www.ThePharmaJournal.com

The Pharma Innovation

ISSN (E): 2277-7695
ISSN (P): 2349-8242
NAAS Rating: 5.23
TPI 2022; 11(12): 3648-3654

www.thepharmajournal.com
Received: 12-10-2022
Accepted: 17-11-2022

Sandip Kumar Gautam
Ph.D. Research Scholar, Department of Soil Science, CSJMU, Kanpur, Uttar Pradesh, India

Satender Kumar
Ph.D. Research Scholar, Department of Soil Science, CCSHAU, Hisar, Haryana, India

Amit Kumar
Ph.D. Research Scholar, Department of Soil Science, CCSHAU, Hisar, Haryana, India

Kautilya Chaudhary
Assistant Scientist, CCSHAU, Hisar, Haryana, India

Corresponding Author:
Sandip Kumar Gautam
Ph.D. Research Scholar, Department of Soil Science, CSJMU, Kanpur, Uttar Pradesh, India

A critical review on soil quality and health: A review

Sandip Kumar Gautam, Satender Kumar, Amit Kumar and Kautilya Chaudhary

Abstract
The soil quality concept emerged in the 1990s in response to the growing worldwide focus on sustainable land use and a holistic approach that highlights that sustainable soil relevant planning more than just soil erosion control. The concept focuses on two areas: education and assessment, both of which are based on sound soil science principles. Many people lack the knowledge, understanding, and appreciation of soil resources, so educational materials such as soil quality test kits, farmer-based scorecards, visual assessment procedures, fact sheets, and video presentations were created. To demonstrate the various functions (e.g. nutrient and water cycling, contaminant filtering and buffering, decomposition of crop residues and other organic matter sources, and recycling of essential plant nutrients) that soils provide as the foundation for sustainable land management, assessment tools for indexing soil quality at various scales were pursued. From plot to national scales, soil sampling and analysis, as well as visual examination, are widely used to assess its status and use potential. Because of the complexity and site-specificity of soils, legacy effects of previous land use, and trade-offs between ecosystem services, selecting relevant soil attributes and interpreting measurements is not easy. In this article, we look at how to define soil quality and related concepts, as well as how to assess it, and how to choose and interpret indicators. Under agricultural land use, we identify the most commonly used soil quality indicators. We also look at new indicators that address important soil properties and processes that are currently overlooked. This necessitates a much greater level of participation from the relevant actors, stakeholders, and end-users than has previously been the case. Soil quality assurance and education seeks to raise awareness and understanding of soil resources as living bodies with biological, chemical, and physical properties and processes that provide wide range of ecosystem services.

Keywords: Soil quality and health, education and assessment, soil resources

1. Introduction
Soil, like air and water, is a critical natural resource that supports a wide range of ecosystem goods and services for humanity's benefit. While the importance of soil's production function has long been identified, the significance of soil's ecosystem services (e.g., carbon sequestration, water purification, groundwater recharge, pathogen control, biological nitrogen fixation, and biodiversity conservation) has only recently been acknowledged. Long after that, there was a concern about maintaining/improving soil quality. Soil processes have led to it being regarded as an ecosystem in and of itself, rather than a component of an ecosystem. While water and air quality characteristics, measures, and principles are clear and universally accepted, the concept of soil quality, also known as soil health, is still going to evolve, with soil quality legislation enacted in only a few countries (Filip 2002, Nortcliff 2002) [21, 43].
Rising knowledge that soil is a critical component of the earth's biosphere, functioning not only in the production of food and fibre but also in the maintenance of local, regional, and global environmental quality has sparked interest in assessing the efficacy and health of our soil resources (Glanz, 1995) [23]. Soil serves as the foundation for both agricultural and natural plant communities. Thus, with most land-based life, the thin layer of soil that covers the earth's surface represents the difference between survival and extinction (Doran *et al.*, 1996) [18]. Inventories of soil productive capacity, on the other hand, show that human-induced deterioration has occurred on nearly 40% of the world's agricultural land as a result of soil erosion, air pollution, exhaustive soil cultivation, desertification, land clearing, salinization, and desertification (Oldeman, 1994) [45]. '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,' according to the Soil Science Society of America Ad Hoc Committee on soil quality (S-581) (Karlen *et al.*, 1997) [35].

Johnson *et al*. (1997) [34] defined soil quality as "a measure of the condition of soil relative to the requirements of one or more biological species and/or any human purpose" in a discussion of the ambiguity of environmental terms and the need to standardise their meanings. Some people prefer the term "soil health" (Doran *et al*., 1996) [18] because it depicts soil as a living, dynamic system whose functions are mediated by a variety of living organisms that need to be managed and conserved. In extreme environments, soil health, biodiversity, and resilience are severely limited, and they are more susceptible to anthropogenic disturbance (Freckman and Virginia, 1997) [22]. Throughout this paper, the terms soil quality and soil health will be used interchangeably. However, the term soil quality is usually associated with a soil's suitability for a specific purpose, whereas the term soil health is used in a broader sense to describe a soil's ability to function as a crucial living system to endure microbial activity, promote environmental quality, and maintain plant and animal health. Soil health is associated with long-term viability in this context. The physical and chemical properties of the soil, as well as the constraints imposed by climate and ecosystem, determine the quality of the soil. Soil quality also includes a component that is influenced by control and land-use decisions. Admittedly, past agricultural and ecosystem management has seriously degraded and decreases the quality of many soils around the world (Saunders, 1992) [54]. Mechanical farming and the continuous production of row crops, in particular, has resulted in physical soil loss, erosion, and large reduces in soil organic matter content, as well as a CO2 release into the atmosphere (Houghton *et al*., 1983) [31]. Furthermore, the expected doubling of the human population in the next century poses a risk to soil and other natural resource degradation (Power, 1996) [51]. As a result, we must develop production systems that maintain and improve soil quality in order to maintain agriculture for future generations.

