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Standardisation of soil quality attributes

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Abstract

An understanding of the nature of soils in natural and human influence ecosystems is essential if progress is to be made in the determination and monitoring of soil quality. This paper briefly discuss the changing circumstances which have resulted in the increased awareness of the importance of soil as a key component of both natural and human influenced environmental systems. These changed circumstances and the recognition of the often crucial role that soils play within these systems has resulted in a demand for measures of soil quality, similar to those used in the characterisation of water and air. Whilst it is relatively straightforward to quantify the fitness to breathe of air, or the fitness to drink with respect to water, it is considerably more difficult to identify similar criteria to be applied to soil. In part this arises because of the wide range of uses to which soils are put and in part because of the complexity of the soil system and the possibility that changes in the soil may be slow and possibly only occur when some threshold is reached. The paper stresses that any index of soil quality must consider soil function, and these functions are varied and often complex. A soil which is considered to be of high quality for one function may not be so for other functions. As a consequence there are potentially many soil properties which might serve as indicators of soil quality, and research is required to identify the most suitable. It may also be questioned whether it is appropriate to pursue this notion of a limited number of soil quality indicators. If an indicator is chosen comparisons between sites and results from different investigators are not possible unless the methods of analysis are given. Standard methods of soil analysis must be developed. These standard methods are distinct from national standard values, or indicator values frequently set by national governments or regulatory agencies. The International Standardisation Organisation (ISO) has developed a programme for the development of standard methods of soil analysis across a range of possible properties including visible, biological, physical and chemical properties. If it is decided that soil quality indicators are required and progress is to be made on developing acceptable indicators of soil quality with agreed standard methods of determination there is need for co-operation amongst soil scientists and those involved in determining appropriate and sustainable use of the soil. © 2002 Elsevier Science B.V. All rights reserved.

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1. Introduction

During the latter part of the 20th century there was a change in the general perception of the importance of the soil as an environmental component and a recognition of the need to maintain or improve the soil's ability to perform the multitude of functions we have come to expect it to perform. At the same time there has been a recognition that the soil is not an inexhaustible resource, and if used inappropriately or mismanaged it may be lost in a relatively short period of time, with very limited opportunity for regeneration or replacement. Even when the soil is damaged remediation may not be possible, and its former predamaged condition impossible to achieve. This changed perception of the importance of soil as an often key environmental component has arisen against a background where there has long been an understanding of the importance of water and air in the environmental systems and how

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they can be damaged. Declines in the quality of these latter two environmental components are relatively simple to assess because we frequently evaluate them in terms of fitness to drink in the context of water or fitness to breathe with air. Further, air and water quality assessments do not seek to attempt to specify a complex integration of static and functionally dynamic chemical, physical and biological factors defining an ideal state for an infinite number of management and environmental scenarios which is the case with any assessment of soil quality (Sojka and Upchurch, 1999). In contrast to the observed changes in air and water quality, where soil quality has declined the indications of this change may not be readily observable and the consequences of any decline in soil quality may not be experienced immediately. Whilst most countries have national criteria for fitness to drink (water) and fitness to breathe (air), with respect to soil, except in the most extreme cases, there are rarely such obvious criteria which can be applied and against which the quality of the soil may be judged. In part the problem of developing an index for soil quality is accentuated by the fact that many changes in soil may occur over long periods of time, and decline in quality may only be obvious when some cumulative impact occurs. A further complicating element is that the soil does not necessarily change as a result of changing external conditions or use, frequently soil has the ability to buffer the effects of potentially damaging conditions or misuses or to filter out potentially harmful materials added to it, at least up to some threshold. In some circumstances the potential of a soil to buffer the consequences of changing external conditions, for example, the applications of sewage sludge containing heavy metals, might be considered a high value property of the soil, and in this context the soil would have high quality, but in performing this buffering the soil may accumulate contaminants which may result in the level of these contaminants exceeding some threshold and as a consequence the amended soil being considered of poor quality. In part this capacity of the soil to buffer the consequences of inputs and changes in external conditions arises because the soil is an exceedingly complex and varied material with many diverse physical, chemical and biological properties and interactions between these properties. It is this complex dynamic nature which often makes it difficult to distinguish between changes as a result of natural developmental and changes due to non-natural external influences.

