Assessment of agricultural sustainability

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Formal assessment systems for agricultural sustainability are necessary for a scientific understanding of policy and planning for sustainable agricultural development. Analytical frameworks for environmental assessments and rural livelihoods assessments, backed by significant international initiatives, have been available for the past decade or so. Agricultural sustainability assessments can benefit greatly from an understanding of such frameworks. The state-of-the-art in environmental, rural livelihoods and agricultural sustainability assessments is evaluated and a framework for assessment of agricultural sustainability is proposed.

Keywords: Agriculture, environment, indicators, livelihood, sustainability.

THE overriding purpose of this study is to contribute to the scientific understanding of policy and planning for sustainable agricultural development. The World Commission on Environment and Development (WCED) defined sustainable development as 'development that meets the needs of the present without compromising the ability of future generations to meet their own needs'[1]. The Commission's report triggered wide scientific and policy interest in sustainable development as it brought into an integrated perspective, the three dimensions of development: economic, environmental and social. This led to a range of studies, backed by significant international initiatives, on development of systematic, analytical frameworks for sustainability assessments built on a broad base of theory in ecological sciences and environmental policy[2–4]. But their focus was largely on industrial and urban aspects of development and only to a limited extent on agricultural development[5].

Agriculture not only significantly affects the environment, but is also impacted directly by changes in the environment[6–8]. The social and economic impacts of environmental changes are also significant in many developing countries as agriculture is the major source of livelihood support in these countries. The agricultural sector was the focus of the poverty alleviation and rural livelihood initiatives of The World Bank, DFID and other national and international organizations. These led to frameworks for assessment of sustainable rural livelihoods, emphasizing more on the social and economic dimensions of sustainable development[9]. While the environmental assessments were at relatively large spatial scales (national, regional), the livelihood assessment frameworks were at relatively small scales (farm, village).

Assessments of agricultural sustainability is complex as it encompasses complex interactions between technologies, environment and society[10]. It also has different components, attributes and priorities at different scales; global national, regional, local and farm[11]. Nevertheless, such interactions and differences in scales have been addressed to varying degrees of theoretical rigour and practical effectiveness in environmental and rural livelihoods assessments. Agricultural sustainability assessments can benefit significantly if these two types of assessments can be integrated. There is also a wide range of empirical work on assessing agricultural sustainability at the farm and regional levels through use of diverse indicators. We propose to draw on these resources in arriving at a theoretical framework for deriving a core set of indicators of agricultural sustainability and integrate them into a single index.

Definitions – indicators and indices

Indicators inform about the state of functioning of a system, whether a machine, a human being, an ecosystem or a country. They help to define goals, link them to objectives, and assess progress toward meeting them. Sustainability indicators are quantifiable and measurable attributes of a system that are judged to be related to its sustainability[12]. By indicating the progress towards or away from the sustainability goals, they serve at least four purposes: decision-making and management, advocacy, participation, and consensus building[13]. Sustainability indicators have multidimensional attributes – economic, environmental and social. Indicators can be meaningfully integrated into an aggregated index. A sustainability index allows integrated assessments about the sustainability of the system, after taking into account all information provided by indicators.

Environmental sustainability assessment frameworks

Initial attempts at environmental assessment were based on aggregation of diverse indicators for specific attributes of

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environmental quality into indices, by arbitrarily weighting each indicator according to its expected contribution. For example, an Environmental Quality Index was defined by taking a weighted sum of air, water, land and other quality indicators[3]. The Pressure–State–Response (PSR) framework devised by the OECD[2] addressed the problem of systematic identification of indicators for environmental sustainability for the first time. It is based on the stress-response framework developed earlier for ecosystems analysis[4]. The framework (Figure 1) relies on the concept of causality: human activities exert pressures on the environment and change its state. Society responds to these changes through environmental, economic and other policies. Activities resulting from these policies in turn exert pressures, completing the PSR feedback loop. Accordingly, the PSR framework has three types of indicators: pressure indicators that measure environmental pressures resulting from human actions (emissions, wastes) and state indicators that assess environmental conditions (ozone depletion, water quality) and response indicators that assess societal response (policies, taxes, laws, management). The framework allows a systematic identification of variables to define indicators but does not address their integration into a single index. Also, in practice, the distinction between state and pressures indicators is not always clear, and some of their indicators may reflect the same attribute.

The PSR framework was modified to DPSIR (**D**riving forces–**P**ressures–**S**tate–**I**mpacts–**R**esponses) framework (Figure 2), to include broader sustainable development issues by adding two components, driving forces and impacts. In the DPSIR framework, the chain of causal links begins with driving forces and through to pressures states, impacts and responses. Driving forces are human activities which underpin environmental change (industry, agriculture) and impacts are results of pressures (on ecosystems, human health) which induce responses. Organizations like the United Nations, The World Bank, FAO, and others have used the PSR/DPSIR frameworks to develop environmental and sustainable development indicators.

