Versión 4

MEASUREMENTS AND INDICATORS OF SUSTAINABILITY

~~REPORT OF A CONSULTANCY TEAM~~

TERMS OF REFERENCE

The consultancy team was given the objective of designing "a common research agenda to develop sustainability indicators for tropical American agroecosystems". Expected outputs included a report summarizing:

- basic agreements on the meaning of sustainability in the agricultural development context of selected agroecosystems,

- a first approximation to the analysis of the concept [of sustainability] at three levels in the system hierarchy, and for identified purposes, e.g., diagnosis, impact assessment and impact prediction,

- a tentative list and characterization of indicators for each of the identified level/purpose combinations,

- a preliminary set of research questions to be addressed and a corresponding research agenda, identifying potential areas of mutual complementarity between the participating institutions.

THE NOTION OF SUSTAINABILITY AND THE ROLE OF INDICATORS

The team found it awkward to examine the theme of "indicators of sustainability" without first discussing what is meant by an "indicator" and what is meant by "sustainability".

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Sustainability

The number of definitions of sustainability (or sustainable agricultural systems) that have emerged during the last several years is too large to count. Nonetheless, many if not most of these definitions fall into one or more of several broad approaches. It should be noted that the approaches or conceptualizations described below are not mutually exclusive -- indeed, many observers (ourselves included) emphasize one of them, while recognizing the others.

1. **Agroecology.** Sustainability is understood in terms of system resilience, or the ability of a system to recover from stress or perturbation, largely due to system diversity featuring multiple pathways for the cycling of energy and nutrients (Conway 1986).

2. **Stewardship.** Sustainability is understood in terms of the role of mankind as a steward of Earth's resources, with a responsibility to non-human species as well as to future generations of mankind, to use and conserve these resources wisely. One implication is that human populations and human economic activities should be curbed (Batie 1989).

3. **Sustainable growth.** Sustainability is understood in terms of a need to minimize damage to the natural resource base while meeting mankind's demands for agricultural products. The CGIAR definition falls primarily into this category (CIMMYT 1989).

One specific definition of a sustainable agriculture (falling primarily into the "sustainable growth" category) was thought by the team to be of particular interest and relevance to IARCs aiming to develop indicators of sustainability:

> *"A sustainable agricultural system is one that can indefinitely meet demands for food and fiber at socially acceptable economic and environmental costs." (Crosson 1992)*

It should be understood that "economic and environmental costs" include the full range of on-farm as well as off-farm costs associated with production activities, including effects on deforestation, erosion, soil fertility loss, loss of soil water-holding capacity, introducton of toxic residues into the environment, effects on biodiversity, etc.

The advantage of this definition is that it highlights the fact that demands cannot be met, nor production increases achieved, without cost. It further highlights the notion of trade-offs among different kinds of costs, and the option of incurring costs in one region in order to reduce costs in another.

As a consequence, the definition allows for the prospect that a system may be sustainable even if some of its components are not, and that a system may be required to dynamically adapt to changing external circumstances in order to be sustainable (CIAT nd).

