Is Agricultural Sustainability a Useful Concept?*

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ABSTRACT

This paper examines conceptual and methodological barriers to using sustainability as a criterion for guiding change in agriculture and proposes elements necessary for approaches to characterizing sustainability to be generally useful. Two broad interpretations of agricultural sustainability have emerged with different underlying goals: sustainability interpreted as an approach to agriculture developed in response to concerns about impacts of agriculture, with motivating adherence to sustainable ideologies and practices as its goal; and sustainability interpreted as a property of agriculture developed in response to concerns about threats to agriculture, with the goal of using it as a criterion for guiding agriculture as it responds to change. Interpreting sustainability as an approach has been useful for motivating change. However, usefulness of this interpretation as a criterion for guiding change is hindered by a lack of generality of prescribed approaches, a distorted view of conventional agriculture and circular logic. Although interpreting sustainability as a system property is logically more consistent, conceptual and practical problems with its characterization have limited its usefulness as a criterion for guiding change. In order for sustainability to be a useful criterion for guiding change in agriculture, its characterization should be literal, system-oriented, quantitative, predictive, stochastic and diagnostic.

INTRODUCTION

In literal English usage, sustainability is the ability to 'keep in existence; keep up; maintain or prolong' (Neufeldt, 1988). The variety of meanings acquired by sustainability as applied to agriculture (Table 1) has been classified according to the issues motivating concern (Douglass, 1984; Weil, 1990),

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TABLE 1.
Interpretations of Agricultural Sustainability

*Sustainability as an ideology*
'Sustainable agriculture is a philosophy and system of farming. It has its roots in a set of values that reflect a state of empowerment, of awareness of ecological and social realities, and of one’s ability to take effective action.' (MacRae et al., 1990)

'...an approach or a philosophy...that integrates land stewardship with agriculture. Land stewardship is the philosophy that land is managed with respect for use by future generations.' (Neher, 1992)

'...a philosophy based on human goals and on understanding the long-term impact of our activities on the environment and on other species. Use of this philosophy guides our application of prior experience and the latest scientific advances to create integrated, resource-conserving, equitable farming systems.' (Francis & Youngberg, 1990)

'...farming in the image of Nature and predicated on the spiritual and practical notions and ethical dimensions of responsible stewardship and sustainable production of wholesome food.' (Bidwell, 1986)

*Sustainability as a set of strategies*
'...a management strategy which helps the producers to choose hybrids and varieties, a soil fertility package, a pest management approach, a tillage system, and a crop rotation to reduce costs of purchased inputs, minimize the impact of the system on the immediate and the off-farm environment, and provide a sustained level of production and profit from farming.' (Francis, 1987)

'...a loosely defined term for a range of strategies to cope with several agriculturally related problems causing increased concern in the US and around the world.' (Lockeretz, 1988)

Farming systems are sustainable if 'they minimize the use of external inputs and maximize the use of internal inputs already existing on the farm.' (Carter, 1989)

'...(a) the development of technology and practices that maintain and/or enhance the quality of land and water resources; and (b) the improvements in plants and animals and the advances in production practices that will facilitate the substitution of biological technology for chemical technology. (Ruttan, 1988)

*Sustainability as the ability to fulfill a set of goals*
'A sustainable agriculture is one that, over the long term, enhances environmental quality and the resource base on which agriculture depends, provides for basic human food and fiber needs, is economically viable, and enhances the quality of life for farmers and society as a whole.' (American Society of Agronomy, 1989)

'...agricultural systems that are environmentally sound, profitable, and productive and that maintain the social fabric of the rural community.' (Keeney, 1989)

'...an agrifood sector that over the long term can simultaneously (1) maintain or enhance environmental quality, (2) provide adequate economic and social rewards to all individuals and firms in the production system, and (3) produce a sufficient and accessible food supply.' (Brklacich et al., 1991)

'...an agriculture that can evolve indefinitely toward greater human utility, greater efficiency of resource use, and a balance with the environment that is favorable both to humans and to most other species.' (Harwood, 1990)
Agricultural sustainability

TABLE 1.—contd.

Sustainability as the ability to continue
'A system is sustainable over a defined period if outputs do not decrease when inputs are not increased.' (Monteith, 1990)

'Sustainability is the ability of a system to maintain productivity in spite of a major disturbance, such as is caused by intensive stress or a large perturbation.' (Conway, 1985)

'...the maintenance of the net benefits agriculture provides to society for present and future generations.' (Gray, 1991)

'Agriculture is sustainable when it remains the dominant land use over time and the resource base can continually support production at levels needed for profitability (cash economy) or survival (subsistence economy).' (Hamblin, 1992)

their historical and ideological roots (Kidd, 1992; Brklacich et al., 1991) and the hierarchical levels of systems considered (Lowrance et al., 1986).

The distinction between sustainability as a system-describing and as a goal-prescribing concept (Thompson, 1992) identifies two current schools of thought that differ in their underlying goals. The goal-prescribing concept interprets sustainability as an ideological or management approach to agriculture. This concept developed in response to concerns about negative impacts of agriculture, with the underlying goal of motivating the adoption of alternative approaches. The system-describing concept interprets sustainability either as an ability to fulfil a diverse set of goals or as an ability to continue. This concept can be related to concerns about impacts of global change on the viability of agriculture and to the goal of using sustainability as a criterion for guiding agriculture as it responds to rapid changes in its physical, social and economic environments.