In one example dealing with assessment of environmental quality in Asian countries[3], the PSR framework was used to identify a total of 79 indicators for a range of attributes – air quality, water quality, changes in land use, energy consumption, biodiversity, social and economic welfare, and health. Principal Components Analysis (PCA) was used to reduce the dimensionality (number of variables) to four components that represented indices for air quality, water quality, land quality and ecosystem quality. The indices were integrated graphically into environmental diamonds (EDs) and into numerical measures, environmental elasticity (EE) and cost of remediation index (COR). EDs are graphical representations of environmental quality of a city/country along each of the four principal component axes against the norms or average values for the cities/countries in the region. EE is the ratio of aggregate environmental change (weighted index of the annual changes in environmental indicators, %) to aggregate economic change (weighted index of changes in economic variables, %). COR provides a measure of the cost of moving from the present state of the environment to a more desirable state.

A more recent example is the Environmental Sustainability Index (ESI) developed by the World Economic Forum (WEF), Yale University and Columbia University[4]. ESI is based on indicators, derived from DPSIR framework, grouped into five core components/thematic categories: (i) environmental systems, (ii) environmental stresses, (iii) human vulnerability, (iv) social and institutional capacity,

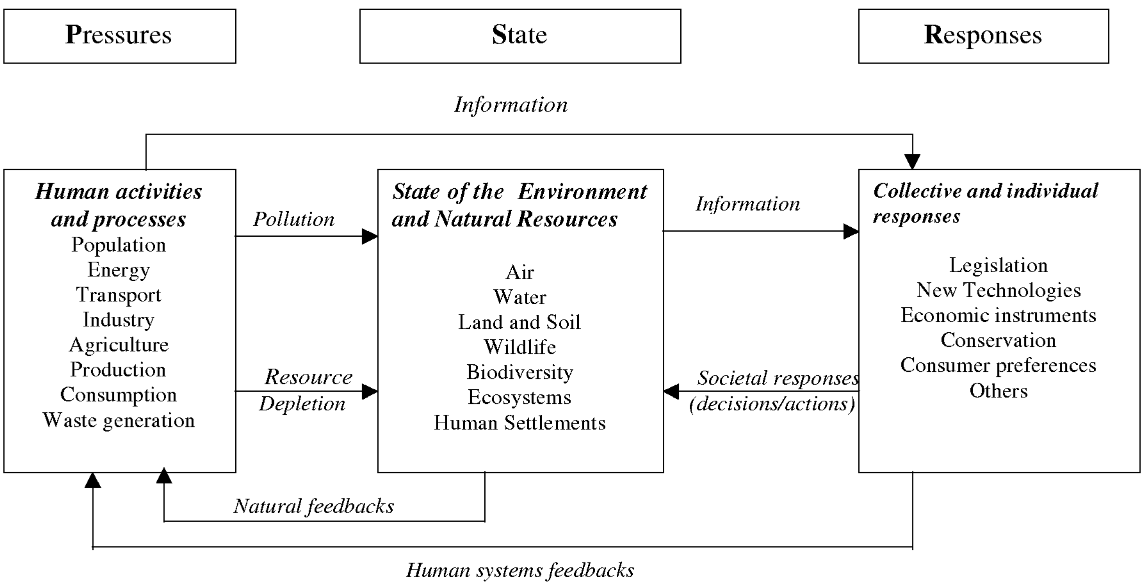

Figure 1. PSR framework (adapted from OECD[2]).

