Considerations in determining soil quality and a conceptual strategy for the appraisal, maintenance and improvement of soil quality.

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Introduction

The need to develop methods for assessing soil quality and land use have arisen out of the “increasing awareness that soil is a critically important component of the earth's biosphere maintaining local, regional and world-wide environmental quality” (Doran & Parkin, 1994). This realisation should drive us towards developing more effective and sustainable management strategies that make productive use of soils without impacting on its ecological role. In order to determining quality criteria it is essential that we define what we mean by soil, land and quality.

Soil

The material that forms at the interface of the atmosphere and the lithosphere which is capable of supporting plant growth (White 1997). It is the product of past and present chemical, physical and biological processes, which have combined to influencing the appearance and character of the material. The ability to support plant growth being the dominant but not exclusive factor with some soils (contaminated/polluted) being unable to support plant life and substrates other than soil being capable of supporting plant life.

Land

With the development of agriculture has come the concept of land. Land is simple the two dimensional framework that we use to map the surface of the earth. Soil often covers land but it may also be covered by water or rock. Although land is an essential prerequisite for the formation of soil and the nature of the soil influences the land use, land exists within a single plane having only width and length, its parameters are fixed. Soil however is a dynamic, three dimensional interaction of the physical, chemical and biological processes.

Development of soil and land concept

The earliest attempt to understand soil formation was by Dockuchaiev. His original soil forming equation of:

$$S = f\text{(climate, parent material, organism) time}$$

Was later modified by Jenny (1941):

$$S = f(C, PM, R, O, V, T......)$$

(Where C = climate, PM = parent material, R = relief/topography, O = fauna, V = vegetation and T = time).

However both authors omit to take into account the spatial aspect (the requirement for land) in the formation of soil. Just as soil cannot form in the absence of a parent material so it cannot form in the absence of space (land). The equation can be easily adjusted to reflect this requirement:

$$S = \frac{f(C, PM, R, O, V,) \times time}{L(space)} \qquad \text{equation 3}$$

(Where L = land (spatiality)).

In this way soil formation can be shown to be a process that involves space as well as time and the dynamic components (C, PM, R, O, V,...). Still a simplification but I believe an improvement on the existing concept.

Quality

Quality is a vague concept that can reflect anything from an individual characteristic to the degree of excellence. Quality is very much dependent on use and, with soils having a variety of uses quality criteria may change. Various authorities have proposed the following definitions for soil quality:

"The capacity of a soil to function within ecosystem boundaries to sustain biological productivity, maintain environmental quality, and promote plant and animal health" (Doran & Parkin 1994).

“The inherent attributes of soils that are inferred from soil characteristics or indirect observations [e.g., compactability, erodibility, fertility]” (SSSA 1987)

“The capacity of soil to produce safe and nutritious crops in a sustained manner over the long-term, and to enhance human and animal health, without impairing the natural resource base or harming the environment.” (Parr et al.1992).

“Fitness for Use”(Pierce and Larson, 1993)

“The capacity [of soil] to function” (Karlen et al.. 1997).

These definitions are somewhat flawed as they either see soil purely in agronomic terms or, as is the case in the last two, are so vague that almost any interpretation could be applicable. To get a definition for soil quality and hence a means of measuring it we need a purpose that applies to all soils and in all situations and one that is not so vague as to satisfy any criteria.

The prejudice of the past

It is only in recent times that we have come to see soil as one of the crucial components in maintaining the biosphere. For the last 10,000 years soils purpose and quality has been determined by its ability to produce crops. If an area of land was not capable of producing crops then regardless of its ecological function we would have ascribed little concept of its value. We have a very long and established agro-centric view that clouds our judgement; an excellent example of what Cline (1962) called our tendency to mould research into patterns of the past and so limit understanding of even new experience to concepts based on knowledge of the past (Cline, 1962).

