24 Environmental Indicators and Sustainable Agriculture

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Abstract

This chapter looks at how indicators can be used to assess agricultural sustainability. Indicators are biophysical, economic and social attributes that can be measured and used to assess the condition and sustainability of the land from the farm to the regional level. Reliable indicators provide signals about the current status of natural resources and how they are likely to change. They can be used to confirm that current farming practices and land-use systems are effective in maintaining the resource base or economic status, identify problems and highlight potential risks. Indicators provide useful information for initiating change or deciding on future on-ground investments.

本文论述健康诊断指标如何应用于农业持续能力的评价。诊断指标是可以量测的生物物理和社会经济特征，用来评价从单个农场到整个地区不同尺度的土地状况和持续发展能力。可靠的诊断指标能体现自然资源的当前状态，及其可能产生的变化。可用于辨别现行的农业生产活动和土地利用系统能否有效维持资源或经济发展水平，确认存在的问题，突出潜在的危机。它能为土地利用方式的修正和未来的土地投资决策提供有用信息。

FARMING practices are changing the environmental resource base. Some changes are for the better (e.g. organic farming), but many are deleterious and could endanger future agricultural activities. Rural and urban environmental changes caused by various human activities, not just farming, are increasingly felt, raising perceptions of the environmental costs of these activities. For example, in the cities, people experience poor air quality; some rivers and beaches are no longer fit for recreational use; and valued natural areas have been lost to suburban and industrial development. Farmers and rural inhabitants have seen soil loss through wind and water erosion; they are aware of areas that can no longer be farmed because of crop and pasture decline, and gully development in saline areas.

Observation of environmental deterioration in farmed areas is not a recent phenomenon.

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Australian farmers in the early 20th century noticed changes that were detrimental to productive agriculture such as an increase in unpalatable grasses and weeds, the advent of saline flows in previously fresh creeks and streams, the need for increased ploughing to retain a tilth in fallowed paddocks and a decline in crop yields and animal production. The signs were there, both visually and in quantifiably reduced yields.

Visible undesirable changes in the condition of the atmosphere, land and water are 'indicators' of degradation brought about through changes in environmental processes resulting from human activity. The changes may be due to the introduction of new processes (e.g. the addition of pesticides to the soil) or to increases or decreases in existing processes (e.g. more recharge leading to rising watertables in Australia and reduced recharge leading to falling watertables in parts of China). Visual indicators such as soil surface crusting, sheet and gully erosion, and stream and river turbidity have alerted us to problems. Thus, we have been using environmental indicators in agriculture for a long time and the concept is nothing new. However, there has recently been greater recognition of the role that indicators of environmental change could have in assessing and monitoring the effect of land use on natural resources. Indicators can be a powerful means for those managing the land to identify potential problems and assess the effect of their management practices on ecosystems (Walker and Reuter 1996; SCARM 1993; US National Research Foundation 2000; Pykh et al. 1999). Provided that indicators are meaningful to a range of users, from farmers to policy makers, they can help to achieve sustainable agriculture. However, indicators must be selected and used carefully if they are to be effective.

Farmers have long used indicators to decide on changes to farm practice. An obvious next step is to develop a more standard, yet simple, way of recording and assessing environmental change that can have immediate application at the farm and catchment levels. Farmers are already 'production literate' but they also need to be 'environmentally literate'. The two literacies working together can help ensure a sustainable future for agriculture.

How Can We Define Indicators?

Indicators are a subset of the many possible attributes that could be used to quantify the condition of a particular landscape, catchment or ecosystem (Walker 1998). They can be derived from biophysical, economic, social, management and institutional attributes, and from a range of measurement types. Indicators have been defined as 'measurable attributes of the environment that can be monitored via field observation, field sampling, remote sensing or compilation of existing data' (Meyer et al. 1992). Ideally, each indicator is precise and accurate in describing a particular process within the environment and will serve to signal undesirable changes that have occurred or that may occur (Landres 1992).

Researchers distinguish several types of indicators. For example, 'compliance indicators' identify deviation from previously defined conditions, 'diagnostic indicators' identify the specific cause of a problem and 'early warning indicators' signal an impending decline of conditions (Cairns and McCormick 1992). It is important to define the purpose of indicators and to select them on the basis of how well they can fulfil the required role.

