Using Indicators to Assess Environmental Condition and Agricultural Sustainability at Farm to Regional Scales

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Abstract

In this chapter we review recent experiences in using soil, terrain, landscape and catchment indicators to assess the condition of the resource base underpinning agricultural activities. We describe the use of indicators in three case studies, and suggest potential indicators for assessing and monitoring system sustainability in the northern grains region of Australia.

It is important to choose indicators that match predetermined regional needs and priorities, be they for farm production or environmental issues. In choosing indicators, current knowledge about their strengths and weaknesses needs to be consolidated (see Chapter 24). For example, publications such as SOILpak (Daniells et al. 1994) or Soil Matters (Dalgliesh and Foale 1998) deal with

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the management of soils in the northern grain belt. In southern Australia, PADDOCKCARE (McCord et al. 2000) consolidates information on 51 farm indicators. PADDOCKCARE, which is available as a CD-ROM, allows farmers to record and graph indicator data over time and to progressively rank and integrate the status of a range of issues assessed by indicators. Dalal et al. (1999) provide an example of selecting indicators for the central Queensland grain region.

Whilst industry and regional benchmarks for assessing economic indicators are available, our focus is on the sustainability of the resource base. The following case studies show how data sets can be integrated and visualised at catchment to regional scale, using biophysical indicators. In each study, we used geographic information systems (GIS) to produce interpolated surfaces of risk. In the Upper Murrumbidgee region, we used surrogate indicators (indirect measures) to assess catchment conditions. In the Mount Lofty Ranges of South Australia, we determined risks for soil salinity, sodicity and acidity by extrapolating from a subcatchment to a subregion using detailed point source data and knowledge of landscape processes. In the Young area of southern New South Wales, we assessed several catchments using report cards based on easily measured indicators. At a regional scale, we developed indicators to assess the sustainability of the northern grains industry. The Overview provides background information about these areas and shows their location (Figure 2 of the Overview).

**Case Study 1: The Upper Murrumbidgee Catchment**

To construct maps of catchment condition, we focused on readily available rather than high quality data, as the latter are often not available for the whole region. We identified key regional issues, then refined the assessment questions and sampling strategy for a small group of indicators, generally surrogates, relevant at the catchment scale. The study area was the Upper Murrumbidgee catchment (Canberra–Yass–Cooma), comprising 169 subcatchments in an area of approximately 12,000 km². The main environmental issues were salinity and sediment movement. The preliminary study of 13 large catchments in this area is described in Chapter 25.

We used seven readily available biophysical indicators (all surrogate indicators):

- percentage of forest cover (surrogate for estimating departures from the original condition and also related to stream salinity);
- percentage forest cover greater than 50 hectares (habitat);
- agriculture on steep slopes (potential erosion);
- road density (human impact);
- roads crossing streams (correlated with sediment input to streams); and
- intact forest along streams (a riparian zone/habitat and sediment filter).

The data were obtained from satellite imagery, AUSLIG¹ road information and digital elevation model (DEM) information, all of which is readily available and can be assembled within one week. We estimated each indicator for a total of 169 catchments and placed the value in one of three classes: (1) good, (2) intermediate and (3) poor.² Catchment condition scores were obtained by summing the weightings for each indicator per catchment to get an aggregate catchment condition value. These values ranged from 8 to 16 and were divided into three catchment classes: 8–10 (good),

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¹ Australian Surveying and Land Information Group.
² The use of good and poor raises semantic issues, and some prefer to use best to worst when the analysis gives a relative ranking. However, in this case we had a reasonable idea of the threshold values and used good to poor ranking. See Chapter 24 for details on weightings and aggregation.
11–13 (intermediate) and more than 13 (poor). Figure 1 shows the distribution of these classes in the Upper Murrumbidgee catchment.

This condition map is best considered a risk map. Catchments in poor condition are most likely to contain areas with evident or likely future environmental degradation, those in intermediate condition are likely to have some problems or to develop problems in the future, and those in good condition are likely to have few biophysical condition problems.