Although the concept of sustainability has been useful for consolidating concerns and motivating change, concrete examples of its use as an operational criterion for guiding efforts to improve agricultural systems are difficult to identify. The objectives of this paper are (1) to examine conceptual and methodological barriers to using the concept of sustainability for guiding change in agriculture; and (2) to propose a set of elements necessary for an approach to characterizing sustainability to provide a useful criterion for guiding agriculture.

SUSTAINABILITY AS AN APPROACH TO AGRICULTURE

The sustainable agriculture movement evolved from several reform
movements in the USA, Canada and Western Europe that developed in response to concerns about impacts of agriculture such as depletion of non-renewable resources, soil degradation, health and environmental effects of agricultural chemicals, inequity, declining rural communities, loss of traditional agrarian values, food quality, farm worker safety, decline in self-sufficiency, and decreasing number and increasing size of farms. These problems became associated with 'conventional agriculture' that was perceived as unsustainable (Dahlberg, 1991). 'Alternative agriculture' is often equated with sustainable agriculture (O’Connell, 1992; Madden, 1987; Harwood, 1990; Dahlberg, 1991; Bidwell, 1986) and reflects the goal of promoting alternatives to conventional agriculture. Reviews by Harwood (1990) and Kidd (1992) trace the historical development of the sustainable, or alternative, agriculture movement.

Differences in values and practices promoted as sustainable have been attributed to differences in the problems emphasized (Carter, 1989) and to different visions of what agriculture should be like (Thompson, 1992). 'Originally, the advocates of alternative approaches to agriculture — all united in their critique of industrial agriculture as being unsustainable — debated among themselves the future direction and shape of agriculture' (Dahlberg, 1991). Some have focused on identifying sustainable alternatives to existing management practices, while others have advocated new philosophical orientations toward agriculture.

**Sustainability as an alternative ideology**

MacRae *et al.* (1990), Neher (1992) and Francis & Youngberg (1990) defined sustainable agriculture as a philosophy (Table 1). Ikerd (1991) described low input, sustainable agriculture (LISA) as more a philosophy than a practice. Examining the concept of conventional agriculture is important, since sustainable agriculture is often described by its contrast with conventional agriculture (Lockeretz, 1988; MacRae *et al.*, 1989; Haupertli *et al.*, 1990; Dobbs *et al.*, 1991; O’Connell, 1992; Hill & MacRae, 1988).

**Conventional agriculture**

The concept of conventional agriculture was developed in order to clarify and justify alternative approaches to agriculture. Conventional agriculture is characterized as 'capital-intensive, large-scale, highly mechanized agriculture with monocultures of crops and extensive use of artificial fertilizers, herbicides and pesticides, with intensive animal husbandry' (Knorr & Watkins, 1984) with a paradigm of 'strength through exhaustion' (Bidwell, 1986). Hill & MacRae (1988) contrasted approaches of conventional and sustainable agriculture (Table 2). Based on a review of actual cropping
### TABLE 2
Contrasting Approaches of Conventional and Sustainable Agriculture as Characterized by Hill and MacRae (1988)

<table>
<thead>
<tr>
<th>Conventional</th>
<th>Sustainable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Symptoms</td>
<td>Causes, prevention</td>
</tr>
<tr>
<td>Reductionist</td>
<td>Holistic</td>
</tr>
<tr>
<td>Eliminate 'enemies'</td>
<td>Respond to indicators</td>
</tr>
<tr>
<td>Narrow focus (neglects side-effects; health and environmental costs ignored)</td>
<td>Broad focus (sub-cellular to all life to globe all costs internalized)</td>
</tr>
<tr>
<td>Instant</td>
<td>Long time frame (future generations)</td>
</tr>
<tr>
<td>Single, simple (magic bullet, single discipline)</td>
<td>Multifaceted, complex (multi- and trans-disciplinary)</td>
</tr>
<tr>
<td>Temporary solutions</td>
<td>Permanent solutions</td>
</tr>
<tr>
<td>Unexpected disbenefits (to person and planet)</td>
<td>Unexpected benefits</td>
</tr>
<tr>
<td>High power (risk of overkill and errors/accidents)</td>
<td>Low power (minimal risk)</td>
</tr>
<tr>
<td>Direct ‘attack’</td>
<td>Indirect, benign approaches (catalytic, multiplier, synergistic effects)</td>
</tr>
<tr>
<td>Imported</td>
<td>Local solutions and materials</td>
</tr>
<tr>
<td>Products</td>
<td>Processes, services</td>
</tr>
<tr>
<td>Physico-chemical (often unnatural, synthetic)</td>
<td>Bio-ecological (natural)</td>
</tr>
<tr>
<td>Technology-intensive</td>
<td>Knowledge/skill intensive</td>
</tr>
<tr>
<td>Centralized</td>
<td>Decentralized (human scale)</td>
</tr>
<tr>
<td>Values secondary</td>
<td>Compatible with higher values</td>
</tr>
<tr>
<td>Expert, paternalistic (arrogant)</td>
<td>Individual/community responsibility (humble)</td>
</tr>
<tr>
<td>Dependent</td>
<td>Self-maintaining/regulating</td>
</tr>
<tr>
<td>Inflexible</td>
<td>Flexible</td>
</tr>
<tr>
<td>Ignores freedom of choice (unjust)</td>
<td>Respects freedom of choice (just)</td>
</tr>
<tr>
<td>Disempowering</td>
<td>Empowering</td>
</tr>
<tr>
<td>Competitive</td>
<td>Co-operative</td>
</tr>
<tr>
<td>Authored</td>
<td>Anonymous (seeking neither reward nor fame)</td>
</tr>
</tbody>
</table>
practices in the US, Madden (1990) appropriately identified conventional agriculture as a caricature.