2. Meaning of soil quality and soil health

Soil quality is defined as a soil's ability to function within its ability and within natural or operated ecosystem boundaries in order to maintain plant and animal productivity, maintain or improve water and air quality, and support human health and habitation (Karlen *et al*. 1997, Arshad and Martin 2002) [35, 6]. Soil health has been defined as the continued capacity of soil to function as an essential living system, within ecosystem and land-use boundaries, to maintain microbial activity, maintain or improve the quality of air and water, and promote plant, animal, and human health, inside of ecosystem and territorial boundaries (Doran *et al*. 1996) [18]. Though soil health has only recently become popular, variations in soils' ability to suppress plant diseases have been known for a long time (Janvier *et al*. 2007) [32]. Arbuscular mycorrhizal fungi improve crop nutrition while also protecting them from pathogens and toxins. Furthermore, a soil rich in organic carbon and nutrients (commonly referred to as high quality soils) may not be considered healthy if it causes crop damage or harbours large parasitic organism population levels (Abawi and Widmer 2000) [1]. Soil health, according to van Bruggen and Semenov (2000) [59], is an aspect of ecosystem health, defined as the soil's resistance and resilience to different stresses and abnormalities. As a result, there is a lot of overlap between soil quality and soil health, though soil health perspectives tend to be more focused on biosphere of soil (Anderson 2003) [5]. Topsoil erosion or deterioration in soil health or quality refers to the loss of soil's vital functions, which also include supplying physical support, water, and essential nutrients for land based plant growth; (ii) regulating water flow in the environment; and (iii) removing contaminates through physical, chemical, and biological processes, i.e., acting as an environmental buffer or filter (Constanza *et al*. 1992a,b, Bastida *et al*. 2006) [7]. Soil quality and health influence agricultural sustainability and environmental quality, which affects plant, animal, and human health (Haberern 1992) [26].

3. Defining soil quality and health

3.1 Inherent soil quality

The natural or inherent arrangement of any soil, which is a feature of geological materials and soil state aspects or variables, influences its quality (e.g., parent material and topography). Mineralogy and particle size distribution are two factors of inherent soil quality that are largely considered static and show tiny change over time. It is widely acknowledged that some soils have poor natural quality and are unfit or unsuitable for a particular purpose (e.g., crop production). Anthropogenic activities such as land use and farming methods can sometimes result in the degradation of a soil that had previously been of good inherent quality due to poor management and/or climatic changes (e.g. soil erosion, desertification). Extrinsic factors, or factors other than soil, that affect crop yield, are also taken into account when determining inherent soil quality for crop production (Janzen *et al*., 1992) [33]. Climate (precipitation, evaporative demand, and air temperature), topographic, and hydrologic parameters are among these variables. The latter two factors are frequently regarded as landscape quality measures. The quality of the landscape is a significant factor in deciding whether or not a piece of land is suitable for a particular purpose. Some land quality characteristics (such as slope and texture) are used to approximate land quality indicators such as trafficability, erosion risk, and drought risk (Pierce and Larson, 1993) [50].

3.2 Dynamic soil quality

Soil properties that occur in response to human use and monitoring are referred to as dynamic soil quality. In general, only a management system that retains or improves the soil quality is considered sustainable (Larson and Pierce, 1994) [37]. Dynamic soil quality attributes are subject to revision over comparatively short time periods, as inferred by the terminology. Total organic matter, for example, can alter over years or decades, whereas pH and labile organic matter fractions can change over months or years. Microbial biomass and populations, soil respiration, nutrient mineralization rates, and macroporosity, on the other hand, can dramatically change over hours to days. As a result, maintaining and improving dynamic soil quality focuses on the features or indicators that are most susceptible to change (e.g., loss or depletion) and are influenced heavily by agronomic practises. Currently, methods for quantifying soil quality focus on either directly characterising different quality factors (such as soil properties) or identifying specific indicators that can demonstrate the attribute in question (Gregorich *et al*., 1994) [24].