**Figure 1.** A preliminary catchment condition assessment for the Upper Murrumbidgee basin.

**Case Study 2: Mount Lofty Ranges**

We integrated soil, vegetation and terrain indicators using a GIS framework and assessed variability in drainage/waterlogging, salinity and acidity/alkalinity using remotely sensed data. Based on the results we developed an index of catchment health and a field manual. The purpose of the manual is to enable landholders and regional advisers to identify problems on properties and plan remedial action.

**Study site**

The regional study area in the Mount Lofty Ranges of South Australia covers approximately 80 km$^2$, including the town of Mount Torrens and an area to the east of the town (Fitzpatrick et al. 1999). The climate is Mediterranean and representative of the eastern part of the Mount Lofty Ranges, with a mean annual rainfall of 650–700 mm. A northeast to southwest topographic high east of Mount Torrens bisects the area: small catchments to the west drain into the Onkaparinga and Torrens catchment systems; catchments to the east form part of the Murray–Darling Basin system. Based on morphological, chemical and physical soil data (Fritsch and Fitzpatrick 1994), landscape DEM data (Davies et al. 1998), and water quality and remote sensing data (e.g. AIRSAR/TOPSAR; Bruce 1996), four focus areas were selected:

- a toposequence (~400 m in length) from the Herrmann area;
- the Herrmann area (~0.20 km$^2$);
- the Herrmann focus catchment (~2.0 km$^2$); and
- the Mount Torrens regional area (~80 km$^2$), comprising 55 smaller catchments.

**Soil degradation index**

We constructed a best-estimate map for each type of soil degradation data and used the maps to develop a soil degradation index (SDI), which itself is part of the broader catchment health indicator (see below).

In the Herrmann focus catchment, the processes by which drainage/waterlogging, salinisation and acidification/alkalisation occur are well understood (Fritsch and Fitzpatrick 1994; Fitzpatrick et al. 1996). We extrapolated spatial patterns of soil...
degradation processes at toposequence scale (400 m within a 0.2 km² key area) to catchment (2 km²) and regional (80 km²) scales (Fitzpatrick et al. 1999). By integrating data obtained on the ground with remotely sensed, DEM and vector GIS data, we created best-estimate maps for soil salinity (Fitzpatrick et al. 2000; see Figure 2), waterlogging/drainage (Davies et al. 2000) and acidity/alkalinity (Merry et al. 2000) for the 80 km² regional area. A prediction that 3% of the soils of the region would be extremely saline or very saline and that 10% would be slightly saline was validated by data from 50 randomly selected sites and other observations across the 80 km² region (see Chapter 21).

**Index of catchment health**

The United States Environmental Protection Authority (Jones et al. 1977) ranked catchments at large regional scales to obtain an index of relative condition. Our approach is similar in that we ranked attribute values from best to worst for soil salinity, waterlogging/drainage and acidity/alkalinity, and then summed rankings across all three categories to give an aggregated score. Thus, the method differs from the aggregation approach used in the Upper Murrumbidgee study. This method has also been applied to smaller catchments and fewer categories of indicators (Bruce et al. 2000; Fitzpatrick et al. 1999).

Most of the 55 small catchments or watersheds lie totally within the rectangular regional boundary. Catchment subdivisions were based on general surface water flows interpreted from topographic shapes and stream flow patterns (Bruce et al. 2000).

We constructed an SDI by ranking each of the 55 catchments according to the area of degradation due to soil salinity, waterlogging/drainage and acidity/alkalinity and then summed the rankings for each catchment to derive new SDIs (Bruce et al.

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**Figure 2.** Three-dimensional representation showing six classes of salinity for part of the 80 km² study area (from Fitzpatrick et al. 2000).
2000). We used regional maps for best estimates of these three categories to produce a composite, regional-scale assessment of soil degradation.

As illustrated in Figure 3, we used the following indexes to rank the 55 catchments in terms of landscape processes and subsequent environmental effects such as stream water quality:

- SDI — developed from the best estimates of salinisation, drainage/waterlogging and acidity/alkalinity;
- land cover index (LI) — developed from land cover and DEMs;
- riparian land cover index (RLI) — developed from the intersection of buffered streams and land cover; and
- road index (RI) — developed from a summation of the weighted lengths of roads.