Beus and Dunlap (1990) identified centralization, dependence, competition, domination of nature, specialization and exploitation as key elements of conventional agriculture from the writings of six conventional agriculture advocates. Although 'conventional agriculture' was applied to mainstream US agriculture as one side of a debate between competing paradigms, its description was admittedly a construct for the purpose of clarifying opposing positions, facilitating comparisons and sharpening the focus of the debate.' A survey of farmers and agricultural groups in Washington state by the same authors (Beus & Dunlap, 1991) suggested that the conventional agriculture that they described does not represent mainstream US agriculture. A random sample of farmers and three of the four groups of conventional agriculturalists surveyed showed greater agreement with the alternative than with the conventional agriculture paradigm.

Characterization of conventional agriculture extends to mainstream research and education institutions where research has been described as too narrow, short-sighted, biased by interests of agribusiness funding sources and distorted by the values of scientists to be able to deal with the issues necessary to achieve sustainability (Bidwell, 1986; Allen & van Dusen, 1988; MacRae et al., 1989; Dahlberg, 1991; Kirschenmann, 1991; Hill & MacRae, 1988). Beus and Dunlap (1990) and Dahlberg (1991) expressed concern that such institutions threaten to dilute the concept of sustainable agriculture by co-opting it while ignoring its more important and radical aspects.

**Alternative values**

Sustainable agriculture has been described as an umbrella term encompassing several ideological approaches to agriculture (Gips, 1988) including organic farming, biological agriculture, alternative agriculture, ecological agriculture, low-input agriculture, biodynamic agriculture, regenerative agriculture, permaculture and agroecology (Carter, 1989; MacRae et al., 1989; Bidwell, 1986; O'Connell, 1992; Kirschenmann, 1991; Dahlberg, 1991).

Beus and Dunlap (1990) listed decentralization, independence, community, harmony with nature, diversity and restraint as key values of alternative agriculture. Social values such as equity, the value of traditional agricultural systems, self-sufficiency, preservation of agrarian culture and preference for small, owner-operated farms have been incorporated into definitions of sustainability (Weil, 1990; Keeney, 1989; Bidwell, 1986; Francis & Youngberg, 1990). The concept of equity is extended to include future generations (Batie, 1989; Norgaard, 1991). Environmental values associated with sustainability include mimicry of nature and an 'ecocentric' ethic. Hauptli et al. (1990) described mimicry of nature:
'...sustainable agriculture attempts to mimic the key characteristics of a natural ecosystem...' The ecocentric position — valuing ecosystems or species without regard to their impact on human welfare — is illustrated by Douglass (1984) who stated that ecology-minded people '...define agricultural sustainability in biophysical terms, and to allow its measurement to determine desirable population levels.'

**Sustainability as a set of strategies**

Francis and Youngberg (1990) described sustainable agriculture as a philosophy that guides the creation of farming systems. Specific management strategies are often suggested by ideological interpretations of sustainability. The strategies promoted as sustainable (Table 3) are based on the types of problems emphasized and on views of what would constitute an improvement.

The strategy most frequently linked to sustainability is reduction or elimination of the use of processed chemicals, particularly fertilizers and pesticides (Stinner & House, 1987; Lockeretz, 1988; Carter, 1989; Hauptli et al., 1990; Madden, 1990; Dobbs et al., 1991). In 1988, the US Department of Agriculture linked sustainability to levels of inputs by establishing the LISA research program (O'Connell, 1990; Dicks, 1992). Arguments for reducing chemical inputs include limited supplies of fossil fuels, decreasing commodity prices necessitating reducing input costs, a need for self-sufficiency, concerns about pollution, and health and safety concerns (Francis & King, 1988; Carter, 1989; Stinner & House, 1989; Conway & Barbier, 1990; MacRae et al., 1990; Rodale, 1990).

York (1991) argued that fewer options exist for reducing fertilizer inputs than pesticide inputs in agricultural systems while maintaining sustainable production. Unlike pesticides, soil nutrient elements generally have no substitutes and are subjected to harvest and other losses that must be replaced by weathering or imported from outside the system if production is to be sustained. The high energy cost unique to N fertilizer production and the potential for biological fixation suggest a need and potential for seeking alternatives to synthetic N fertilizers that does not exist for mineral-based nutrients such as P and K.

The important distinction between production systems that currently employ high levels of chemical inputs and those that employ low levels (Weil, 1990) is often overlooked. Zandstra (1994) described sustainability as a function of chemical input levels (Fig. 1a). Excessive input levels were said to degrade natural resources through accumulation while inadequate levels degrade resources through exhaustion. This concept is in sharp contrast to the decreasing relationship between chemical input levels and sustainability proposed by Stinner and House (1987) (Fig. 1b).
TABLE 3
Strategies Frequently Associated with Sustainability