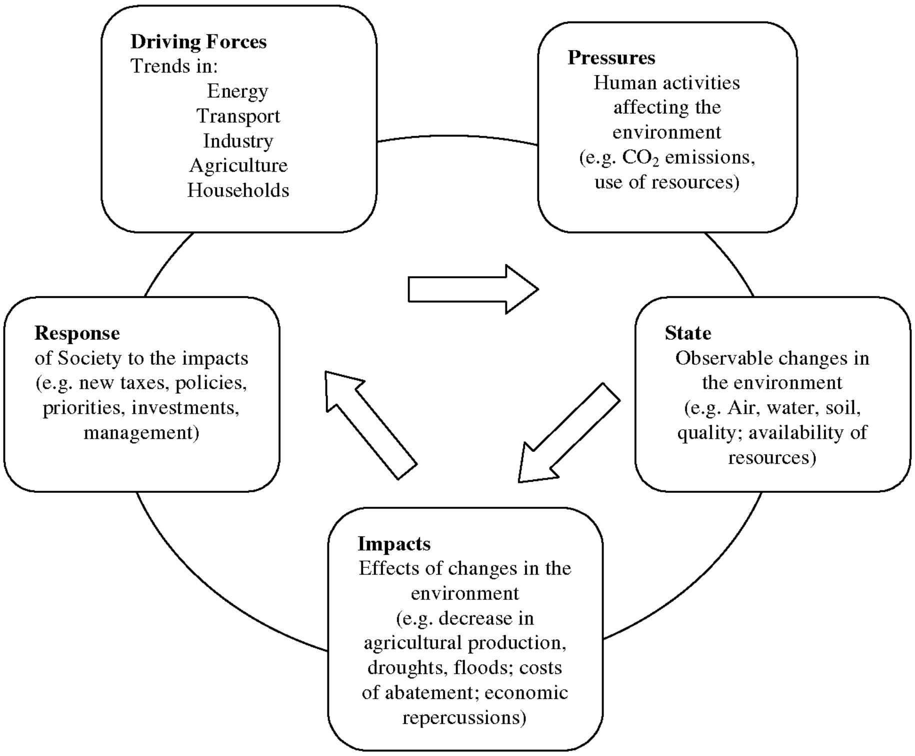

Figure 2. DPSIR framework (adapted from Woodhouse *et al.*[21]).

and (v) global stewardship. Each component comprises 3 to 6 indicators and each indicator is in turn measured by 2 to 6 variables (Table 1). In all, there are 21 indicators and 76 variables for the five components. The 21 indicators are weighted equally for computing the ESI – thus implicitly weighting those components with more indicators more heavily. The advantage of ESI is that it permits cross-national/regional comparisons of environmental sustainability in a quantitative fashion. It also includes within its definition, social indicators in its components (reducing human vulnerability and social and institutional capacity). The ESI enables priority-setting among areas within countries and regions based on environmental performance, quantitative assessment of the success of policies and programmes, tracking of environmental trends, investigation into interactions between environmental, social and economic performance, and into the factors that influence environmental sustainability. Its derivation process also enables monitoring performance by individual components. For these reasons, the use of ESI has been growing and there are several studies describing its application even at sub-national level, for example, in China[14].

To summarize, environmental assessment has progressed from initial empirical beginnings in an arbitrary choice of indicators and weighting functions to deriving indicators using formal analytical frameworks (PSR/DPSIR). This was possible because of a globally evolving consensus on addressing issues related to environmental change and on frameworks for such assessments. For this reason, they have been used most often to identify and report on environmental indicators, rather than the full spectrum of sustainability indicators. However, for more complete sustainability assessments, they need to be modified to integrate social and economic indicators more rigorously.

Agricultural sustainability indicators

Sustainable agriculture is defined as a practice that meets current and long-term needs for food, fibre, and other related needs of society while maximizing net benefits through conservation of resources to maintain other ecosystem services and functions, and long-term human development[8]. This definition emphasizes multidimensional (economic, environmental and social) goals of sustainable agricultural development. Thus, while green-revolution agriculture addressed mainly productivity issues, sustainable agriculture must not only address productivity issues more intensively, but do so keeping multidimensional (economic, environmental and social) concerns of sustainability in sight.

Unlike environmental assessments, where there have been significant international and national initiatives, most initiatives on agricultural sustainability have been at individual scientist and group levels. As a result there are differing approaches, guided by local priorities and practices, and only limited attempts at developing systematic frameworks. The different approaches can be broadly

Table 1. Components, indicators and variables of ESI (adapted from Esty *et al.*[4])