Using these indexes, catchments were ranked based on the zonal summation of raster GIS attributes per vector subcatchment polygon. To normalise for different catchment areas, the index value was divided by the area of the catchment.

We combined the rankings by summing each ranking for all catchment characteristics. The final

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**Figure 3.** Data model used for the generation of catchment indices (from Fitzpatrick et al. 1999). DEM is digital elevation model.
catchment indicator (CI) of health was calculated using the following model:

\[ CI = SDI + RI + LI + RLI \]

We then grouped catchments into quintiles, and rated soil and surface water quality.

To give land managers graphic tools on which to base management decisions, we produced maps such as the final CI map, which used different colours to indicate differences in quality (e.g. catchments with red tones were considered to have poor quality soil and water). The Herrmann focus catchment in the Mount Torrens region fell in the poorest category. Our knowledge of the area suggested that other catchment rankings were valid, but they require validation on the ground.

In the ‘Catchment Condition’ project of the National Land and Water Audit, Walker et al. (2001) developed a decision system called CatCon that enables indicator aggregations and spatial scenarios to be produced easily.\(^3\)

**Application of the approach to other areas**

Information gained through use of indicators has been used to help landholders better assess problem sites and develop property management plans. The approach can help Landcare groups, government agencies and others to make resource management decisions and assess the social and economic viability of a region.

**Case Study 3: Catchment Condition Report Card for the Young Area**

A great strength of an indicator approach is that it can identify individual activities that are causing specific problems, which is useful in planning and implementing remedial actions. Walker et al. (1996) applied landscape indicators to a mixed farming area around Young in the Upper Murrumbidgee catchment. The outputs were presented in a report card that summarised the indicator values, classes and trends (see Table 1 for an example of a report card).

Table 1 shows a report card for two groups of paddocks—one with annual pastures (low capital input), the other with improved perennial pastures (lucerne established after lime and phosphate fertiliser application)—with each indicator giving a measure of some aspect of system health. Standards to rank each indicator from very good to very poor were established using locally collected data. The table shows that the condition of annual pastures was generally poor and deteriorating: weeds and bare soil were high, plant rooting depth was shallow and the saline watertable had stayed at a constant level. For perennial pastures, the trends were generally good and improving. Depth to the watertable had increased (the watertable was saline and needed to be well below rooting depth). The rooting depth was greater than in the annual pastures and was expected to improve water use efficiency (WUE); the higher percentage yield implied that the pastures were making better use of the available water.
rainfall; and stream water quality, especially turbidity, was satisfactory for most indicators.

There were some negative signs for the perennial pasture system. The trend in pH indicated that liming was necessary to maintain production, and the low macroinvertebrate biodiversity counts in nearby streams implied a higher than acceptable level of salinity in water moving from paddocks. An increase in stream electrical conductivity (EC) could indicate that more areas might be affected by salinisation in the future; therefore, a more detailed examination, such as mapping EC with appropriate equipment, could be warranted.

Overall, the health of the landscape had slowly degenerated. The following actions were suggested to reverse the downward trend:

- changes in crop rotations (generally wheat in this area) towards longer periods of permanent pasture to improve soil and water health (these improvements at the farm scale would have flow-on effects in improving the general health of the landscape);
- possibly tree planting across the contours and above evident discharge areas (salinity levels have been partially stabilised under the perennial pasture system but are still of some concern); and
- closer monitoring of streams, because their poor biological condition implies that pollution other than salinity is a problem.

The report card approach gives landholders sufficient information to decide on positive actions. Decisions about what to do in any specific example will depend on commodity prices versus continuing slow declines in the health of the landscape.

Table 1. A trend report card for paddocks with annual pastures and perennial pastures.

