Chapter 1

Soil Quality Management – Concepts and Terms

P. Schjønning, S. Elmholt and B.T. Christensen
Danish Institute of Agricultural Sciences, Department of Agroecology, PO Box 50, DK-8830 Tjele, Denmark

Summary

The industrialization of agriculture and the concurrent increase in societal concerns on environmental protection and food quality have put the focus on agricultural management and its impact on soil quality. Soil quality involves the ability of the soil to maintain an appropriate productivity, while simultaneously reducing the effect on the environment and contributing to human health. This development has changed society's expectations of science and there is an urgent need to improve the communication among researchers from different scientific disciplines. The interaction of scientists with decision makers is a topic of utmost relevance for future developments in agriculture. *Reflexive objectivity* denotes the exercise of raising one's consciousness of the *cognitive context*, i.e. societal priorities, and the values and goals of the researcher. The term *sustainability* comprehends the priorities in the cognitive context and thus constitutes a valuable tool for expressing the basis of scientific work. Soil quality evaluations should include awareness of the *stability* of any given quality attribute to disturbance and stress. This implies addressing *resistance* and *resilience* of the soil functions and/or the physical form in question. Most existing literature on soil quality focuses on assessment of soil quality rather than the management tools available to influence soil quality. Identification of *management thresholds* rather than soil-quality *indicator thresholds* is suggested as an important means of implementing the soil quality concept. The major challenges facing modern agriculture include proper nutrient cycling, maintained functions and diversity of soil, protection of an appropriate physical form and avoidance of chemical contamination. It is suggested that these challenges and problems as related to the soil quality concept are discussed in the framework expounded above.

Agricultural Research in a Changing World

The foundation of modern agriculture was laid more than 150 years ago. At that time an awareness of the role of plant nutrients in crop production emerged, supported by experiments showing the beneficial effects of adding mineral fertilizers to the soil. However, the most rapid development has occurred since the early 1950s. This development has been driven not only by scientific achievements, but also by access to affordable energy, traction power and other technological achievements that reduced the time and manpower required for agricultural production. Mineral fertilizers, pesticides and cultivars that respond effectively to increased nutrient levels were important requisites in the dramatic increase in productivity. The development of modern agriculture was supported by government policies introducing systems of production and commodity subsidies with the overall aim to secure adequate and reliable sources of food of good quality and at affordable prices. The side effects were structural changes towards larger and more specialized production units and a massive movement of labour force from agriculture to the industry and service sectors. Government policies also involved a substantial increase in the research supporting agricultural production.

In the developed and industrialized countries, modern agriculture achieved these primary goals, and even more so, as demonstrated by surplus production and subsidized export of agricultural products. This has contributed to a switch in societal concerns from sheer productivity to sustainability of agriculture, including the effects of production methods on the environment, the diversity of the natural flora and fauna, the welfare of domestic animals, and the soil resource itself. The quality of air, water and – as yet to a minor extent – soil has come more into focus.

Almost every aspect of modern agriculture is now under scrutiny from concerned producers, environmentalists and consumers, from researchers and government as well as non-governmental organizations, and agricultural sustainability is on the agenda of most political movements and parties. Concerns, attitudes and opinions about agricultural production are effectively communicated and amplified by news media. At the same time, the number of economic subsidies devoted to agriculture is being questioned. The demands for economic and ecological sustainability are bound to introduce changes in the production concepts of modern agriculture. This development has increased the demand for scientifically based solutions that incorporate a wider range of aspects. Scientists have been involved in problem solving and development in society for centuries, but the pressure from society for a proactive role of science is much greater than previously.

Another aspect is the increased interaction between *descriptive* and *prescriptive* branches of science (Ellert *et al*., 1997). Typically, scientists in ecology, geography and other classical scientific disciplines perceive soil as an ecosystem component, and their approach is descriptive and observational in nature. Agricultural researchers, on the other hand, are concerned primarily with the production of food and fibre, and perceive soils mainly as media to support plant growth. Fertility trials, crop rotation studies, tillage experiments, etc. have provided the basis for an increasing productivity. Thus, researchers involved in agricultural sciences are accustomed to producing prescriptions with the clear aim of increasing yields. Ellert *et al*. (1997) advocated a combination of the conceptual/ descriptive approaches of ecologists and the quantitative/prescriptive approaches of agronomists.

However, the vast amount of scientific literature concerned with ecosystem health, sustainable farming, soil fertility and soil quality reveals problems in communication. As an example, Doran *et al*. (1996) reported on communication failures due to different opinions on the use of values in science. In the section below we discuss some basic issues regarding the role of science in society, which we believe may facilitate communication. The philosophical deductions should be regarded as a layman's view, not as a professional contribution to the theory of science.

Science and Society – the Need for Reflexive Objectivity

Agricultural research is an applied science with the main objective of improving production methods and developing production systems. In consequence, agricultural science influences its own subject area, agriculture, in important ways (Lockeretz and Anderson, 1993). In general, science that influences its own subject area is defined as *systemic science* (Alrøe and Kristensen, 2002). This characteristic is also true for health, environmental and engineering sciences. The fact that science plays a proactive role in the world that it studies makes the criterion of objectivity as a general scientific ideal less straightforward. The general understanding of objectivity is derived from the *positivistic* criterion of verifiability of knowledge. Freeman and Skolimowski (1974) defined 'object' as 'the totality of external phenomena constituting the not-self' and hence 'objective' as 'something that is external to the mind'. That is, objectivity is defined as opposite to the subjective. However, when the 'subject' (the scientist in systemic sciences) is part of the 'object' (the system studied), an extra dimension is added to his/her role as a scientist. It is, therefore, important that the scientist is able to view her- or himself as part of the system (self-reflection). As an example, the researcher involved in the optimization of crop yields by management strategies should be able to recognize the consequences of his/her prescriptions on other aspects than just yield. This ability to take an 'objective' stance but at the same time being aware of the intentional and value-laden aspects of science is denoted *reflexive objectivity*, and the framework in which these reflections take place is labelled the *cognitive context* (Alrøe and Kristensen, 2002). The cognitive context may be divided into three dimensions: the observational, the societal and the intentional (Fig. 1.1). The observational context includes the actual methodological aspects of the research, the societal context is the group or segment for which the research is relevant, and the intentional context is the goals and values employed.