Component	Indicator	Variable
Environmental systems	Air quality	Concentration of NO_2 and SO_2, TSP, indoor air pollution
	Biodiversity	% of territory in threatened regions, threatened bird species (% of total), threatened mammal species (% of total), threatened amphibian species (% of total), national biodiversity index
	Land	Percentage land area with very low anthropogenic impact, % land area with very high anthropogenic impact
	Water quality	Dissolved oxygen concentration, electrical conductivity, phosphorus concentration, suspended solids
	Water quantity	Freshwater available per capita, internal groundwater available per capita
Reducing environmental stresses	Air pollution	Coal consumption, NO_x, SO_x and VOC emissions, number of vehicles (all per populated land area)
	Ecosystem stress	Forest cover change rate, acidification exceedence from anthropogenic sulphur deposition
	Population pressure	Percentage change in projected population, total fertility rate.
	Waste and consumption	Ecological footprint per capita, waste recycling rates, generation of hazardous waste
	Water stress	BOD emissions in freshwater, fertilizer consumption per ha, pesticide consumption per ha, % area under severe water stress
	Natural resources management	Productivity, over fishing, % of total forest area certified for sustainable management, subsidies, salinized area due to irrigation (% of irrigated area), agricultural subsidies
Reducing human vulnerability	Environmental health	Death rate from intestinal infectious diseases, child death rate from respiratory diseases, children under five mortality rate
	Basic human sustenance	Percentage of undernourished, % population with access to drinking water
	Natural disaster vulnerability	Average number of deaths per million inhabitants from floods, cyclones, droughts; environmental hazard index
Social and institutional capacity	Environmental governance	Ratio of gasoline price to world average, corruption measure, government effectiveness, % protected area, environmental governance, rule of law, agenda 21 initiatives per million people, civil liberties, % variables missing from CGSDI dashboard, IUCN member organizations per million population, knowledge creation, democracy measure
	Eco-efficiency	Energy efficiency, renewable energy production as % of energy consumed
	Private sector responsiveness	Dow Jones sustainability index, average ecovalue rating of firms, no. of ISO 14001 certified companies, environmental innovation, participation in responsible care programme
	Science and technology	Innovation index, digital access index, female primary education completion rate, tertiary enrolment rate, researchers/million population
Global stewardship	Participation in international collaboration	Memberships in environmental intergovernmental organizations, contribution to international funding, participation in international environmental agreements
	Greenhouse gas emissions	Carbon emissions/million US $, carbon emissions per capita
	Reducing transboundary environmental pressures	SO_2 exports, import of polluting goods and raw materials as % of total imports of goods and services

classified into three groups: those based on agroecosystems[5], total factor productivity[15], and farm-level assessment frameworks[16].

An agroecosystem is 'an ecological and socio-economic system comprising domesticated plants and/or animals and the people who husband them, intended for the purpose of producing food, fibre or other agricultural products'[5]. Agroecosystems defined in this way are hierarchical – starting from cropping systems and livestock systems to farming systems, village systems and so on, to global level systems (Figure 3). At each level, they have distinct attributes for which sustainability indicators can be derived. There is a proliferation of indicators in the literature, accounting for the multidimensional attributes of agricultural sustainability. One set of suggested indicators[17] is based on six easily measurable variables; yield, profit, frequency of crop failure, soil depth, organic carbon and permanent ground cover. The production system is considered sustainable with respect to each indicator if it exceeds a designated threshold level. The six indicators have also been aggregated into a farm-level sustainability index by taking the average of the individual indicator values. These indicators are being used to assess agricultural sustainability at farm and regional levels by the USDA (http://waterhome.brc.tamus.edu/NRCSdata/Gomez/).

Table 2. Attributes proposed for evaluation of sustainability (adapted from Lopez-Ridaura *et al.*[18])

Attributes	Conway[5]	Smith and Dumanski[16]	Mitchel *et al.*[26]	Kessler[27]	Lopez-Ridaura *et al.*[28]	Capillon and Genevieve[29]	Bossel[30]	Ridaura *et al.*[18]
Productivity	X	X		X	X	X		X
Stability	X			X	X			X
Equity	X			X	X			
Adaptability					X		X	X
Resilience					X	X		X
Security		X					X	
Self-reliance					X			
Acceptability		X				X		
Sustainability	X							
Protection		X						
Viability		X						
Futurity			X					
Social equity			X					
Ecological integrity			X					
Responsiveness to change								
Empowerment								
Diversity				X				
Autonomy				X				
Health				X				
Security				X				
Optionality				X				
Efficiency				X				
Reliability					X			X
Reproducibility						X		
Effectiveness							X	
Existence							X	
Freedom of action							X	
Co-existence							X	

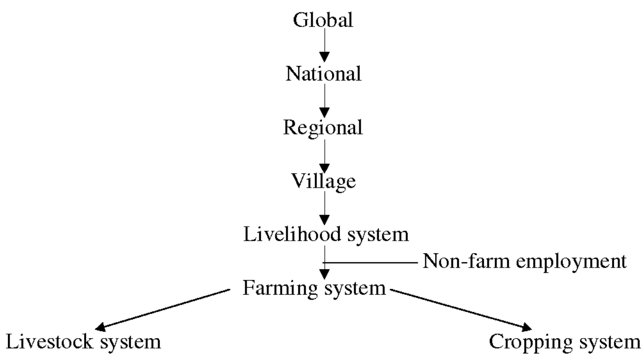

Figure 3. Hierarchy of agroecosystems (adapted from Conway[5]).