Over the past two decades as the importance of the soil as an often key component of natural and man-influenced ecosystems has been recognised, there has been an increased demand to establish criteria to determine soil quality and to develop indices which may be used to rank and compare the quality of soils at different locations or at the same location through time. More recently these indices of soil quality have often been linked to attempts to evaluate the sustainability of land use activities as part of national and international programmes on sustainable land management. Sojka and Upchurch (1999) have suggested that in many circumstances the concepts associated with soil quality have been used in close association with the concepts of sustainability, and this has frequently resulted in a degree of confusion and the inappropriate use of the term ‘soil quality’. In the UK, following the publication of the 19th Report of the Royal Commission on Environmental Pollution, entitled ‘Sustainable Use of Soils’ (RCEP, 1996), a demand for indicators of soil quality has arisen, although in most cases little information has been provided on what these indicators should be and how they should be used. For example, a recent UK government directive states that 60% of future house buildings must occur on previously used ‘brownfield’ sites. The enforcement of such a policy is only possible if there are criteria against which the quality of the soil at these sites and its suitability for the proposed use may be assessed. Similarly Doran and Parkin (1994) concluded that although there was considerable activity devoted to the development and evaluation of sustainable soil management systems together with the development of associated soil quality indices, these efforts are often hampered by a lack of agreement on what constitute acceptable measurements of sustainability.

Within the European Union there is as yet no consensus on how soil quality should be defined. Howard (1993) reviewed the broad themes of soil quality in a European context that prevailed in the early 1990s. Howard noted that there were very different perceptions of soil quality as well as different national and international frameworks for protecting and monitoring soil quality. In the last decade of the 20th century there was considerable Europe-wide discussion on this topic, but there is, as yet, no agreement on

how to measure soil quality. Singer and Ewing (1998) highlighted this lack of consensus, suggesting that the international debate on soil quality has been further complicated by the fact that in the USA the notion of soil quality includes soil fertility, soil productivity, resource sustainability and environmental quality, whereas in Canada and much of western Europe the focus has been predominantly on contaminated land.

The objectives of the paper are: (i) to review the concept of soil quality in relation to function; (ii) to consider the attributes of soil to be included as indicators of soil quality; (iii) to highlight the need to have well defined and agreed methods of determination of soil attributes if comparisons from soil to soil and soil quality evaluation to soil quality evaluation are to be made; and (iv) briefly outline the standardisation process and the definition of an international standard.

2. Can soil quality be determined independent of function?

Although there has been an increased recognition of the importance of the need to measure and monitor the nature of the soil to derive measures of soil quality, frequently approaches have been rather unfocused. If progress is to be made in developing measures which have a wide degree of acceptability there is the need to ask the question 'Soil quality for what?' A further question which is frequently overlooked, but equally important 'At what scale?', what size of unit is being evaluated and what size of sample or what number of samples over a specified area are required to make the evaluation. Probably the most widely accepted concept of soil quality, and in a global context probably the most significant is with respect to agricultural production. Whilst the productivity element is important, to be sustainable agricultural production must be supported by conservation measures that ensure the long-term maintenance of the activity. In this context soil quality might be defined as 'the fitness of a specific kind of soil to function with its surroundings, support plant and animal productivity, maintain or enhance water and air quality and support human health and habitation (Karlen et al., 1997). To perform this production function, and indeed many of the other functions, the soil must provide the following basic functions, the actual combinations and relative importance of each will vary depending upon the specific function under consideration.

- Provide a physical, chemical and biological setting for living organisms.
- Regulate and partition water flow, storage and recycling of nutrients and other elements.
- Support biological activity and diversity for plant growth and animal productivity.
- Filter, buffer, degrade, immobilise and detoxify organic and inorganic substances.
- Provide mechanical support for living organisms and their structures.