Indicators are perhaps best viewed as communication tools that can turn scientific knowledge into a form better understood by a range of community groups, policy makers and others (Walker et al. 1996). Questions have been raised about the credibility of indicators for resource assessments, but this applies only if indicators are poorly selected. In selecting indicators it is necessary to look at certain criteria such as reliability, interpretability, data availability, established threshold values (needed to set class boundaries) and known links to processes (Walker and Reuter 1996;

Jackson et al. 2000). There are better grounds to question the aggregation of indicators into an index (e.g. catchment health rating) or subindex (water quality), since this involves the addition of disparate measures, usually in a simplistic way. Fuzzy approaches (Roberts et al. 1997) offer a possible means to be mathematically correct, but the interpretation of any given index is still an issue.

Steps in Using Environmental Indicators

Indicator development starts with defining a problem — identifying the issues and their value to society. We then ask questions to specify the issues more clearly. This involves making balanced and integrated judgments on the economic, social and environmental condition of a region's rural enterprises (SCARM 1998). The next step is to choose attributes to use as indicators; for example, current condition (or status) and the direction and magnitude of any change in condition. Certain indicators will be influenced by changes in other indicators, and these interactions must be taken into account.

Questions that could be used to determine the specific issues, for example for the grains industry, are:

- Where is farm productivity falling and the natural resource base declining?
- Where is farm productivity increasing or stable and the resource base stable?
- Where is farm productivity improving and the natural resource base declining?

These questions can be asked at individual paddock, catchment and region scales. By using different sets of indicators to answer these questions and by analysing the responses, an assessment report can be produced. If the report shows that current farming practices are having detrimental impacts on the resource base, it can be used as the basis for remedial action. Indicators can then be used to monitor the outcomes of whatever action is taken. These steps are depicted in Figure 1.

Many of the chapters in this book illustrate the use of indicators in summarising research knowledge. This section examines various issues involved in selecting suitable indicators of catchment and farm health, and in developing appropriate monitoring programs.

Interpreting Indicators at Different Scales

Different spatial scales often require different questions to be asked, requiring different indicator sets and thresholds (Walker et al. 2001). Table 1 illustrates the different kinds of questions asked at different scales. Table 2 lists some of the indicators that are relevant at particular scales. They include single indicators (e.g. soil nitrogen), composite indicators (e.g. cropping on steep slopes as an estimate of erosion risk) and aggregated indexes (e.g. soil moisture index or soil fertility indexes).

Data collected in farm surveys can be aggregated and reported at regional and even national level, provided that sampling intensity and measurement quality are adequate and the indicators reflect regional or farm diversity.

At the national and State scale (Table 1) the interest is mainly on policy development and identifying 'hot spots' that require immediate attention. 'State of environment' reporting at the national and State levels are examples. The approach is 'top-down': the initiative is taken by people from State and national bodies and the results handed over for implementation. The data used are generally readily available data with little attempt to collect detail. These issues are discussed more fully in Chapter 26.

Indicators for regional or local government/ provincial scales could also refer to a particular sector, reflecting concerns about the production and