The different attributes for which sustainability indicators have been derived for agroecosystems by different groups are summarized in Table 2. Most attributes listed in Table 2 are scale-independent. For example, both productivity and stability can be defined at field, farm, region or country scales. From the list in Table 2, a set of five basic attributes for indicators of agricultural sustainability have been identified[18]: productivity and stability (based on factors internal to the system) and reliability, resilience and adaptability (based on factors external to the system). Productivity is the capacity of the system to produce specific outputs to realize objectives (e.g. yield, profitability). Stability is the ability of the system to reproduce processes needed to attain specified outputs (e.g. input use efficiency). Stability in this sense is derived from ecology and refers to preservation of the natural resources base. It is different from the conventional statistical sense (variance) in which it is often used. Resilience is the capability of the system to return to stable equilibrium after facing shocks or disturbances (e.g. drought, flood, markets). Reliability is a measure of the extent to which the system can remain close to stable equilibrium when facing 'normal' perturbations (e.g. yield variability). Adaptability refers to the ability of the system to adapt its functioning to an entirely new set of conditions (e.g. climate change, WTO regime).

The second approach to agricultural sustainability assessment is based on Total Factor Productivity (TFP)[15]. TFP is the ratio of the total value of all measurable outputs to the total value of all inputs for a given production system. It can be applied at farm and regional levels. Its basic premise is that a non-negative trend in TFP indicates a sustainable system. The TFP approach has been criticized because it does not internalize external costs, such as environmental degradation. To overcome this, a Total Social Factor Productivity (TSFP) was suggested as a better indicator. TSFP includes environmental costs of production, but valuation of environmental costs is complex and inconclusive. Both approaches (TFP and TSFP) assume steadily increasing production, defining sustainability as the 'capacity of a system to maintain output at a level approximately equal to or greater than its historical average' and 'technology contributes to sustainability if it increases the slope of the trend line'[15]. TFP is also scalable from farm to higher levels.

The third approach to agricultural sustainability assessments is based on farm-level frameworks[16]. This approach is advocated strongly by The World Bank and FAO for deriving sustainability indices specific to natural resources like land quality index (LQI), soil quality index, biodiversity index, etc. The LQI programme of the World Bank is based on the Framework for the Evaluation of Sustainable Land Management (FESLM), which identifies five pillars of land management: productivity, security, protection, viability and acceptability. These accommodate economic, environmental and social dimensions of sustainability. The FAO and World Bank have subsequently tried to align FESLM with the PSR/DPSIR frameworks by grouping indicators for land quality under pressure, state and response indicators (http://www.fao.org/docrep/W4745E/w4745e08.htm). The pressure group indicators include those activities that relate to the degree of intensification and diversification of agricultural land uses, and result in increased pressure on land quality. This may include the number of crops in a cropping system per year or per hectare, type and intensity of tillage, degree of removal of biomass, integration with livestock systems, number of food and fibre products produced annually, etc. State indicators include those which express changes in biological productivity, extent and impact of soil degradation, annual and long-term balance of nutrients, pollution, changes in organic matter content, water-holding capacity, etc. Response indicators include number and types of farmer organizations for soil conservation, extent of change in farm technologies, risk management strategies, incentive programmes for adoption of conservation technologies, etc. There are however, no attempts at aggregation of indicators into indices in the FESLM or its adaptation to the PSR framework.

To summarize, much of the interest in agricultural sustainability assessments is at farm-level, but many attributes are scalable to higher levels. The focus is largely on biophysical indicators, and not much on socio-economic indicators. Some indicators lend themselves to easy aggregation to single indices and scaling up to regional levels. In other cases, attempts at aggregation have been qualitative, in the form of multidimensional sustainability polygons or amoeba diagrams. The application of formal frameworks like PSR or DPSIR is not common and limited to farm-level.

The sustainable rural livelihoods assessment framework

The sustainable rural livelihoods (SRL) framework addresses links between poverty, natural resources management and rural livelihoods. It was developed over the last decade, primarily to address needs of policies and interventions to reduce poverty in developing countries. 'A livelihood comprises capabilities, assets (stores, resources, claims and access) and activities required for a means of living: a livelihood is sustainable which can cope with and recover from stress and shocks, maintain or enhance its capabilities and assets, and provide sustainable livelihood opportunities for the next generation; and which contributes net benefits to other livelihoods at the local and global levels and in the long and short term'[19].