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Very good</th>
<th>Good</th>
<th>Fair</th>
<th>Poor</th>
<th>Very poor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bare soil</td>
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<tr>
<td>Root depth</td>
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<tr>
<td>Soil pH</td>
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<td>Stream pH</td>
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<td>Stream EC</td>
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<tr>
<td>Turbidity</td>
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<tr>
<td>Macroinvertebrates</td>
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<td>Waterable depth</td>
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Perennial pastures (mean for four paddocks on similar soils)

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Very good</th>
<th>Good</th>
<th>Fair</th>
<th>Poor</th>
<th>Very poor</th>
</tr>
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<tbody>
<tr>
<td>Bare soil</td>
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<tr>
<td>Root depth</td>
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<tr>
<td>Soil pH</td>
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<td>Soil EC</td>
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<tr>
<td>Words</td>
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<tr>
<td>Stream pH</td>
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<tr>
<td>Stream EC</td>
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<tr>
<td>Turbidity</td>
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<td></td>
</tr>
<tr>
<td>Macroinvertebrates</td>
<td></td>
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<tr>
<td>Waterable depth</td>
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</tbody>
</table>

EC = electrical conductivity
Application to the Northern Grains Region

The northern grains region lies on the subtropical slopes and plains of eastern Australia (SCARM 1998) between latitudes of 21°30’ (north of Clermont, Queensland) and 33° (south of Dubbo, New South Wales). It comprises three agroecological zones: western, eastern and central Queensland (Fig. 4). The region is bounded on the east by the Great Dividing Range (152°E at its eastern extremity) and on the west by rainfall isohyets suitable for dryland cropping (146°E at its western extremity). Agriculture is the dominant land use. In 1997–98, 25% of the region was cropped and 25% was sown to pastures (ABARE 1999). The remaining land was used for extensive grazing or nonagricultural uses such as state forests, national parks and mining. Between 1995 and 1999, 17.5% of the Australian grain crop was harvested from this region, of which 65% was produced in the eastern zone (Knopke et al. 2000).

Land use

The region incorporates a variety of farm enterprises; the ratio of cropped land to pasture land ranges from 0 to 1. The cropping–pasture mix tends to ebb and flow according to commodity prices and farmers’ aspirations, but the following general types of farms can be identified in the region:

• **Mixed farming.** Livestock and cropping enterprises are integrated and use the same land. This form of land use is usually practised more in the older, eastern areas of the region.

• **Cropping only.** Intensive, continuous cropping is mostly undertaken on the more fertile lands of the region and where there are small areas of irrigation. Few, if any, livestock graze these areas.

• **Separate cropping and livestock industries on the same farm.** Cropping and livestock enterprises are undertaken on the same farm, but each is located in a separate area, often determined by factors such as soil type and slope. On the fertile Darling Downs of Queensland and the Liverpool Plains of New South Wales, cropping is practised on flat to undulating alluvial plains, while livestock graze the steep nonarable slopes. In the western part of the region, traditional livestock farms are gradually changing into mixed, but nonintegrated, farming enterprises.

• **Livestock only.** Much of the region is used only for cattle and sheep grazing, as the land is unsuitable for cropping or the landowner does not wish to produce crops.

Areas of dryland and irrigated cotton growing fall into the first three categories. Dryland grain cropping in the region is dominated by winter and summer production of cereals (chiefly wheat, sorghum, barley and corn). The dominant soil types for cropping are Vertosols (black, grey and brown cracking clays), Sodosols (solodised solonetz and solodic), Chromosols (red-brown earths) and Ferrosols (Krasnozems and Euchrozems) (Webb et al. 1997). The moderate to high water-holding capacity of the Vertosols is important for the production of winter crops because most rain falls in the summer, particularly in the north. Webb et al. (1997) provide more information about the region, its soils and the characteristics of its climate.

Figure 4. The northern grains region of Australia consists of three subregions: western, eastern and central Queensland.
Sustainability issues for the northern grains region at various scales

The first step in using indicators is to identify the key sustainability issues facing the region. These vary at paddock, farm, catchment and regional level, as shown in Tables 2–4.

At the paddock and farm scale, soil health is a key issue. Soil erosion causes loss of surface structure, decreased storage of plant available water, and loss of soil nutrients in eroded sediments. Other issues include increased risk of salinisation, sodicity, soil acidification and structural damage, crop pests and weeds and diseases; and reduced diversity and abundance of soil fauna. These issues are related to site-specific factors such as soil type, climate, agronomic management and farm history. In some cases, the problems may not be recognised by land managers because they are relatively insidious or not well understood (e.g. subsoil compaction, deep drainage, vertical and lateral leakage of solutes, and the conservation of beneficial soil organisms).

