

THE ROLE OF SOIL QUALITY CRITERIA IN ASSESSING FARM PERFORMANCE

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ABSTRACT

The environmental impact of industrial agriculture is under close scrutiny, by Governments, concerned citizens, and farmers. This paper discusses the need to incorporate environmental factors in measures of farm performance, as part of the continuous review of long term sustainability. The concept of natural capital allows natural resources to be considered in similar ways to other assets of the farm business. It is suggested that soil quality criteria, selected to match the site characteristics and purpose of the landowner, be included in these measures, despite continuing disagreement about the concept and difficulties in its application. The intuitive appeal of a soil quality paradigm is the potential to integrate the many dimensions of sustainability, encouraging responsible land management. It is further suggested that soil structure is a key indicator of soil quality, and methods for its assessment are summarised.

INTRODUCTION

In recent years, there has been growing concern about the environmental impact of industrial agriculture. In Australia, the environmental effects of modern agriculture have been well documented, with recent data describing a significant proportion of the land area described as degraded or at risk. Although there is potential conflict between ecological and economic objectives, there is increasing recognition of the responsibility of farmers to manage this balance. Consumers and government also play a part in influencing farmers responses, with market forces and quality certification seen as important mechanisms to encourage change.

Managing this balance is at the heart of sustainable agriculture. Although debate continues on a definition of sustainable agriculture, it is generally accepted to comprise several spheres of influence: goals associated with farm production and business performance, personal and community or social goals, and environmental impact. A more precise definition may not be relevant, as the relative importance of these components will be different for various stakeholders, and will vary over time. For many years, farmers have monitored their production and business performance, using standardised key indicators and benchmarking. There is increasing relevance of applying similar techniques to

environmental matters, but methodologies and benchmark values are not yet fully developed.

By considering natural resources as an asset of the farm business, in much the same way as other assets, the change in value of natural capital can be assessed. For example, degrading soil structure as a result of particular crop establishment practices would represent a measurable depreciation of natural capital, with some studies attempting to link this to the market value of land (Ringrose-Voase et al. 1997). However, this approach faces a number of difficulties. There are few agreed measures of environmental 'performance' at the farm level, and many are subjectively assessed, so they need to be selected to match the biophysical characteristics of the region, and the business position of the stakeholders. It has also been suggested that such an approach is not appropriate for natural resources that cannot be replenished.

ENVIRONMENTAL MONITORING AND FARM PERFORMANCE

Monitoring the state of the environment is now standard procedure in many countries/regions. For example, in its most recent State of the Environment Report, the Environment Protection Authority of New South Wales, Australia, includes analyses of rural land, water and air quality. This represents a recent extension of environmental monitoring from urban based industrial activity, where some progress has been made in the control of pollution, to a catchment wide approach.

Such regional level indicators are useful in identifying trends, and assisting guide policy development, but there are a number of areas requiring refinement. Regional data is difficult to transfer to individual farm businesses. Such reporting does not define improvement strategies. Quality criteria for land, water and air are interrelated. The approach requires the adoption of quality standards. This is readily applied to air and water quality, as these are directly consumed by humans, and standards can also be developed that reflect the preferred condition of terrestrial and riverine ecosystems, but standards are difficult to define for other elements of agroecosystems (eg soil structure).

Such difficulties do not diminish the need, and work continues in the search for appropriate methodologies. For example, Halberg (1999) supports the use of environmental indicators in assessment of farm performance, for improved decision-making by farmers as well as environmental and ethical auditing. In a study of high intensity livestock farmers in Denmark, Halberg (1999) selected a number of soil quality and farm performance indicators, emphasising nutrient balance, energy balance, contamination risk, and biodiversity. Although further refinement of the indicators and their interpretation is recommended, they were found useful by farmers.

Market mechanisms are under development to encourage conventional farmers to conserve natural resources. Rural land has the potential to capture carbon, improve catchment health and maintain biodiversity. These functions are valued highly by society, but are not traditionally included in measures of farm performance. Whilst greenhouse gas emission has driven the development of carbon trading, there is potential to earn credit for biodiversity enhancement and salinity reduction measures (Commonwealth of Australia 2000). In Australia, such trading systems have proven difficult to implement, but a number of pilot schemes are now in place (Brand et al. 2000).