In the SRL framework (Figure 4), sustainable livelihood strategies of individuals and households depend on access, use and development of five different types of assets – natural capital (land, water, biodiversity), physical capital (infrastructure, machinery), human capital (labour, skills), financial capital (savings, disposable assets), and social capital (rights, support systems). Understanding assets is critical to understanding available options. The framework also identifies two distinct categories which govern livelihood strategies. The first is the vulnerability context in which the assets exist (trends, shocks and local cultural practices that affect livelihoods). The second is structures and processes which define livelihood options. Structures include organizations (government, private) and processes include policies, laws and incentives. Access, control and use of assets are influenced by structures and processes. The assets, and existing structures and processes, guide development of livelihood strategies which lead to outcomes and which in turn impact the assets. Three types of strategies have been identified[20]: agricultural intensification or extensification, livelihood diversification, and migration. The strategies are both natural resources-based and non-natural resources-based.

The SRL framework can be compared with the DPSIR framework, where driving forces correspond to the vulnerability context, pressures to livelihood strategies, state to biophysical outcomes, impact to socio-economic outcomes and response to structures and processes[21]. The DPSIR framework is essentially linear, whereas the SRL framework structures and processes constitute both response (*R*) and part of the context (*D*) because of the feedback relationships. The linear dependence between impact (*I*) and state (*S*) in the DPSIR framework implies a linear relationship between socio-economic outcomes on the environment (biophysical conditions). The framework also effectively integrates with the FESLM or agroecosystems-based assessments at the farm-level to facilitate identification of livelihood indicators.

To summarize, the SRL framework has been widely used in the past decade by various development agencies to derive strategies for improving livelihoods. The framework permits a more desegregated analysis of changes in environment and socio-economic conditions in terms of five types of capital. Though it is applied specifically for individual, household, or village-level development

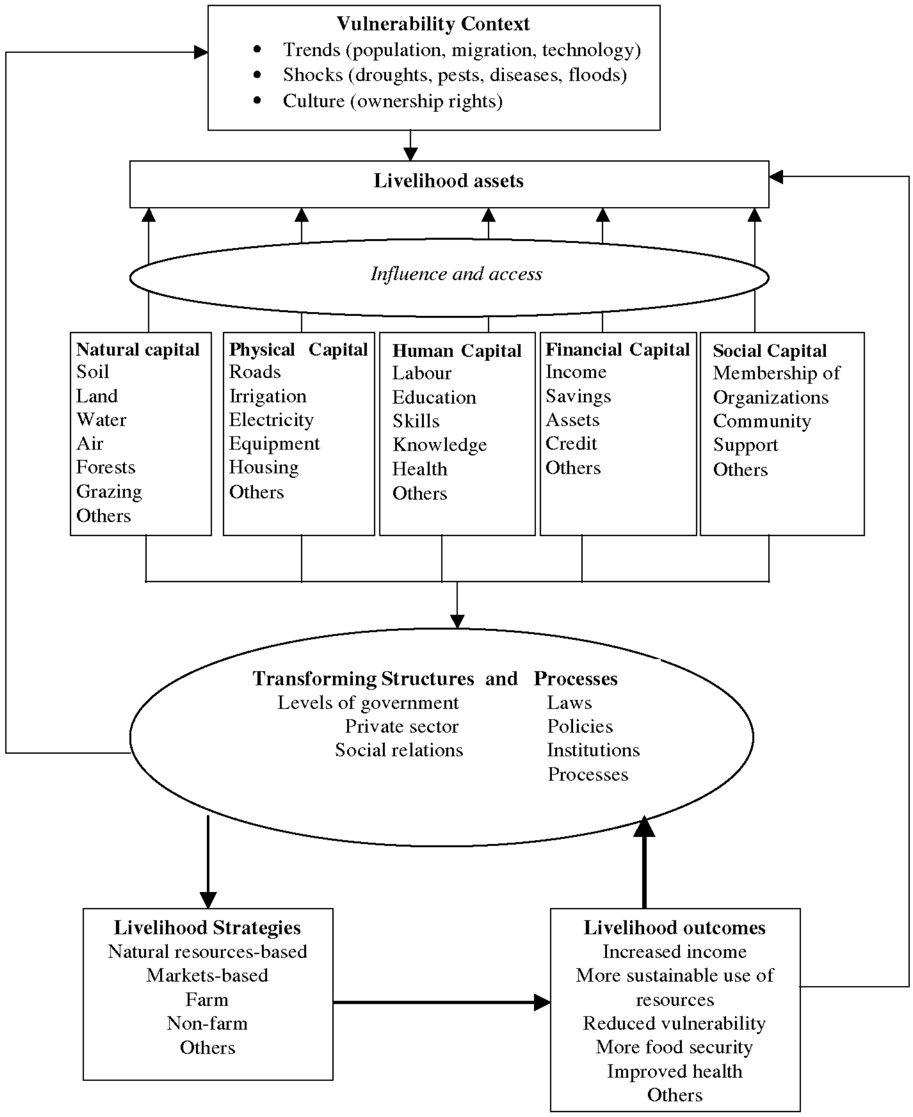

Figure 4. Sustainable rural livelihoods framework (adapted from Woodhouse *et al.*[21]).

strategies, the outcomes can be effectively understood only in the total context which is visible at the wider spatial extent level of catchment, district, region or agroecological zone. It is essential, therefore, that the full range of scale over which the outcomes can be visualized is kept in sight while applying the framework.