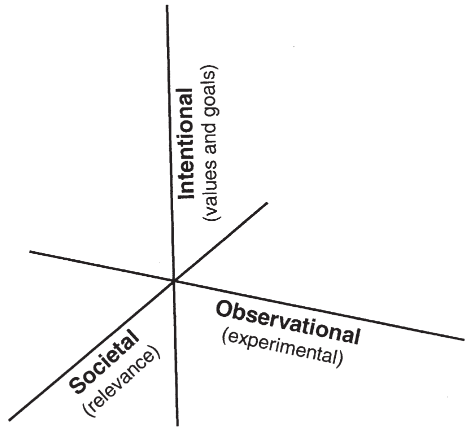

Fig. 1.1. The three dimensions of the cognitive context in science. Cognition (perception) is dependent on observational aspects (experimental set-up), societal priorities, and intentions and goals for the scientist or scientific group performing the scientific studies. Please consult the text for details. Based on Alrøe and Kristensen (2002).

The *observational context* comprises the characteristics of a scientific work, which are evaluated by the procedure of peer review (such as the experimental set-up, statistical treatment of data and discussion of results in relation to other relevant studies). The selection of research topics and the choice of methods will frame the outcome of the work (Dumanski *et al.*, 1998), and the methodological aspects of a work are more important to the results and conclusions than often realized. For example, a study of phosphorus availability in soil might reach quite different conclusions depending on the analytical method. Extraction by sulphuric acid would yield much more P than a resin (anion exchange membrane based) methodology. Obviously, you would say. The point is, however, that when judging the results, one uses present-day knowledge of the lability of different P-pools in soil. There may well be plant–soil interactions of importance for P-uptake by plants that we have yet to realize. And such knowledge might induce new methodologies. Our cognition regarding P availability in soil is thus highly dependent on how we establish our analyses.

The relevance of the scientific work depends on the *societal context* pervading at the time of the study. There is no 'universal' science that is independent of social context. When pesticides became available to farmers in the mid 20th century, the most relevant task for agricultural researchers was to optimize their use for maximum production and minimum costs. When – on the other hand – an agricultural scientist is engaged in the development of organic farming, completely different topics dominate. The paradigm associated with organic farming gives priority to quality aspects of crops, soil and the environment. Concerning pesticides, today's scientists in industrialized countries are engaged in studies of the detrimental rather than the beneficial effects of pesticides (e.g. groundwater pollution, bioaccumulation, side effects on non-target organisms). These examples serve to illustrate that the societal context has changed dramatically during the period discussed here.

The *intentional context* in science is perhaps the most controversial. It has to do with values and goals for the specific research group or scientist. Sojka and Upchurch (1999) gave a critical review on the concept of soil quality. Some of their concerns were abstracted as 'we are . . . reluctant to endorse redefining the soil science paradigm away from the value-neutral tradition of edaphology and specific problem solving to a paradigm based on variable, and often subjective societal perceptions of environmental holism'. That is, the authors support the classical understanding of objectivity in science. In their paper, however, they draw attention to articles dealing with different aspects of soil quality and raise the query of whether a high biodiversity in soil is more valuable than animals at the other end of the food chain. We interpret their statement as giving a high production of foods (for higher animals) a higher priority than a high biodiversity in the soil. This is of course a legitimate standpoint, but the point is that this opinion also reflects an 'intention' or a 'value/goal'. Awareness of these values is what reflexive objectivity is all about. And the example clearly illustrates that reflexive objectivity in the 'room' of the cognitive context would facilitate or even be a prerequisite for communication. We concur with the statement by Jamieson (1992) and Ellert *et al*. (1997) that frank discussions about the values involved in concepts like soil quality may be equally or more important than the technical development and use of indicators to manage ecosystems.

Scientific work cannot be fully understood when detached from the societal and intentional contexts. Campbell *et al*. (1995) stated that the classification of sustainability and 'health' of an agroecosystem require the establishment of specific judgement criteria, and concluded that such judgement criteria must be established from a viewpoint that is ecologically, politically, socially and economically acceptable. As stated by Munasinghe and Shearer (1995) there is bound to be conflict among such interests. The task of scientists is thus to provide information that enables decision makers to choose among conflicting objectives by assessing the trade-offs among these objectives and the consequences of their application.

The Soil Quality Concept

The term *quality* implies value judgement (degree of excellence). Thus *soil quality* is concerned with some measure of a property or function of soil (good/bad, low/high, etc.). Fundamentally, classification of data and information about soil seems to be a basic human need, and the concept of 'soil capability' ('good' or 'bad' for a specific purpose) is as old as civilization itself (Carter *et al*., 1997). Patzel *et al*. (2000) stated that 'soil quality encompasses an indefinite (open) set of tangible or dispositional attributes of the soil'. Thus the concept of soil quality may be regarded as a 'vessel' for various attributes of interest in any given situation. As an example, soil quality in the context of highway constructions is concerned with the bearing capacity of the soil medium but does not consider soil functions for plant growth. Although some people may regard this open (indefinite) concept as truly 'academic' and of little use, we think it facilitates reflections on the value-laden character of the soil quality concept. Any decision on quality attributes enclosed by the concept of soil quality will necessarily be based on viewpoints, values and goals from the societal and intentional contexts.

Blum and Santelises (1994) and Blum (1998) considered the functions and services of soil as related to human activity and grouped them into six categories. Three ecological uses are: (i) the production of biomass; (ii) the use of soils for filtering, buffering and transforming actions; and (iii) the provision of a gene reserve for plant and animal organisms. Three other functions relate to non-agricultural human activities; (iv) a physical medium for technical and industrial structures; (v) a source of raw materials (gravel, minerals, etc.); and (vi) a cultural heritage. This classification of human interest in and interaction with soil may facilitate an operational definition of soil quality.

Several definitions of soil quality have been advanced (see Karlen *et al*., Chapter 2, this volume). Most definitions relate soil functions to: (i) biological productivity; (ii) the environment; and (iii) different expressions of plant, animal and/or human health (e.g. Doran and Parkin, 1994; Doran *et al*., 1996). A committee appointed by the Soil Science Society of America (SSSA) offered the following definition (Fig. 1.2): *Soil quality is 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* (Allan *et al*., 1995; Karlen *et al*., 1997). Although this definition creates a framework for considering soil quality, it does not eliminate the value-laden character of the concept. To determine soil quality, the functions or services expected of the system must be defined and delineated (Ellert *et al*., 1997). Judgement of what is good or bad is influenced by subjective and/or societal priorities and decisions. Accordingly, Pankhurst *et al*. (1997) noted that most authors contributing to their book on biological indicators of soil health emphasized the holistic nature of the soil health concept and accepted subjective assessments of what is healthy. The same holds for the soil quality concept.