Bridgeman (1927) stated "it is possible to analyse nature into correlations without. . . any assumption whatever as to the character of those correlations," and “to go beyond empirical correlation into the realm of hypotheses of reasons for them is to "prejudice the future". In attempting to define soil quality, criteria, based on long and established thought patterns rather than objective reason of the recent evidence has shaped and hence prejudiced the outcome.

We cannot assess soil quality on the basis of plant or animal health alone, as these are not solely dependent on the soil but on wider environmental factors in which soil is just one of them. We therefore need a measure of soil quality that is independent of these factors, a universal soil function. The huge variability in soil textures, biology, chemistry, etc, already prevents us from having a universal classification systems so it is unlikely that we can derive quality indexes from comparative assessment of soil attributes; whether measured or inferred. What is therefore required is a measure of soil quality based on a function of soil rather than its attributes.

The simple definitions, "Fitness for Use" (Pierce et al, 1993) and "the capacity [of soil] to function" (Karlen et al.. 1997), are more apt and permit the formulation of the concept of soil quality as an exclusive function of soil rather than as a measure of its productivity. By applying the above definitions to Doran and Parkin’s (1994) function “maintaining the world’s biosphere” we can derive a concept that is potentially universal, independent of other factors and is not prejudiced by the past or any use “we” ascribe to it, this is the soils *primary function*. This *primary function* will continue to operate as long as the soil is in existence and it is to the degree that it fulfils this role that should be the measure of its quality.

The Primary Function

The primary function provides clarity over purpose with one over-riding and universal soil objective: maintaining the world’s biosphere. All that is now required is a means of measuring how well a soil is maintaining the biosphere and an adjustment of our goals so as not to conflict with the soils primary function. One possible resolution is the *dynamic assessment* approach proposed by Larson et al (1997) in which the dynamics of the system, as a measure of its sustainability, are used to assess soil quality. They base their evaluation on the argument that “a management system is sustainable only when soil quality is maintained or improved [and] a quantitative assessment of the changes in soil quality provides a measure of sustainable management”. In quantifying the dynamics they propose that soil quality (Q) can be defined as the state of existence of a soil relative to a standard or in terms of a degree of excellence. It is expressed as a function of attributes of soil quality (q_1) defined as:

$$Q = f(q_1 ....n) \qquad \text{equation 4}$$

The magnitude of Q is determined by the collective contribution of all q_1 and, as a concept, Q is multidimensional.

The concept of Q however is only an indication of current quality and does not reflect changes in quality. If sustainability is our goal then it is necessary to measure changes in Q if we are to develop management strategies aimed at maintaining soil health. Changes in soil quality, dQ/dt , can be defined (Larson *et al* 1991) as:

$$dQ/dt = f \; \frac{\frac{(q_1t - q_1t_0)}{q_1t_0} \; . \; . \; . \; . \; \frac{(q_nt - q_nt_0)}{q_nt_0}}{dt} \qquad \text{equation 5}$$

The immediate problem with this approach is that it is the sum or mean of the quality values of the soils attributes rather than a qualitative value of the soil as a whole. It could be described as the sum of the parts and with such a complex system it may not equal the whole. This situation is complicated not just by the difficulty in assessing the various attributes but also in weighting them into an equation and giving them comparable values. What is needed is a common denominator or function that is applicable to all. One approach is to conceptualise the soil as an energy system and to use the transformations, losses and gains of energy as a measure of soil quality.

The Efficiency Function [E_f]

Soils are a dynamic living system (Karlen, et al 1997) upon which we have traditionally based value on the agricultural and more recently environmental productivity. However the primary function of soils is in the maintenance of the worlds biotic systems, the imposition of agriculture is a very recent event in pedological terms. Soils have been acting as a single organism contributing greatly to maintaining an ecological balance by acting as reservoirs for water, nutrients, carbon etc. The changes or fluxes of energy (nutrients, carbon etc..) into and out of the soil can be measured and losses computed. Energy transformations and exchanges can then be used to calculate the turnover and efficiency of the system. These figures can then be used to create an index of how efficient the soil is, a universal function [E_f] that can be applied to all soils as in equation 4 below:

$$E_f = \frac{\text{energy output + changes in stored energy}}{\text{energy input}} \qquad \text{equation 6}$$