These basic functions of the soil are often combined to provide more general functions, such as, the support of natural ecosystems and processes, the production of food and fibre, as a base for buildings, to extract groundwater, as a filter for applied materials, and as a source of raw materials (Moen et al., 1986; Vegter et al., 1988). It must be recognised that soils frequently perform several functions simultaneously, not independently. Any evaluations of the quality of the soils must consider this multifunctional role. To evaluate the quality of the soil with respect to these functions may require very different forms of soil information, and the critical or threshold values for each property will probably vary depending upon function. Each of these soil functions may require different forms of information if quality is to be assessed relative to that function. In this context there have been some developments of national guidelines which give allowable values for particular soil properties related to single or narrow groups of functions. For example, with respect to the development of potentially contaminated land in the UK, the ICRCL trigger values (ICRCL, 1987) were presented for a range of soil contaminants and for different types of land use. In The Netherlands guidelines for soil clean-up were introduced in 1983 (Moen et al., 1986). In Germany, the 1998 Soil Protection Act includes both trigger and precautionary values as anticipated by Bachmann et al. (1997). Whilst these guideline values have been widely used it is often unclear upon what basis they were selected.

Changes in soil quality may occur for a number of reasons, Pierzynski et al. (1994) suggested three broad headings for the causes of reductions in soil quality:

- because of unacceptable concentrations of contaminants;
- because of limits to soil function (this will probably include contamination, but also other limits to soil function such as acidification, salinisation, compaction and erosion);
- because the soil is a source of contaminants (chiefly concerned with leaching and run-off losses of solutes, suspended and particulate materials to other parts of the landscape, but also of considerable importance where brownfield sites are to be brought back into productive use).

It is therefore of paramount importance that consideration of actual and potential functions of the soil are considered in soil quality evaluations, and in these evaluations it is also important to consider what changes are resulting in a decline or loss of function. Sojka and Upchurch (1999) in their substantial review of the 'Soil Quality Debate' suggest that the search for a single, affordable, workable soil quality index, which seems to be the aim of many, particularly those concerned with establishing guidelines for environmental management, is unattainable.

3. Indicators of soil quality — which attributes should be chosen?

Whilst there may be doubts in some quarters over the efficacy of developing indices of soil quality, there is continuing demand for such indices. Given the complex nature of the soil and the exceptionally large number of soil properties that may be determined, it is important to be able to select properties that are appropriate to the task. Depending upon the nature of the function under consideration the actual properties selected will vary. It is possible to group together attributes that might be used as indicators of soil quality into four broad groupings:

3.1. Physical attributes/indicators

These are principally concerned with the physical arrangement of the solid particles and pores, and include soil texture, dry bulk density, porosity, aggregate strength and stability, soil crusting, soil compaction and top soil depth.

3.2. Chemical attributes/indicators

Here the list of potential soil attributes is very large and the final selection will depend upon the function under consideration. Attributes include, pH, salinity, aeration status, organic matter content, cation exchange capacity, status of plant nutrients, concentrations of potentially toxic elements, and possibly the most important attribute, the capacity of the soil to buffer against change.

3.3. Biological attributes/indicators

Biological attributes may be very dynamic and exceptionally sensitive to changes in soil conditions, which is why there is often a preference for biological attributes for short-term evaluations. Attributes that might be measured include, the populations of micro-, meso- and macroorganisms, respiration rate or other indicators of microbial activity, and more detailed characterisation of soil organic matter.

3.4. Visible attributes/indicators

It is often the observation of the visible attributes that brings to our attention the changes in soil quality and causes public awareness and alarm, but in many respects when there is visible evidence of the decline in soil quality the process of decline may have proceeded too far and the chance of restoring the quality may have been lost. The visible attributes include evidence of erosion in the form of rills and exposure of subsoil, surface ponding of water, surface run-off and poor plant growth.

3.5. Soil organic matter as an indicator

Soil organic matter has been widely promoted as a key indicator of soil quality, particularly in agricultural soils (see for example, Royal Commission for Environmental Pollution, 1996), but there has been no consensus on what the critical level of soil organic matter should be in an agricultural soil and how this level will vary between soils of different textural classes under different environmental conditions. Soil organic matter whilst a relatively simple property to measure may be characterised in many different ways. Gregorich et al. (1994) and Bolinder et al. (1999) have discussed

