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Quantitative Indicators of Soil Quality: A Minimum Data Set

John W. Doran
USDA-ARS and University of Nebraska
Lincoln, Nebraska

Timothy B. Parkin
USDA-ARS and National Soil Tilth Laboratory
Ames, Iowa

Interest in evaluating soil quality has been stimulated by increasing awareness that *soil* is a critically important component of the earth's biosphere (Glanz, 1995). Soil functions in the production of food and fiber and also in the maintenance of the environment through acting as a filter and environmental buffer for water, air, nutrients, and chemicals. The quality and health of soils determine agricultural sustainability (Acton & Gregorich, 1995), environmental quality (Pierzynski et al., 1994), and, as a consequence of both—plant, animal, and human health (Haberern, 1992). Past management of nature to meet the food and fiber needs of increasing populations has taxed the resiliency of natural processes to maintain global balances of energy and matter (Doran et al., 1996). Within the last decade, inventories of the soil's productive capacity indicate severe degradation on well more than 10% of the earth's vegetated land as a result of soil erosion, atmospheric pollution, excessive tillage, over-grazing, land clearing, salinization, and desertification (Lal, 1994; Sanders, 1992). Findings from a project of the United Nations Environment Program on Global Assessment of Soil Degradation indicate that almost 40% of agricultural land has been adversely affected by human-induced soil degradation, and that more than 6% is degraded to such a degree that restoration of its original productive capacity is only possible through major capital investments (Oldeman, 1994). The quality of surface and subsurface water has been jeopardized in many parts of the world by intensive land management practices and the consequent imbalance in C, N, and water cycling in soil. At present, agriculture is considered the most widespread contributor to nonpoint source water pollution in the USA (CAST, 1992a; National Research Council, 1989). The present threat of global climate change and ozone depletion, through elevated levels of atmospheric gases and altered hydrological cycles, necessitates a better understanding of the effects of land management on soil processes. Soil management practices such as tillage, cropping patterns, and pesticide and fertilizer use are known to influence water quality. These manage-

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Methods for Assessing Soil Quality, SSSA Special Publication 49.

ment practices also influence atmospheric quality through changes in the soil's capacity to produce, consume, or store important atmospheric gases such as carbon dioxide, nitrogen oxides, and methane (CAST, 1992b; Mosier et al., 1991; Rolston et al., 1993).

Developing *sustainable* agricultural management systems is complicated by the need to consider their utility to humans, their efficient use of resources, and their ability to maintain a balance with the environment that is favorable both to humans and most other species (Harwood, 1990). We are challenged to develop management systems that balance the needs and priorities for production of food and fiber with those for a safe and clean environment. In the USA, the importance of soil quality in maintaining this balance was iterated in a recent National Academy of Science publication, "Protecting soil quality, like protecting air and water quality, should be a fundamental goal of national environmental policy" (National Research Council, 1993). The same report recommended that U.S. Department of Agriculture (USDA) and the U.S. Environmental Protection Agency (USEPA) initiate an integrated effort to develop quantifiable standards and cost-effective monitoring methods that can be used to evaluate the effects of farming systems management on soil quality. Defining indicators of soil quality, however, is complicated by the need to consider the multiple functions of soil in maintaining productivity and environmental well-being and to integrate the physical, chemical, and biological soil attributes that define those functions (Papendick & Parr, 1992; Rodale Institute, 1991).

QUANTITATIVE INDICATORS OF SOIL QUALITY

Much like air or water, the *quality* of soil has a profound effect on the health and productivity of a given ecosystem and the environments related to it; however, unlike air or water for which we have quality standards, the definition and quantification of soil quality is complicated by the fact that it is not directly consumed by humans and animals as are air and water. Soil quality is often thought of as an abstract characteristic of soils that cannot be defined because it depends on external factors such as land use and soil management practices, ecosystem and environmental interactions, socioeconomic and political priorities, and so on. Perceptions of what constitutes a good soil vary depending on individual priorities for soil function and intended land use; however, to manage and maintain our soils in an acceptable state for future generations, *soil quality* must be defined, and the definition must be broad enough to encompass the many functions of soil. These considerations led Doran and Parkin (1994) to define *soil quality* as: "The capacity of a soil to function, within ecosystem and land-use boundaries, to sustain biological productivity, maintain environmental quality, and promote plant and animal health."