Most catchment-scale issues relate to water quality. Catchment-scale issues tend to have downstream and offsite impacts on whole communities, affecting towns, cities, forests, national parks, beaches, estuaries and coral reefs as well as agriculture. For example, widespread soil erosion in the Fitzroy River catchment, which drains much of the central Queensland agricultural area, has led to high levels of suspended sediments, nutrients and pesticides in streams and groundwater (Noble et al. 1997). For many local towns, this in turn impacts upon their sole water supply. In the Liverpool Plains in northern New South Wales, six key natural resource management issues pertinent to the sustainability of the catchment have been identified: dryland salinity (and groundwater recharge).

Table 2. Performance indicator levels in Queensland showing the number of businesses in each category.

<table>
<thead>
<tr>
<th>Farm indicators</th>
<th>Performance targets</th>
<th>Queensland sample (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Weak</td>
<td>Medium</td>
</tr>
<tr>
<td>Disposable income Per family ($’000)</td>
<td>&lt; 30</td>
<td>30–60</td>
</tr>
<tr>
<td>Farm input costs Operating costs/farm income (%)</td>
<td>&gt; 60</td>
<td>60–50</td>
</tr>
<tr>
<td>Land productivity Operating surplus/land value (%)</td>
<td>&lt; 8</td>
<td>8–15</td>
</tr>
<tr>
<td>Farm size Land value per family ($’000)</td>
<td>&lt; 400</td>
<td>400–800</td>
</tr>
<tr>
<td>Debt servicing Financing costs/total income (%)</td>
<td>&gt; 15</td>
<td>15–7</td>
</tr>
<tr>
<td>Machinery Machinery market value/farm income (ratio)</td>
<td>&gt; 1.2</td>
<td>1.2–0.8</td>
</tr>
<tr>
<td>Nonfarm income Net nonfarm income per family ($’000)</td>
<td>&lt; 5</td>
<td>5–15</td>
</tr>
</tbody>
</table>
Technology transfer

flooding, soil erosion, water quality and quantity, biodiversity and riparian zone degradation (Dames and Moore 2000).

At the regional level, most sustainability issues relate to soil nutrient depletion, soil structural degradation, soil erosion, diseases, pests, weeds and chemical contamination of food and the environment (Clarke and Bridge 1997). Until recently, cropping in the region was often characterised by nutrient ‘mining’, as nutrients (particularly nitrogen) removed through harvested grain, stubble removal (either hay-baling or burning) and soil erosion were not replaced (Dalal and Probert 1997). Although many farmers now replace ‘harvested’ nutrients with fertiliser inputs, the regional balance is still negative (Knopke et al. 2000). SCARM (1998) found phosphorus and potassium balances for broadacre industries in the subtropical slopes and plains to be consistently negative during the period 1986–95, with no indication of improvement. Another regional issue is stream eutrophication and turbidity (Knopke et al. 2000).

Table 3. Business health indicators.

<table>
<thead>
<tr>
<th>Indicators</th>
<th>Performance targets</th>
<th>Qld median</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Business health</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Disposable income/family ($’000)</td>
<td>&lt; 10</td>
<td>30–60</td>
</tr>
<tr>
<td>Net worth—Net assets/family ($’000)</td>
<td>&lt; 500</td>
<td>500–1000</td>
</tr>
<tr>
<td><strong>Income drivers</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Production system Farm income per hectare per 100 mm annual rainfall ($/ha/100 mm rain)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Intensive cropping</td>
<td>&lt; 40</td>
<td>40–50</td>
</tr>
<tr>
<td>• Mixed farms</td>
<td>&gt; 60</td>
<td>60–70</td>
</tr>
<tr>
<td>Farm input cost—Operating costs/farm income (%)</td>
<td>&gt; 40</td>
<td>50–60</td>
</tr>
<tr>
<td>Farm size—Land value/family ($’000)</td>
<td>&lt; 400</td>
<td>400–800</td>
</tr>
<tr>
<td>Debt servicing—Financing costs/total income (%)</td>
<td>&gt; 15</td>
<td>15–7</td>
</tr>
<tr>
<td>Machinery—Machinery market value/farm income (ratio)</td>
<td>&gt; 1.2</td>
<td>1.2–0.8</td>
</tr>
<tr>
<td><strong>Nonfarm income</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Net nonfarm income/family ($’000)</td>
<td>&lt; 5</td>
<td>5–15</td>
</tr>
<tr>
<td><strong>Resource use</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Land productivity—Operating surplus/land value (%)</td>
<td>&lt; 8</td>
<td>8–15</td>
</tr>
<tr>
<td>Labour—Income per labour unit ($’000)</td>
<td>&lt; 100</td>
<td>100–150</td>
</tr>
<tr>
<td>Return on capital—Return on farm capital (%)</td>
<td>&lt; 2</td>
<td>2–7</td>
</tr>
</tbody>
</table>
Table 4.  Associating farm productivity issues in the northern grains region with commonly advocated indicators.