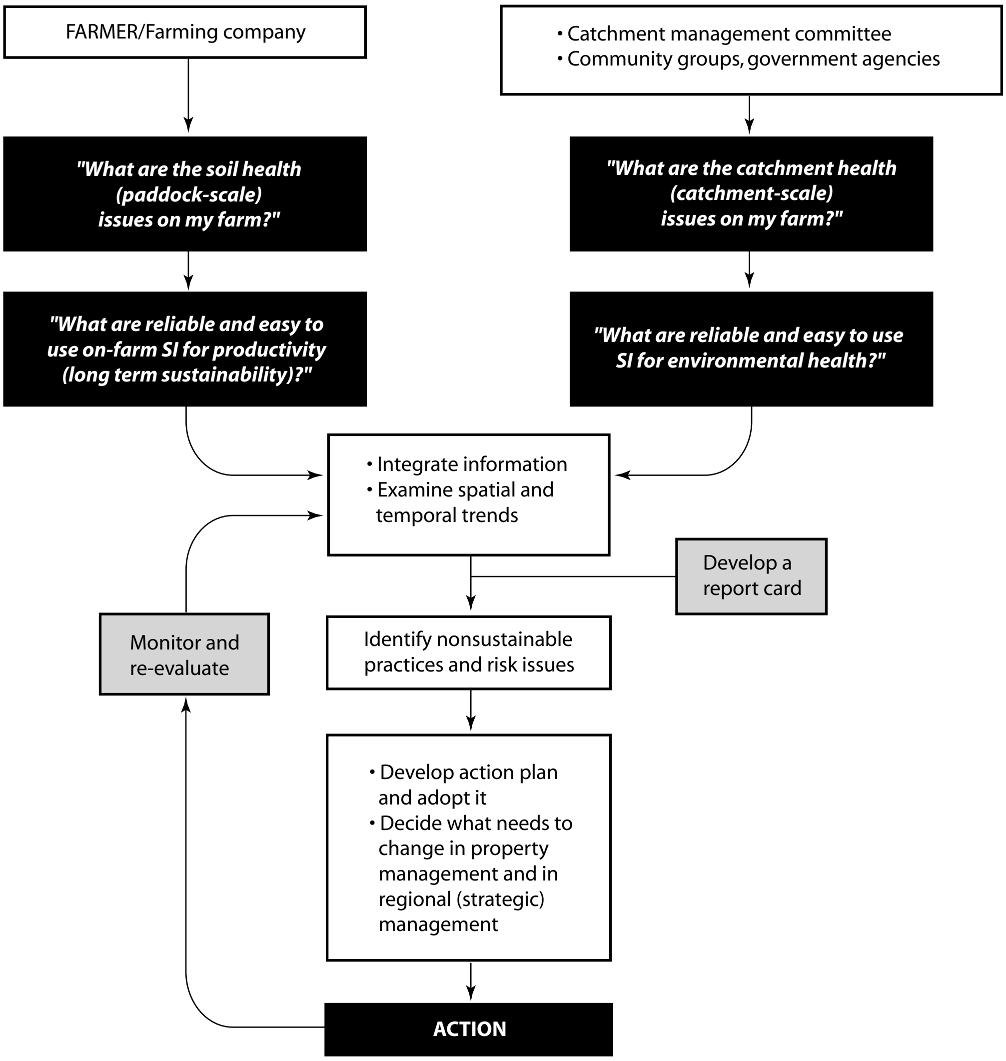

Figure 1. A logical decision tree for using sustainability indicators (SI).

economic future of a region. Examples of the kind of information available for indicator development at this scale are given in Section 3 of this Volume.

At the farm level, questions refer to specific management problems—how to identify undesirable changes and what action to take. The approach is 'bottom-up', with emphasis on self-help. The focus is on changing practices at the paddock scale in a way likely to improve farm and catchment health. Examples in this book are found in Chapters 21 and 28.

A Structured Approach to Using Sustainability Indicators

Indicators must be relevant, robust and scientifically defensible. There is little point in using indicators that have known weaknesses or that cannot be interpreted reliably. For example, mean soil worm density is difficult to interpret because of regional and seasonal variability; mean soil pH has little meaning at a catchment scale but is useful at a farm scale or for a particular soil landscape. We need to set criteria against which the merits of an indicator can be judged—for example, by rating

Table 1. The categories of questions asked at different scales.

National scale Top-down approach	Regional/catchment scale Top-down approach	Farm/site scale Bottom-up approach
Purpose of indicators		
National/State assessment	← Two-way linking process → Social–economic–natural resources	Site assessment
Socioeconomics (resource economics)		Socially acceptable economic choices
Policy development		On-ground action
Agricultural sustainability		Condition of the land (paddock)
State of environment (SoE) reporting		Assessing trends for a farm
Agricultural production		Whole environment/conservation urban/rural links
Indicator programs or groups interested in using them		
• DEST (SoE reporting) • State SoE reporting • SCARM (sustainability program) • ABARE (Outlook conference) • ABS (national statistics) • Research and development corporations such as LWRRDC, GRDC and RIRDC • State EPAs	• CALP boards • Regional land management boards • MDBC • State water/land/agriculture departments • NLP • Indicators of catchment health developed by CSIRO • ALGA • ABARE	• Farmer groups • Farm planning groups • Land care groups • Providers of extension services • ACF/SAWCAA • Streamwatch • Waterwatch • Farm 500
Questions		
1. How degraded are Australia's natural resources? 2. Where are the urgent problems? 3. How sustainable are our agricultural practices? 4. What are the broad trends in costs versus profits for agricultural enterprises? 5. What policies can be developed to encourage sustainable agriculture?	1. How can production, quality of life and profits be increased? 2. What methods need to be developed to better manage natural, social and economic resources? 3. What effects are agricultural practices having on natural, social and economic resources? 4. What impacts are social and economic events having on resource management?	1. How can I best manage my farm? 2. How can I make a living on my farm? 3. What sort of life can I have? 4. How can I assess land and water health on my farm? 5. How much will it cost to fix a biophysical/resource depletion problem?