Quantitative assessment of soil quality is invaluable in determining the sustainability of land management systems. A framework for evaluation or an index of soil quality is needed to identify problem production areas, make realistic estimates of food production, monitor changes in sustainability and environmental quality as related to agricultural management, and to assist government agencies in formulating and evaluating sustainable agricultural and land-use policies (Acton, 1993; Granatstein & Bezdicek, 1992). Effective identification of appropriate indicators for soil health assessment depends on the ability of any approach to consider the multiple components of soil function, in particular, productivity and environmental well-being. Identification of indicators and assessment approaches is further complicated by the multiplicity of physical, chemical, and biological factors that control biogeochemical processes and their variation in intensity over time and space. Practical assessment of soil quality and health, however, requires consideration of the multiple functions of soil and their variations in time and space (Larson & Pierce, 1991).

INDICATORS OF SOIL QUALITY AND HEALTH: A MINIMUM DATA SET

The rapid acceleration of technological growth associated with industrial and postindustrial societies poses a risk to the health of natural ecosystems that are slow to change. Within the context of ecosystem health, Constanza et al. (1992) concluded that an ecological system is healthy if it is active, maintains its organization and autonomy over time, and is resilient to stress. They proposed a long-term strategy for the assessment and improvement of ecosystem health, based on the model used in the practice of human and animal medicine. The assessment of human health in medicine follows a six step sequence: (i) identify symptoms; (ii) identify and measure vital signs; (iii) make a provisional diagnosis (iv) conduct tests to verify the diagnosis; (v) make a prognosis; and (vi) prescribe a treatment.

Assessing soil quality and health can be likened to a medical examination of humans in which certain measurements are taken of the quality of certain parameters as basic indicators of system function (Larson & Pierce, 1991). In a medical exam, the physician takes measurements of body system functions such as temperature, blood pressure, pulse rate, and perhaps certain blood or urine chemistries. The physician also will take note of visible, outward signs of health status. If these basic indicators are outside specific ranges, more diagnostic tests can be conducted to help identify the cause of the problem and find a solution. For example, excessively high blood pressure may indicate a potential for system failure (death) through stroke or cardiac arrest. Because one of the causes of high blood pressure may be improper diet, lack of exercise, or high stress level, the physician may request a secondary blood chemistry test for cholesterol, electrolytes, etc. Assessment of stress level as a causative factor for high blood pressure is less straightforward and generally involves implementing some change in lifestyle followed by periodic monitoring of blood pressure to assess change. This is a good example of using a basic indicator both to identify a problem and to monitor the effects of management on the health of a system.

Applying this human health analogy to soil quality and health is fairly straightforward. Larson and Pierce (1991) proposed that a minimum data set (MDS) of soil parameters be adopted for assessing the health of world soils, and that standardized methodologies and procedures be established to assess changes in the quality of those factors. A set of basic indicators of soil quality and, therefore, health has not previously been defined, largely due to difficulty in defining soil quality and health, the wide range across which soil indicators vary in magnitude and importance, and disagreement among scientists and soil and land managers over which basic indicators should be measured.

Acton and Padbury (1993) defined soil quality attributes as measurable soil properties that influence the capacity of soil to perform crop production or environmental functions. Soil attributes are useful in defining soil quality criteria and serve as indicators of change in quality. Attributes that are most sensitive to management are most desirable as indicators and some such as soil depth, soil organic matter, and electrical conductivity are often affected by soil degradation processes (Arshad & Coen, 1992).

To be practical for use by practitioners, extension workers, conservationists, scientists, and policy makers the set of basic soil quality–health indicators should be useful across a range of ecological and socioeconomic situations. Indicators should:

1. Correlate well with ecosystem processes (this also increases their utility in process oriented modeling);
2. Integrate soil physical, chemical, and biological properties and processes and serve as basic inputs needed for estimation of soil properties or functions which are more difficult to measure directly.
3. Be relatively easy to use under field conditions and be assessable by both specialists and producers.
4. Be sensitive to variations in management and climate. The indicators should be sensitive enough to reflect the influence of management and climate on long-term changes in soil quality but not be so sensitive as to be influenced by short-term weather patterns.
5. Be components of existing soil data bases where possible.