<table>
<thead>
<tr>
<th>Sustainability issue / component</th>
<th>Scale</th>
<th>Suggested sustainability indicators</th>
<th>Possible action to take</th>
<th>Investor (who pays?)</th>
<th>Likely time to achieve benefit</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Declining productivity</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Poor WUE by crops (declining crop yields)</td>
<td>P, F</td>
<td>• % of potential yield • WUE</td>
<td>• Adopt improved agronomy • Identify yield limiting constraints including subsoil factors • Use water balance / push probe to better target yields</td>
<td>• Farmer / Farmer / advisory companies / research funds / Farmer / adviser</td>
<td>• Within season • Few years • Within season</td>
</tr>
<tr>
<td><strong>Declining profitability</strong></td>
<td></td>
<td></td>
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<td></td>
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</tr>
<tr>
<td></td>
<td>P, F</td>
<td>• $WUE • Disposable income per family • Net profit per hectare</td>
<td>• Optimise inputs and rotation sequence (opportunity cropping) • Be aware of commodity price shifts</td>
<td>• Farmer / adviser / researchers • Farmer / cooperatives / commodity markets</td>
<td>• Few years • Within season</td>
</tr>
<tr>
<td><strong>Declining product quality</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Declining protein in cereals</td>
<td>P, F</td>
<td>• % protein of crop • Nonlegume legume ratio in rotations</td>
<td>• Attend N budgeting workshop • Increase N applications • Rotate annual cereal crops with legumes</td>
<td>• Farmer / agriculture departments / cooperatives / grain boards / grain companies</td>
<td>• Within season</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>• % protein at local silo • Nonlegume legume ratio in rotations</td>
<td>• Grow pulses or legume-based pastures</td>
<td>• Farmer</td>
<td>• Season after pulse crop</td>
</tr>
<tr>
<td></td>
<td>P, F, R</td>
<td>• % legume in pasture • Nonlegume legume ratio in rotations</td>
<td>• Increase pasture legume composition</td>
<td>• Farmer</td>
<td>• Season after pasture removal (effect may last several seasons)</td>
</tr>
</tbody>
</table>

F = farm; N = nitrogen; P = paddock; R = region; WUE = water use efficiency
Suggested indicators for the northern grains region

Tables 4 and 5 list potential sustainability indicators at paddock to farm scale; Table 4 shows those more relevant at the catchment to regional scales. Some indicators are common to different scales. The tables also describe actions that could be taken in order to solve problems, suggest who is likely to invest in solving either farm or environmental problems, and provide estimates of how long after remedial treatment benefits are likely to accrue. Clearly, not all indicators will be used simultaneously. Individual farmers or rural communities need to determine the most pressing issues.

A popular and effective means for creating a greater knowledge base for targeting local issues are programs such as ‘Farming for the Future’, where farmers learn together in facilitated action-learning groups. A recent survey by Lobry de Bruyn (1999) found that farmers across northwestern New South Wales monitored soil health through soil tests, crop performance (yield and protein), visual observation of plants and soil, and the structure and workability of soil (by a soil ‘feel’ test).