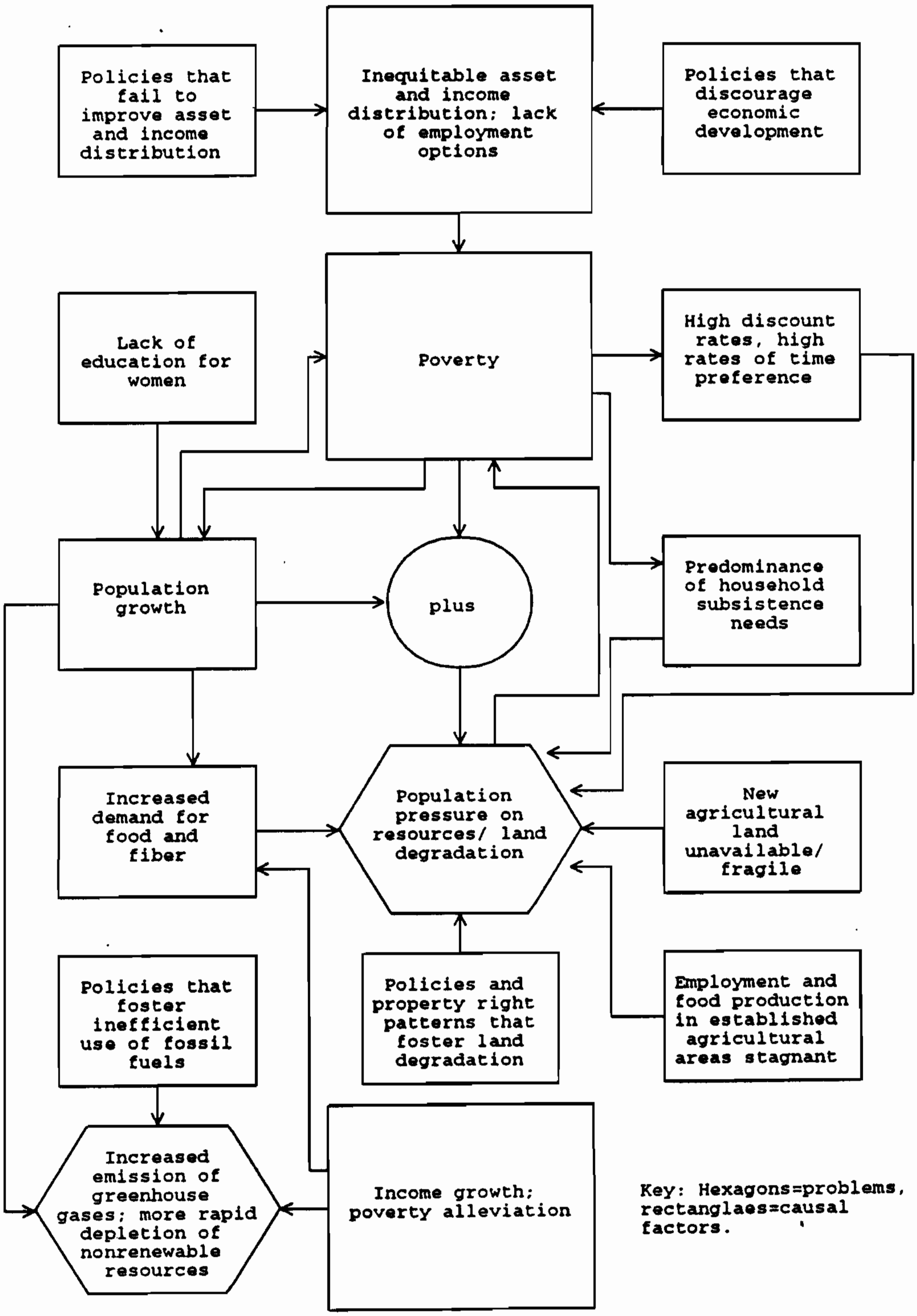
In informal conversations with selected CIAT staff, the above definition generally was found useful and acceptable.

<u>Sustainability in a Developmental Context</u>

When addressing issues of sustainability, an understanding of the causes of "unsustainability" is exceedingly important. "Unsustainability", not surprisingly, is understood as the degradation of natural resources devoted to agricultural purposes and the consequent hindering, or crippling, of the ability of an agricultural system to indefinitely meet demands for food and fiber at socially acceptable costs (including environmental costs, broadly defined). Low levels of diversity in a system (and, typically as a consequence, low levels of resilience) can leave it vulnerable to swift, unexpected declines in productivity.

An understanding of the causes of unsustainability is particularly important at higher levels of system aggregation, where sustainability becomes enmeshed with broad developmental issues. Unsustainability has been traced to population pressure on resources (PPR), poverty and marginalization, insecure property rights, and certain kinds of public policy. The interactions among these factors are fairly complex and space considerations prohibit a full discussion. Some of the important interactions, however, are summarized in Figure 1 (Harrington 1993).

Fig. 1. Poverty, income growth and problems of sustainability



Indicators

The team came to understand the notion of an indicator as a variable that compresses information concerning a relatively complex process, trend or state into a more readily understandable form. Thus a distinction can be made between a "measurement" (precise, well-defined, often complex or highly technical) and an "indicator" (highly correlated with a corresponding measurement, but easily observed and readily understood).