It should be said that such systems are consistent with a market philosophy to land use. Not all stakeholders share this philosophy. There are many who believe that land stewardship is an inherent responsibility of all citizens, that should not be subject to market forces, and that market forces are not relevant (indeed harmful) when applied to cultural values. There is an implication that intrinsic landscape and environmental values, spread over a time frame measured in generations, will be threatened by short term production and extraction activities because it is profitable for individual firms to do so. Off-site effects need to be considered in some way, which is difficult to do with ecosystem processes such as groundwater hydrology. In a global market, national interest could be overridden by international investment and trading practices.

Various authors have described a hierarchical model for agroecosystems, arguing that ecological characteristics of the system take priority over social and business goals. Lefroy et al. (1993) argue that at the catchment level at least, ecological values and constraints should have priority, since ecological tolerances are less negotiable, and economic and social values are partly determined by human demands and expectations. Management decisions which impact on the natural resource base, upon which economic and social well-being are built, are elevated in importance, as long term sustainability is not possible with a degrading resource trend. However, the agricultural context cannot be avoided, and a balance between protection of the resource base and protection of the farm business needs to be struck.

In Australia, most urban residents place a high value on the rural landscape and its historical culture, but are not involved in management of the land, and are generally not prepared to contribute to its maintenance via increased commodity or retail price. (At the time of writing, it has been recommended to the Australian Government that the tax system should be amended to include an environment levy, similar to income raising for other projects considered to be in the national interest, such as universal health insurance). Farmers are expected to compete without direct price support in a global marketplace, with little sympathy if they are unable to do so, and at the same time are expected to be caring stewards of the landscape. It is suggested that the development of appropriate performance indicators will assist in resolving this conflict, demonstrating the balance between positive and negative impacts.

Much of the above discussion applies to developed agricultural systems and markets, and may not be relevant in other situations. Communities need to debate the balance between environmental impact and food security, and the beneficial and harmful market distortions that may be present.

IMPORTANCE OF SOIL QUALITY

Whilst carbon balance, biodiversity and water quality are important components of sustainable landscapes, it is suggested that efforts should be focussed on how specific objectives or targets will be achieved. Appropriate vegetation management strategies will not be successful if soil quality is compromised, and although soil quality indicators alone are insufficient, the design of sustainable farming systems should focus on the maintenance and improvement of soil quality (Doran and Parkin 1994). Roberts (1995) nominates soil quality as one of the prime indicators of resource base sustainability. Soil quality, with particular reference to erosion risk, is one of 13 'issues' identified by the Organisation for Economic Cooperation and Development requiring the development and application of indicators. This is part of a wider program of policy development relating to the impact of agriculture (and other elements of economic activity) on the environment (Parris 1996). There is a direct link between soil quality and catchment health (Walker and Reuter 1996), where a catchment may be a composite of land management units including farms. There are also similarities with the concept of rangeland health, which has been the subject of assessment for some time (National Research Council 1994).

Attempts have been made to define soil quality, but partly because of the dynamic nature and spatial variability of its inherent characteristics, the lack of objective data to quantify soil quality, and the complexity of the interactions between soil, plants, and animals, a universally accepted definition has not been agreed. This may not be possible or necessary, given that criteria for assessment of soil quality will partly depend on the specific application and the social and economic aspects that influence it (Hamblin 1996).

One approach is to focus on the functional importance of soil in the environment; that is, as a medium for the physical, chemical and biological processes that support plant growth; in the partitioning of water flow through the landscape; and as a buffer for environmental change (National Research Council 1993). The following definition of soil quality, proposed by Karlen et al. (1997) to encourage debate rather than as a final statement, has evolved from this line of thinking and includes the role of humans in the ecosystem: "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". This definition goes some way to include the intrinsic value of soil, as recommended by Warkentin (1995), but is rejected by

Sojka and Upchurch (1999). Dalal (1998) suggests this definition be expanded to include the enhancement of soil biodiversity.