3.3 Soil versus land quality

Extrinsic factors, such as landscape quality, are taken into account when assessing inherent soil quality, as previously stated. There has previously been some ambiguity in distinguishing between soil and land quality definitions (Pettapiece and Acton, 1995) [64]. Land is a term that better represents the natural assimilation of soil, water, climate, landscape, and vegetation attributes, and it is now identified that soils are part of a larger environmental system (FAO, 1976; Hamblin, 1995; Pettapiece and Acton, 1995) [20, 27, 64]. As a result, one aspect of land quality is soil quality. The recent pedological attention on soil as a spatial three-dimensional entity also illustrates the difference between soil and land quality. In this comparison, pedology has progressed from site analysis to two-dimensional soil profile analysis to three-dimensional pedon analysis, with a focus on three-dimensional polypedon or landscape units in recent years. The cartographic concept of a catena reflects these developments. Interest in GIS and spatial statistics is also emphasising spatial aspects. The state of the combined or integrated entity of soil, water, and vegetation is described by land quality, which is a broader concept than soil quality (FAQ, 1976) [65]. Land quality, like soil quality, can be defined by attributes and indicators. Much research is currently being done on the development of land quality indicators, which are the key entities that can be analysed and monitored to assess land quality. The term "soil health" refers to the state of the It has long been recognised that, through crop quality, there is an indirect relationship between soil health and animal and human health (Warkentin, 1995) [62]. Soil health here refers to the balance and availability of plant nutrients, as well as the absence of plant diseases and pests. The above approach to soil quality has recently led to the concept of characterising a soil's health (Larson and Pierce, 1991; Doran and Parkin, 1994; Doran *et al*., 1996) [36, 18]. From the individual (i.e., organism) to a community of individuals (i.e., system), the concept of "health" can be considered at many levels of biological organisation (Park and Cousins, 1995) [47]. In the first, health is a composite picture of the state of an organism's (e.g., the human body) various parts and functions, which is assessed by characterising a variety of factors. Soil health is a composite representation of the state of the soil's many physical, chemical, and biological properties, its shape and morphology, and the processes that interact to determine this quality, using the soil-as-an-organism analogy. Although the terms "soil health" and "soil quality" may appear to be interchangeable. Sparling (1997) [57] points out that a soil with poor quality for a specific purpose, such as sand, can still be healthy. Overall, there is no single measurement that can be used to quantify soil health, just as there is no single measure of organism or community health. It must be estimated or inferred using the same framework (i.e., function, process, attributes, and indicators) as described in the next section for soil quality. Using terms similar to soil quality, Doran *et al*. (1996) [18] defined soil health as "a soil's continued capacity to function as a vital living system, within ecosystem and land-use boundaries, to sustain biological productivity, maintain the quality of air and water environments, and promote plant, animal, and human health."

3.4 Soil quality and land sustainability

Soil quality is regarded as a critical component of long-term agriculture (Warkentin, 1995) [62]. The latter is defined as "economically viable agricultural and agri-food systems that meet current societal need for safe and nutritious food while retaining or improving natural resources and environmental quality for coming generations" (Globescan, 1996) [24]. Overall, the term "sustainability" refers to the land use system's productivity, economic, social, and environment factors (Smyth and Dumanski, 1995) [56]. Maintaining or improving farm productivity; avoiding or minimising adverse impacts on natural resources and associated ecosystems; maximising the net social benefit derived from agriculture; and boosting versatility of farming systems to manage climate and market risks are the main areas involved with agricultural sustainability. Despite the fact that sustainability concerns are much broader than soil quality, the strong emphasis on conserving the natural resource base ensures that good soil quality is an essential aspect of sustainable agriculture (Miller and WaU, 1995; Royal Commission on Environmental Pollution, 1996) [51]. Unlike natural ecosystems, where equilibriums are established that start reducing nutrient export, agro ecosystems are defined by management inputs that enhance nutrient recycling while decreasing natural soil buffering (Warkentin, 1995) [62]. Natural ecosystems, according to Addiscott (1995) [2], are characterised by the principle of minimum entropy production, whereas agro ecosystems tend to degrade ordered complex structures, resulting in the production of environmentally inappropriate small molecules (e.g., N2O). Agricultural systems should be managed to produce a steady state, maintain the capacity for self-organization (i.e., maintain biological potential), and hinder viscous dissipation processes that produce excess small molecules, as these molecules frequently cause environmental or human health problems. As previously stated, the concept of "quality" entails intent, application, and evaluation.