Integration and proposed framework

There are discontinuities of scale between the three frameworks: environmental assessment, agroecosystems and SRL frameworks. The indicators they emphasize are also different. The question of integration across scales and multidimensional attributes therefore needs to be resolved satisfactorily if the broader goal of sustainable development of agriculture is to be attained.

The problem of integration across scales has been central to natural resources management engineering and its economics. In these areas, it has been usually resolved by integrating process models of natural resources in a Geographical Information Systems (GIS) framework[22,23]. Most of these process models, however, deal only with the biophysical processes and therefore only with the environmental dimension of sustainability. Similar integration has also been achieved to a limited extent in economic models[24]. The methods and results of these models are specific to the region they are developed for and not sufficiently general or simple enough for application at the broader policy level.

For more general applications, simple analytical frameworks which permit quick and systematic sampling and comparisons of sufficiently general indicators across regions and over time are required. One approach to this is to

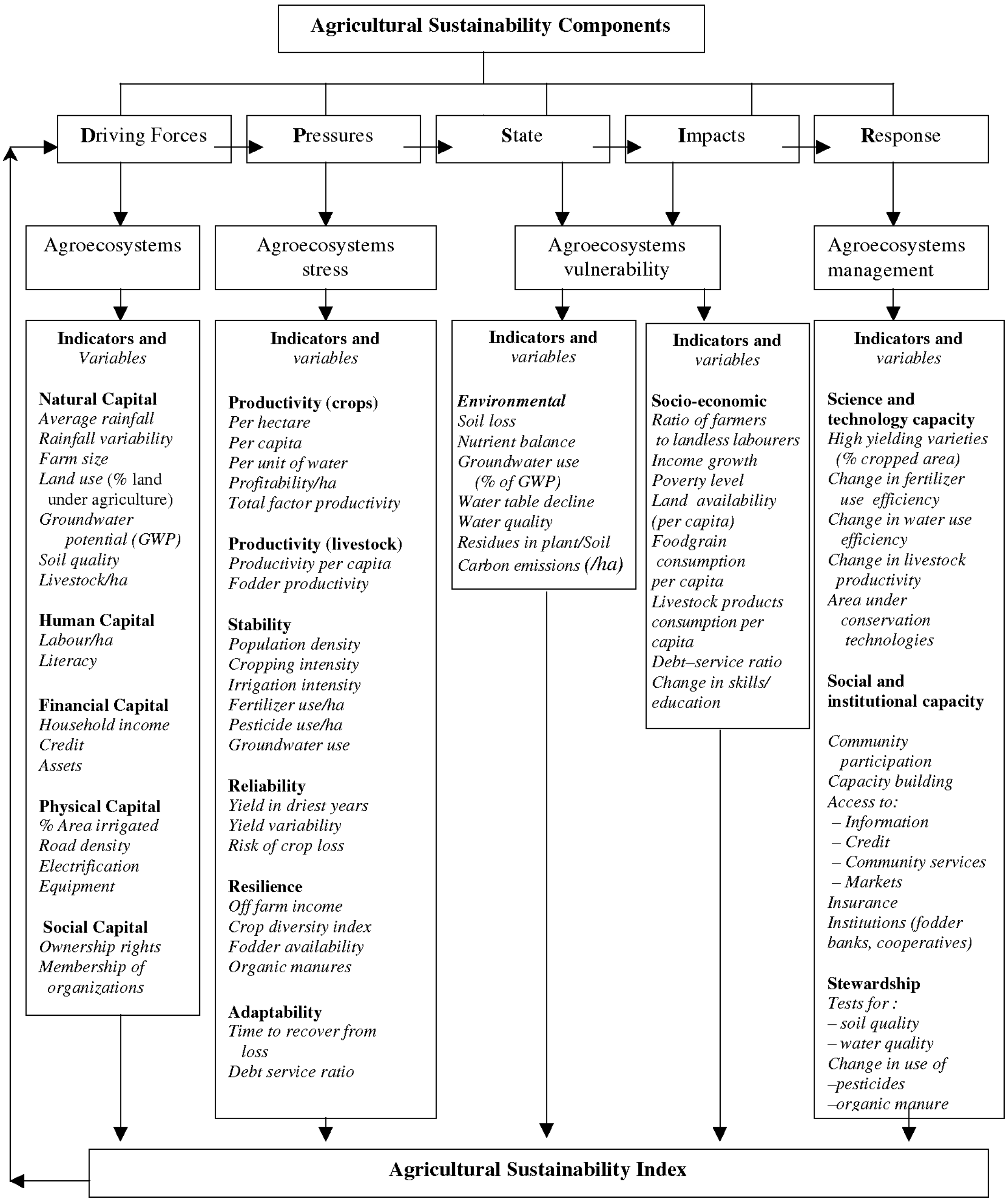

Figure 5. Agricultural sustainability assessment framework.