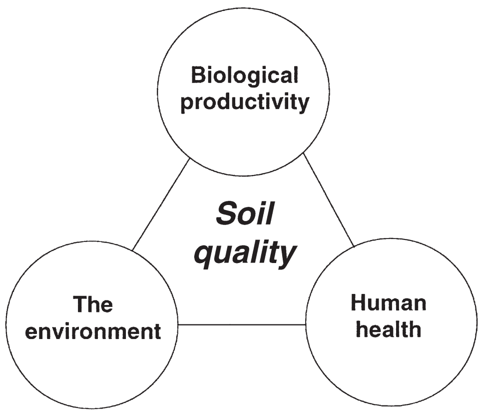

Fig. 1.2. Soil quality with its three concerns: biological productivity, the environment and human health. Based on Allan *et al*. (1995).

Early papers on soil quality emphasized terms like *fitness for use* in regard to agricultural use of soil (Larson and Pierce, 1991, 1994). Letey *et al*. (2003) preferred the term *use* to *function* because 'use' highlights the management aspect of the term. However, a function like carbon sequestration in soil and its interaction with greenhouse gases occurs irrespective of agricultural use; only the magnitude of this soil function can be manipulated by agricultural management.

As opposed to other definitions of soil quality, the SSSA definition mentions humans only in the 'health' part of the text. Concerns regarding plants and animals are associated with the 'productivity' part. We find this noteworthy because the expression 'promotion of plant and animal health' (Doran and Parkin, 1994; Doran *et al*., 1996) in its extended interpretation is very ambitious (animals include nematodes and collembola, for example). We agree that the activity and the diversity of the soil community are important, and that a large biomass and a high biodiversity in soil may link to the degree of soil quality. However, our attitude emphasizes that agriculture by definition is a human activity designed for the production of food and fibres.

Sustainability

The term 'sustainability' is frequently used in scientific papers dealing with agricultural systems and is closely linked to societal and individual priorities. The term may be regarded as a manifestation of priorities, values and goals of researchers and society. A link between soil quality and sustainability is important because soil quality should not remain an abstract concept but rather something to be strived for by management (Bouma *et al*., 1998).

Sustainability entered public debate following the work of the World Commission on Environment and Development, labelled the 'Brundtland Report' (WCED, 1987). To *sustain* means to 'keep up, maintain' (Oxford Advanced Learner's Dictionary of Current English, 1974). If applied only in this sense, sustainability does not make much sense for the constantly changing human society. Originally, sustainability more accurately translates into sustainable *development* (Bossel, 1999). Accordingly, the concept of sustainable development was proposed by the Brundtland Commission as 'economic development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs' (WCED, 1987).

When applying the concept of sustainability to agriculture, a somewhat more tangible definition has to be constructed, although Swift (1994) noted that the concept would still be complex. It would embody issues of economic viability, the quality of life and human welfare, and ecological stability and resilience over time. Several other papers and documents have discussed the issue of sustainability in greater depth, all emphasizing the combination of biophysical and social aspects of the concept (e.g. Stewart *et al*., 1991; Smyth and Dumanski, 1993; Lal, 1994, 1998; Herdt and Steiner, 1995; Munasinghe and Shearer, 1995).

Smyth and Dumanski (1993) stated that

> Sustainable land management combines technologies, policies and activities aimed at integrating socio-economic principles with environmental concerns so as to simultaneously: (i) maintain or enhance production and services; (ii) reduce the level of production risk; (iii) protect the potential of natural resources and prevent degradation of soil and water quality; (iv) be economically viable; and (v) socially acceptable.

Bouma *et al*. (1998) underscored the five criteria for sustainability in this definition, i.e. productivity, security, protection, viability and acceptability, and suggested that these criteria should also be used for judging soil quality. We have adopted this suggestion for framing the soil quality discussion in this book. We further endorse the viewpoint of Stewart *et al*. (1991) and Pankhurst (1994) that sustainability should be considered dynamic because, ultimately, it will reflect the changing needs of an increasing global population.

Stability in Terms of Resistance and Resilience

Evaluation of systems requires estimates of their stability when stressed or disturbed. Stability may express: (i) the *resistance* to change in function or form during a stress event, or (ii) the capacity to recover functional and structural integrity (*resilience*) after a disturbance. It is important to distinguish between resistance and resilience. In population ecology, resistance is defined as 'the capacity to resist displacement from an equilibrium condition', whereas resilience is defined as 'the capacity of a population (or system) to return to an equilibrium following displacement in response to a perturbation' (Swift, 1994). We tend to follow Seybold *et al*. (1999) by using the term *resistance* instead of *stability*, which occasionally has been used to express the capacity of resisting disturbance (e.g. Kay, 1990). We find that stability is more appropriate as a common denominator for resistance and resilience.

Eswaran (1994) emphasized that soil resilience relates to either '*performance*' or '*state or structure*' of the system. The same applies to resistance. According to Eswaran, 'performance' refers to functions and processes in the soil while 'state or structure' refers to the pedological composition of the material. The latter is analogous to the *structural form* (Kay, 1990), although Eswaran had a larger time span in mind than Kay. Thus, resilience relates to the ability of recovering functions as well as to physical form. Figure 1.3 illustrates the relationship between the terms discussed.

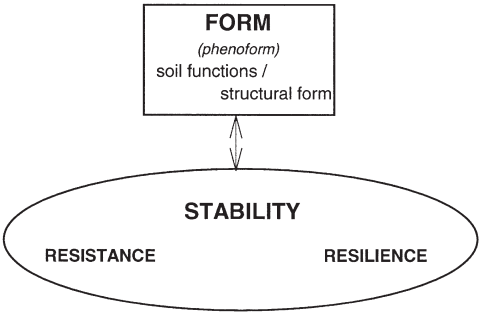

Fig. 1.3. Soil stability in terms of resistance and resilience as related to the suggested term *form* comprising soil functions as well as structural form. A stable form may be due to a high resistance and/or a high resilience. The arrow indicates that a given stability is assigned to a given form, but also that the stability may change with a change in (pheno)form. Based on Kay (1990) and Droogers and Bouma (1997).