4. Soil quality: indicator of sustainable land management

The need to evaluate their utility to humans, resource efficiency, and ability to maintain a balance with the environment that is beneficial to both humans and most other species makes developing soil conservation systems difficult (Harwood, 1990) [29]. We face a particular challenge in developing agricultural management systems that balance the needs for food and fibre production with those for environmental preservation. "A sustainable agriculture — sustains the people and preserves the land," says Tom Franzen, a midwestern farmer in the United States. Soil quality is viewed as the most important link between agricultural conservation management techniques and the achievement of sustainable agriculture's major goals (Parr *et al*., 1992; Acton and Gregorich, 1995) [48, 64]. In short, the primary indicator of sustainable land management is the assessment of soil quality or health, as well as the direction of change over time (Karlen *et al*., 1997) [35] Although the importance of soil to plant productivity is widely acknowledged, soil quality also has an impact on water and air quality. In many parts of the world, intensive land management practises and the resulting imbalance of C, N, and water cycling in soil have jeopardised the quality of surface and subsurface water. Agriculture is the most common source of nonpoint source water pollution in the United States (National Research Council, 1993) [66]. In North America and Europe, nitrate nitrogen is the most common water contaminant, with the main sources being conversion of unmanaged land to intensive agriculture, animal manures, and atmospheric deposition. Over the last 30 years, human changes to the nitrogen cycle have nearly doubled the rate of nitrogen input to terrestrial ecosystems, resulting in large increases in nitrogen transfer from land to the atmosphere, rivers, estuaries, and coastal oceans (Vitousek *et al*., 1997) [61]. Water quality is influenced by soil management practises such as tillage, cropping patterns, and pesticide and fertiliser use. Furthermore, changes in the soil's capacity to produce or consume important atmospheric gases like carbon dioxide, nitrous oxide, and methane can have an impact on atmospheric quality (Rolston *et al*., 1993; Mosier, 1998) [52, 41]. Because of the current threat of global climate change and ozone depletion caused by increased levels of greenhouse gases and altered hydrological cycles, a better understanding of the impact of land management on soil processes is required (Bengtsson, 1998) [18]. In conclusion, soil quality and health determine agricultural sustainability, environmental quality, and plant, animal, and human health (Papendick and Parr, 1992; Acton and Gregorich, 1995) [48, 64]. (Haberern, 1992; Harris *et al*., 1996) [26, 28]. Scientists contribute significantly to long-term land management by translating scientific knowledge and information about soil function into practical tools and approaches that land managers can use to assess the long-term viability of their management practises (Bouma, 1997) [11]. To identify problem production areas, make realistic food production estimates, monitor changes in sustainability and environmental quality as related to agricultural management, and assist government agencies in formulating and evaluating sustainable agricultural and land-use policies, soil quality/health assessment is required. The use of a single approach for assessing or indexing soil quality is complicated, preventing land managers and policymakers from using it in a practical or meaningful way (Harris *et al*., 1996) [28]. However, the most fruitful method of linking science and practise in assessing the sustainability of management practises will likely be the use of simple indicators of soil quality and health that are meaningful to farmers and other land managers (Romig *et al*., 1995) [53].

4.1 Use of soil organisms as indicators of soil quality and health

Criteria for soil quality and health indicators include their usefulness in defining ecosystem processes and integrating physical, chemical, and biological properties, sensitivity to management and climatic variations, and accessibility and utility to agricultural specialists, producers, conservationists, and policymakers (Doran and Parkin, 1996) [18]. Soil organism measurements meet many (though not all) of the criteria for useful indicators of sustainable land management. As a result, the conference published in this issue focused on soil organisms (including their abundance, diversity, food web structure, and community stability; Brussaard *et al*., 1997) [67]. The majority of the papers in this issue go on to discuss which of the currently known organisms and ecological parameters are the best indicators.

4.2 Sensitivity to variations in management

A soil parameter must respond sensitively to changes in management to be useful as an indicator of the long-term viability of land management practises. Specifically, 'the indicators should be sensitive enough to reflect the influence of management and climate on long-term changes in soil quality, but not so sensitive that they are influenced by short-term weather patterns,' according to the report (Doran and Parkin, 1996) [18]. Because soil organisms are sensitive to anthropogenic disturbances, they meet this criterion (Pankhurst *et al*., 1997; Wolters and Schaefer, 1994) [45, 63]. Appl. Soil Ecol. 9 (1998) 306–428, a special issue dedicated to 'Soil Organisms and Soil Resource Management,' contains numerous additional examples. Furthermore, both Rosemeyer and Abawi (this issue) describe changes in the abundance and diversity of bacteria, fungi, and other microbes as a result of management.

4.3 Well correlated with beneficial soil functions

Because soils and their biota provide ecosystem functions that benefit humans, soil health is worth quantifying. These ecosystem services, which include storing and releasing water, decomposing plant and animal residues, transforming and recycling nutrients, sequestering and detoxifying organic toxicants, and promoting plant health by suppressing plant-pathogenic microbes and phytophagous fauna, can be of significant value (Costanza *et al*., 1997) [7]. Direct measurements of soil function are frequently possible and desirable. Decomposition rate was directly measured in participatory research with US farmers, for example, by periodically examining samples of buried paper Direct measurements of some soil functions, on the other hand, may be too expensive (for example, direct measurements of nutrient transformations) or require too many observations over a long period of time (for example, the capacity of a soil to supply water for plant growth during a drought may be observable only during rare drought years). In such cases, it may be preferable to measure surrogates or proxies that are well correlated with the soil function rather than measuring the soil function directly. Soil organisms meet this criterion because their abundance and diversity are frequently linked to a variety of beneficial soil functions (Pankhurst *et al*., 1997) [45]. However, when choosing which organism or community parameter to use as a proxy for soil function, caution is required (Bengtsson, 1998) [18].

4.4 Useful for elucidating ecosystem processes

An indicator of soil quality must do more than predict whether a soil will provide a beneficial function to aid farmers, ranchers, conservationists, foresters, and other land managers in selecting appropriate interventions. The indicator should also explain why the soil will or won't perform as expected. Plant productivity and health, for example, are valuable indicators because they are highly correlated with a variety of soil functions (Anderson, 1988; Doran *et al*., 1996) [4, 18]. Nonetheless, if plant productivity or health is measured and found to be less than ideal, it is unclear what action should be taken. As a result, indicators are needed to help land managers understand the cause-and-effect chain that connects land management decisions to plant and animal productivity and health. Soil organisms meet this criterion because they play a direct role in a variety of ecosystem processes, including nutrient conversion into plant-available forms (Anderson, 1988) [4] and noxious organism suppression (Bongers and Bongers, 1998) [10]. Furthermore, soil organisms play an important indirect role in processes such as water infiltration by affecting soil structure (Anderson, 1995) [3].