Where more than one problem is identified, combined corrective measures often produce a synergistic response. For example, some 16% (195,000 ha) of the Liverpool Plains catchment is considered to be at risk from salinisation, with 50,000 ha currently exhibiting symptoms of dryland salinity (LPLMC 2000). This is a significant local issue and one worth monitoring and addressing, because farm profit and environmental outcomes are linked. Soil tests (EC), piezometer monitoring (water table height and EC), observations of salt scalds, dominance of pastures by salt-tolerant plant species and permanently waterlogged areas within paddocks are all useful indicators for identifying salinity. Where salinisation is identified or where the risk of salinisation is high, farmers may fence off salt-affected land, plant deep-rooted perennials, use salt-tolerant species, or use reverse interceptor banks (especially on sloping duplex soils) to divert lateral subsoil water. Landowners usually pay for these actions, but Landcare funding is sometimes available. It is important to realise that where changes to groundwater hydrology are sought, the results of these actions may not be manifest for several years or even decades.

The above example of salinity deals with farm and paddock-scale remedial actions. Broader-scale solutions are typically required to prevent salinity in the first place. At a catchment scale, indicators of salinity include soil, groundwater and streamwater EC, electromagnetic surveys (mapping of EC within the landscape), and DEM (inferring and mapping likely areas of salinity hazard based on landscape position). Catchment management strategies are typically funded by federal or State governments. An example at a State level is the New South Wales Salinity Strategy (August 2000), which set interim end-of-valley salinity targets for salt load and EC to be achieved by 2010. An example of a catchment-scale response is the Liverpool Plains Catchment Investment Strategy, which proposes an environmental management system to be used as a tool for sharing the cost of implementing solutions to problems such as dryland salinity (LPLMC 2000). One recommended action is to cease cropping in designated land management units where deep drainage is most likely, and instead establish and maintain tree cover (farm forestry).

Future directions

Farming and rural communities will adopt sustainability indicators only if they believe they will improve the short-term benefits and long-term viability of their enterprises. It is worth remembering that the farming community has always used broad indicators in farming practice and management. This is often thought of as ‘experience’ and it extends to reading the likely weather, knowing when to fertilise, examining trends in commodity prices and exchange rates and
Table 5. Associating soil health issues in the northern grains region with commonly advocated indicators.