A soil may exhibit a high resistance but a poor resilience with respect to some specific property. This would be the case if subjecting a dry clay soil to heavy mechanical loads. The soil strength and thus its resistance to compaction is high. If, however, the 'structural form' collapses, which would happen at a very high load, it would probably be associated with a compaction along the 'virgin compression line' (Larson *et al.*, 1980). And the resilience – the ability to recover – from such compaction effects is poor (e.g. Håkansson and Reeder, 1994). Alternatively, a soil may exhibit a poor resistance but a high resilience for some attribute. A number of microbial soil functions show examples of this when subjected to, for example, pesticide applications. Pesticides may cause response deficits of more than 90% and yet the soil function may return to its original level so quickly that the ecotoxicological effect can be regarded as insignificant when compared to natural stress effects (Domsch *et al.*, 1983).

Although the stability of soil systems should be assessed both in terms of resistance and resilience, the latter property particularly deserves attention when evaluating soil quality in managed ecosystems. As any form of agriculture disturbs the original equilibrium of the native ecosystem, it is evident that resilience is a key parameter when judging the sustainability of agricultural systems. The concept of resilience was originally coined by Holling (1973) with emphasis on the persistence of *relationships* within a system. Resilient systems may show the capacity to occupy more than one state of equilibrium (Swift, 1994). Each state of equilibrium may maintain a qualitative structural and functional integrity but the quantitative properties may differ among equilibria. This dimension of the resilience concept is crucial when dealing with managed ecosystems. Any form of agricultural activity disturbs the original equilibrium of the native ecosystem, and soil resilience can be invoked to connote the ability of management to maintain the performance of the soil (Eswaran, 1994). This interpretation may be controversial, but is logical when dealing with managed ecosystems. Management is an integrated part of the agroecosystem, and resilience should be related to equilibria in the *managed* system, not the performance or state that would prevail in the *original*, *native* ecosystem (Blum, 1998).

Resilience has been defined from various points of view for various purposes (Szabolcs, 1994). One important aspect is the time scale. The rate of soil formation from the parent rock is extremely low compared with the potential rate of soil loss in unsustainable agricultural systems (Lal, 1994; Pennock, 1997). Lal (1994) reviewed the estimates of rates of soil formation for a number of soil types and concluded that most soils can be considered a non-renewable resource within the human life span. However, a soil subjected to severe gully erosion may be judged resilient also to this disturbance if regarded in the context of geological time spans of hundreds or thousands of years. Thus, the time factor has to be considered when discussing soil resilience.

It should be emphasized that the expression of resilience has no meaning without an explicit statement of the agents, forces or effects (disturbance) facing the soil (Szabolcs, 1994). Blum (1998) discussed the potential 'disturbances' and classified the corresponding 'type' of resilience into three groups: (i) resilience to physical disturbances; (ii) chemical resilience; and (iii) resilience to biological disturbances.

Soil-quality Indicators

Soil quality assessment typically includes the quantification of *indicators* of soil quality. Such indicators may be derived from reductionistic studies, i.e. specific soil parameters obtained from different disciplines of soil science (e.g. Larson and Pierce, 1991). However, descriptive indicators, which are inherently qualitative, can also be used in assessing soil quality (Seybold *et al.*, 1998; Munkholm, 2000). Soil-quality indicators condense an enormous complexity in the soil. They are measurable surrogates for processes or end points such as plant productivity, soil pollution and soil degradation (Pankhurst *et al.*, 1997). Herdt and Steiner (1995) and Carter *et al.* (1997) drew attention to situations where individual indicators show opposite or different trends. Larson and Pierce (1994) and later Doran and Parkin (1996) realized the weaknesses in expressing soil quality information in single numbers, at least in comparative studies of soil management. As stated by Doran and Parkin, such indicators may provide little information about the processes creating the measured condition or performance factors associated with respective management systems. Thus, the interpretation of soil-quality indicators requires the experience and 'skill' of the researcher and/or soil manager. Doran (2002) realized that several soil-quality indicators would be too complex to be used by land managers or policy makers. Hence, he suggested concentrating on simple indicators, which have meaning to farmers. The use of indicators like topsoil depth and soil protective cover in a given management system were hypothesized to be the most fruitful means of linking science with practice in assessing the sustainability of management practices (Doran, 2002). Schjønning *et al.* (2000) showed that quantitative soil mechanical properties derived by analytical procedures in the laboratory correlated well with qualitative behaviour of soil in the field. It seems important to evaluate such links when considering the use of soil-quality indicators obtained by reductionistic studies in controlled environments.

Larson and Pierce (1991) suggested a *minimum data set* to describe the quality of a soil. This data set should consist of a number of indicators describing the quality/health of the soil. Using an analogue to human medicine, reference values for each indicator would set the limit for a healthy soil (Larson and Pierce, 1991). The use of indicators has been widely discussed in the literature on soil quality (e.g. Doran and Jones, 1996). Lilburne *et al.* (2002) and Sparling and Schipper (2002) presented achievements obtained in a New Zealand soil quality project. In contrast to most other soil quality assessments, their focus was on a regional rather than on a farm or field scale. Management was similarly addressed in terms of distinct land uses (e.g. arable cropping, dairy farms, pine plantations). Much effort was allocated to identify the most adequate indicators, and seven key parameters were chosen: soil pH, total C and N, mineralizable N, Olsen P, bulk density and macroporosity (Sparling and Schipper, 2002). Lilburne *et al.* (2002) identified the difficult task of isolating the relevant target/threshold values of indicators. Sparling and Schipper (2002) acknowledged the problem in addressing satisfactorily all combinations of soil types and land uses. Generally, however, they found the approach useful to raise an awareness of soil quality issues among regional council staff, scientists and the general public.

We agree that indicators *per se* as well as their thresholds may be important in order to make the soil quality concept operational. The authors of the individual chapters of this book have been encouraged to identify indicators and thresholds whenever it was possible to establish generally applicable limits. However, we realized that this endeavour would be difficult due to the vast number of soil types and agroecosystems addressed. The human species is well defined compared with soils and a body temperature of 37°C is an established threshold for a healthy person, at least regarding infectious diseases. Seybold *et al.* (1998) and Sojka and Upchurch (1999) stressed the difficulty in dealing with the 18,000–20,000 soil series occurring in the USA. Considering the diverse agricultural uses of soils (e.g. growing different crops with dissimilar soil requirements) and the different optima associated with each specific use, Sojka and Upchurch (1999) emphasized *understanding* rather than *rating* of the soil resource. However, within a well-defined scenario, for example research in agricultural management at one specific site or region, the quantification of soil attributes and the use of these as indicators of soil quality may be quite useful (e.g. Campbell *et al*., 1997).