ABARE = Australian Bureau of Agriculture and Resource Economics; ABS = Australian Bureau of Statistics; ACF = Australian Conservation Foundation; ALGA = Australian Local Government Association; CALP boards = catchment and land protection boards; DEST = Department of the Environment, Sport and Territories; EPA = environmental protection agency; GRDC = Grains Research and Development Corporation; LWRRDC = Land and Water Resources Research and Development Corporation; NLP = National Landcare Program; MDBC = Murray–Darling Basin Commission; RIRDC = Rural Industries Research and Development Corporation; SAWCAA = Soil and Water Conservation Association of Australia; SCARM = Standing Committee on Agriculture and Resource Management; SoE = State of environment

Table 2. Examples of linkages between issues, sustainability indicators and scales.

Scale	Issue	Sustainability indicator
National	Average real net farm income Access to key services	Farmer's terms of trade Distance to regional centres
State	Health of river basins	Trends in water quality
Agricultural industry	Meeting commodity market specifications Farmer's skills	Trends in silo protein levels for wheat % farmers using property management plans
Region	Health of rural environments	% land affected by salinity Condition and extent of native vegetation
Catchment	Meeting water quality targets	Trends in water quality % area with protected riparian vegetation
Farm	Optimising farm returns Planning the annual farm business	Disposable income per family Forecast trends in commodity prices
Paddock	Yield performance Soil health assessment	% potential yield or $ water use efficiency Reliable soil tests

each indicator in terms of relevance, ease of capture and reliability. Table 3, which broadly follows Jackson et al. (2000) and Walker et al. (2000), summarises the criteria for selecting reliable sustainability indicators.

Threshold guidelines for resource condition

Figure 2 shows how a hypothetical resource indicator in an agroecosystem might change with time. Initially, sample values vary within accepted thresholds. For example, even if a system has been changed from a natural to a managed agroecosystem, it may be performing within acceptable limits. Such a system is considered stable (e.g. not leaking nutrients or water to streams or groundwater systems) within the set thresholds. This is the concept of 'conditional stability' developed by Walker (1999). In later years, values may move outside threshold limits. For example, increased electrical conductivity could signal increasing salinity in soil or streams, or decreased soil nitrogen levels could indicate nutrient depletion under intensive cropping regimes. The main problem is in setting threshold values that apply nationally. Some thresholds are well defined (e.g. some water quality measures are related to human health), but values are more difficult to set in landscapes and catchments. Values are known to vary regionally and thresholds vary with spatial scale. This variability makes the idea of setting environmental targets difficult to define absolutely.

A suite of indicators is needed to examine changes in resource condition. For example, commercial soil sampling services offer clients multiple tests on each sample submitted. The results can then be

Table 3. Challenges for selecting reliable sustainability indicators (SIs).

Criteria	Challenges
Reliability	Is a standard method available to measure the SI?
	Are low errors associated with measurement?
	Is the SI measurement stable?
	Can the SI be interpreted and ranked reliably?
	Does the SI respond to change or disturbance?
	Is the SI accepted by farming communities?
Data capture and cost	Can SI data be easily captured?
	Is the data capture at low cost?
	Does the SI need to be monitored regularly?
Ranking and assessment	Can the SI data be mapped or graphed?
	Can SI assessments be integrated soundly in space and time?
	Do previous SI data exist?