4.5 Comprehensible and useful to land managers

The farm owner or operator, rancher, forester, golf course superintendent, conservationists, and others who manage the land are the ultimate determinants of soil quality and health. As a result, the land manager is the final arbiter of which soil quality indicators are worth measuring. To develop measurements of soil organisms that are understandable and useful to land managers, a lot of thought and creativity is required. Earthworm abundance has been successfully used as an indicator in farmer-participatory soil health programmes in both the United States and Ecuador (Carroll *et al*., this issue). Furthermore, measurements of nematode abundance and diversity (Bongers and Bongers, 1998) [10], mite abundance and diversity (Behan-Pelletier, this issue), and bacteria abundance and diversity (Nelson and van Bruggen, this issue) could provide a wealth of information on soil functions and processes, but they would likely necessitate too much specialised training for land managers. It's still unclear whether land managers will have access to these potentially valuable biological indicators.

4.6 Easy and inexpensive to measure

Because the land manager is the most important determinant of soil quality and health, indicators of soil quality and sustainability should be both accessible and cost-effective in terms of both time and money. This argues against using species richness ('biodiversity') as an indicator, because quantifying species richness requires extensive taxonomic knowledge and can be time-consuming and expensive. It may, however, be possible to develop functional diversity measures that non-taxonomists can measure (Bengtsson, 1998) [18]. In general, quantifying soil organisms is neither prohibitively costly nor necessitates the use of specialised equipment (e.g. Blair *et al*., 1996; Pankhurst *et al*., 1997) [45]. However, more research is required to develop sampling protocols (Dick *et al*., 1996) [16] that are compatible with the time constraints imposed by land managers' typically hectic and unpredictable schedules. In conclusion, soil organism measurements are sensitive to anthropogenic perturbations, well correlated with beneficial soil functions, and excellent teaching tools because they elucidate ecosystem processes. However, developing meaningful soil organism measurements that can be quantified within the time and skills available to land managers is a challenge. As with any indicator, the usefulness of quantifying soil organisms as part of a programme to improve soil quality and health will be determined by the program's objectives.

5. Resources for future work on soil health

Here is a partial list of organisations and published resources on soil quality and health as it relates to sustainable management. The two publications Acton and Gregorich, 1995) well reflect Canadian contributions, which were among the first to be active in this area. The Soil Science Society of America's Division S-3 (Soil Biology and Biochemistry) has a soil quality working group with over 100 members from the US and other countries. This organisation was a strong supporter of two important soil quality references (Doran *et al*., 1994; Blair *et al*., 1996; Dick *et al*., 1996; Doran and Parkin, 1996;; Harris *et al*., 1996; Romig *et al*., 1996) [18, 16, 53]. Other authors who have focused on soil health and soil organisms include Doran *et al*. (1994a) [17], Pankhurst *et al*. (1997) [45], the Soil Ecology Society, and the Ecological Society of America's soil ecology section. Individual scientists' international efforts in the GCTE (Global Change and Terrestrial Ecology) and the Scientific Committee on Problems of the Environment (SCOPE), for which several workshops have recently identified a number of gaps in below-surface knowledge (see http://www.nrel.colostate.edu/soil/scope.html), are also deserving of recognition. The Natural Resources Ecology Lab in Fort Collins, Colorado, has a Soil Biodiversity and Ecosystem Functioning page (see http://www.nrel.colostate.edu/soil/home.html). The National Academy of Sciences recently approved the formation of a US National Committee on Soil Science, which will increase soil visibility in the United States. This committee will now represent soil biologists and other soil scientists in international decisions on biodiversity loss, invasive species, and global change, particularly in major scientific contributors to global sustainability policy, such as the International Congress of Scientific Unions (ICSU) (Personal communication from Diana Wall, Director of the Natural Resource Ecology Lab, 20 October 1998). In 1985, the International Organization for Standardization (ISO) formed a Technical Committee (ISO/TC 190) to study the development of methodologies for monitoring soil quality. Hortensius and Nortcliff define the scope of this Technical Committee and its work programme (1991). Dr. Richard Wellings (Secretary, ISO/TC 190, NNI, P.O. Box 5059, 2600 GT Delft, The Netherlands; fax: +31-15-2690-190) can provide more information. Doran and Stamatiadis present the findings of an international workshop on "Soil Health as an Indicator of Sustainable Land Management," which took place in Athens, Greece, on June 24–25, 1999. (1999). The proceedings of this workshop will be published as a special issue of Agriculture, Ecosystems, and Environment in 2001.