<table>
<thead>
<tr>
<th>Strategy</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Self-sufficiency through preferred use of on-farm or locally available 'internal' resources to purchased 'external' resources.</td>
<td>a,b,g,d</td>
</tr>
<tr>
<td>Reduced use or elimination of soluble or synthetic fertilizers.</td>
<td>a,e,f,h,i,k</td>
</tr>
<tr>
<td>Reduced use or elimination of chemical pesticides, substituting integrated pest management practices.</td>
<td>a,c,d,e,f,h,i,j,k</td>
</tr>
<tr>
<td>Increased or improved use of crop rotations for diversification, soil fertility and pest control.</td>
<td>a,c,d,e,f,h,i</td>
</tr>
<tr>
<td>Increased or improved use of manures and other organic materials as soil amendments.</td>
<td>a,c,f,h,j,k</td>
</tr>
<tr>
<td>Increased diversity of crop (and animal) species.</td>
<td>a,d,g,i</td>
</tr>
<tr>
<td>Maintenance of crop or residue cover on the soil.</td>
<td>a,d,e</td>
</tr>
<tr>
<td>Reduced stocking rates for animals.</td>
<td>a,c,d</td>
</tr>
</tbody>
</table>


Studies in Mali, Benin, Zambia, and Tanzania provide examples of resource degradation due to inadequate chemical inputs (Budelman & van der Pol, 1992). In each case, supplies of soil nutrients were exhausted rapidly due to a combination of harvest, erosion, leaching, denitrification and volatilization, with harvest being the greatest loss. Nutrient budgets estimated for several crops in southern Mali were always negative for N and K, and variable but generally better for P. The authors concluded that the only way to make these cropping systems sustainable is with increased use of fertilizers.

Discussion

Interpreting sustainability as an approach to agriculture has been useful for motivating change. Sustainability as an ideology has provided a common banner for various agricultural reform movements (Gips, 1988; Dahlberg, 1991). Research and promotion of sustainability interpreted as
a set of strategies has become part of policy in the USA in the form of provisions in the 1990 Farm Bill (O'Connell, 1992; Yetley, 1992).

Interpreting sustainability as an approach is not useful for guiding change in agriculture for several reasons. Firstly, approaches developed in response to problems in North America and Europe may be inappropriate in regions where circumstances and problems are different. The alternative agriculture movement has its roots primarily in regions characterized by high levels of resource consumption, food surpluses, high levels of chemical inputs, relatively deep, fertile soils and relatively stable
populations. In contrast, many less developed tropical regions are characterized by lower levels of resource consumption, frequent or chronic food shortages, lower levels of chemical inputs, relatively fragile soils and rapidly growing populations. Attempts to link strategies to sustainability by definition fail to consider the need to match technologies to specific environments.

Dicks (1992) argued that interpretations of sustainability in the US have been shaped by food surpluses. A shift in concern from global food security to environment quality in the 1980s (York, 1991) led to the perspective that ‘...the question is not can we produce more food, but what are the ecological consequences of doing so?’ (Douglass, 1984). However, much of the concern about sustainability in less developed countries is related to the need to increase productivity to meet future needs of growing populations (Ruttan, 1988; York, 1988, 1991; Lynam & Herdt, 1989; Plucknett, 1990). The potential for the desperation imposed by poverty to shorten people's planning horizons (Ashby, 1985) raises questions about the ecological consequences of failing to produce more food (Mellor, 1988; Oram, 1988). The alternative agriculture movement has not adequately addressed the need to feed rapidly growing populations in order to prevent both human and ecological disaster.

The second problem is that a distorted caricature of conventional agriculture may cause approaches that may enhance sustainability to be ignored or rejected because of their association with conventional agricultural institutions. Although the philosophical roots of the alternative agriculture movement were formed outside the academic community (Rodale, 1990; Bidwell, 1986), most of the practices it promotes as sustainable are largely products of mainstream research and educational institutions (Francis & Sahs, 1988; York, 1988).

Thirdly, establishing the contribution of an approach to sustainability through definition eliminates the perceived need to evaluate approaches that may be poor or harmful in a particular context. If strategies are identified as sustainable based on their effect on agricultural systems, and agricultural systems are then judged to be sustainable based on their implementation of sustainable strategies, then a form of circular logic results. It is logically impossible to evaluate the contribution of an approach to sustainability when adherence to that approach has already been used as a criterion for evaluating sustainability. This circular logic is a fourth reason why interpreting sustainability as an approach is not useful for guiding change.

Because of the temporal nature of sustainability, errors of either ignoring approaches that enhance sustainability or promoting approaches that threaten it may not be obvious when the approaches are implemented.
The evaluation needed to recognize errors and improve approaches is not possible if sustainability is interpreted as a philosophy or a set of strategies. Thompson (1992) warned that ‘our society may collapse because of shortsighted stupidity on the part of pro-growth, resource exploiting power elites, but the collapse will only be tragic if it is shortsightedness or ignorance on the part of environmentally and ethically concerned people that helps bring it about.’

SUSTAINABILITY AS A PROPERTY OF AGRICULTURE

The concept of sustainability as an approach to agriculture evolved in parallel with the concept of sustainability as a system property. While Dahlberg (1991) argued that ‘sustainability’ was first used by an emerging alternative agriculture movement to prescribe a particular set of values, Kidd (1992) countered that the system describing concept developed earlier, but did not use the word ‘sustainability’ until later. As a property of agriculture, sustainability is interpreted as either the ability to satisfy a diverse set of goals or an ability to continue through time.

Sustainability as an ability to satisfy goals

A sustainable agricultural system is often defined as one that fulfils a balance of several goals through time. These goals generally include some expression of maintenance or enhancement of the natural environment, provision of human food needs, economic viability and social welfare (Table 1).