The need for basic soil quality and health indicators is reflected in the question commonly posed by producers, researchers, and conservationists: "What measurements should I make or what can I observe that will help me evaluate the effects of management on soil function now and in the future?" *Too often scientists confine their interests and efforts to the discipline with which they are most familiar.* Microbiologists often limit their studies to soil microbial populations, having little or no regard for soil physical or chemical characteristics that define the limits of activity for microorganisms, plants, and other life forms. The proper approach in defining soil quality and health indicators must be holistic, not reductionistic. The indicators chosen also must be measurable by as many people as possible, especially managers of the land, and not limited to a select cadre of research scientists. Indicators should describe the major ecological processes in soil and ensure that measurements made reflect conditions as they exist in the field under a given management system. They should relate to major ecosystem functions such as C and N cycling (Visser & Parkinson, 1992) and be driving variables for process oriented models that emulate ecosystem function. Some indicators, such as soil bulk density, must be measured in the field so that laboratory analyses for soil organic matter and nutrient content can be better related to actual field conditions at time of sampling. Soil bulk density also is required for calculation of soil properties such as water-filled pore space (WFPS), which serves as an excellent integrator of soil physical, chemical, and biological soil properties and aeration dependent microbial processes important to C and N cycling in soil (Doran et al., 1990). A diagramatic representation of the relationship between soil WFPS and microbial activity is given by Parkin et al. (1996, this publication) in Fig. 14–2. Many basic soil properties are useful in estimating other soil properties or attributes that are difficult or too expensive to measure directly. A listing of these basic indicators and input variables and the soil attributes they can be used to estimate are given in Table 2–1.

Starting with the MDS proposed by Larson and Pierce (1991), Doran and Parkin (1994) developed a list of basic soil properties that meet many of the aforementioned requirements of indicators for screening soil quality and health. This initial list of soil quality indicators as reviewed and revised by the North Central Region 59 Technical Committee on Soil Organic Matter and the Soil Quality Working Group of the U.S. Department of Agriculture, Agricultural Research Service, is presented in Table 2–2. This recommended minimum data set of soil quality indicators forms the primary context for many of the methods discussed in other chapters of this book.

The appropriate use of soil quality indicators depends largely on how well these indicators are understood with respect to the ecosystem of which they are part. Thus, interpretation of the relevance of soil biological indicators apart from soil physical and chemical attributes and their ecological relevance is of little value and, with respect to assessment of soil quality or health, can actually be misleading. Data presented describing soil quality and financial performance of biodynamic and conventional farming management systems in New Zealand, are

Table 2–1. A limited listing of soil attributes or properties that can be estimated from basic input variables using pedotransfer functions or simple models.

Soil attribute or property	Basic input variables†	Reference
Cation-exchange capacity‡	Organic C + clay type and content	Larson & Pierce, 1994
Water retension characteristic (AWHC)	% sand, silt, clay, + organic C + BD†	Gupta & Larson, 1979
Hydraulic conductivity	Soil texture	Larson & Pierce, 1994
Aerobic and anaerobic microbial activity	WFPS† as calculated from BD and water content	Linn & Doran, 1984 Doran et al., 1990
C and N cycling	Soil respiration (soil temperature + WFPS)	Parkin et al. , 1996
Plant/microbial activity or pollution potential	Soil pH + EC†	Smith & Doran, 1996
Soil productivity	BD, AWHC†, pH, EC, and aeration	Larson & Pierce, 1994
Rooting depth	BD, AWHC, pH	Larson & Pierce, 1994
Leaching potential	Soil texture, pH, organic C (hydraulic conductivity, CEC, depth)	Shea et al. , 1992

† AWHC, available water holding capacity; BD, soil bulk density; EC, soil electrical conductivity; WFPS, water-filled pore space.

‡ Cation-exchange capacity ($\mathrm{cmol_c\ kg^{-1}}$) can be estimated by:

$$[(\%\ C/.58)\ X\ 200] + [\%\ clay\ X\ (average\ exchange\ capacity\ of\ clay\ types)]$$

where Montmorillonite = 100, Illite = 30, and Kaolinite = 8 $\mathrm{cmol_c\ kg^{-1}}$ (meq 100 $\mathrm{g^{-1}}$)

Table 2–2. Proposed minimum data set of physical, chemical, and biological indicators for screening the condition, quality, and health of soil (after Doran & Parkin, 1994; Larson & Pierce, 1994).