6. Conclusions

In terms of objectives, tools and methods, and overall approach, our review revealed how soil quality assessment has evolved over time (Fig. 5). In order to assess soil quality, a number of steps must be taken (Fig. 6), each of which is addressed to varying degrees in the large number of approaches developed over the last three decades and reviewed in this article. A clear definition of the objectives, such as whether the soil assessment will be used as a basis for management recommendations, as an educational tool, or as part of a monitoring programme, is a good place to start. In order to increase adoption of the developed assessment approach, target users should be identified and involved from the start. Such an approach was used in the Horizon 2020 project LANDMARK, where stakeholder workshops were used to develop the assessment of soil functions and indicators (http://landmark2020.eu/work-package/work-package-1/). Stakeholder-based assessment necessitates the use of different tools for different types of knowledge. Visual soil assessment tools, for example, are aimed at farmers to help them understand the state of soil structure in the field, whereas more detailed knowledge of productivity requires laboratory measurements, which are available to farmers through the Cornell soil health assessment (Moebius-Clune *et al*., 2016) [40] and newly developed commercial soil testing services based on spectroscopic methods. The selection of soil quality indicators should be based on mechanistic links between indicators and soil functions or ecosystem services, which have occasionally been proposed (Creamer *et al*., 2016) [15] but are rarely firmly established through experimental validation (e.g. van Eekeren *et al*., 2010) [60]. Because some soil functions are primarily related to the topsoil, whereas others are related to the entire soil profile, a clear definition of the targeted soil function(s) will determine the soil depth to be evaluated. The ability to choose indicators based on targeted soil threats, soil functions, and ecosystem services, which is deemed possible by using the logical-sieve method, would be an asset of a novel soil quality framework (Stone *et al*., 2016a) [58]. Soil threats, functions, and ecosystem services are all conceptually linked (Fig. 2), and concepts focusing on either of these can be reconciled if the targeted soil function or ecosystem service, as well as the associated indicator choice, are scale-dependent (Norton *et al*., 2016; Schulte *et al*., 2015) [55]. Future approaches to soil quality, such as functional land management (Schulte *et al*., 2015) [55] used in the LANDMARK project, should clearly incorporate (multi-) functionality. The ability to choose between substitute and proxy indicators would be extremely useful, but it is currently unavailable.

7. References

1. Abawi GS, Widmer TL. Impact of soil health management practices on soil borne pathogens, nematodes and root diseases of vegetable crops. Applied Soil Ecology. 2000;15:37-47.
2. Addiscott TM. Entropy and sustainability. Eur. J Soil Sci. 1995;46:161-168.
3. Anderson J. Soil organisms as engineers: microsite modulation of macroscale processes. In: Jones, C.G., Lawton, J.H. (Eds.), Linking Species and Ecosystems. Chapman & Hall, London; c1995. p. 94-106.
4. Anderson JM. The role of soil fauna in agricultural systems. In: Wilon, J.R. (Ed.), Advances in Nitrogen Cycling in Agricultural Ecosystems. CAB International, Wallingford; c1988. p. 89-113.
5. Anderson T. Microbial eco-physiological indicators to assess soil quality. Agriculture Ecosystems and Environment. 2003;98:285-293.
6. Arshad MA, Martin S. Identifying critical limits for soil quality indicators in agroecosystems. Agriculture Ecosystems and Environment. 2002;88:153-160.
7. Bastida F, Moreno JL, Hernandez T, Garcia C. Microbiological degradation index of soils in a smiarid climate. Soil Biology and Biochemistry. 2006;38:3463-3473.
8. Bengtsson J. Which species? What kind of diversity? Which ecosystem function? Some problems in studies of relations between biodiversity and ecosystem function. Appl. Soil. Ecol. 1998;10:191-199.
9. Blair JM, Bohlen PJ, Freckman DW. Soil invertebrates as indicators of soil quality. In: Doran, J.W., Jones, A.J. (Eds.), Methods for Assessing Soil Quality. Soil Science Society of America, Special Publication 49, Madison, WI; c1996. p. 273-291
10. Bongers T, Bongers M. Functional diversity of nematodes. Appl. Soil Ecol. 1998;10:239-252.
11. Bouma J. Soil environmental quality: a European perspective. J Environ. Qual. 1997;26:26-31.
12. Gurung S, Mandal RA, Mathema AB. Valuation of ecosystem services provided by Jal Binayak community forest, Nepal. Int. J Geogr Geol. Environ 2021;3(2):25-