Lynam and Herdt (1989) argued that an interpretation of sustainability based on several qualitative goals fails to provide a criterion useful for guiding agricultural research. If a system is defined as sustainable when it protects the natural environment, provides adequate food and maintains producer profitability, then there is no logical way to rank, for example, the relative importance of commodity price variability and nitrate leaching into aquifers as determinants of sustainability. Furthermore, the subjectivity of goal specification links criteria for determining sustainability to the goals and values of the analyst or the author of a definition rather than to the agricultural system. At the farm level and higher, goals belong to the actors within the system and are, therefore, exogenous. Kidd (1992) argued that it is not helpful to ‘use sustainability loosely as a general purpose code word encompassing all of the aspects of agricultural policy that the authors consider desirable.’
Sustainability as an ability to continue

The final concept interprets sustainability as a system's ability to continue through time. Hildebrand (1990) suggested that sustainability may be interpreted as the length of time that a system can be maintained. According to Hamblin (1992), sustainability implies that agriculture remains the dominant land use. Lynam and Herdt (1989) and Jodha (1990) expressed sustainability in terms of maintaining some level of output. Monteith (1990) added consideration of the possible confounding interaction of changes in input and output levels. The definitions of Fox (1991) and Hamblin (1992) emphasized the continuing ability to meet human needs. Conway (1985), Conway and Barbier (1990) and Altieri (1987) emphasized the ability to withstand disturbances.

Interpreting sustainability as an ability to continue is consistent with literal English usage of 'sustain' and its derivatives. Its potential usefulness comes from suggesting criteria for characterizing sustainability, providing a basis for identifying constraints and evaluating proposed approaches to its improvement. This potential usefulness has been limited by inadequacy of current approaches for characterizing sustainability.

APPROACHES TO CHARACTERIZING SUSTAINABILITY

Characterization is a prerequisite to applying the concept of sustainability as a criterion for identifying constraints, focusing research, and evaluating and improving agricultural policy and practices. The conceptual problem of defining sustainability and methodological problems imposed by its temporal nature have hindered development of approaches for characterizing sustainability.

Sustainability involves future outcomes that cannot be observed in the time-frame required for intervention (Lynam & Herdt, 1989; Harrington, 1992). Conway (1994) argued that defining sustainability in terms of preservation or duration has little practical value because of the infeasibility of long-term experiments.

The variety of approaches reviewed here reflects the different interpretations of sustainability and methodological difficulties that result from its temporal nature. Characterization by adherence to prescribed approaches is based on an interpretation of sustainability as an approach to agriculture. Characterization by multiple qualitative indicators and attempts to integrate such indicators are consistent with interpreting sustainability as an ability to satisfy diverse goals. Sustainability as an ability to continue is usually characterized by time trends or resilience.
Adherence to prescribed approaches

In a study comparing conventional and sustainable farms in South Dakota, Dobbs et al. (1991) identified farms as sustainable if they reduced chemical inputs relative to typical farms, and included rotations, legumes, tillage and cover crops for management of fertility, erosion and weeds. Sustainable farms were sampled by sending questionnaires to farmers they ‘...believed might be using greatly reduced or even zero levels of synthetic chemicals in their farming operations.’ Cordray et al. (1993) characterized sustainability of farmers in Washington and Oregon based on changes in agricultural chemical use and adoption of alternative production practices. Taylor et al. (1993) developed a quantitative index of sustainability based on production practices of Malaysian cabbage farmers. Practices were assigned values according to their ‘inherent sustainability’ determined by the consensus of the research team, weighted by their expected contribution to sustainability, then combined into a composite index evaluated for each farm.

Taylor et al. (1993) were the only authors in the above studies to acknowledge the necessity of assuming a relationship between farmer practices and future viability if practices are to serve as a basis for characterizing sustainability. Even if evidence supporting such a relationship were presented, circular logic prevents using sustainability measured by adoption of particular practices as a criterion for evaluating and improving agricultural practices.

Multiple qualitative indicators

Torquebiau (1992) used a set of indicators to characterize sustainability of tropical agroforestry home gardens. Several system attributes that were believed to influence sustainability were identified related to the resource base, system performance and effects on other systems. Measurable indicators were identified for each system attribute. A negative change in an individual indicator indicated unsustainability. Jodha (1990) developed a set of indicators of unsustainability of mountain agriculture in the Himalayan region consisting of visible changes in natural resources and farming practices that indicate system degradation, changes in farming practices that compensate for less visible changes in the environment and inappropriate development initiatives that may lead to negative impacts. Neher (1992) described an approach that is being developed to monitor agroecosystem health at regional and national scales in the USA. A number of indicators of environmental quality and agricultural performance are to be measured to provide a baseline, then monitored to identify changes.
Monitoring sets of qualitative indicators is consistent with interpreting sustainability as the ability to meet a diverse set of goals and the belief that no single indicator can exist (Geng et al., 1990; Norgaard, 1991). However, diverse sets of indicators are difficult to interpret and do not provide mechanisms for diagnosing causes of unsustainability, or for evaluating effects of proposed interventions. Such indicators do not facilitate establishing cause-effect relationships between diverse system properties.

