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Ecological and economic indicators for sustainability

By Craig A. Bond and Karen Klonsky

The notion of agricultural sustainability means different things to different people, with the definition of a sustainable system dependent upon what is to be sustained, in what form, at what scale, with what degree of certainty, and over what time period. Broadly, however, there is some consensus that "sustainability" encompasses economic (financial), environmental (ecological), and social dimensions of a system. However, unlike a typical economic problem where the goal might be to maximize profits, or an environmental problem where the goal might be to minimize pollution, the three dimensions of sustainability may be in competition. For example, increasing producer profitability might involve application of certain chemicals that have the potential to enter waterways and flow downstream, thus causing damage to individuals not directly involved in the production process. If decreasing this pollution resulted in increased costs (or lower income) for the producer, then overall profits would be lowered. Economists refer to this type of situation as a "negative externality," and it exemplifies possible tradeoffs between dimensions of the sustainability issue.

The natural question to ask, then, is what is the *optimal* allocation of resources for society that balance one sustainability dimension against the other? In order to answer this question, we need information about 1) the nature of the technical relationships between elements of the agricultural and broader human and environmental systems; and 2) the valuations that individuals place on alternative attributes of those systems. Of course, this task is a monumental one for complicated agroecosystems (not to mention the varied preferences of individuals), and a complete accounting of every variable and parameter is simply impossible. The inherent uncertainty about these relationships, however, drives a demand for information about these links, with the data satisfying this demand known as *indicators*.

photo by Jeff Mitchell

Project research assistant Stephanie Ma gathers samples after a storm at a grower's field.

Roles of Indicators

While it may be tempting to define sustainability in broad terms, such as the oft-cited World Commission on Environment and Development's 1987 assertion that a sustainable system "meet[s] the needs of the present without compromising the ability of future generations to meet their own needs," such definitions provide little practical guidance for system management or even information collection. As there are often competing objectives of various stakeholders, the focus of indicators should be to provide information about the tradeoffs associated with various management (or resource allocation) strategies, with a focus on adequately describing the behavior of the competing elements of a system over time and/or space.

Indicators have been classified into means-based and effects-based categories, with the former referring to measures of management practices shown or assumed to have a certain impact on the larger system, while the latter refer to measures of the system attributes directly. From a purely evaluative perspective, the "effects" indicators are usually most relevant, as it is most likely the quantity or quality changes of the characteristics themselves, rather than the means of getting there, that are valued by stakeholders. Clearly, the more direct the link between the measure of particular practice and a particular outcome, the more confidence one can have in an "effect" or "management" indicator to predict system impacts. However, in many cases, the link between the management decision and the system element might be uncertain, highly variable, or both. In fact, in agronomic field trials on experimental production systems, the goal may be to identify these links; in others, the links may be well-established by previous literature, and means-based indicators may be sufficient to indicate various trade-offs.

Types of Indicators

An economic framework provides a natural way to classify alternative stakeholder impacts and conceptually describe the interface between agriculture, the broader environment, and the social systems that comprise the rural economy. Generally speaking, the framework considers the agroecosystem from the

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standpoint of a social planner evaluating the relationships between inputs and outputs from the production process, and the factors that influence these relationships. More specifically, farmers convert inputs (natural, man-made, human, and social) into outputs ("goods" and "bads"), subject to technological and institutional constraints and risk preferences. Examples of sustainability indicators in each category of inputs and outputs are presented in Tables 1, 2, and 3.

Table 1: Input Based Sustainability Indicators

	Indicator Type		Scale		Sustainability Dimension		
	Means-Based	Effect-Based	Farm Level	Regional Level	Economic	Ecological	Social
Inputs							
Natural Capital Indicators							
Soil							
Soil physical, chemical, and biological properties		S	S		S	S	
Soil Erosion		S	S	x	S	S	
Fertilizer Use	S		S	x	S	S	
Use of Tillage Practices	S		S	x	S	S	
Use of hedgerows and walls	x		x	x	x	x	
Use of alternative cropping systems (rotation, intercropping, etc.)	S		S	x	S	S	
Land							
Area of Deforestation	x	x		x	x	x	x
Categories of land use	x	x		x	x	x	x
Inherent land quality (slope, altitude, etc.)		S	S	x	S	S	
Water							
Water use	S		S	x	S	S	
Depth of groundwater table		S	S	x	S	S	x
Water storage capacity		S	S	x	S	S	x
Concentrations of pollutants in ground and surface water		S	S	x	S	S	x
Water salinity		S	S	x	x	S	x
Energy							
Categories of energy use	S	S	S	x	S	S	
Man-made and Human Capital Indicators							
Pesticide Use	S		S	x	S	S	
Fertilizer Use	S		S	x	S	S	
Labor Use	S		S	x	S		x
Machinery Use	S		S	x	S	S	
Livestock Use	S		S	x	S	S	

"S" denotes collection or computation for the SAFS project. "x" denotes additional possible indicators.