Both "measurements" and "indicators" can serve the functions of quantifying, analyzing, simplifying and communicating processes that in themselves may be exceedingly complex. Indicators should be identified and developed in different ways in accord with the objectives of those expected to use them (Winograd 1993).

It appears that CIAT has already made a considerable investment identifying desirable characteristics of sustainability indicators (CIAT nd, Jones nd). It has been argued that a good indicator should:

- be easily measurable;

- be cost effective, taking advantage where possible of available information.

- change as a system moves away from equilibrium;

- give particular warning of degradation processes that are irreversible (or where the costs of reversing the process are likely to be socially unacceptable);

- take account of the full cycle through which a system moves through time;

- provide links to other system levels at which degradation processes might more readily be addressed;

- be proactive in forecasting future trends in resource quality and agricultural system productivity, as well as tracking corresponding trends from the past.

This latter point is particularly important in relatively new systems, or in land types where intensification of farming is just beginning, and where few (relevant) trends from the past are available as a basis for forecasting the future.

The team agrees that these characteristics are desirable.

INDICATORS OF SUSTAINABILITY: WHY, AND FOR WHOM?

Decisions on the kinds of sustainability indicators that ought to be developed arguably should be influenced by expectations on major audiences of interest. For whom are indicators being developed? On what issues and themes are indicators expected to shed light? For what purposes are indicators expected to be used?

Not surprisingly, the answer to these questions likely will vary over researchers. Many CIAT scientists feel that the Center initially should develop indicators of sustainability for internal use. Purposes include understanding system performance and degradation processes in targeted agroecosystems, setting research priorities, and assessing research impacts. As CIAT gains experience in developing and using indicators, i.e., as it becomes an "indicators factory", it increasingly can share this experience with other research centers, including national programs.

It should be noted that CIAT already has considerable experience (and an abundance of relevant data) in developing indicators. This confers a comparative advantage on CIAT in indicators development.

It was acknowledged that external requests, e.g., from the donor community, have been a factor in stimulating work on the development of indicators. Most staff interviewed by the team claimed, however, that the work is important in itself for the Center, and is primarily directed towards the needs of the Center.

Some scientists suggested that indicators should be developed and used for the purpose of informing agricultural policymakers, particularly when alternative policies differentially favor resource-conserving vs. resource-degrading production practices or land use strategies. The team feels that it is entirely suitable to use indicators for the purpose of informing policymakers of the economic and environmental costs of different production practices or land use strategies, as policies are devised and implemented that favor one set over others.

A warning is in order, however: CIAT should not spread itself too thin in aiming to develop and use too broad a spectrum of indicators, aimed at too many audiencies, for too many purposes. A slow, relatively cautious beginning is in order.

CATEGORIES OF INDICATORS

Those who would develop indicators of sustainability must avoid the easy descent into a mere "shopping list", i.e., a detailed but unstructured conglomeration of any and all variables that may conceivably become important at one time or another, in one way or another, at one level or another, in understanding trends associated with sustainability. To avoid this trap, categories of indicators (and the linkages among these categories) must be defined. Suggested categories of indicators are described below. Linkages among categories are shown in Figure 2.