**Integrated, quantitative indicators**

Increasing recognition of the need for quantification has motivated efforts to combine diverse indicators of sustainability into integrated, quantitative measures. One goal of the project described by Neher (1992) for monitoring agro-ecosystem health is to combine indicators into an aggregate measure of agricultural sustainability in a manner that balances productivity, environmental soundness and socio-economic viability goals. Lal (1991) proposed a sustainability coefficient as a function of output per unit of input at optimal per capita productivity or profit, output per unit of decline in the most limiting or least renewable resource and the minimum assured output level. Sands and Podmore (1993) proposed an environmental sustainability index as an aggregation of sub-indices of soil productivity, ecosystem stability and potential to degrade the environment. Selection of components of the sub-indices and the form of aggregation functions were indicated as important research topics. Stockle et al. (1994) proposed a framework for evaluating sustainability based on nine system attributes: profitability, productivity, quality of soil, water, and air, energy efficiency, fish and wildlife habitat, quality of life, and social acceptance. Production system sustainability is determined by scoring attributes as weighted functions of quantifiable, long-term constraints, then combining weighted attribute scores into an integrated measure.

The consistent inability to specify aggregation functions in these studies points to the weakness of interpreting sustainability as the ability to fulfil diverse sets of goals as a conceptual foundation for characterization. Diagnosis is limited by need to decide a priori the relative importance of different types of constraints to sustainability. Stockle et al. (1994) acknowledged and defended the subjectivity needed to aggregate diverse system attributes into an integrated measure of sustainability.

**Time trends**

Time trend approaches express sustainability in terms of the direction and degree of measurable changes in system properties through time.
Lynam and Herdt (1989) regarded a system as sustainable if there was a non-negative trend in its output. They proposed total factor productivity (the total value of system outputs divided by the value of system inputs) as the output criterion, because it accounts for changes in the value of inputs. Ehui and Spencer (1992) extended total factor productivity to account for changes in the value of natural resource stocks, particularly soil nutrients. Hedgerow inter-cropping in Nigeria was determined to be unsustainable without correction for soil nutrient flows, but sustainable after accounting for nutrients. Monteith (1990) proposed determining sustainability from a contingency table of trends of inputs and outputs (Table 4). Cereal production was determined to be sustainable in the Karimnagar district in Andhra Pradesh, India, based on increasing yields and decreasing land use during 27 years. Decreases in both land use and yields in the Adilabad district prevented inference about sustainability.

Characterizing sustainability by time trends is appealing because of its simplicity. The slope of the estimated trend line provides a quantitative index with an intuitive interpretation as a rate of system deterioration or enhancement. Trends represent an aggregate response to several determinants of sustainability, eliminating the need to devise and defend aggregation schemes.

The assumption needed to infer sustainability from trends — that future rates of system degradation can be approximated by past rates — is often difficult to defend. Unsustainability can express itself either as a gradual change or as an abrupt collapse (Conway, 1985; Trenbath et al., 1990). Furthermore, much of the concern about sustainability comes from recognition that agricultural systems are being impacted by unprecedented changes in population pressure, resource demands, market structures and technology.

Another weakness is the manner in which time-trend approaches interpret temporal variability. Variability tends to hinder sustainability by driving subsistence farmers to desperation, leading to environmental degradation that may not recover during normal or good periods (Mellor,

<table>
<thead>
<tr>
<th>Outputs</th>
<th>Decreasing</th>
<th>Constant</th>
<th>Increasing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decreasing</td>
<td>Indeterminant</td>
<td>Unsustainable</td>
<td>Unsustainable</td>
</tr>
<tr>
<td>Constant</td>
<td>Sustainable</td>
<td>Sustainable</td>
<td>Unsustainable</td>
</tr>
<tr>
<td>Increasing</td>
<td>Sustainable</td>
<td>Sustainable</td>
<td>Indeterminant</td>
</tr>
</tbody>
</table>
Price and yield variability have also been shown to increase the probability of farm failure in the US (Grant et al., 1984; Perry et al., 1986). However, when characterization is based on time trends, either variability is ignored or it implicitly enhances sustainability by reducing the probability of identifying a significant negative trend.

A final criticism is that applications of time trends to sustainability have examined levels of system performance without considering the levels of needs and goals of the individuals or segments of society who decide on the fate of those systems.

**Resilience**

Conway (1985) defined sustainability as resilience ‘…the ability of a system to maintain productivity in spite of a major disturbance.’ He suggested that measurement of five system properties are necessary to characterize resilience: inertia, elasticity, amplitude, hysteresis and malleability (Conway, 1994). Cramb (1993) based inferences about the sustainability of two shifting cultivation systems in eastern Malaysia on both trends and resilience. Pepper production was determined to be sustainable because production in 1989 recovered to its 1980 level in response to price recovery after production diminished (in 1985) due to a period of low prices. Rubber production was considered more sustainable at Batu Linang than at Nanga Tapih, as indicated by recovery of depressed production in response to price recovery.

Like time trends, resilience can be viewed as an aggregate system response to determinants of sustainability. However, inability to identify a single measure of resilience (Conway, 1994) leads to the same problems of interpretation faced when using a diverse set of indicators to characterize sustainability. Assumptions about the likelihood and timing of disturbances have been avoided by interpreting sustainability as an intrinsic property of an agricultural system in isolation from its environment (Conway & Barbier, 1990). However, York (1988) argued that (un)sustainability is not an intrinsic property but rather a response to changing environmental and socioeconomic circumstances. Predictions about future sustainability cannot be made in the absence of assumptions about changes and variability in those higher-level systems that comprise a system’s environment. Resilience shares with time-trend approaches the criticism that it ignores the goals of the human actors within agricultural systems.