Indicator Threshold and Management Threshold

Threshold was defined by Smyth and Dumanski (1993) as 'levels beyond which a system undergoes significant change; points at which stimuli provoke response'. Thus threshold links to resilience. As an example, Smyth and Dumanski mentioned the threshold for erosion as the level (extent of erosion) beyond which erosion is no longer tolerable (in order to maintain sustainability). Gomez *et al*. (1996) adopted this definition and used the term threshold to denote the boundary between sustainable and unsustainable indicator values. Thus, thresholds are values of a variable beyond which rapid, often exponential, negative changes occur (Pieri *et al*., 1995). Because of their intimate association with resilience, we encourage that focus is on *thresholds* rather than on *references*, *baselines* or *benchmarks*, often employed in the literature on soil-quality indicators.

A main issue when considering the quality of agricultural soil is how to identify sustainable management. One major aim of this book is to promote a shift from *assessing* soil quality to *managing* soil quality. Of course management cannot be addressed without evaluating soil attributes (i.e. indicators), but by focusing on the effects of management we intended to establish a more relevant foundation for the soil quality concept. Our ambition was to concentrate on the challenges facing agriculture in the context of maintaining soil quality. When the common knowledge on soil functions and properties (including indicator thresholds) is combined with that derived from studies on the effects of specific management tools, the potential outcome can be *management thresholds*, i.e. the most severe disturbance any management may accomplish without inducing significant changes towards unsustainable conditions. Regarding soil acidity, soil pH is a soil-quality indicator for which a threshold can be established, whereas the rate of liming (e.g. kg $CaCO_3$/ha/year) required to maintain the pH at some prescribed level represents the management threshold.

The *management threshold* approach may seem less ambitious than the *indicator threshold* approach, which includes the identification of a universal minimum dataset. However, the former may be more successful in solving key management problems in agriculture. Exerting all efforts in coping with the problem of non-universality in indicator thresholds implies the risk of never approaching the management problems. The management approach, however, also needs to consider differences among soil types and agro-ecosystems, and should be based on a thorough understanding of the reaction of individual soils to management. Figure 1.4 illustrates the differences in the two approaches discussed.

Challenges in Modern Agriculture

Modern agriculture faces a number of challenges, which are subject to intense research, but they are seldom defined and discussed in the context of all three aspects of the soil quality concept (Fig. 1.2). As an example, farmers are challenged to manage plant nutrients in order to maintain production volumes, minimize losses of nutrients to the environment and create a high quality in plant products for animal and human consumption.

When addressing the challenges of modern agriculture, a main issue is the identification of management procedures that are sustainable, that is, simultaneously meet societal concerns and recognize the vulnerability of the soil system to degradation. The authors of all chapters have been encouraged to explain their judgement of *sustainability*. Ideally, management options are considered in relation to the three 'concerns' of the SSSA

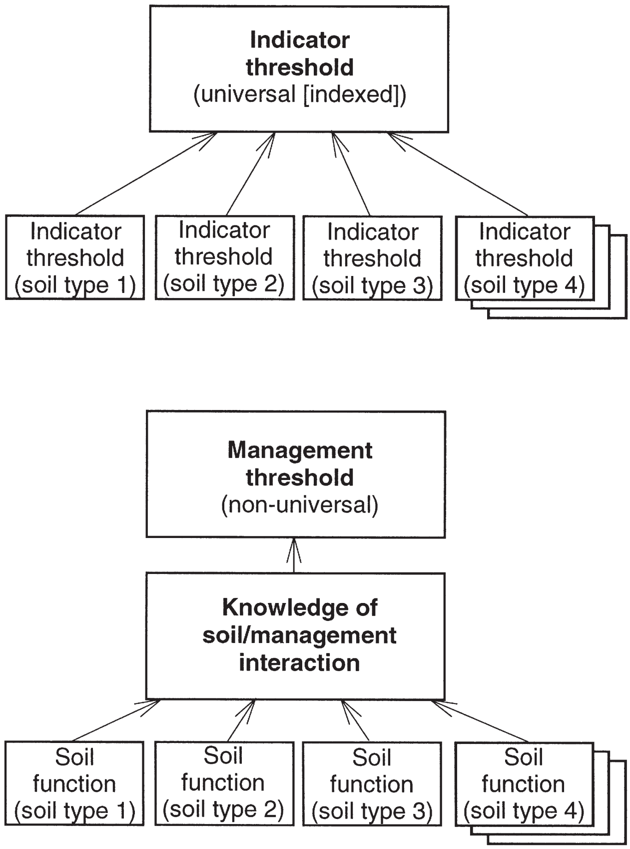

Fig. 1.4. Schematic illustration of the 'indicator threshold' approach typically applied in soil quality studies (top) and the 'management threshold' approach suggested for this volume (bottom). In the 'indicator threshold' approach, the focus is on identifying (universal) thresholds for specific soil-quality indicators, whereas for the 'management threshold' approach, the focus will be put on identifying thresholds (probably non-universal) for specific management tools.

definition of soil quality (Fig. 1.2); that is, how will different soil management affect biological *productivity*, the *environment* framing the managed soil system and *human health*. The latter relates primarily to the quality of products for human consumption. We have further asked for a consideration of soil stability to a given management practice, applying the concept suggested above (Fig. 1.3). This implies identifying *resistance* as well as *resilience* of the soil to the influence from the specific management applied. Finally, a goal-directed approach includes discussion and, if possible, identification of *soil indicator thresholds* as well as *management thresholds* for the soil characteristics and the management procedures discussed in each chapter (Fig. 1.4).

Figure 1.5 summarizes the approach used in this book for discussing soil management as related to soil quality. In the centre stands the major challenges and management tools, which will be discussed in relation to: (i) the three aspects of soil quality; (ii) the stability of 'form' (physical form or soil functions); and (iii) the potential of identifying soil-quality indicator thresholds as well as management thresholds. Figure 1.5 also illustrates how these considerations are framed by the understanding of sustainability and further by societal priorities, and the values and goals of the scientist (the cognitive context).