Problems, Causes and Solutions

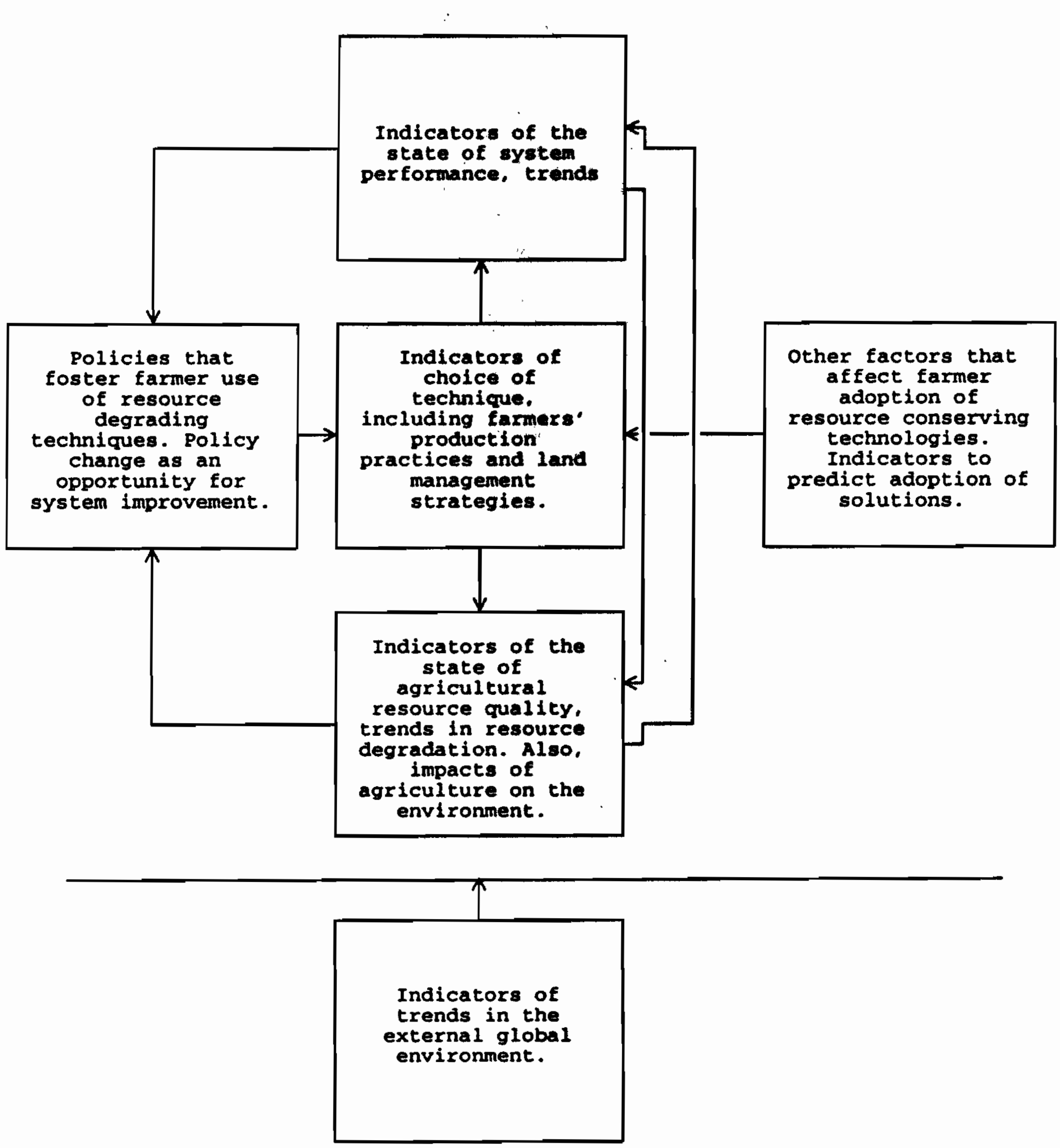
Measurements and indicators relevant to the sustainability of agricultural systems may be developed for:

- sustainability problems (declining system performance associated with resource degradation),

- causes of these problems (including, but not restricted to, the policy environment), and

- potential solutions to these problems (adoption of new technology, system evolution, infusion of resources from higher levels of system aggregation, etc., possible spurred by policy change).

Figure 2. Categories of indicators



This problem-cause-solution paradigm is widely used in research with a farming systems perspective (Tripp and Woolley 1989). An adaptation of this paradigm (referred to as "pressure-state-response") has been developed independently in the context of the study of environmental indicators (Winograd 1993).

In the following discussion, problem indicators will be emphasized. The role of indicators associated with causes and solutions will be addressed in a later section.

Indicators of Trends in Agricultural System Performance

Measurements and indicators are needed for assessing trends in the performance of an agricultural system. Performance, in this case, is understood as the efficiency with which a system converts inputs to outputs, where:

- inputs and outputs include all costs and benefits to society, whether on-farm or off-farm,
- inputs and outputs include positive and negative effects on the environment and on the quality of those natural resources devoted to agriculture, as well as more conventional production inputs and outputs, and
- inputs and outputs are valued at undistorted prices.