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

useful in illustrating this concern (Reganold et al., 1993; Table 2–3). Our analyses, however, are not intended as criticisms of this published work as the authors should be commended for their vision in choice of physical, chemical, and biological indicators of soil quality. One point of discussion, is the importance of expressing the results of soil quality tests on a volumetric rather than a gravimetric basis and in units for which ecological relevance can be readily ascertained. As illustrated in Table 2–3, the magnitude of differences in soil C, total N, respiration, and mineralizable N between management systems for samples expressed by weight of soil are 8 to 10% greater than where expressed on a volume basis using soil bulk density estimates. In cultivated systems soil bulk density can vary considerably across the soil surface due to mechanical compaction and throughout the growing season due to reconsolidation of soil after tillage. Soil bulk density also is directly proportional to the mass of any soil component for a given depth of soil sampled. Where samples are taken in the field under management conditions of varying soil densities, comparisons made using gravimetric analyses will err by the difference in soil density at time of sampling. The observed differences due to management in the New Zealand study were statistically significant; however, since results were expressed on a gravimetric basis, they may not be valid nor ecologically relevant. In cases such as this, where values for soil bulk density at time of sampling are not available, the use of soil indicator ratios (in this case mineralizable N to C) can reduce errors of interpretation associated with use of results expressed on a weight basis. Reganold and Palmer (1995) recommend calculating soil measurements on a volume basis per unit of topsoil or solum depth for most accurate assessment of management effects on soil quality.

Table 2–3. Reported and ecologically relevant mean values of aggregated soil quality data for 0- to 20-cm layer of 16 biodynamic (Bio.) and conventional (Conv.) farms in New Zealand (after Reganold et al. , 1993)

Soil property	Biodynamic farms	Conventional farms	Ratio Bio./Conv.
Reported units & values			
0–5 cm bulk density, Mg m^{-3}	1.07	1.15	0.93*
Topsoil thickness, cm	22.8	20.6	1.11*
C, %	4.84	4.27	1.13*
Total N, mg kg–^{1})	4840	4260	1.14*
Mineralizable N, mg kg^{-1}	140.0	105.9	1.32*
Respiration, μL O$_2$ h^{-1}g^{-1}	73.7	55.4	1.33*
Ratio: Mineralizable N to C, mg g^{-1}	2.99	2.59	1.15*
Extractable P, mg kg^{-1}	45.7	66.2	0.69*
pH	6.10	6.29	0.97*
Ecologically relevant units & values			
0–20 cm bulk density†, g cm^{-3}	1.2	1.3	0.92
C, Mg C ha^{-1}	116.2	111.0	1.05
Total N, kg N ha^{-1}	11616	11076	1.05
Mineralizable N, kg N ha^{-1}14 d^{-1}	336	275	1.22
Respiration in laboratory, kg C ha^{-1} d^{-1}	2275	1850	1.23
Ratio: Mineralizable N to C	2.89	2.48	1.17*
Extractable P (excess)‡, kg P ha^{-1}	110 (50)‡	172 (112)	0.63*
pH units above 6.0 lower limit	0.1	0.3	0.33

* Values differ significantly at 0.01 probability level.

† Estimated, since data was only given for 0- to 5-cm depth.

‡ Threshold value for environmentally sound soil P level set at 60 kg P ha^{-1}.

Ellert and Bettany (1995) also illustrated the importance of accounting for differences in soil bulk density when estimating the storage of organic matter and nutrients in soil under different management schemes. They preposed sampling to different depths such that an equivalent mass of soil was compared for varying management situations; use of equivalent sampling depths, however, requires measurement of soil bulk density.

Choice of units of expression for soil quality indicators also can have an important bearing on determining the ecological relevance of measured values. In the New Zealand study, respiration of laboratory incubated soils from biodynamic farms averaged 73.7 mL O_2 $h^{-1}g^{-1}$, significantly greater (33%) than that from conventional farms. One interpretation of these results could be that the soils of the biodynamic farms are healthier since respiration was greater; however, if one assumes that for aerobic respiration a mole of O_2 is consumed for each mole of carbon dioxide produced, and the results are adjusted for soil density and expressed as kilogram of C released per hectare per day, a different picture emerges. The quantities of C released in 1 d from both the biodynamic and conventional farms are incredibly high and represent 2.0 and 1.7%, respectively, of the total C pools of these surface soils. While the values for soil respiration from disturbed soils incubated in the laboratory only represent a potential for release of readily metabolizable C (labile C), the results clearly demonstrate that more may not be better and that high rates of respiration may be ecologically detrimental as they represent potentials for depletion of soil organic C with accelerated enrichment of the atmosphere with carbon dioxide. When expressed in ecologically relevant units, it becomes obvious that the respiration rates observed in this study are of limited use in evaluating the status of soil quality and health between these different farming management systems when used as the only indicator.