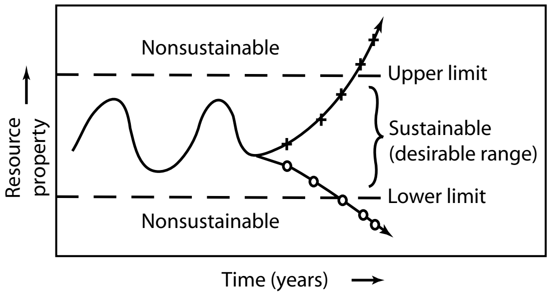

Figure 2. Conceptual diagram showing the requirement for validated upper and lower limits to assess temporal trends (A, B) in a resource property (indicator values) (Reuter 1998).

compared to relevant guidelines[1] and used to summarise trends. Farmers and their advisers can carry out these tests themselves at relatively low cost using practical 'do-it-yourself' test kits. Kits are available through the Western Australian Farm Management Society and Charles Sturt University. Rengasamy and Bourne (1997) have also developed a kit for assessing soil salinity, acidity and sodicity.

[1] For example, there are Australian guidelines for interpreting soil (Peverill et al. 1999), plant (Reuter and Robinson 1997) and water quality tests for assessment of stream condition (Ladson and White 1999).

Benchmarking farm business health

The Australian Bureau of Agricultural and Resource Economics (ABARE) has defined economic indicators of farm performance (ABARE 1999). These are derived as complex national or industry indexes, or estimated from aggregated data from various sources such as annual ABARE farm surveys, the Australian agricultural census and agricultural financial surveys from the Australian Bureau of Statistics (ABS). ABARE and ABS publish regular updates showing trends for economic indicators.

Dealing with large annual variations

When there are large annual variations in indicator values, it is important to know the trends over time. Many economic indicators, such as disposable income per family or profit at full equity, vary greatly from year to year through the combined effects of seasonal weather conditions, shifts in commodity prices and other market forces (e.g. interest rates). For these indicators, trends in data, acquired annually, should be assessed at constant dollar value over several years or decades to understand the magnitude and direction of longer term changes. The impact of rainfall on economic indicators can be partly circumvented by expressing data in units of rainfall received in any given season — the so-called dollar water use efficiency ($WUE) indicator.

National assessments of sustainable agriculture

The Standing Committee on Agricultural Resource Management (SCARM) published a series of reports during the 1990s. These culminated in a pioneering but incomplete report on the assessment of sustainable agriculture in Australia's 11 agroecological zones. Initially, 'sustainable agriculture' was defined and guiding principles were developed for assessing the level of sustainability achieved by the agricultural sector (SCA 1991). Subsequently, an indicator framework was devised for making these assessments (SCARM 1993). A pilot feasibility study was undertaken to evaluate the validity and availability of data for these indicators (SLWRMC 1996). A final report (SCARM 1998) documented the data and trends. Table 4 lists the indicators used by SCARM to assess sustainability in Australian agriculture. It also lists possible indicators that were not identified in the report but are now acknowledged to be important for a complete assessment of sustainable agriculture in Australia. Some of these indicators are now used in the National Land and Water Resources Audit.

Comparing Different Condition or Sustainability Assessments

It is often useful to compare agricultural performance with catchment condition or with other indexes (e.g. economic or social indexes). Figure 3 shows a cross-comparison matrix of ranked assessments of farm production and ranked assessments of catchment condition. The focus in the figure is on combinations that do not conform to expected (i.e. the diagonal). For example, if a

Table 4. Composite indicators and attributes used by SCARM (1998) to assess sustainability in Australian agriculture, together with some additional attributes required for a more complete assessment.

SCARM indicators	Attributes assessed by SCARM (1998)	Attributes not assessed by SCARM (1998)
Long-term real net farm income	• Real net farm income • Total factor productivity • Farmer's terms of trade • Average real net farm income • Debt servicing ratio	• Costs of land degradation • Costs and benefits from remediating degraded resources • $ water use efficiency (for rainfed and irrigated farms)
Natural resource condition	• Phosphate and potassium balance • Soil condition: acidity and sodicity • Rangeland condition and trend • Diversity of agricultural plant species • Water use by vegetation	• Nitrogen and sulfur balances • Extent of soil structural decline • Level of groundwater reserve exploitation • Extent of land salinisation • Assessment of catchment condition
Off-site environmental impacts	• Chemical residues in products • Salinity in streams • Dust storm index • Impact of agriculture on native vegetation	• Impacts of soil erosion on river water quality • Extent of nonreserve native vegetation on farms
Managerial skills	• Level of farmer education • Extent of participation in training and Landcare • Implementation of sustainable practices	• Adoption by industry of best management practices • Extent of farmer access to the internet
Socioeconomic impacts	• Age structure of the agricultural workforce • Access to key services	• Capacity of rural communities to change • Extent of diversification within rural regions • Extent to which current infrastructure, policies and laws support sustainable agriculture