The development of indicators of system performance is fundamental to:

- an understanding of sustainability trends in agroecosystems in which IARCs are actively pursuing research,
- the identification of research opportunities within agroecosystems,
- the setting of research priorities among agroecosystems,
- the assessment of research impacts, particularly the effects on system performance of new technology, or of technical change associated with

policy adjustments facilitated by information brought to light through research.

System performance can be assessed (data permitting) at virtually any level of system aggregation. It must be recognized, however, that declining trends in system performance at one level of aggregation may contribute to resource conservation goals at another level of aggregation. For example, contamination of groundwater with herbicide, pesticide and nitrate residues in high-productivity areas of northwest India may be one of the costs of a slower pace of degradation in fragile areas or forest margins. Similarly, a resource quality problem at one level of system aggregation may be "fixed" with an infusion of resources made available at a higher level of aggregation.

A declining trend in the performance of an agricultural system indicates that the system (at that level of aggregation) is not sustainable. However, the mere existence of such a trend says little about the biological or physical resource degradation processes causing this decline.

<u>Indicators of Trends in the Quality of Agricultural Resources</u>

Indicators of resource degradation and indicators of declining system performance are highly complementary, especially when the former can be established as the cause of the latter.

Information on declining resource quality -- in the absence of information on the corresponding effects on system performance -- leaves unanswered the question, "what does it matter if resources degrade?".

Similarly, information on declining system performance -- in the absence of corresponding information on the underlying processes of resource degradation -- leaves unanswered the question, "what's causing the system to be unsustainable, and what can be done about it?".

Indicators of declining resource quality are most helpful when they focus clearly on degradation processes that cause a decline in system performance. This avoids the "shopping list" approach, whereby all conceivable variables associated with resource quality are included as potential sustainability indicators. Establishing cause and effect links, however, can be challenging.

It should be noted that long-term threats to system may coexist with near-term threats of a different kind. This may require a broader array of resource quality indicators. It has been suggested, for example, that near-term indicators of land quality change may focus on soil biological activity, whereas longer-term indicators may focus on soil minerology -- each set of indicators corresponding to a different threat to resource quality and, as a consequence, to system performance.

An example of specific links between indicators of system performance and resource degradation is provided by Cassman and Pingali (1993). The trend in total factor productivity (a system performance measure) for intensive rice systems in Asia was found to be declining. After considerable effort, a land quality change was identified -- specifically, the capacity had declined of organic matter formed under anaerobic conditions to mineralize and release nitrogen for crop production.

<u>Indicators of the Effect of Agriculture on the Environment</u>

Given today's widespread concerns about the state of the planet, indicators of the impact of agricultural practices on the environment should go beyond the effects on agricultural resources. Current and alternative practices can be compared with regard to their (past or expected future) effects on:

- rates of deforestation,

- rates of erosion,

- changes in soil health,

- changes in water abundance or water quality,

- changes in environmental pollution,

- biodiversity,

- carbon dioxide capture or release.

Properly, the costs associated with these environmental impacts should be included as costs when assembling measures of agricultural system performance. In practice, however, many of these impacts are exceedingly difficult to measure, much less value in monetary terms. A specialized set of indicators may be needed, then, to fill this gap.

The obvious question, of course, is when to stop. Given limited resources, and even more limited expertise in assessing environmental impacts, how thorough should Centers be in assessing differential impacts of technology on the environment?

Indicators of the Effect of the External Environment on Agriculture

Some indicators can serve to trace out environmental trends, external to agriculture, that are likely to impinge in important ways on the sustainability of national or global agricultural systems. These indicators provide the broad context or perspective in which more detailed indicators, or more specific agricultural development activities, can be understood. The development of "sustainable" agricultural practices at the agroecosystem level, undertaken in ignorance of broader global trends, has been compared by some observors to the rearranging of deck chairs on the Titanic. It should be clear that IARC scientists should be users, not developers, of these indicators.