Change in soil quality is therefore nominated as a key measure of (terrestrial) farm performance, provided methods for objective measurement of site-specific indicators are deployed. It significantly underpins the amount and quality of farm produce and therefore farm income, the extent and diversity of vegetation, and the amount and quality of overland water flow and groundwater. Soil quality can be manipulated by management practices. It provides a vehicle for integration of the many dimensions of sustainability.

APPLYING MEASURES OF SOIL QUALITY

Few would argue the importance and role of air and water quality standards, nor the need to monitor these. Soil quality is closely linked to these, given the role of soil in sustaining plant production, buffering hazardous materials, cycling nutrients and carbon, and partitioning infiltration and runoff from rainfall. This is supported by National Research Council (1993), where “protecting soil quality, like protecting air and water quality, should be a fundamental goal of (US) national environment policy”. Quantitative methods are required for this, and the translation of indicator values into policy.

However, the notion of minimum or acceptable standards for soil quality is yet to be accepted. Sojka and Upchurch (1999) discuss the scientific weaknesses of such an approach. Air and water quality are defined by the concentrations of specific contaminants, compared to the pure state of the substance, as they relate to established levels of tolerance. (An exception applies to soil contamination by chemicals, salt, acid, etc. For example, Eijsackers (1998) describes the use of soil quality indicators for monitoring soil pollution, and the development of national standards in a number of European countries). There is no comparable natural cycle of regeneration of soil, compared to the hydrologic cycle, even if nutrient and energy cycles are considered. For many soil quality criteria, such as soil respiration, values are difficult to interpret and highly variable, and the judgement of ‘good’ and ‘bad’ are relative to the situation at the time and off-site effects. Sojka and Upchurch (1999) therefore find little if any parallel.

There is also disagreement on the application of soil quality ‘rules’ to land management decision-making and agricultural policy. The concerns of Sojka and Upchurch (1999) arise from the difficulty in meeting any definition of soil quality from data derived from discrete measurements, and applying a quantitative approach to soil quality policy in the absence of full information. In particular, they express concern about the development of generic soil quality indices describing “overall worth, value or condition of soil”.

It appears that the debate is significantly influenced by the paradigm of the participants - the disciplinary and reductionist approach of scientists versus the

wholistic view of ecologists. However, it is equally important that those responsible for land management decisions make better judgements within this spectrum of views, and it is therefore necessary to develop models of management that incorporate objective soil quality criteria. There is general agreement that objective measurements of appropriate soil properties, selected from a large suite of possibilities covering chemical, physical and biological attributes, can be useful in designing land management rules in specific contexts. A soil quality paradigm has intuitive appeal, because issues such as sustainability require more than just scientific input.

Significant difficulties remain in applying a soil quality approach. Spatial and temporal variability are substantial, and key indicators of soil quality, and their method of measurement, need to be decided. If soil quality criteria are to be applied at the farm level, they need to be relevant, measurable, repeatable, meaningful and useful. Benchmark and threshold values need to be determined, comparable between sites of measurement. Values need to be incorporated into management decision models. Key indicators need to be selected. Southon and Cattle (2000) have summarised the extensive literature on the selection of soil quality indicators. Walker and Reuter (1996) have evaluated key indicators for the Australian context, at the catchment level.

SOIL STRUCTURE AS AN INDICATOR OF SOIL QUALITY

Despite the above difficulties, it is proposed that soil structure is a key indicator of soil quality. Soil structure partly determines the partitioning and rate of movement of water (and captured solutes and sediments) through the landscape, the water available to plants for growth, the physical conditions for root penetration and gas exchange in the root zone, and the characteristics of the habitat of soil biota. Soil structure can respond rapidly to certain management interventions. However, measurement of soil structure is itself difficult, with a number of techniques possible.

Bulk density is a common measure of degree of compaction or total porosity. However, the relationship between bulk density and plant growth is dependent on other soil characteristics (pore size distribution, organic matter, soil texture, etc.). There is a strong link between soil structure and fundamental hydraulic properties of soil. Field measurement of soil water content and permeability are described by Geering (1995). Resistance of soil aggregates to crushing is a measure of soil strength related to structure as well as other factors, including organic matter content. It can be assessed by measuring soil shear strength or modulus of rupture. Penetration resistance is a simple technique that can be applied in the field, but requires a large amount of data to give a reliable analysis. Aggregate stability is an important measure of the ability of soil to maintain structure under cycles of drying and wetting, and a simple field test is available.