<table>
<thead>
<tr>
<th>Sustainability issue / component</th>
<th>Scale</th>
<th>Suggested sustainability indicators</th>
<th>Possible action to take</th>
<th>Investor (who pays?)</th>
<th>Likely time to achieve benefit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil health</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Poor surface structure / reduced water infiltration</td>
<td>P, T</td>
<td>• Dispersion / slaking tests&lt;br&gt;• Exchangable sodium percentage&lt;br&gt;• Soil organic carbon&lt;br&gt;• Soil consistency&lt;br&gt;• Water intake rate&lt;br&gt;• Surface crust / sealing / pugging</td>
<td>• Grow pastures&lt;br&gt;• Apply gypsum&lt;br&gt;• Reduce tillage&lt;br&gt;• Increase organic matter</td>
<td>Farmer</td>
<td>Few years up to a decade</td>
</tr>
<tr>
<td>Subsurface compaction</td>
<td>P, T</td>
<td>• Effective rooting depth&lt;br&gt;• Soil consistency&lt;br&gt;• Visual assessment&lt;br&gt;• Push probe measurement</td>
<td>• Avoid trafficking (machinery or grazing animals) on wet soils&lt;br&gt;• Practise controlled traffic</td>
<td>Farmer</td>
<td>Few years up to a decade</td>
</tr>
<tr>
<td>Soil erosion</td>
<td>P, T, C</td>
<td>• % bare soil&lt;br&gt;• Slope class&lt;br&gt;• Exchangeable sodium percentage&lt;br&gt;• Presence of still/gully erosion&lt;br&gt;• Soil movement under fences</td>
<td>• Maintain groundcover&lt;br&gt;• Reduce tillage&lt;br&gt;• Stubble retention&lt;br&gt;• Grassed waterways&lt;br&gt;• Contour banks</td>
<td>Farmer&lt;br&gt;Landcare groups&lt;br&gt;Catchment management committees</td>
<td>Straight after introduction of most actions</td>
</tr>
<tr>
<td>Sodicity</td>
<td>P, E, C</td>
<td>• Dispersion tests&lt;br&gt;• Exchangable sodium percentage&lt;br&gt;• Sodicity meter</td>
<td>• Apply gypsum&lt;br&gt;• Use low sodium irrigation water&lt;br&gt;• Plant pastures instead of crops</td>
<td>Farmer</td>
<td>Within first season after application</td>
</tr>
<tr>
<td>Sustainability issue / component</td>
<td>Scale</td>
<td>Suggested sustainability indicators</td>
<td>Possible action to take</td>
<td>Investor (who pays?)</td>
<td>Likely time to achieve benefit</td>
</tr>
<tr>
<td>----------------------------------</td>
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<td>-------------------------</td>
<td>----------------------</td>
<td>-----------------------------</td>
</tr>
<tr>
<td>Soil health</td>
<td>P, F, C, R</td>
<td>• Electrical conductivity • Electromagnetic surveys • Digital elevation modelling • Salt scales observed • Areas dominated by salt-tolerant species • Permanently waterlogged areas within paddocks</td>
<td>• Fence off salt-affected land • Plant deep-rooted perennials • Use salt-tolerant species • Use reverse interceptor banks (especially on sloping duplex soils) to divert lateral subsoil water</td>
<td>Farmer, Landcare</td>
<td>Years to decades</td>
</tr>
<tr>
<td>Nutrient deficiencies</td>
<td>P, F</td>
<td>• Soil and plant tests • Nutrient balance sheet (inputs x efficiency / outputs)</td>
<td>• Match projected and actual nutrient exports with fertiliser application • Use regular soil/plant testing</td>
<td>Farmer, Fertiliser industry</td>
<td>Within first season after action (effects may last for several years)</td>
</tr>
<tr>
<td>Acidification</td>
<td>P, F, C</td>
<td>• Trends in soil pH</td>
<td>• Adopt liming practices • Use less acidifying practices</td>
<td>Farmer, Agribusiness</td>
<td>Several years</td>
</tr>
<tr>
<td>Crop diseases</td>
<td>P, F, C</td>
<td>• Crop rotation index • Plant diagnosis • Soil DNA probes • Climate prediction model</td>
<td>• Identify disease problem • Alter tillage practices • Adopt better crop rotations • Use disease-resistant varieties</td>
<td>Farmer, Plant breeders, Plant pathologists</td>
<td>Within season or within new rotation</td>
</tr>
</tbody>
</table>

C = catchment; DNA = deoxyribonucleic acid; F = farm; P = paddock; R = region; T = toposequence
so on. Making the effort to collect relevant environmental data beyond soil tests should not be a major shift in attitude, provided the tests can be interpreted in a way that is meaningful to the productivity of the farm or region. The adoption of environmental measures in Farm 500 (a group of 500 Australian farmers collecting environmental and production indicators) and the collection of information in ‘precision farming’ demonstrate that many farmers believe that benefits can be obtained.

If farmers are to adopt the indicators, they must first be shown how to collect, store and interpret the data. After that, the greatest success is likely to come from self-help groups.

**Conclusions**

Several packages to help land managers to address sustainability issues at the paddock, farm and catchment scale have now been developed and implemented in some of Australia’s southern farming regions. A common feature of the cases discussed in this chapter is the incorporation of knowledge about the soil and landscape characteristics with various direct and indirect (surrogate) indicators, and the conversion of this information to a regional scale using technologies such as DEM, GIS and remote sensing. This level of complexity is not always necessary; the message here is to encourage farmers to clearly identify the issues to be assessed, to ask assessment questions likely to provide the information they need, to identify the best indicators, and then to record the indicators consistently and accurately.

Australia’s northern grains region, where soil and catchment degradation are recognised as significant issues, would benefit from the kind of knowledge and decision-support packages that we have described for southern Australia. We have assembled a suite of sustainability indicators to help identify paddock, farm and catchment health issues and to monitor the situation after remedial action. We hope these may form the beginning of wider recognition of soil and catchment sustainability issues in the north.

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