Table 2: Institutional and Economic Sustainability Indicators

	Indicator Type		Scale		Sustainability Dimension		
	Means-Based	Effect-Based	Farm Level	Regional Level	Economic	Ecological	Social
Social Capital and Institutions							
Access to land, water, markets, and credit		x	x	x	x		x
Quality of life measures		x			x		x
Provision of services (health care, education, etc.)		x			x		x
Land Tenure		x	x	x	x		x
Market Characteristics (esp. prices)		S	S	S	S		x
Risk							
Yield variability		S	S	x	S		x
Probability of system failure		x	x	x	x		x
Use of risk-reducing management practices	S		S	x	S	S	x
Input self-sufficiency	x	x	x	x	x		x
Biodiversity		S	S	x	x	S	x
Revenues, Costs, and Employment							
Farm profits (revenues less costs)		S	S		S		
NPV of returns		S	S		S		
Farm assets		S	S	x	S		
Leverage ratios		x	x		x		
Regional/national income		x		x	x		x
Ag employment		x		x	x		x
Subsidies/Env. payments		x	x	x	x		x
Credit Availability		x	x	x	x		x

"S" denotes collection or computation for the SAFS project. "x" denotes additional possible indicators.

Developing Sets of Sustainability Indicators

Clearly, the collection of every data element listed in Tables 1-3 would be prohibitively expensive and not at all optimal once the benefits of the information gained are taken into account. How, then, should an indicator set be developed?

Indictors should be closely related to and representative of the characteristics of the agricultural system. The proper indicator set will therefore be specific to the research project and should be chosen to provide information about the tradeoffs of alternative management practices. The following guidelines should be followed:

1) *Be clear about the objectives of the monitoring effort and who will use the associated information.*
   To provide information about links between practices, crop performance, and ecological impacts, care should be taken to collect data and test hypotheses about the effects of alternative management practices on variables of interest. In addition, it is critical to provide information of value to the end-users who ultimately make or influence management decisions, often in the form of the tradeoffs.
2) *Develop a conceptual model of the system and subsystems of interest.*
   There is no one "right" conceptualization, or model, of complicated economic/ecological systems. Developing an indicator set that represents the key components of the conceptual model protects against ad hoc data collection efforts, and provides the framework for information sets of significant value. A key component of the conceptual model is the identification of the various stakeholders that affect and are affected by the system, and variables that represent their (often competing) interests.
3) *Balance the costs and benefits of information collection.*
   Information gathering is costly, and there are incremental benefits and costs to gathering each piece of data. To allow comparisons over space and time, indicators should also be quantitative where possible.

The agricultural sustainability indicators provided here are by no means an exhaustive list of all possible variables, nor does the list provide the optimal data set for any specific project. However, it does provide an overview of possible agricultural sustainability indicators useful in the study of tradeoffs between economic performance and environmental quality.

Sustainable management of agroecosystems involves making choices that affect the well-being of various stakeholders in differential ways across both space and time. Often, changes in technology can serve to increase the welfare of all relevant groups (such as a production technology that keeps yields and costs constant but decreases runoff), but some allocation decisions must adversely affect at least one stakeholder group. The challenge is thus to collect information that clarifies these potential tradeoffs, allowing decision-makers to make better management choices.

Sustainability Indicators for SAFS

The Sustainable Agriculture Farming Systems/Center for Integrated Farming Systems (SAFS/CIFS) project uses experiment station resources to focus on the links between alternative farming practices (e.g. conservation tillage, cover crops, and manure) and the impacts on economic and ecological system performance at the field level. A natural resource economics conceptualization of the system is used to classify indicators that are being collected, indicated by an "S" in Tables 1, 2, and 3. The indicators will be used to evaluate the feasibility and profitability of alternative production systems (producer stakeholders), as well as provide information about the potential environmental impacts of these practices (both producer and non-producer stakeholders). Future newsletters will report these results.

Table 3: Output Based Sustainability Indicators

	Indicator Type		Scale		Sustainability Dimension		
	Means-Based	Effect-Based	Farm Level	Regional Level	Economic	Ecological	Social
Output and Production							
Goods							
Crop/tree/animal yields		S	S	x	S		
Production per capita		x		x	x		x
Technology							
Output/input ratio		S	S	x	S		
Total factor productivity		S	S	x	S		
Total social factor productivity		S	S	x	S	S	
Bads (Externalities)							
Air pollution (concentrations and emissions)		x	x	x			x
Water pollution (concentrations and emissions, leaching and runoff)		S	S	x	x	S	
Food pollution (related to pesticides)		x	x	x	x	x	
Land pollution (acidification, etc.)		x	x	x	x	x	
Soil erosion		S	S	x	S	S	
Nutrient losses/balances		S	S	x	S	S	
Biodiversity measures/depletion		S	S	x	S	S	x
Habitat destruction		x		x		x	x
Land Use	x	x		x	x	x	x
Pesticide Use	S		S	x	S	S	
Fertilizer Use	S		S	x	S	S	
Other management practices	S		S	x	S	S	

"S" denotes collection or computation for the SAFS project. "x" denotes additional possible indicators.