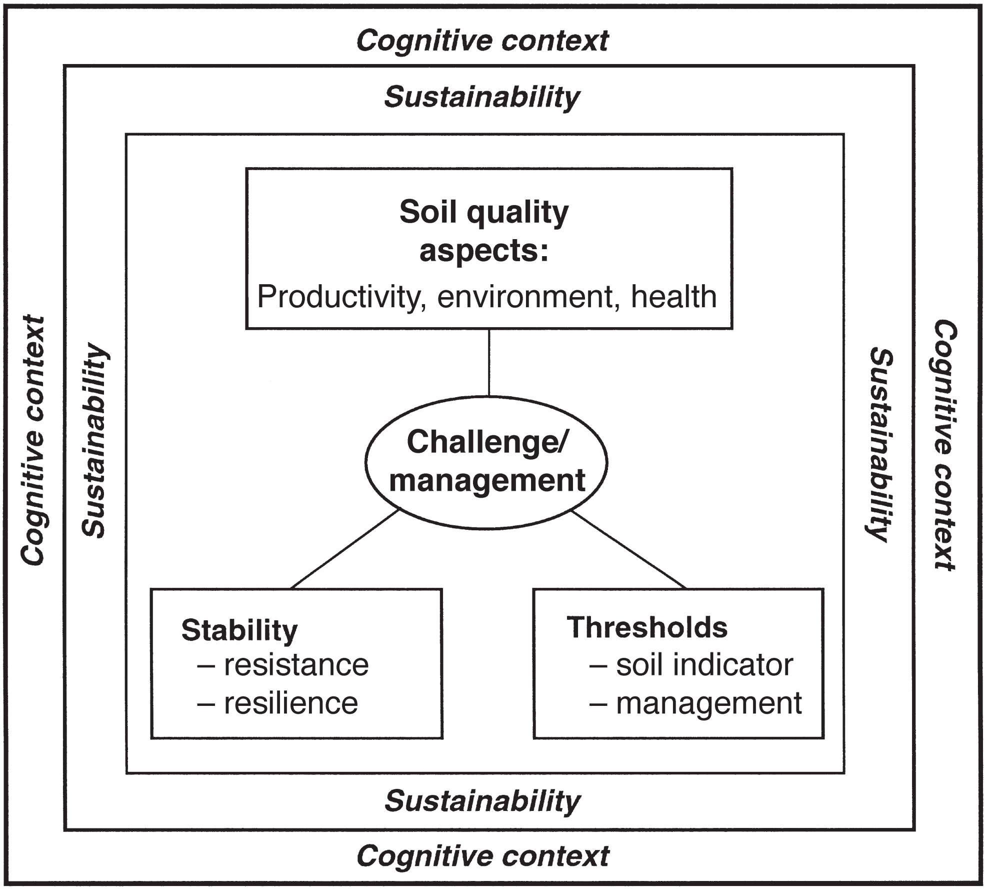

Fig. 1.5. Illustration of the approach used in focusing major challenges in modern agriculture as related to scientifically based terms and as framed by societal values and priorities. Note that only the societal and intentional dimensions of the cognitive context (cf. Fig. 1.1) are active in defining sustainability.

Outlining the Book Content

One major concern in agriculture is an adequate supply of nutrients to the crops. Chapters 3, 4, 5 and 6 of this volume address aspects crucial to basic soil processes and plant nutrition. Soil acidity influences most soil functions. Nitrogen, phosphorus and potassium are three important macronutrients, i.e. nutrients taken up by crops in amounts of kilograms per hectare. More general aspects of the soil ecosystem are topics of Chapters 7, 8 and 9, which deal with soil diversity, including carbon dynamics and biodiversity. The physical form of soils is treated in Chapters 10, 11 and 12, with emphasis on physical degradation of agricultural soils. Chemical contaminants are major threats to soil quality. Chapters 13 and 14 evaluate the potential hazards from the use of organic waste materials and pesticides.

The contributions addressing specific management problems are framed by four conceptual chapters. Chapter 2 reviews the history of and advances in soil quality research. Chapter 15 is an important reminder that systems research may reveal mechanisms not perceived in analytical research. Finally, any work on soil quality should reflect on how the knowledge gained can be implemented. Hence, Chapters 16 and 17 discuss how to put soil quality knowledge to work for industrialized and developing countries, respectively. Figure 1.6 gives an outline of the book content.

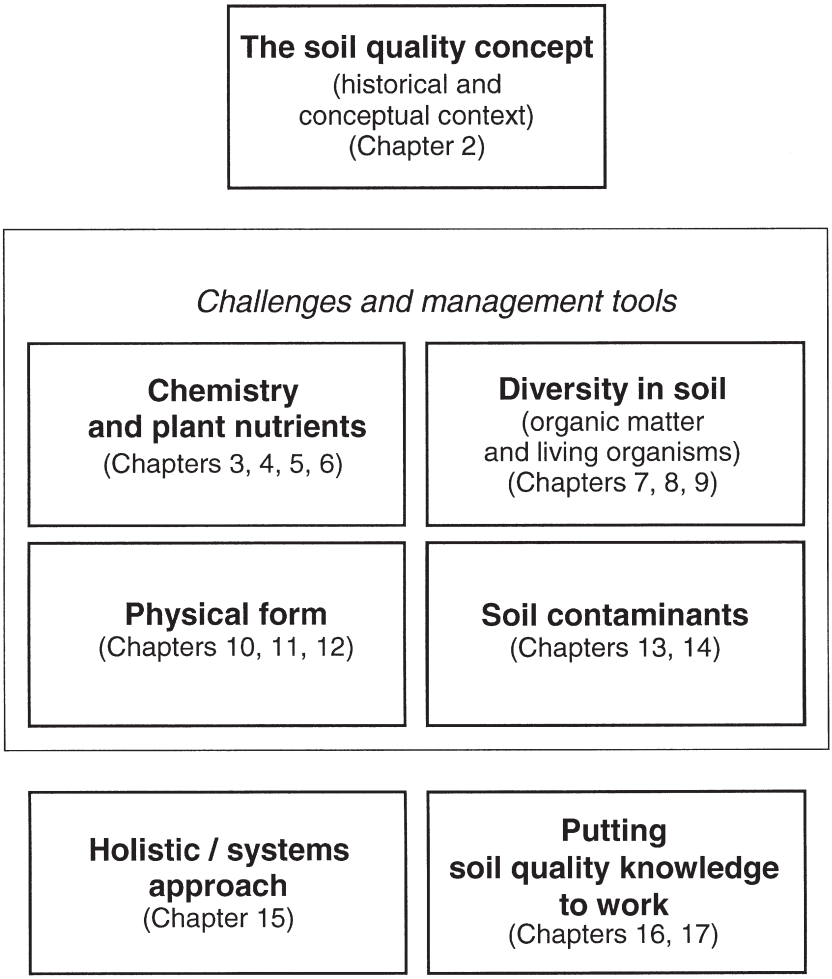

Fig. 1.6. An outline of the book chapters indicating the four groups of challenges addressed in specific chapters.