this with respect to changes in soil quality in Canadian soils and have suggested that it may be appropriate to measure the gross soil organic matter content, but in addition a number of other related properties might prove to be more closely linked to changes in soil quality related to specific functions. The properties of soil organic matter they suggest include, total soil organic carbon and nitrogen light fraction and particulate macroorganic matter, mineralizable carbon and nitrogen, microbial biomass, soil carbohydrates and soil enzymes. Sojka and Upchurch (1999) suggest a more cautious approach towards the adoption of soil organic matter as a more or less universal index of soil quality. They suggest that although there is evidence in many soils that an increase in soil organic matter levels tends to improve the quality of the soils, for example, in many soils an increase in soil organic matter increases aggregate stability, there are many frequently unrecognised negative environmental and crop production impacts associated with soil organic matter. For example, they suggest that increasing soil organic matter levels increases the application requirement of many soil incorporated pesticides, they also suggest that the increased aggregation may result in more rapid flow through soils with consequent rapid transport of applied nutrients and other soil amendments.

3.6. Selection of indicators

Without clear guidance on the selection of indicators, the evaluation of soil quality is potentially unfocused and of little merit. The importance of indicators is that they:

1. provide reference material to measure trends and patterns;
2. relate soil quality to other components of the system;
3. where trigger or precautionary levels are set the quality may be assessed against these.

The final selection of indicator attributes should be based on:

- land use;
- relationship between soil function and the indicator;
- the ease and reliability of measurement;
- spatial and temporal patterns of variation and the importance of this variation;
- the sensitivity of the measurement to changes in soil management;
- comparability with routine sampling and monitoring programmes;
- the skills required for the use and interpretation of the indicator.

4. Scale of soil quality evaluations

A frequently ignored consideration in many of the attempts to evaluate soil quality is the scale at which the evaluation is to be undertaken. The observations are generally based upon samples of the soil. Samples may be taken, for example, which might consist of a single sample taken from one horizon, a composite of samples taken from a single horizon at a number of locations, or a number of samples from a single horizon at a number of locations, dealt with as a set of individual samples. All of these may be considered valid samples, but any interpretations based on the results of analyses from these samples must take account of the number and nature of the samples. This problem of sampling and the representativeness of samples are closely coupled to the spatial variability of soils. It has long been recognised that soils often exhibit complex patterns of variability, with different soil properties within a sampling unit (e.g. a field, a landscape position or a soil mapping unit) often showing markedly different degrees of variability and frequently variability in different spatial patterns (Beckett and Webster, 1971). This is particularly important when considering soil quality indicators linked to microbial soil properties, as these are noted as often being highly spatially variable over distances of a few square micrometers (Parkin, 1993), in addition to being temporally very variable. Whilst this variability is recognised, and raises serious concerns about the choice of soil microbial properties as reliable soil quality indicators, there is considerable evidence of variation in both the nature and magnitude of spatial variation in many other soil properties. For example, Khan and Nortcliff (1982) investigated the spatial pattern of selected micronutrients in a relatively homogeneous landscape in southern England and concluded that there were marked differences between the patterns for individual micronutrients. Similarly Warrick and Nielsen (1980) reported investigations of

the sample sizes required to obtain estimates within given levels of precision of the physical properties of soils in a uniform field. They report that to achieve the same level of precision in the estimates of bulk density, percent clay and hydraulic conductivity, required, 2, 110 and 1300 samples, respectively. These two sets of results are not untypical and highlight the need to be aware of the spatial variability of soil properties when choosing indicator variables of soil quality.

5. Soil quality indicators — which method?

Whilst identifying the soil quality indicators is an important step forward, they have only limited value if the methods used in determining these indicators are not fully defined. For example, when dealing with metals in soils as potentially toxic elements, many of the indicators of soil quality have used 'total' content of the metals as the indicator. As was shown by Duncan et al. (1995) for the determination of lead, zinc and chromium in soils, the final value of the 'total' content of these metals may vary considerably with the method of analysis used. Perhaps more importantly, the relative values for the different methods and three metals studied showed no consistent pattern. It is therefore imperative that when indicators of soil quality are specified the method to be used in their determination must also be specified. Similarly when presenting results it is imperative that the methods used are indicated, without this information the comparison of different sets of data may be of little value. These methods must include the full details of sample collection, storage, pretreatment, as well as the method of analysis. Without standardisation of these procedures it will be impossible to compare results between different sites and different laboratories. The methods are not an end in themselves, rather they provide a means to achieve the end of determining soil quality. Soil quality will be determined with respect to the ability to perform a selected function or functions using the standard methods, which must be related to the functions being investigated.