Pore size distribution has a direct effect on bulk density and porosity, as well as plant root development, soil hydraulic characteristics, and habitat for soil biota, and is therefore considered an important characteristic of soil structure, particularly when the continuity of vertical macropores is considered. However, direct measurement of pore sizes and their distribution and connectivity is a difficult task in the field, usually assessed by referring to permeability measurements over a range of soil tensions. Three dimensional characterisation of macropores has been investigated by Perret et al. (1999) using X-ray CAT scanning and three dimensional reconstruction software, on undisturbed soil cores extracted from the field. However, the technique, whilst providing excellent and reliable images for interpretation, requires elaborate equipment, and constructs the 3-D model from multiple 2-D scans. An alternate approach under development is to use a digitised image of the soil pores, constructed from a soil sample impregnated with resin. Analysis of the image allows quantitative assessment of pore relations, and has been applied to comparative assessment (Koppi et al. 1992). Work in progress at The University of Sydney is using image analysis to measure pore size distribution under alternate sheep grazing strategies, and under alternate crop establishment methods.

It is suggested that a composite of measures is necessary to quantify soil structure. For all measures of soil structure, indeed for most soil properties, spatial variability remains an issue. Within-field variation of soil properties is likely to be high. Benchmarking this variability may be necessary, but to achieve statistical rigour is beyond what can be expected of farm managers. This has led some to suggest that monitoring stations be established (Friesen and Blair 1984). Recent developments in portable NIR measurement of soil properties will enhance spatial resolution.

MODELING SOIL QUALITY FOR FARM MANAGEMENT

There is substantial effort applied to the generation of soil quality models. A model of soil quality could be applied to the assessment of land management practices, development of land management policies, rating of land for production or conservation purposes, and for allocation of financial resources (Parr et al. 1992). The integration of soil quality into economic models would be useful in economic analysis of agricultural systems and related policy (Jaenicke and Lengnick 1999). The use of models for these purposes necessarily requires a judgement about soil quality that is often beyond the scope of the measurement of its component parts. Sojka and Upchurch (1999) warn of the dangers of this development, and the risks of extrapolating scientific data into policy determination.

Jaenicke and Lengnick (1999) summarise some of the research into soil quality models, categorising them into two types: those where individual soil quality attributes are aggregated into a soil quality index to model soil quality at a single point in time, and those which attempt to model the change in soil quality under

some management regime over time. They highlight the need to apply some value weighting to the component attributes, and that this has been a weakness in such approaches applied to soils. They attempt to merge these research efforts with research into economic models of system productivity and efficiency, with initial soil quality as an input and final soil quality as an output, where indexes can be decomposed into various components. This provides an interesting perspective, but is based on economic theory beyond the scope of this paper.

Some authors advocate the use of a single index for soil quality that will permit a numerical comparison and dynamic analysis. Granatstein and Bezdicek (1992) describe the use of an integrating index, to help evaluate the interactions between physical, chemical and biological parameters that determine soil quality. Larson and Pierce (1994) describe the possible application of statistical quality control procedures. Harris et al. (1996) describe the use of scoring functions, and Doran and Parkin (1994) the use of their soil quality index. Sojka and Upchurch (1999) warn of the risks of an index approach.

In an alternate approach, Gomez et al. (1996) describe a Framework for Evaluation of Sustainable Land Management at the farm level, and its application to comparative assessment. They allocate indicators into two groups; those that contribute to farmer satisfaction, and those that provide for resource conservation. A radar graph is used to give a visual representation of relative sustainability. This approach scores each soil quality element relative to a benchmark value, but does not presume the relative worth of each element. Such an approach may have value at the farm level.

CONCLUSION

Farm managers will need to adopt systems that monitor the environmental impact of their activities, either as a result of Government direction, as a requirement of the quality assurance certification demanded by their customers, or as part of their approach to long-term sustainability of their business. It is likely that a suite of indicators will need to be monitored, adapted to each situation, using sampling and measurement techniques designed for the purpose. It is suggested that soil quality criteria be included, highlighting soil structure as a key indicator, despite current difficulties with this approach.

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