References

Allan, D.L., Adriano, D.C., Bezdicek, D.F., Cline, R.G., Coleman, D.C., Doran, J.W., Haberen, J., Harris, R.G., Juo, A.S.R., Mausbach, M.J., Peterson, G.A., Schuman, G.E., Singer, M.J. and Karlen, D.L. (1995) SSSA statement on soil quality. In: *Agronomy News*, June 1995, ASA, Madison, Wisconsin, p.7.

Alrøe, H.F. and Kristensen, E.S. (2002) Towards a systemic research methodology in agriculture. Rethinking the role of values in science. *Agriculture and Human Values* 19, 3–23.

Blum, W.E.H. (1998) Basic concepts: degradation, resilience, and rehabilitation. In: Lal, R., Blum, W.E.H., Valentine, C. and Stewart, B.A. (eds) *Methods for Assessment of Soil Degradation*. CRC Press, Boca Raton, Florida, pp. 1–16.

Blum, W.E.H. and Santelises, A.A. (1994) A concept of sustainability and resilience based on soil functions: the role of ISSS in promoting sustainable land use. In: Greenland, D.J. and Szabolcs, I. (eds) *Soil Resilience and Sustainable Land Use*. CAB International, Wallingford, UK, pp. 535–542.

Bossel, H. (1999) *Indicators for Sustainable Development: Theory, Method, Applications. A Report to the Balaton Group*. International Institute for Sustainable Development, Manitoba, Canada, 124 pp.

Bouma, J., Finke, P.A., Hoosbeek, M.R. and Breeuwsma, A. (1998) Soil and water quality at different scales: concepts, challenges, conclusions and recommendations. *Nutrient Cycling in Agroecosystems* 50, 5–11.

Campbell, C.A., Janzen, H.H. and Juma, N.G. (1997) Case-studies of soil quality in the Canadian prairies: long-term field experiments. In: Gregorich, E.G. and Carter, M.R. (eds) *Soil Quality for Crop Production and Ecosystem Health*. Developments in Soil Science 25, Elsevier, Amsterdam, pp. 351–397.

Campbell, C.L., Heck, W.W., Neher, D.A., Munster, M.J. and Hoag, D.L. (1995) Biophysical measurement of the sustainability of temperate agriculture. In: Munasinghe, M. and Shearer, W. (eds) *Defining and Measuring Sustainability. The Biogeophysical Foundations*. The World Bank, Washington, DC, pp. 251–273.

Carter, M.R., Gregorich, E.G., Anderson, D.W., Doran, J.W., Janzen, H.H. and Pierce, F.J. (1997) Concepts of soil quality and their significance. In: Gregorich, E.G. and Carter, M.R. (eds) *Soil Quality for Crop Production and Ecosystem Health*. Developments in Soil Science 25, Elsevier, Amsterdam, pp. 1–19.

Domsch, K.H., Jagnow, G. and Anderson, T.H. (1983) An ecological concept for the assessment of side-effects of agrochemicals on soil microorganisms. *Residue Reviews* 86, 65–105.

Doran, J.W. (2002) Soil health and global sustainability: translating science into practice. *Agriculture, Ecosystems and Environment* 88, 119–127.

Doran, J.W. and Jones, A.J. (eds) (1996) *Methods for Assessing Soil Quality*. Soil Science Society of America Special Publication Number 49, 410 pp.

Doran, J.W. and Parkin, T.B. (1994) Defining and assessing soil quality. In: Doran, J.W., Coleman, D.C., Bezdicek, D.F. and Stewart, B.A. (eds) *Defining Soil Quality for a Sustainable Environment*. Soil Science Society of America Special Publication Number 35, pp. 3–21.

Doran, J.W. and Parkin, T.B. (1996) Quantitative indicators of soil quality: a minimum data set. In: Doran, J.W. and Jones, A.J. (eds) *Methods for Assessing Soil Quality*. Soil Science Society of America Special Publication Number 49, pp. 25–37.

Doran, J.W., Sarrantonio, M. and Liebig, M.A. (1996) Soil health and sustainability. In: Sparks, D.L. (ed.) *Advances in Agronomy*. Academic Press, San Diego, California, pp. 1–54.

Droogers, P. and Bouma, J. (1997) Soil survey input in explanatory modeling of sustainable soil management practices. *Soil Science Society of America Journal* 61, 1704–1710.

Dumanski, J., Pettapiece, W.W. and McGregor, R.J. (1998) Relevance of scale dependent approaches for integrating biophysical and socio-economic information and development of agroecological indicators. *Nutrient Cycling in Agroecosystems* 50, 13–22.

Ellert, B.H., Clapperton, M.J. and Anderson, D.W. (1997) An ecosystem perspective of soil quality. In: Gregorich, E.G. and Carter, M.R. (eds) *Soil Quality for Crop Production and Ecosystem Health*. Developments in Soil Science 25, Elsevier, Amsterdam, pp. 115–141.

Eswaran, H. (1994) Soil resilience and sustainable land management in the context of AGENDA 21. In: Greenland, D.J. and Szabolcs, I. (eds) *Soil Resilience and Sustainable Land Use*. CAB International, Wallingford, UK, pp. 21–32.

Freeman, E. and Skolimowski, H. (1974) The search for objectivity in Peirce and Popper. In: Schilpp, P.A. (ed.) *The Philosophy of Karl R. Popper*. The Open Court Publishing Co., La Salle, Illinois, pp. 464–519.

Gomez, A.A., Kelly, D.E.S., Syers, J.K. and Coughlan, K.J. (1996) Measuring sustainability of agricultural systems at the farm level. In: Doran, J.W. and Jones, A.J. (eds) *Methods for Assessing Soil Quality*. Soil Science Society of America Special Publication Number 49, pp. 401–409.

Herdt, R.W. and Steiner, R.A. (1995) Agricultural sustainability: concepts and conundrums. In: Barnett, V., Payne, R. and Steiner, R. (eds) *Agricultural Sustainability: Economic, Environmental and Statistical Considerations*. John Wiley & Sons, Chichester, UK, pp. 1–13.

Holling, C.S. (1973) Resilience and stability of ecological systems. *Annual Review of Ecology and Systematics* 4, 1–23.

Håkansson, I. and Reeder, R.C. (1994) Subsoil compaction by vehicles with high axle load – extent, persistence and crop response. *Soil and Tillage Research* 29, 277–304.

Jamieson, D. (1992) Ethics, public policy, and global warming. *Science Technology & Human Values* 17, 139–153.

Karlen, D.L., Mausbach, M.J., Doran, J.W., Cline, R.G., Harris, R.F. and Schuman, G.E. (1997) Soil quality: a concept, definition, and framework for evaluation. *Soil Science Society of America Journal* 61, 4–10.