34.
13. Costanza R, d'Arge R, de Groot R, Farber S, Grasso M, Hannon B, *et al*. The value of the world's ecosystem services and natural capital. Nature. 1997;387:253-259.
14. Costanza R, Funtowicz SO, Ravetz JR. Assessing and communicating data quality in policy relevant research. Environmental Management. 1992b;16:121-131.
15. Creamer RE, Hannula SE, Van Leeuwen JP, Stone D, Rutgers M, Schmelz RM, *et al*. Ecological network analysis reveals the inter-connection between soil biodiversity and ecosystem function as affected by land use across Europe. Applied Soil Ecology. 2016;97:112–1
16. Dick RP, Thomas DR, Halvorson JJ. Standardized methods, sampling, and sample pretreatment. In: Doran, J.W., Jones, A.J. (Eds.), Methods for Assessing Soil Quality. Soil Science Society of America, Special Publication 49, Madison, WI; c1996. p. 107-121.
17. Doran JW, Parkin TB. Defining and assessing soil quality. Pages 3-21 in J.W. Doran, D.C. Coleman, D.F. Bezedick, and B.A. Stewart, eds. Defining soil quality for a sustainable environment. Soil Sci Soc. Am. Special Pub. No. 35, Am. Soc. Agron., Madison, Wise, U.S.A; c1994.
18. Doran JW, Parkin TB. Quantitative indicators of soil quality: a minimum data set. In: Doran, J.W., Jones, A.J. (Eds.), Methods for Assessing Soil Quality. Soil Science Society of America, Special Publication 49, Madison, WI; c1996. p. 25-37.
19. Doran JW, Sarrantonio M, Lieberg MA. Soil health and sustainabi Uty. Adv. Agron. 1996;56:1-54.
20. FAO. A framework for land evaluation. Soils Bull. 32, Food and Agriculture Organization, United Nations, Rome, Italy; c1976.
21. Filip Z. International approach to assessing soil quality by ecologically-related biological parameters. Agriculture, Ecosystems and Environment. 2002;88:169-174.
22. Freckman DW, Virginia RA. Low-diversity Antarctic soil nematode communities: distribution and response to disturbance. Ecology. 1997;78:363-369.
23. Glanz JT. Saving Our Soil: Solutions for Sustaining Earth's Vital Resource. Johnson Books, Boulder, CO, USA; c1995.
24. Globescan. Sustainable development trends: results of 1995 survey of sustainable agriculture. Page 12. in Synergistics, Toronto, Ont., Canada; c1996.
25. Gregorich EG, Carter MR, Angers DA, Monreal CM, Ellert BH. Towards a minimum data set to assess soil organic matter quahty in agricultural soils. Can. J Soil Sci. 1994;74:367-385.
26. Haberern J. Viewpoint: A soil health index. Journal of Soil Water Conservation. 1992;47:6.
27. Hamblin AP. Land quality indicators: when, how and for whom? Ecol. Econ. 1995;12:341-348.
28. Harris RF, Karlen DL, Mulla DJ. A conceptual framework for assessment and management of soil quality and health. In: Doran, J.W., Jones, A.J. (Eds.), Methods for Assessing Soil Quality. Soil Science Society of America, Special Publication 49, Madison, WI; c1996. p. 61-82.
29. Harwood RR. A history of sustainable agriculture. In: Edwards, C.A., Lal, R., Madden, P., Miller, R.H., House, G. (Eds.), Sustainable Agricultural Systems. Soil and Water Conservation Society, Ankeny, Iowa, USA; c1990. p. 3-19.
30. Hortensius D, Nortcliff S. International standardization of soil quality measurement procedures for the purpose of soil protection. Soil Use Manage. 1991;7:163-166.
31. Houghton RA, Hobbie JE, Melillo JM, Moore B, Peterson BJ, Shaver GR, *et al*. Changes in the carbon content of terrestrial biota and soils between 1860 and 1980: a net release of CO2 to the atmosphere. Ecol. Monog. 1983;53:235-262.
32. Janvier C, Villeneuve F, Alabouvette C, Edel-Hermann V, Mateille T, Steinberg C. Soil health through soil disease suppression: which strategy from descriptors to indicators. Soil Biology and Biochemistry. 2007;39:1-23.
33. Janzen HH, Larney FJ, Olson BM. Soil quality factors of problem soils in Alberta. Pages 17-28 in Proceedings of 29th Annual Alberta Soil Science Workshop, Lethbridge, Alta., Canada; c1992.
34. Johnson DL, Ambrose SH, Bassett TJ, Bowen ML, Crummey DE, Isaacson JS, *et al*. Winter-Nelson, A.E. Meanings of environmental terms. J Environ. Qual. 1997;26:581-589.
35. Karlen DL, Mausbach MJ, Doran JW, Cline RG, Harris RF, Schuman GE. Soil quality: a concept, definition, and framework for evaluation. Soil Sci. Soc. Am. J. 1997;61:4-10.
36. Larson WE, Pierce FJ. Conservation and enhancement of soil quality. in Evaluation for sustainable land management in the developing world. IBSRAM Proc, Technical papers, Bangkok, Thailand. 1991;12(2):175-203
37. Larson WE, Pierce FJ. The dynamics of soil quality as a measure of sustainable management. Pages 37-51 in J.W. Doran, D.C. Coleman, D.F. Bezedick, and B.A. Stewart, eds. Defining soil quality for a sustainable environment. Soil Sci Soc. Am. Special Pub. No. 35, Am. Soc. Agron., Madison, Wise. U.S.A; c1994.
38. Lavkulich LM. Soil: the environmental integrator. Pages 1^3 in C.B. Powter, S.A. Abboud, and W.B. McGill, eds. Environmental soil science: anthropogenic chemicals and soil quality criteria. Can. Soc. Soil Sci., Edmonton, Alta., Canada; c1995.
39. Miller FP, Wali MK. Soils, land use and sustainable agriculture: a review. Can. J Soil Sci. 1995;75:413-422.
40. Moebius-Clune BN, Moebius-Clune DJ, Gugino BK, Idowu OJ, Schindelbeck RR, Ristow AJ, *et al*. Comprehensive Assessment of Soil Health. The Cornell framework manual. third ed; c2016.
41. Mosier AR. Soil processes and global change. Biol. Fertil. Soils. 1998;27:221-229.
42. Nortcliff S. Standardisation of soil quality attributes. Agriculture, Ecosystems and Environment. 2002;88:161-168.
43. Norton L, Greene S, Scholefield P, Dunbar M. The importance of scale in the development of ecosystem service indicators? Ecological Indicators. 2016;61:130-140.
44. Oldeman LR. The global extent of soil degradation. In: Greenland, D.J., Szabolcs, I. (Eds.), Soil Resilience and Sustainable Land Use. CAB International, Wallingford, Oxon, UK; c1994. p. 99-118.
45. Pankhurst C, Doube BM, Gupta VVSR. (Eds.), Biological Indicators of Soil Health. CAB International, Wallingford; c1997.
46. Papendick RI, Parr J. Soil quality: The key to a sustainable agriculture. Am. J. Altern. Agric. 1992;7:2-3.
47. Park J, Cousins SH. Soil biological health and agro-ecological change. Agric. Ecosys. Environ. 1995;56:137-148.
48. Parr JF, Papendick RI, Hornick SB, Meyer RE. Soil quality: attributes and relationship to alternative and sustainable agriculture. Am. J Altern. Agric. 1992;7:5-11.
49. Petersen GW, Bell JC, McSweeney K, Nielsen GA, Robert PC. Geographic information systems in agronomy. Adv. Agron. 1995;55:67-111.
50. Pierce FJ, Larson WE. Developing criteria to evaluate sustainable land management. in J.M. Kimble, ed. Proceedings of the eight intern, soil management workshop: utilization of soil survey information for sustainable land use. USDA, Soil Conservation Service, National Soil Survey

