Monitoring Land Quality
Assuring More Sustainable Agricultural Production Systems

Sustainable agricultural development, conservation of natural resources, and promotion of sustainable land management are key objectives of the new World Bank rural investment program (World Bank, 1997).

Land used for agricultural production is an essential element to improve environmental management, including source/sink functions for greenhouse gases, nutrient recycling, amelioration and filtering of pollutants, and transmission and purification of water as part of the hydrologic cycle.

While routine indicators of project performance based on cost-benefit analyses (input-output factors, risk and economic performance indicators) are necessary to monitor the activities and components of a project, land quality indicators (LQIs) are required to evaluate environmental impacts. The quantitative assessment of physical impacts, such as depletion of soil nutrients, loss of organic matter, soil erosion, and water contamination, may appear to be costly during project implementation. However, the long-term negative impact of reduced land quality, such as decreased efficiency of fertilizers and increased erosion, fuel consumption, and pest infestations, often raises rehabilitation costs. The LQI approach focuses on preventive maintenance rather than rehabilitation.

**Land Quality Indicators — The World Bank’s Program**

Identification of LQIs is a key requirement of sustainable land management. Land quality, however, like sustainable land management, requires operational definitions and specific, measurable indicators if it is to be more than an attractive, conceptual phrase. Indicators are already in regular use to support decision making at global, national, and subnational levels for air and water quality, but few such indicators are available to assess, monitor, and evaluate changes in the quality of land resources. Land refers not to soil alone, but to the combined terrain — water, soil, and biotic resources that provide the basis for land use. Land quality refers to the condition, or ‘health’, of land, specifically to its capacity for sustainable land use and environmental management (Box 1).

The LQI program monitors the environment and the sector performance of managed ecosystems (agriculture, forestry, conservation, and environmental management). The program is being developed on both a national and regional scale, but it is also part of a larger global effort to improve natural resource management (Pieri et al., 1995). The LQI program recommends addressing issues of land management by agroecological zones. This approach favors incorporating farmer (local) knowledge into the overall process of improving agricultural and environmental land management.

Although a single indicator of land quality is not realistic, a very large number that reflects all possibilities is also not useful. To help resolve this problem, a panel of scientists and administrators recommended a core set of strategic land quality indicators.
**Box 1. Clarifying terminology for soil and land quality**

Soil quality is the capacity of a specific soil to function within natural or managed ecosystem boundaries to sustain plant and animal production, maintain or enhance water quality, and support human health and habitation (SSSA, 1995).

**Land quality** is the condition, state, or ‘health’ of the land relative to human requirements, including agricultural production, forestry, conservation, and environmental management (Pieri et al., 1995).

**Sustainable land management** combines technologies, policies, and activities aimed at integrating socioeconomic principles with environmental concerns to simultaneously maintain or enhance production, reduce the level of production risk, protect the potential of natural resources, and buffer against soil and water degradation. Sustainable land management must also be economically viable and socially acceptable (Smyth and Dumanist, 1993).

These concepts span a range of detail, application, and levels of integration with socioeconomic data, and must be applied for different types and scales of land use. Soil quality is a condition of a site that can be studied using soil data alone. Land quality is a condition of the landscape, and requires integration of soil data with other biophysical information such as climate, geology, land use, and the impacts of land management. Sustainable land management requires the integration of biophysical conditions (land quality) with economic and social demands. It is an assessment of the impacts of human habitation and a condition of sustainable development.

**LQIs for Immediate Application**

- **Nutrient balance.** Describes nutrient stocks and flows as related to different land management systems used by farmers in specific agroecological zones and specific countries (Box 2).
- **Yield gap.** Describes current yields, yield trends, and actual potential farm-level yields in cereal equivalents (Box 3).
- **Land-use intensity.** Describes the extent of diversification of production systems over the landscape, including livestock and agroforestry systems. It reflects the degree of flexibility (and resilience) of regional farming systems and their capacity to absorb shocks and respond to opportunities.
- **Land-use diversity** (agrodiversity). Describes the extent of diversification of production systems over the landscape, including livestock and agroforestry systems. It reflects the degree of flexibility (and resilience) of regional farming systems and their capacity to absorb shocks and respond to opportunities.
- **Land cover.** Describes the extent, duration, and timing of vegetative cover on the land during major erosive periods of the year. Land cover is a surrogate for erosion, and along with land-use intensity and diversity, it offers increased understanding on issues of desertification.

1. Currently, indicator guidelines are available only for nutrient balance and yield gap; the other indicators are in various stages of development.

**Box 2. Estimating nutrient balance**

Soil nutrient depletion is common in many tropical regions due to low rates of fertilization, but nutrient overloading may occur where fertilizer use is heavily subsidized. Neither of these extremes is ideal, and the objective should be to assure that nutrients removed by harvest and those lost by erosion and leaching are replaced. A nutrient accounting procedure describing the different inputs and outputs of soil nutrients is recommended. Minimum required data are a soil map, production figures, and some basic characteristics of land-use systems.