catchment is biophysically in poor condition and production is high, the system is probably maintained by high inputs of fertiliser and may not be environmentally sustainable. The matrix, which was developed by Walker et al. (2000), is not meant to show causal relationships, but suggests where more investigation is needed. It is particularly useful in broadly comparing biophysical indexes with production, economic and social indexes and in interpreting sustainability at catchment and regional scales. The matrix is based on a list of core indicators for benchmarking economic and resource health within catchments (Walker and Reuter 1996). The initial list was drawn up in 1996; other indicators were added following a national workshop (see Table 3 in Reuter 1998).

Conclusion

Most programs involved in monitoring and assessing environmental condition are ultimately associated with issues of sustainability. The word 'sustainability' has many connotations, including longevity, continuity, function and stability. There are thus different questions to ask and different approaches available. Process-based models have a place and also have limitations; so do indicators. Process-based models, as illustrated in other chapters in this book, can be useful to develop a range of scenarios, but in the context of indicators they can be particularly useful in setting workable threshold values. Unfortunately, many process modellers and reductionist scientists have relegated environmental indicators to the soft sciences, little

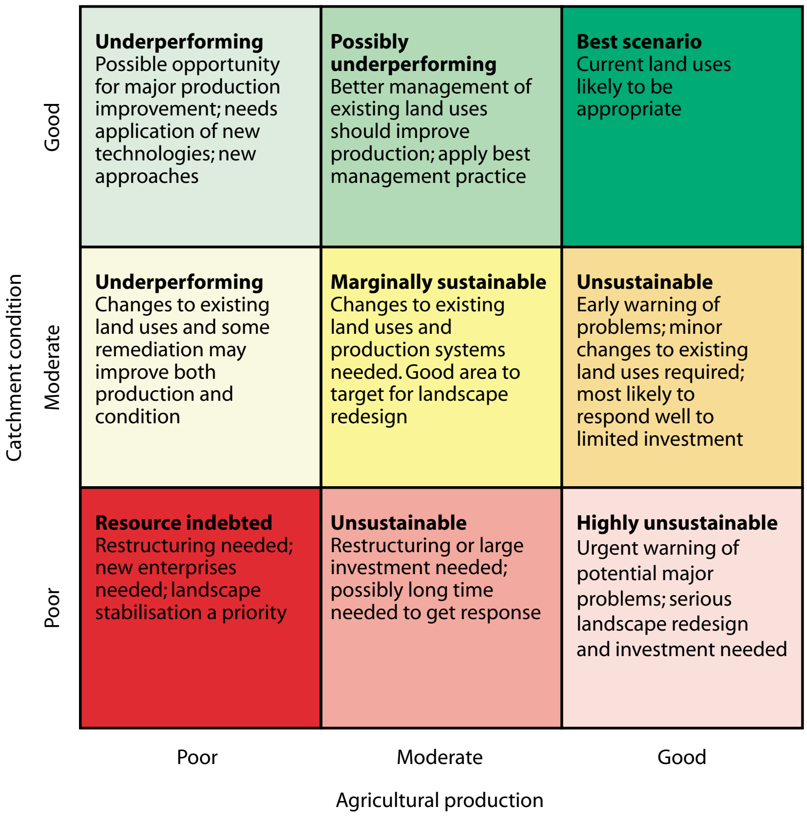

Figure 3. Possible interpretation of the catchment condition–agricultural production cross-comparison matrix.

realising that indicators have a process base. This attitude is usually based on ignorance about the derivation and use of indicators. The establishment of the new journal *Environmental Indicators*[2] will help to establish indicators as a credible systems approach to sustainability issues.

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