**System simulation**

Simulation has been used to characterize the sustainability of crop produc-
tion in response to soil dynamics. Singh and Thornton (1992) illustrated the use of long-term simulation of crop sequences replicated with stochastic inputs of weather data to examine trends and variability in yields. Lerohl (1991) used the erosion-productivity impact calculator (EPIC) (Williams et al., 1984) to study the long-term impact of predicted soil erosion on productivity of crop rotations on four soil types in Alberta, Canada. Sustainability was inferred in all soil-rotation combinations because no negative trend in crop yields could be detected during a simulated 100-year period.

Other studies have used crop simulation models to examine relationships between production and environmental degradation. Singh and Thornton (1992) illustrated the use of CERES-maize (Jones & Kiniry, 1986) to simulate the effects of soil type and rate of application of N fertilizer on distributions of maize grain yield and NO$_3^-$ leaching into groundwater from upland fields in Chiang Mai, Thailand. Alocilja and Ritchie (1993) used CERES-maize and a multiple goal optimization technique to identify sets of N fertilization schedules that were optimal in the sense that neither production nor water quality could be improved without decreasing satisfaction of the other goal.

Several whole-farm simulation studies have looked at the effect of various factors on farm survivability. For example, Perry et al. (1986) examined effects of production costs, labour availability, rice grain quality, land tenure, trends and variability of rice and soybean prices and yields, beginning equity, types of rotations, and participation and terms of government farm programmes on probability of farm survival during a five-year period. Production and environmental processes were not simulated. Although this and similar studies have not generally used the word 'sustainability', the use of farm survival as a criterion is consistent with an interpretation of sustainability as economic viability (Madden, 1987; Lockeretz, 1988; Dicks, 1992; Neher, 1992). Survivability addresses the shortcomings of other approaches by integrating levels, trends and variability in system performance with the needs and goals of farmers.

System simulation is a tool, and does not suggest a particular criterion for evaluating sustainability. Simulation can be used to examine long-term, future impacts of alternative interventions across the range of expected variability in a manner that is not possible with empirical observation and experimentation. The value of simulation is limited by capabilities of, and confidence in simulation models, by availability and reliability of input data, and by a lack of methods for designing and interpreting simulation studies for characterizing sustainability. So far, there has been little integration of models of crop and animal production, environmental degradation, economic processes and farmer decisions.
ELEMENTS OF A USEFUL APPROACH FOR CHARACTERIZING SUSTAINABILITY

In order for sustainability to be a useful criterion for guiding change in agriculture, several elements should be incorporated into approaches to its characterization (Table 5). Firstly, characterization should be based on a *literal* interpretation of sustainability (Fox, 1991). Regardless of the merits of goals and ideals frequently incorporated into definitions of sustainability, if the idea of continuation through time is omitted, then those ideals and goals are something other than sustainability.

Secondly, characterization should be *system-oriented*. A literal interpretation suggests that sustainability is an objective property of an agricultural system. It cannot be a property of approaches to agriculture if it is to serve as a basis for evaluating and improving approaches. Lynam and Herdt (1989) argued that sustainability is a relevant criterion for evaluating technology only when the system is clearly specified, including its boundaries, components and context in hierarchy. Sustainability has meaning only in the context of specific temporal and spatial scales. Fresco and Kroonenberg (1992) cited a number of examples in which disturbances that threaten sustainability at one spatial and temporal scale could be seen as natural cycles at broader scales. Both constraints to sustainability and factors that can be managed for its enhancement depend on the level of the system (Spencer and Swift, 1992). The objectivity that results from a system-oriented approach is

<table>
<thead>
<tr>
<th><strong>Element</strong></th>
<th><strong>Explanation</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Literal</td>
<td>Defines sustainability as an ability to continue through time, consistent with literal English usage</td>
</tr>
<tr>
<td>System-oriented</td>
<td>Identifies sustainability as an objective property of a particular agricultural system whose components, boundaries and context in hierarchy are clearly specified</td>
</tr>
<tr>
<td>Quantitative</td>
<td>Treats sustainability as a continuous quantity, permitting comparisons of alternative systems or approaches</td>
</tr>
<tr>
<td>Predictive</td>
<td>Deals with the future rather than the past or present</td>
</tr>
<tr>
<td>Stochastic</td>
<td>Treats variability as a determinant of sustainability and a component of predictions</td>
</tr>
<tr>
<td>Diagnostic</td>
<td>Uses an integrated measure of sustainability to identify and prioritize constraints</td>
</tr>
</tbody>
</table>
essential for guiding change, but may work against motivating change because it may call prescribed approaches into question.

Thirdly, an approach to characterizing sustainability should be quantitative. Although MacRae et al. (1989) cited quantification as a barrier to sustainability, others see it as a prerequisite to using sustainability as a criterion for evaluating and improving agricultural systems (Monteith, 1990; Harrington, 1992). Sustainability is often treated as a discrete property: ‘A farm is either sustainable or it’s not sustainable. Simply by definition, you cannot create a system that is half sustainable’ (Rodale, 1990). However, comparisons among agricultural systems or alternative approaches are possible only when sustainability is treated as a continuous quantity (Lynam & Herdt, 1989; Harrington, 1992).

Fourthly, since sustainability deals with future changes, its characterization must be predictive of the future rather than merely descriptive of the past or present (Harrington, 1992). Sustainability has little meaning after the fact. The deterministic view that ‘...a farm will either last for a very long period, or it won’t’ (Rodale, 1990) does not take into account the uncertainty of predictions resulting from the inherent variability of the farming system’s environment. A stochastic approach, the fifth element, recognizes variability as a determinant of sustainability and appropriately expresses predictions in terms of probabilities.