Input and output parameters determine the soil nutrient balance:

<table>
<thead>
<tr>
<th>Input</th>
<th>Output</th>
</tr>
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<tbody>
<tr>
<td>1. Mineral fertilizer</td>
<td>1. Crop and animal products</td>
</tr>
<tr>
<td>2. Organic fertilizer</td>
<td>2. Crop residues (if removed)</td>
</tr>
<tr>
<td>3. Wet and dry deposition</td>
<td>3. Leaching</td>
</tr>
<tr>
<td>5. Sedimentation</td>
<td>5. Soil erosion</td>
</tr>
<tr>
<td>6. Animal feeds</td>
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</tbody>
</table>

**Inputs.** Nutrient inputs from mineral fertilizer (1) can be derived from agricultural statistics or obtained from surveys. Inputs from manure and other organic fertilizers (2) depend on prevailing livestock management systems (caution: to avoid double accounting, ensure that manure derived from on-farm feeds is differentiated from manure brought in from other areas). Data on deposition by rain and dust (3) is generally not readily available, but estimates can be derived from precipitation data. Nitrogen fixation (4) is estimated as a percentage of the total nitrogen uptake of leguminous crops, and non-synthetically fixed nitrogen can be included. Sedimentation (5) is relevant only in areas that are naturally flooded or irrigated. Animal feeds (6) are inputs only if purchased outside the farm.

**Outputs.** Nutrients in harvested products (1) are derived from crop-specific nutrient contents and yields obtained from agricultural statistics. Removed crop residues (2) are related to production and based on estimates of residues left in the field. Leaching (3) and gaseous losses (4) apply mostly to nitrogen, and are correlated with soil fertility, fertilizer application, crop nutrient uptake, soil clay content, and precipitation. Nutrient losses through soil erosion (5) are obtained by multiplying soil loss with soil nutrient content. Soil nutrient balance can be calculated for individual farms, but also at community, region, and national scales. The required information and the accuracy of the assessments decrease as the scales decrease.
LQIs Still in the Research Stage

- **Soil quality.** Describes the conditions that make the soil a living body, i.e., soil health. The indicators will be based on soil organic matter, particularly the dynamic (microbiological) carbon pool most affected by environmental conditions and land-use change.

- **Land degradation** (erosion, salinization, compaction, organic matter loss). These processes have been the subject of extensive research and have a strong scientific base, but reliable data are not always available.

- **Agrobiodiversity.** This concept involves managing the gene pools used in crop and animal production, but also soil micro- and meso-biodiversity important for soil health. On a macro scale, it involves integrated landscape management, including maintenance of natural habitat, as well as managing the co-existence of wildlife in agricultural areas.

LQIs Being Developed by Other Sectors

- **Water quality**
- **Forest land quality**
- **Rangeland quality**
- **Land contamination/pollution**

These indicators are the biophysical components of sustainable land management. Although useful in their own right, they must still be complemented with indicators of the other pillars of sustainable land management — economic viability, system resilience, and social equity and acceptability (see Box 4, next page). Considerable additional work is required to develop these pillars to the same level of detail as the land quality (biophysical) indicators.

Conclusion

In general, but particularly in developing countries, it is essential that scarce resources devoted to land management be used more cost-efficiently and that policymakers have at least rough indicators of whether environmental conditions and land quality are getting better or worse (Box 5). Land quality indicators are useful for decisionmakers to monitor and improve project performance as related to socioeconomic and environmental impact, and to assess the trend toward or away from land-use sustainability.

**Box 3. Estimating yield gap**

Yield gaps are calculated values obtained by using a reliable crop growth model and integrated climate, soil, and land management databases. Several calculations are required.

**Potential yields.** These yields are based on photosynthetically active radiation, and conditioned by temperature and phenological development over the growing season. Daily or monthly radiation and temperature measurements are required to assess production at this level. Estimated biomass is converted to harvestable product using a harvest index. Potential yields are rarely obtained other than in greenhouses and on experiment stations.

**Water- and nutrient-limited yields.** These estimates are calculated from the potential yield, but adjusted according to the amount of precipitation received and the capacity of local soils to supply nitrogen, phosphorus, and potassium. A dynamic soil water model is used, and the supply and uptake of each nutrient is estimated. Required data are soil chemical characteristics, organic matter, pH, phosphorus, and exchangeable potassium.

**Baseline yields.** The lowest water-limited and nutrient-limited yields are baseline yields. These yields are what can be obtained with good land management, but without input of nutrients or water.

**Actual yields.** These are yields that are currently realized by farmers. They can be obtained from an agricultural census or surveys.

**Yield gap indicators.** These indicators estimate what could be obtained using low inputs or yield potential from crop breeding and high inputs. They are calculated by comparing actual yields (in cereal equivalents) to baseline yields (water- and nutrient-limited yields).

More information will soon be posted on the Sustainable Land and Crop Management home page, which will be available through http://www-esd.worldbank.org/html/esd/agr/agrrmain.htm.

