the index. Weighting can target the wrong functions or may represent social, political, cultural, institutional, and economic biases that do not accurately reflect the management problem or needs. We are far better served by having separate soil productivity indices, soil environmental indices and pedobiological indices that do not confuse the user or run the risk of creating significant negative unintentional outcomes in other functions.

There is regional and taxonomic bias in the concept. This is obvious from the models and maps that have been produced by the soil quality infrastructure that fail to account for documented regional agricultural inputs, environmental damages and economic production. An indexing system that devalues the least subsidized and most profitable soils while ignoring environmental problems in highly-rated soils does a disservice to American agriculture, our environment and the health of citizens. Andrews and Moorman (2002) implied that these criticisms are about regionalism and that because soil quality experiments have now been conducted in several states the criticism has been dealt with. They are wrong. The criticism is about the failure of the soil quality paradigm's indexing approach, which simply becomes obvious when evaluated on a regional scale. It was not our choice to model the nation's soil quality to a single relative scale. Soil scientists cannot be expected to ignore analysis of the model output given its implications and given its failure to explain production or input requirements. We stress the importance of management, because that is what agriculture and soil science and land stewardship embody. That set of values by its very nature is about erasing regional constraints through management. It de-emphasizes regional setting, initial conditions and indexing and looks to performance and outcome. To us every hectare is important. We eschew the labeling of soils as low quality, with the risk of marginalizing their importance. If the soil quality paradigm is positive potential-based, then we suggest placing less emphasis on identifying and classifying relative soil limitations and returning to emphasis on researching the management requirements to eliminate them.

Soil performs a multitude of functions simultaneously. Only management can address the simultaneous needs of soil function. Integrated indexing of simultaneous functions has not been achieved. If it is, again, it will require establishment of response thresholds and index deconstruction to individual inputs for interpretation. What will the index do if the assessed status can only meet the criteria for one function by interfering with another? Ultimately the answer will lie in management to cope with the simultaneous and contradictory needs. It will be a pity if that need cannot be met because research resources were absorbed by indexing efforts instead of finding management solutions.

To meet our obligations to the future, we feel we should prioritize the targeting of our research toward known discrete problems, that are clearly identifiable and defensible, and whose solution can be clearly pointed to with easily measured impact and cost benefit analysis. If we expect to be supported in the work toward solution of known important problems, we need to stay on message, not confuse the public by constantly renaming the problems we are attempting to solve, nor watering down their specific individual importance by homogenizing them in ambiguous feel-good vocabularies that mean all things and nothing to the tax paying public.

The philosophical basis of the soil quality paradigm would lead one to believe that an entirely new and highly complicated soil assessment construct is needed to identify the planet's or individual farmers' most critical problems impacting food and fiber production, economic return and environmental protection. Nothing could be further from the truth. The problems are obvious. The expression of the problems is anything but subtle, and sadly, their impacts on production and the environment are often egregious, not veiled. The key deficiency in natural resource based research is not the ability to locate, identify, and rate problems. The deficiency is our inability to solve them, affordably, promptly, effectively, permanently, sustainably and using approaches, technologies and communication techniques that can be understood by, are practical for and that will be accepted by managers. We do not need investment in developing new yield plateau plots; we need new management to raise the plateaus. The challenge of our generation is to achieve this while simultaneously continuing to improve our protection of the environment.

In the not so distant future, a generation or two, when the authors of this chapter are already achieving the status of mere anecdotal asterisks, the Malthusian projections alluded to in the earlier paragraphs will either be realities, or potential problems that were averted. The latter scenario demands that we make significant choices *now* about how we choose to prioritize our research and invest our research dollars and energy. We submit that choosing to elevate the direct solution of known critical problems is a wiser path than the development of subjective indices for debatable assessment of subtle soil status variations. The next generation of soil scientists, agronomists and environmental stewards and our children and grandchildren will be better served by full stomachs, clean water, clean air and preserved wild lands than by incremental improvement in an arbitrary soil rating.

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