From this approach it is possible to construct a concept of soil quality based on the E_f of the soil as an energy system. Thus soil quality can be defined as: **a function of the efficiency of the soil within an ecosystem.**

The advantage of such an approach is that it applies equally to all soils regardless of variation and without the need for modification. From this it should be possible to calculate the sustainability of any given use at any scale; local to global and still give a valued measure of the quality of soils at that scale. It can also be used to assess quality of soil with quality of use. Soil quality indexes could then be used to predict future soil health and the threat that inefficiency may pose to the system's survival.

E_f in conjunction with land use

Using the modified soil forming equation [equation 3] it may be possible to compare soil quality with quality of land use, thus creating a mechanism by which the effectiveness of soil and land use can be assessed. From this it may be possible to calculate the intrinsic value of that use in relation to the primary function of the soil. This however requires a fuller appreciation than I currently possess of the various uses and degrees of need for such use within society. If nothing else this situation serves to show the difficulties of the multi-disciplinary approach which requires both an understanding of consequence and a need to integrate into the practicalities of a functioning society.

$$\text{Intrinsic value of a given use} = \frac{\text{soil quality } [E_f]}{\text{quality of land use}} \qquad \text{[provisional equation 7]}$$

Summary.

The issue of soil quality is a complex one that requires new concepts to define it from a non-humanistic angle. We must recognise that in the "greater scheme of things" humanity is a condition and not an ends. We exist because of the biosphere and are

wholly dependent upon it. Our imposition and use of and upon land is an extremely recent event and whilst it is important to mankind it is a minor function of the soil. In short we must put the cart of humanity back behind the horse of reality less the paradigm of soil quality will continue to elude us.

References

Bridgeman, P.W. (1927) The Logic of Modern Physics. MacMillan, New York.

Cline, M.G. (1962). Logic of The New System of Soil Classification. Soil Science, 96:17-22.

Doran, J.W., & Parkin, T.B. (1994). Defining and assessing soil quality. In Defining soil quality for a sustainable environment (SSSA Special publication No 35). SSSA, Madison.

Island Planning (Jersey) Law (1964) as amended. States of Jersey. States Greffe Bookshop, St Helier, Jersey. U.K.

Karlen, D.L., Mausbach, M.J, Doran, J.W., Cline, R.G., Harris, R.F., Schuman, G.E. (1997). Soil Quality: A concept, definition and framework for evaluation. 61: 4-10. SSSA Madison.

Soil Sc. Soc. of Am. (1987). Glossary of soil science terms. SSSA, Madison, WI. [Cited in Doran, J.W., & Parkin, T.B. (1994). Defining and assessing soil quality. In defining soil quality for a sustainable environment (SSSA Special publication No 35). SSSA Madison].

Parr, J.F., Papendick, R.I., Hornick, S.B. & Meyer, R.E. (1992). Soil quality: Attributes and relationships to alternative and sustainable agriculture. Am. J. Altern. Agric. 7:5-11. [Cited in Doran, J.W., & Parkin, T.B. (1994). Defining and assessing soil quality. In defining soil quality for a sustainable environment (SSSA Special publication No 35. SSSA, Madison].

Pierce, F.J. and Larson, W.E. (1993). Developing criteria to evaluate sustainable land management. p.7-14 In J.M. Kimble (ed.) Proc. of the 8th int. Soil Management Workshop; Utilization of Soil Survey Information for Sustainable Land Use. May 1993. USDA-SCS, National Survey Centre, Lincoln, NE. [cited in Doran, J.W., & Parkin, T.B. (1994). Defining and assessing soil quality. In Defining soil quality for a sustainable environment (SSSA Special publication No 35).). SSSA Madison].

White, R.E. (1997). Principles and practice of soil science. 3rd edition. Blackwell Science ltd, Oxford.