Part I: Growers review winter cover crops, conservation tillage

by Lyra Halprin, Gene Miyao and Aaron Ristow

[Editor's Note: The complete story (Parts I and II) is available online at safs.ucdavis.edu/newsletter/. Part II will appear in print in the fall SAFS newsletter, Vol. 7, No. 1.]

Growers have been part of the interdisciplinary SAFS/CIFS team since the project's inception at UC Davis in 1988. From the start, the project's focus was to combine the best features of both on-farm and experiment station research. It was established under controlled conditions on a research farm, yet considers the practical applicability of its farming practices, which are regularly evaluated by farmer cooperators. At least three growers representing organic and conventional farming operations and two UC Cooperative Extension farm advisors have participated in all major project decisions. One of the basic premises of the project is that organic and low-input farming systems must be economically productive to be adopted by farmers. Research at the SAFS/CIFS project has long demonstrated the importance of premium prices, and the need for cost-effective and reliable fertility and weed management practices to achieve economic viability.

Farmer Adoption

The project receives attention each year from farmers, industry, researchers, and the general public. Ideas that were once considered to be impractical or radical are gaining in popularity. As consumer demand for organic foods increases, more growers are considering the transition to organic farming systems and seek out the SAFS/CIFS team to get information and advice. Others are simply interested in reducing costs or improving soil quality. Information and experience generated by the project since 1989 is valuable in informing growers of some of the agronomic, economic, and ecological consequences of their many options.

At a panel discussion at the project field day in June 2004, four growers representing diverse farm sizes and growing practices discussed the importance of crop and system diversity in their operations (safs.ucdavis.edu/newsletter/v05n2/page3.htm).

We recently checked back with them and several other growers who have worked with the project to discuss their use of conservation tillage and cover crops, and what researchers could do to help other farmers adopt these practices.

Jeff Main. Jeff and Annie Main have farmed organically on 20 acres in the Capay Valley since 1984. They continue to plant a variety of cover crops on their farm, where they grow 60 to 80 different tree and annual crops. Cover crops can be used to provide much more than weed suppression and nitrogen, Jeff Main said.

"Farmers have just scratched the surface on cover crops," he said. "There are lots and lots of varieties. We don't want to limit ourselves to what we traditionally consider to be cover crops, i.e. legumes and grasses."

Main said he hasn't made major changes in his farming systems, which includes the use of deep-rooted cover crops instead of deep tillage.

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"Good farmers would put more back into their soil if they could, but if the resources aren't there, obviously they cannot," he said. "Farmers are innovators, but without time or money, it's hard to expect innovation and creative thinking."

Main noted that this year his farm must pay $600 for a new insurance policy "strictly to cover our presence at the Davis Farmers Market for liability."

"It's a brand new cost, forced on us," he said. "This new coverage equals our cover crop budget for the whole farm. The trend is toward more protection and more regulation, and every one costs more time or money or both."

Charlie Rominger. Charlie Rominger is a partner in a 2700-acre family farming operation in Yolo County, which is moving toward more organic, more no-till and less conventionally farmed land. In 2005, they enrolled in the federal government's Conservation Security Program through the Natural Resources Conservation Service, which pays farmers for using conservation practices rather than for producing commodity crops. Some of the Rominger fields qualified for incentive payments, but others did not.

"Even though on one field we had hedgerows, a tail-water pond and a windbreak, we did not qualify for incentive payments because we used conventional tillage at that site," Rominger said. "In order to expand our conservation tillage, we bought a conservation tillage bed implement, which chews up the residue but leaves most of it on the surface."

His biggest disappointment was that the federal conservation program couldn't pay.

"We made the changes, but then the government froze the budget for the conservation program and we didn't get the reward," he said. "Incentive programs do encourage farmers to be innovative, but only if there is follow-through."

Rominger said he has learned from conservation tillage research, and would like to see research on a "true no-till farming system" for irrigated row crops in the Sacramento Valley, including a more diverse crop rotation and livestock.

Conservation Tillage Field Day, Thursday, June 22, 2006

Join us for field tours and field demonstrations at the SAFS site. Location: Russell Ranch, seven miles west of the UC Davis campus on Russell Blvd., ½ mile west of County Road 95. Sign-in/registration starts at 7:30 a.m. with program beginning at 8 a.m. Events conclude at 2:30 p.m. More information at the SAFS Web site safs.ucdavis.edu, or contact Z. Kabir at (530) 754-6497, Kabir@ucdavis.edu.

More information on UC Davis sustainable agriculture farming systems projects is available online at
safs.ucdavis.edu,
including expanded newsletter articles, SAFS/LTRAS updates, and other resources.

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