derive sustainability indicators at the lowest level of spatial hierarchy (SRL framework) and aggregate to larger scales (agroecosystem and other regional scales) using spatial analysis tools like GIS. This approach has been adapted by the World Bank for mapping and monitoring poverty, and by FAO and other organizations in food security and vulnerability assessments. In another application[25], the role of agroecological factors in regional agricultural growth and poverty distribution in India was examined. The spatial units for this study were identified at three levels: National Sample Survey Organization (NSSO) sampling regions (NSSR), agroecological zones and administrative districts. NSSO samples data on some key sustainable livelihood indicators like poverty, consumption, literacy, etc. at rural households level. Agroecological zones provide appropriate spatial units to track agricultural production conditions and their impacts on productivity and poverty. Administrative districts contain spatial data on development indicators like infrastructure, irrigation and roads and also some key social structure indicators. Overlaying the three spatial data layers in GIS generates spatial units that are homogonous with reference to rural poverty and consumption, social structures, agroecological conditions and infrastructure.

A similar approach is proposed for assessing agricultural sustainability. The widely accepted DPSIR framework is used to identify causal chains. The agroecosystems and SRL frameworks are used to identify multidimensional attributes of agricultural sustainability indicators at the farm and higher levels. Further, for aggregating the indicators into an agricultural sustainability index, the general approach followed by the widely accepted ESI is adopted.

The indicators for agricultural sustainability are identified in two stages. In the first stage, the DPSIR framework is used to assemble a list of indicators based on their categories and the cause–effect relationships. Next, the indicators are treated as building blocks or variables for agricultural sustainability, to be grouped into components. Four broad components are proposed for assessing agricultural sustainability: agroecosystems, agroecosystems stress, agroecosystems vulnerability and agroecosystems management. (Recall that for ESI, indicators were grouped into five components: environmental systems, reducing stress, reducing human vulnerability, social and institutional capacity, and environmental stewardship. For agricultural sustainability assessments, the last two are combined into one component.) Adopting the same process as for development of ESI, enables a level of standardization and subsequent integration into other national and global assessments. The suggested framework with its four components, their respective indicators and the data variables used to form the indicators is shown in Figure 5.

The driving force indicators in the proposed framework define the context of agricultural production systems. They are grouped under the component agroecosystems. Five indicators derived from the SRL framework for livelihoods assessment (natural, human, financial, infrastructure and social capital for the system in question) characterize the agroecosystems component. The pressure indicators define stress on the system as characterized by trends in major multidimensional attributes of agricultural sustainability (productivity, stability, reliability, resilience and adaptability). The state and impact indicators determine the vulnerability of the agroecosystems and are characterized by respective environmental and socio-economic impacts indicators. Finally, the response indicators define policy instruments and management and institutional strategies adopted for ensuring sustainability of agroecosystems in the long run. The variables that characterize each indicator are also identified in Figure 5. The variables can be normalized by the same process as in the case of those derived for the ESI. The indicators can be derived by taking the averages for the variables, and the agricultural sustainability index by averaging the values for the indicators (as in the case of ESI).

The social and economic variables and indicators listed in Figure 5 are scalable and can be aggregated from farm and village levels to district, agroecological zone or national levels. Data for many of the agricultural productivity, land use and weather, variables is available annually at the district level in India. The socio-economic impact indicators are available for the NSS regions and the soil and some environmental data are available at the agroecological zone level. The above framework can therefore be integrated across a range of spatial scales through the use of GIS tools.

Conclusion

It was shown that experience gained in environmental assessments towards the standardization of procedures and datasets on the one hand, and in agroecosystems analysis and sustainable livelihoods assessments at more localized levels on the other, can be integrated and gainfully adopted for agricultural sustainability assessments. The indicators at the lower levels of spatial hierarchies can be scaled to higher levels using GIS tools. The main issue is of developing extensive datasets at the rural livelihoods level, which can be scaled to more regional agricultural sustainability and environmental assessments.

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Received 3 October 2005; revised accepted 17 February 2006