Center, Washington, D.C, U.S.A; c1993. p. 7-14.
51. Power JF. Requirements for a sustainable agriculture for the next generation. In: Nath, B., Lang, I., Mesaros, E., Robinson, J.P., Hens, L. (Eds.), Proceedings of the International Conference on Environmental Pollution, Vol. 1, Budapest, Hungary, 15–19 April 1996. European Centre for Pollution Research, University of London, London, UK; c1996. p. 92-98.
52. Rolston DE, Harper LA, Mosier AR, Duxbury JM. Agricultural Ecosystem Effects on Trace Gases and Global Climate Change. American Society of Agronomy, Special Publication 55, Madison, WI, USA; c1993.
53. Romig DE, Garlynd MJ, Harris RF, McSweeney K. How farmers assess soil health and quality (Special Issue on Soil Quality). J Soil Water Conserv. 1995;50:229-236.
54. Saunders DW. International activities in assessing and monitoring soil degradation (Special Issue on Soil Quality). Am. J Alter. Agric. 1992;7:17-24.
55. Schulte RPO, Bampa F, Bardy M, Coyle C, Creamer RE, Fealy R, *et al*. Making the most of our land: managing soil functions from local to continental scale. Frontiers in Environmental Science; c2015. p. 3.
56. Smyth AJ, Dumanski J. A framework for evaluating sustainable land management. Can. J Soil Sci. 1995;75:401-406.
57. Sparling GP. Soil microbial biomass, activity, and nutrient cycHng as indicators of soil health. in CE. Pankhurst, B.M. Doube, and V.V.S.R. Gupta, eds. Biological indicators of soil health. CAB International. WaUingford, U.K; c1997. p. 97-119.
58. Stone D, Ritz K, Griffiths BG, Orgiazzi A, Creamer RE. Selection of biological indicators appropriate for European soil monitoring. Applied Soil Ecology. 2016a;97:12-22.
59. van Burggen AHC, Semenov AM. In search of biological indicators for soil health and disease suppression. Applied Soil Ecology. 2000;15:13-24.
60. van Eekeren N, de Boer H, Hanegraaf M, Bokhorst J, Nierop D, Bloem J, *et al*. Ecosystem services in grassland associated with biotic and abiotic soil parameters. Soil Biology and Biochemistry. 2010;42:1491-1504.
61. Vitousek PM, Aber JD, Howarth RW, Likens GE, Matson PA, Schindler DW, *et al*. Human alteration of the global nitrogen cycle: sources and consequences. Ecol. Appl. 1997;7:737-750.
62. Warkentin BP. The changing concept of soil quality. J Soil Water Cons. 1995;50:226-228.
63. Wolters V, Schaefer M. Effects of acid deposition on soil organisms and decomposition processes. In: Benckiser, G. (Ed.), Effects of Acid Rain on Forest Processes. Wiley, New York; c1994. p. 83-127.
64. Acton Donald F, Gregorich LJ. The health of our soils: toward sustainable agriculture in Canada. 1995.
65. Galbraith Ronald E, Thomas M Jones. Moral Reasoning: A Teaching Handbook for Adapting Kohlberg to the Classroom. 1976.
66. National Research Council. Understanding child abuse and neglect. National Academies Press, 1993.
67. Brussaard, *et al*. Biodiversity and ecosystem functioning in soil. Ambio. 1997;26:563-570.