**Box 5. Applying LQIs in Tunisia**

The objective of the Tunisia project is sustainable intensification of agricultural production, along with improved environmental management of crop and range land. The components of the project include soil and water conservation, agricultural and pastoral intensification, rehabilitation of irrigation perimeters, rural infrastructure, role of women, and institution strengthening. Participatory rural appraisal, community-driven initiatives, and sustainable management of local resources are important elements in the project.

Among other activities, the project includes a GIS-based system to monitor and evaluate land and water quality and rural land-use changes. Indicators for wind and water erosion, soil fertility, deforestation, salinization, and crop yield were developed using combinations of the agricultural census, remote sensing, and special surveys (e.g., cultivation of erosive lands, percentage of land cover during erosive periods, fragmentation of forest fringes, etc.). These data will be used to monitor whether or not technical interventions and agricultural intensification are leading toward or away from sustainability.

References


Box 4.
Using PRA to develop LQIs for sustainable management

The sustainability of different land-use systems on 53 farms with sloping topography in Indonesia, Thailand, and Viet Nam was assessed using the Framework for Evaluating Sustainable Land Management (FESLM). Detailed socioeconomic and biophysical surveys characterized the land management systems, outlined their constraints and potential, and identified indicators and thresholds of sustainability in line with the five pillars of sustainability of FESLM — productivity, risk management and security, conservation and protection, economic viability, and social acceptability (Smyth and Dumanski, 1993).

A suite of sustainable land management indicators, with associated thresholds, was identified. Farmers provided feedback on the indicators after their farming systems were evaluated. The indicators are a useful first step toward the development of a more generic system to evaluate the sustainability of agricultural systems. The indicators were identified by farmer cooperators from survey information.

The information was summarized from research by the International Board for Soil Research and Management (IBSRAM).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Indicators</th>
<th>Comments</th>
</tr>
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<tbody>
<tr>
<td>Productivity Yield</td>
<td>&lt; village mean by 0-25%</td>
<td>Average over 10 years</td>
</tr>
<tr>
<td></td>
<td>&lt; village mean by 25%</td>
<td></td>
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<tr>
<td></td>
<td>&lt; village mean by &gt; 25%</td>
<td></td>
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<tr>
<td>Plant growth</td>
<td>Vigorous</td>
<td></td>
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<td></td>
<td>Normal</td>
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<tr>
<td></td>
<td>Stunted</td>
<td></td>
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<tr>
<td>Risk management and security Drought frequency</td>
<td>&gt; 2 years continuous</td>
<td></td>
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<td></td>
<td>2 years in 7</td>
<td></td>
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<tr>
<td></td>
<td>&lt; 2 years in 7</td>
<td></td>
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<tr>
<td>Income from livestock</td>
<td>&gt; 25% of total income</td>
<td></td>
</tr>
<tr>
<td></td>
<td>10-25% of total income</td>
<td></td>
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<tr>
<td></td>
<td>&lt;10% of total income</td>
<td></td>
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<tr>
<td>Conservation and protection Total soil eroded</td>
<td>&gt; 4.5 cm, rills on &gt; 50%</td>
<td>Amount observed over last 10 years</td>
</tr>
<tr>
<td></td>
<td>0.7-4.5 cm, rills 25-50%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>&lt; 0.7 cm, rills &lt; 25%</td>
<td></td>
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<tr>
<td>Cropping intensity and extent of protection</td>
<td>2-3 crops with conservation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2-3 crops, no conservation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1 crop with conservation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1 crop, no conservation</td>
<td></td>
</tr>
<tr>
<td>Economic stability Net farm income</td>
<td>Rising</td>
<td>Total family income</td>
</tr>
<tr>
<td></td>
<td>Constant</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Declining</td>
<td></td>
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<tr>
<td></td>
<td>Fluctuating</td>
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<tr>
<td>Off-farm income</td>
<td>&gt; 25% of total income</td>
<td>Usually require at least 10%</td>
</tr>
<tr>
<td></td>
<td>10-25% of total income</td>
<td></td>
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<tr>
<td></td>
<td>&lt;10% of total income</td>
<td></td>
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<tr>
<td>Availability of farm labor</td>
<td>2 full-time adults</td>
<td>Labor per farm unit</td>
</tr>
<tr>
<td></td>
<td>1-2 full-time adults</td>
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</tr>
<tr>
<td></td>
<td>1 full-time adult</td>
<td></td>
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<tr>
<td>Size of land holding</td>
<td>&lt; 1 ha</td>
<td>1.2-2.0 ha per family holding</td>
</tr>
<tr>
<td></td>
<td>1-2 ha</td>
<td></td>
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<tr>
<td></td>
<td>&gt; 2 ha</td>
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<tr>
<td>Social acceptability Land tenure</td>
<td>Full ownership</td>
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</tr>
<tr>
<td></td>
<td>Long-term user rights</td>
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<tr>
<td></td>
<td>No official land title</td>
<td></td>
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<tr>
<td>Training in soil conservation</td>
<td>Once in 3 years</td>
<td>Focus on younger farmers</td>
</tr>
<tr>
<td></td>
<td>Once in 5 years</td>
<td></td>
</tr>
<tr>
<td></td>
<td>None available</td>
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