Expression of soil quality indicators in ecologically relevant units, as shown in Table 2–2, facilitates establishing limits on interpretation thresholds that are at the same level of scale at which soils are managed. Ecologically relevant data from the New Zealand study (Table 2–3) will be used to illustrate this point. Levels of mineralizable N above that needed for crop production for biodynamic farms and extractable P levels above crop needs for conventional farms could represent a lower level of soil quality and health as a result of greater potential for environmental contamination through leaching, runoff, or volatilization losses. Specific upper limits for environmentally sound levels of soil P and N exist and are determined by local climatic, topographic, soil, and management situations (Sharpley et al., 1996). Again, an example that with respect to soil quality and health, more is not necessarily better and ecologically relevant units are needed for proper evaluation. Soil pH is another example of a soil quality attribute that must be referenced to a definable standard for upper and lower limits that are defined by the cropping system or biological processes of greatest ecological relevance. The above discussion serves to highlight the difficulty we have in interpreting the results of laboratory incubations and the need for in-field measurements of respiration and N cycling.

Indicators of soil quality and health are commonly used to make comparative assessments between agricultural management practices to determine their sustainability; however, the utility of comparative assessments of soil quality are limited because they provide little information about the processes creating the measured condition or performance factors associated with respective management systems (Larson & Pierce, 1994). Also, the mere analysis of soils, no matter how comprehensive or sophisticated does not provide a measure of soil quality or health unless the parameters are calibrated against designated soil functions (Janzen et al., 1992).

Quantitative Assessments

Quantitative assessments of soil quality and health will require consideration of the many functions that soils perform, their variations in time and space, and opportunities for modification or change. Criteria are needed to evaluate the impact of various practices on the quality of air, soil, water, and food resources. Soil quality and health can not be defined in terms of a single number, such as the 10 mg L^{-1} NO_3–N standard applied for drinking water, although such quantitative standards will be valuable to overall assessment. Assessments must consider specific soil functions being evaluated in their land use and societal contexts. Threshold values for key indicators must be established with the knowledge that these will vary depending upon land use, the specific soil function of greatest concern, and the ecosystem or landscape within which the assessment is being made. For example, soil organic matter concentration is frequently cited as a major indicator of soil quality. Threshold values established for highly weathered Ultisols in the southeastern USA indicate that surface soil organic matter levels of 2% (1.2% organic C) would be very good, while the same value for Mollisols developed under grass in the Great Plains, which commonly have higher organic matter levels, would represent a degraded condition limiting soil productivity. As pointed out by Janzen et al. (1992), the relationship between soil quality indicators and various soil functions does not always comply to a simple relationship increasing linearly with magnitude of the indicator, as is commonly thought. Simply put, bigger is not necessarily better.

Soil quality and health assessments will have to be initiated within the context of societal goals for a specific landscape or ecosystem. Examples include establishing goals such as enhancing water quality, soil productivity, biodiversity, or recreational opportunities. When specific goals have been established or are known, then critical soil functions needed to achieve those goals can be agreed upon, and the criteria for assessing progress toward achieving those goals can be set. Periodic assessments of soil quality and health with known indicators, thresholds, and other criteria for evaluation will then make it possible to quantify soil quality and health.

To accomplish such goals, several approaches for assessing soil quality have been proposed (Acton & Padbury, 1993; Doran & Parkin, 1994; Karlen et al., 1994; Larson & Pierce, 1994). A common attribute among all these approaches is that soil quality is assessed with respect to specific soil functions. Larson and Pierce (1994) proposed a dynamic assessment approach in which the dynamics, or change in soil quality, of a management system is used as a measure of its sustainability. They proposed use of a minimum data set of temporally variable soil properties to monitor changes in soil quality over time. They also proposed use of pedotransfer functions (Bouma, 1989) to estimate soil attributes which are too costly to measure and to interrelate soil characteristics in evaluation of soil quality (Table 2–1). Simple computer models are used to describe how changes in soil quality indicators impact important functions of soil, such as productivity. An important part of this approach is the use of statistical quality control procedures to assess the performance of a given management system rather than its evaluation by comparison to other systems. This dynamic approach for assessing soil quality permits identification of critical parameters and facilitates corrective actions for sustainable management.