Examples of broad trends in the external environment include:

- global climate change, with corresponding implications for crop and varietal distribution and adaptation associated with temperature change, or with changes in rainfall levels and intensities.

- the availability and prices of external inputs, including energy used in fertilizers and pesticides, farm machinery, and transport and marketing of agricultural products and inputs.

- rates of expansion in demands for agricultural products associated with population growth and income growth and distribution.

What About Indicators for Policymakers?

Policymakers comprise an important audience for indicators of sustainability, given the importance that policies can have in causing land degradation -- or in fostering adoption of resource conserving techniques. Policies can contribute to "unsustainability" in two ways: directly, or indirectly through their effects on population growth, poverty, common property resources and externalities. Here are some examples of direct policy effects:

Deforestation and subsequent soil erosion have been linked with policies that directly favor commercial logging (low tax rates or overt subsidies, public road construction in forested areas, poor enforcement of forestry regulations) (Repetto and Gillis 1988). Policies that directly restrain farmer adoption of erosion-controlling practices include subsidies on external inputs, interventions that increase rates, and policies that reduce the security of land tenure (Anderson and Thampapillai 1991).

Policy change often can foster resource conservation. For example, policies that prohibit the burning of maize stover, along with subsidies on backpack sprayers for herbicide application, have transformed farmers' maize stover management practices in much of southern Mexico. As a consequence, erosion rates have dropped dramatically (van Nieuwkoop 1993). Similarly, the transfer of ownership and management of common property resources from government agencies to effective community institutions has been shown to foster more appropriate resource use (Lurie 1991).

Nonetheless, it would seem unnecessary to develop a special set of indicators for policymakers. Rather, information on trends in agricultural system performance, trends in land degradation, the relationships of these with farmers' selection of production techniques and land management strategies, and the role of policy in influencing farmers' choices, should be adequate -- if synthesized, selected, sifted, filtered and organized in ways that bring this information to bear in cogent and compelling ways.

What About Indicators to Predict Farmer Adoption of Resource Conserving Practices?

When declining agricultural system performance is at issue, and when this problem can be traced to resource degradation, solutions commonly are sought through technical change (understood to include changes in agricultural production techniques as well as adjustments to land management strategies). Technical change may come about through policy adjustments that create incentives for farmer adoption of land conserving practices; through farmers' own adaptations to changing circumstances; or through use of new inputs or practices developed in cooperation with formal research and extension structures.

Indicators used to predict the likelihood of farm-level technical change are not, in general, "indicators of sustainability". Nonetheless, they are indisputably useful. Indicators that can help forecast the likely adoption by farmers of resource conserving practices can be of immense help in honing arguments to policymakers as well as in setting priorities within research institutions.

What About Indicators and System Typologies?

In developing "indicators of sustainability", a critical assumption is that sustainability (or unsustainability) can be measured by a small set of efficient indicators at various levels of system aggregation. The cost of monitoring sustainability occasionally may be supported by international agen- cies, but typically must be paid for by the relevant economies. This implies that indicators at the field level should have a cost concomitant with the production revenue, that of the farm likewise and so to the watershed.

The efficient set of indicators may vary between ecosystems and even between production systems and soil types. To identi- fy the best set of indicators it may be necessary to produce a classification or typology of the areas or production systems. This could then be used to identify which indicators may be common to all systems and which are specific to only some classes.

An obvious example could be that an indicator based on strength of fallow regrowth would not apply to systems without fallow. Field level indicators based on key indicator weed species would only apply in areas where the species were endemic.

Research should aim at producing a series of indicator sets with as wide an application as possible while retaining the power of indicators that are system specific. An analogy might be with the action thresholds of IPM.

What About Indicators and Different Levels of System Aggregation?

It has been noted that agricultural systems are deemed unsustainable when system performance is declining because of processes of resource degradation. It also has been noted that this only holds true for a given level of system aggregation.