6. What is a standard?

The complex nature of the soil has been highlighted above, together with the difficulties in identifying indicators of the quality of the soil. It has been stressed that unless the process of determining the values of these indicators is standardised the task of comparison is probably of little value and may be impossible. With regard to standardisation it is important to recognise that there is a difference between standards set by governments (precautionary values, thresholds, trigger values, etc.) and standard methods (e.g. the procedures for determining soil particle size) which are developed by standardisation organisations. The analytical procedures are an important component of the standard methods, but constitute only one step in an often complex process. The evaluation of soil quality is likely to involve the following steps:

step 1: identification of the purpose of the study;
step 2: selection of the indicator parameter;
step 3: site identification and description;
step 4: development of a sampling protocol;
step 5: sampling and storage;
step 6: sample preparation and pretreatment;
step 7: sample analysis and presentation of the results;
step 8: interpretation of the results in relation to purpose;
step 9: actions arising from the interpretations.

Although most attention has been paid to analytical procedures, it is important that equal attention is given to all the other steps in the process, because failure to satisfactorily undertake these other steps may invalidate the whole evaluation process.

7. International standardisation

With the increasing awareness, particularly in Europe, of the need to determine and monitor soil quality in a manner which allows comparisons within and between countries, the International Standardisation Organisation (ISO) established in 1985, a Technical Committee (TC 190) to consider the development of methodologies for monitoring the quality of soil. It should be stressed that the Technical Committee is not concerned with the actual assessment of soil quality, but simply seeks to provide a set of proven, widely used standard methods which can be reliably used by those seeking to evaluate soil quality. Progress in the development of the scope of this Technical Commit-

tee and the work programme have been outlined by Hortensius and Nortcliff (1991), Hortensius (1993) and Hortensius and Welling (1996). The Technical Committee is structured with six sub-committees.

SC1: terminology, description and codification;
SC2: sampling;
SC3: chemical methods;
SC4: biological methods;
SC5: physical methods;
SC7: soil and site assessment.

Each of these sub-committees has a series of Working Groups which focus on a particular aspect of the broad subject area. Over 45 countries are involved in the activities of ISO TC 190. Following initially very slow progress, there are now over 40 international standards published and over 40 ongoing projects. Many of these standards have been simultaneously adopted as national standards.

All the initial workload of the Technical Committee was concerned with the description, sampling and analysis of soils. The most recently established sub-committee, SC7, is a move away from this development of methods addressing the criteria to be involved in the evaluation of soils. There are currently five Working Groups.

WG1: soil characterisation for reuse of soils and other materials;
WG2: characterisation of soil for protection of water;
WG3: ecotoxicological characterisation of soil and soil materials;
WG4: characterisation of soil and soil materials with respect to human exposure;
WG5: monitoring of establishment of sites.

The work of this sub-committee is not involved in establishing indicator values, as this is the responsibility of governments, but to provide guidance on the range of tests which may be appropriate for the evaluation of soil quality with respect to the particular functions or potential impact on a receptor.

8. Conclusions

The evaluation of soil quality has in the last two decades become an important activity, anticipated to increase in importance as we become more aware of the need to protect and preserve soil and its ability to sustain its functions. We must also be aware of the sensitivity of soil to damage and be able to recognise any changes in the soil which are precursors to the loss of function. It is essential therefore, that in any evaluation of soil quality there is a clear understanding of the function or functions of the soil — natural functions and user oriented functions — which are being addressed, and the properties of the soil which may be measured to assess quality with respect to these functions. Once attributes of the soil that can serve as indicators of soil quality have been selected, it is essential to ensure that standard methods of sampling, pretreatment and analysis are selected appropriate to this evaluation. The ISO programme on soil quality is endeavouring to present a suite of standard procedures covering many aspects of description, sampling, and analysis and evaluation procedures to assist in establishing indices of soil quality. Progress developing acceptable indicators of soil quality with agreed standard methods of determination can only be done with the co-operation across the broad spectrum of soil scientists and those involved in determining appropriate and sustainable use of the soil. This co-operation should ensure that the soil properties chosen relate to the functions identified and are appropriate for the purpose.

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