Karlen and Stott (1994) presented a framework for evaluating site-specific changes in soil quality. In this approach they define a high quality soil as one that: (i) accommodates water entry; (ii) retains and supplies water to plants; (iii) resists degradation; and (iv) supports plant growth. They described a procedure by which soil quality indicators that quantify these functions are identified, assigned a priority or weight that reflects its relative importance, and are scored using a systems engineering approach for a particular soil attribute such as resistance to water erosion. Karlen et al. (1994) also demonstrated the utility of this approach in discriminating changes in soil quality between long-term crop residue and tillage management practices.

Doran and Parkin (1994) described a performance-based index of soil quality that could be used to provide an evaluation of soil function with regard to the major issues of: (i) sustainable production; (ii) environmental quality; and (iii) human and animal health. They proposed a soil quality index consisting of six elements:

$$SQ = f(SQE1, SQE2, SQE3, SQE4, SQE5, SQE6)$$

where Soil Quality Elements are:
SQE1 = food and fiber production
SQE2 = erosivity
SQE3 = groundwater quality
SQE4 = surface water quality
SQE5 = air quality; and
SQE6 = food quality.

One advantage of this approach is that soil functions can be assessed based on specific performance criteria established for each element, for a given ecosystem. For example, yield goals for crop production (SQE1); limits for erosion losses (SQE2); concentration limits for chemicals leaching from the rooting zone (SQE3); nutrient, chemical and sediment loading limits to adjacent surface water systems (SQE4); production and uptake rates for gases that contribute to ozone destruction or the greenhouse effect (SQE5); and nutritional composition and chemical residue of food (SQE6). This list of elements are restricted primarily to agricultural situations but other elements such as wildlife habitat quality could be easily added to expand the applications of this approach.

This approach would result in soil quality indices computed in a manner analogous to the soil tilth index proposed by Singh et al. (1990). Weighting factors are assigned to each soil quality element, with relative weights of each coefficient being determined by geographical considerations, societal concerns, and economic constraints. For example in a given region, food production may be the primary concern, and elements such as air quality may be of secondary importance. If such were the case, SQE1 would be weighted more heavily that SQE5. Thus this framework has an inherent flexibility in that the precise functional relationship for a given region, or a given field, is determined by the intended use of that area or site, as dictated by geographical and climatic constraints as well as socioeconomic concerns.

Assessment of soil quality and health is not limited to areas used for crop production, although this is the major emphasis of this book. Forests and forest soils are important to the global C balance as related to C sequestration and atmospheric levels of carbon dioxide. Soil organic matter and soil porosity, as estimated from soil bulk density, have recently been proposed among international groups as major soil quality indicators in forest soils (Richard Cline, 1995, personal communication). Criteria for evaluating rangeland health have recently been suggested in a National Research Council (1994) report that describes new methods to help classify, inventory, and monitor rangelands. Rangeland health is defined as the degree to which the integrity of the soil and the ecological processes of rangeland ecosystems are sustained. Assessment of rangeland health are based on the evaluation of three criteria: degree of soil stability and watershed function, integrity of nutrient cycles and energy flows, and presence of functioning recovery mechanisms.

SUMMARY

The minimum data set presented here provides a list of indicators deemed necessary for assessment of soil quality but does not provide a framework by which measurement of soil quality indicators can be interrelated to assess soil quality. This is discussed in detail by Harris et al. (1996, this publication); however, the process of identification and measurement of the basic physical, chemical, and biological components comprising the soil ecosystem facilitates appreciation by the researcher, consultant, or land manager of the broad effects of agricultural and land management on soil function and soil quality. Also, it can serve to identify specific soil attributes that are most important or need more detailed study within the unique constraints of soil, climatic, tillage, and cropping management systems, etc. and the social, economic and environmental concerns that may be unique to a certain geographical region. The specific use of soil quality indicators for on-farm assessment of soil quality is presented Sarrantonio et al. (1996, this publication).

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