Kay, B.D. (1990) Rates of change of soil structure under different cropping systems. *Advances in Soil Science* 12, 1–52.

Lal, R. (1994) Sustainable land use systems and soil resilience. In: Greenland, D.J. and Szabolcs, I. (eds) *Soil Resilience and Sustainable Land Use*. CAB International, Wallingford, UK, pp. 41–67.

Lal, R. (1998) Soil quality and agricultural sustainability. In: Lal, R. (ed.) *Soil Quality and Agricultural Sustainability*. Ann Arbor Press, Chelsea, Michigan, pp. 3–12.

Larson, W.E. and Pierce, F.J. (1991) Conservation and enhancement of soil quality. In: *Evaluation for Sustainable Land Management in the Developing World*. International Board for Soil Research and Management, Bangkok, Thailand, pp. 175–203.

Larson, W.E. and Pierce, F.J. (1994) The dynamics of soil quality as a measure of sustainable management. In: Doran, J.W., Coleman, D.C., Bezdicek, D.F. and Stewart, B.A. (eds) *Defining Soil Quality for a Sustainable Environment*. Soil Science Society of America Special Publication Number 35, pp. 37–51.

Larson, W.E., Gupta, S.C. and Useche, R.A. (1980) Compression of agricultural soils from eight soil orders. *Soil Science Society of America Journal* 44, 450–457.

Letey, J., Sojka, R.E., Upchurch, D.R., Cassel, D.K., Olson, K., Payne, B., Petrie, S., Price, G., Reginato, R.J., Scott, H.D., Smethurst, P. and Triplett, G. (2003) Deficiencies in the soil quality concept and its application. *Journal of Soil and Water Conservation* 58, 180–187.

Lilburne, L.R., Hewitt, A.E., Sparling, G.P. and Selvarajah, N. (2002) Soil quality in New Zealand: policy and the science response. *Journal of Environmental Quality* 31, 1768–1773.

Lockeretz, W. and Anderson, M.D. (1993) *Agricultural Research Alternatives*. University of Nebraska Press, Lincoln, Nebraska, 239 pp.

Munasinghe, M. and Shearer, W. (1995) An introduction to the definition and measurement of biogeophysical sustainability. In: Munasinghe, M. and Shearer, W. (eds) *Defining and Measuring Sustainability. The Biogeophysical Foundations*. The World Bank, Washington, DC, pp. xvii–xxxii.

Munkholm, L.J. (2000) *The Spade Analysis – a Modification of the Qualitative Spade Diagnosis for Scientific Use. DIAS report*, *Plant Production* No. 28. The Danish Institute of Agricultural Sciences, Tjele, Denmark, 73 pp.

Oxford Advanced Learner's Dictionary of Current English (1974) Oxford University Press, Oxford.

Pankhurst, C.E. (1994) Biological indicators of soil health and sustainable productivity. In: Greenland, D.J. and Szabolcs, I. (eds) *Soil Resilience and Sustainable Land Use*. CAB International, Wallingford, UK, pp. 331–351.

Pankhurst, C.E., Doube, B.M. and Gupta, V.V.S.R. (1997) Biological indicators of soil health: synthesis. In: Pankhurst, C.E., Doube, B.M. and Gupta, V.V.S.R. (eds) *Biological Indicators of Soil Health*. CAB International, Wallingford, UK, pp. 419–435.

Patzel, N., Sticher, H. and Karlen, D.L. (2000) Soil fertility – phenomenon and concept. *Journal of Plant Nutrition and Soil Science* 163, 129–142.

Pennock, D.J. (1997) Effects of soil redistribution on soil quality: pedon, landscape, and regional scales. In: Gregorich, E.G. and Carter, M.R. (eds) *Soil Quality for Crop Production and Ecosystem Health*. Developments in Soil Science 25, Elsevier, Amsterdam, pp. 167–185.

Pieri, C., Dumanski, J., Hamblin, A. and Young, A. (1995) *Land Quality Indicators*. World Bank Discussion Papers 315, The World Bank, Washington, DC, 63 pp.

Schjønning, P., Munkholm, L.J., Debosz, K. and Elmholt, S. (2000) Multi-level assessment of soil quality – linking reductionist and holistic methodologies. In: Elmholt, S., Stenberg, B., Grønlund, A. and Nuutinen, V. (eds) *Soil Stresses, Quality and Care. Proceedings from NJF Seminar 310, 10–12 April 2000, Ås, Norway*. *DIAS report* 38, Danish Institute of Agricultural Sciences, Tjele, Denmark, pp. 43–52.

Seybold, C.A., Mausbach, M.J., Karlen, D.J. and Rogers, H.H. (1998) Quantification of soil quality. In: Lal, R., Kimble, J.M., Follett, R.F. and Stewart, B.A. (eds) *Advances in Soil Science*. CRC Press, Boca Raton, Florida, pp. 387–404.

Seybold, C.A., Herrick, J.E. and Brejda, J.J. (1999) Soil resilience: a fundamental component of soil quality. *Soil Science* 164, 224–234.

Smyth, A.J. and Dumanski, J. (1993) *FESLM: an International Framework for Evaluating Sustainable Land Management*. World Resources Reports 73, Land and Water Development Division, FAO, Rome, 77 pp.

Sojka, R.E. and Upchurch, D.R. (1999) Reservations regarding the soil quality concept. *Soil Science Society of America Journal* 63, 1039–1054.

Sparling, G.P. and Schipper, L.A. (2002) Soil quality at a national scale in New Zealand. *Journal of Environmental Quality* 31, 1848–1857.

Stewart, B.A., Lal, R. and El-Swaify, S.A. (1991) Sustaining the resource base of an expanding world agriculture. In: Lal, R. and Pierce, F.J. (eds) *Soil Management for Sustainability*. Soil and Water Conservation Society, Ankeny, Iowa, pp. 125–144.

Swift, M.J. (1994) Maintaining the biological status of soil: a key to sustainable land management? In: Greenland, D.J. and Szabolcs, I. (eds) *Soil Resilience and Sustainable Land Use*. CAB International, Wallingford, UK, pp. 235–247.

Szabolcs, I. (1994) The concept of soil resilience. In: Greenland, D.J. and Szabolcs, I. (eds) *Soil Resilience and Sustainable Land Use*. CAB International, Wallingford, UK, pp. 33–39.

WCED (1987) *Our Common Future: the Brundtland Report*. Report from the World Commission on Environment and Development (WCED). Oxford University Press, Oxford.