When a system that is "unsustainable" on its own interacts in significant ways with higher level systems, the conclusion on "unsustainability" may need to be adjusted. The following mechanisms should be kept in mind:

- a higher system level may provide opportunities for substitution of inputs, e.g., declining soil fertility at the field level may be ameliorated by farm yard manure made available at the whole farm level,

- a higher system level may provide opportunities for enterprise substitution, e.g., soil erosion associated with upland field crop production may be ameliorated by a shift by farmers to perenniel horticultural crops due to investments in rural infrastructure (road, bridges).

- a higher system level may provide subsidies to a lower system level in order that degradation within that subsystem help forestall or avert more serious degradation another subsystem, e.g., investment in intensive agriculture in favored agricultural areas may, through income and employment generation and poverty alleviation, reduce the need for poor people to rely on subsistence employment by farming fragile uplands.

This latter point is of some interest to CIAT. The question may be raised for Latin America whether an effective way of forestalling land degradation in the uplands and forest margins is to promote expanded employment through investments in favored agricultural areas, such as the highly productive valleys.

(TO BE WRITTEN - IMPLICATIONS FOR INDICATORS AT DIFFERENT SYSTEM LEVELS)

TWO METHODS FOR QUANTIFYING SYSTEM PERFORMANCE

In an earlier section, agricultural system performance was described as the efficiency with which a system efficiently converts inputs to outputs, when full economic and environmental costs are included in the analysis. Declining trends in system performance indicate that the system, at that level of aggregation, is not sustainable.

A number of approaches have been developed to quantify system performance, as defined above. Two of these approaches are described below. Both approaches qualify as measurements but not indicators, given that both are relatively complex and data-intensive.

Total Factor Social Productivity

Total factor productivity (TFP) is defined as the sum of the value of all outputs from a production system divided by the sum of the value of all inputs (Lynam and Herdt 1988). TFP estimates long have been used at the level of the macroeconomy to identify the role of technological change in economic growth: when the contributions of increased levels of inputs are accounted for, the residual is attributed to technical change. Index numbers have been developed that allow accurate estimates of trends associated with changes over time in TFP.

TFP trends can be used to track changes in system performance and resource quality when technology is held constant. Whitaker and Lalitha (1993) used this method to assess the sustainability of well-defined cropping patterns in India, using long-term trial data. Ehui and Spencer (1990) developed the method further by including as a cost of production the value of soil nutrients lost through land degradation.

Herdt and Lynam (1992) have recently called for the development ways to estimate total factor social productivity (TFSP), which is an extension of TFP to include all costs, economic and environmental, associated with the production system in question. They recognize, of course, the difficulty involved in estimating environmental impacts and valuing these impacts so that they can be included in a single index.

Trends in TFSP meet very well the desirable characteristics of a measure of system performance, as used in this report. TFSP indices do not make good "indicators", however, due to complexities and difficulties in their estimation and communication to a wide array of audiencies.

Present Value of the Economic Returns to Alternative Agricultural Technologies Adjusted for Environmental Costs

Farm-level enterprise or whole-farm budgets have been used to assess the profitability to farmers of alternative production practices, enterprises or enterprise mixes. When a suitably wide range of costs are included in the analysis, however, economic or social profitability (adjusted for environmental costs) can be estimated. A "wide range of costs" implies off-farm as well as on-farm costs, and environmental costs as well as agricultural production costs, with all costs valued at undistorted prices.

Faeth et al (1991) report the results of such an analysis for the United States. It was shown that many cropping systems and production practices currently used by farmers appear to be profitable on the surface, but turn out to produce negative social value when allowance is made for depreciation of soil resources, and adjustements are made for the value of subsidies (economically, a mere transfer from one social group to another). In this case, given the sensitivity of farmer selection of technology to prevailing agricultural sector policies, the analysis was primarily aimed policymakers.

INDICATORS: A NEED FOR SHORT CUTS

The two measurements of agricultural system performance de- scribed above; proxies, correlations, be selective, conditions for extrapolation, handle very long term changes, iterative using case studies

MEASUREMENTS, INDICATORS AND DATA SOURCES. To be written

- long-term trials
- farmer monitoring
- retrospective information from farmers
- secondary data
- modeling

A RESEARCH AGENDA FOR THE DEVELOPMENT OF SUSTAINABILITY INDICATORS

To be written, based on the table.

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