Finally, characterization of sustainability should be diagnostic. Sustainability is a useful concept when its characterization focuses research and intervention by identifying and prioritizing its constraints. Diagnosis can be accomplished by testing hypotheses about constraints using a measure of sustainability that is both comprehensive and integrated. ‘Unsustainability’ may be easy to recognize when a dominant constraint is apparent. In the absence of obvious constraints, inferences about sustainability are difficult and must be based on a comprehensive measure that accounts for the range of possible determinants. Diagnosis is facilitated by use of a single measure of sustainability that combines the range of possible determinants into a single, integrated measure of system response. An integrated measure is necessary for comparing, for example, the relative impact of nitrate leaching into aquifers and product price volatility on sustainability.

Weaknesses of the reviewed approaches for characterizing sustainability can be related to failures to incorporate the proposed elements (Table 6). Characterization based on adherence to prescribed approaches fails because it is not founded on a literal interpretation of sustainability. Attempts to relate sustainability defined as an approach to the ability to continue result in circular logic. Lack of integration limits the usefulness of multiple indicators of sustainability for diagnosing and prioritizing
TABLE 6
Approaches to Characterizing Agricultural Sustainability. A Check (/) Indicates the Approach Incorporated the Specified Element. A Question Mark (?) Indicates it Addressed Some Aspect of the Element.

<table>
<thead>
<tr>
<th>Approach</th>
<th>Reference</th>
<th>Literal</th>
<th>System-oriented</th>
<th>Quantitative</th>
<th>Predictive</th>
<th>Stochastic</th>
<th>Diagnostic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduced use of chemicals relative to other farmers in South Dakota</td>
<td>Dobbs et al., 1991</td>
<td></td>
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<tr>
<td>Quantitative index of cabbage farmer practices in Malaysia</td>
<td>Taylor et al., 1993</td>
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<tr>
<td>Adoption of alternative practices and reduced chemical use on US Pacific Northwest farms</td>
<td>Cordray et al., 1993</td>
<td></td>
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<tr>
<td>Indicators of resource base, system performance and external effects in agroforestry gardens</td>
<td>Torquebiau, 1992</td>
<td></td>
<td></td>
<td>√</td>
<td>√</td>
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<tr>
<td>Indicators of visible, masked and potential degradation in Himalayan farming systems</td>
<td>Jodha, 1990</td>
<td></td>
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<tr>
<td>Indicators of regional 'agro-ecosystem health'</td>
<td>Neher, 1992</td>
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<tr>
<td>Index of assured output and output per unit input and per unit limiting resource decline</td>
<td>Lal, 1991</td>
<td></td>
<td></td>
<td>√</td>
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<td></td>
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<tr>
<td>Index of productivity, stability and degradivity</td>
<td>Sands &amp; Podmore, 1993</td>
<td></td>
<td></td>
<td>√</td>
<td>√</td>
<td></td>
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<tr>
<td>Subjectively weighted index of constraints to nine system attributes</td>
<td>Stockle et al., 1994</td>
<td></td>
<td></td>
<td>√</td>
<td>√</td>
<td></td>
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<tr>
<td>Non-negative time trend in output</td>
<td>Lynam &amp; Herdt, 1989</td>
<td></td>
<td></td>
<td>√</td>
<td>√</td>
<td>√</td>
<td>?</td>
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<tr>
<td>Approach</td>
<td>Reference</td>
<td>Literal</td>
<td>System-oriented</td>
<td>Quantitative</td>
<td>Predictive</td>
<td>Stochastic</td>
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<tr>
<td>Total factor productivity accounting for natural resources in cropping systems in Nigeria</td>
<td>Ehui &amp; Spencer, 1992</td>
<td>√</td>
<td>√</td>
<td>√</td>
<td></td>
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<tr>
<td>Regional trends in inputs and outputs in India</td>
<td>Monteith, 1990</td>
<td>√</td>
<td>√</td>
<td>√</td>
<td>?</td>
<td>?</td>
<td></td>
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<tr>
<td>Properties representing resilience</td>
<td>Conway, 1994</td>
<td>√</td>
<td>√</td>
<td>?</td>
<td></td>
<td>?</td>
<td></td>
</tr>
<tr>
<td>Production trends and resilience in shifting cultivation in Malaysia</td>
<td>Cramb, 1993</td>
<td>√</td>
<td>√</td>
<td>?</td>
<td></td>
<td>?</td>
<td></td>
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<tr>
<td>Simulated trends and variability in crop production and NO₃⁻ leaching</td>
<td>Singh &amp; Thornton, 1992</td>
<td>√</td>
<td>√</td>
<td>√</td>
<td>√</td>
<td></td>
<td>√</td>
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<tr>
<td>Simulated crop production trends in response to simulated soil erosion in Canada</td>
<td>Lerohi, 1991</td>
<td>√</td>
<td>√</td>
<td>√</td>
<td>√</td>
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<tr>
<td>Simulated survivability of Texas rice farms</td>
<td>Perry et al., 1986</td>
<td>√</td>
<td>√</td>
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constraints. Integration of indicators has been difficult because the underlying interpretation of sustainability as an ability to meet diverse goals is not integrated. Time trends and resilience are based on literal interpretations of sustainability. Trends represent an integrated system response potentially useful for diagnosis, and can be predictive by extrapolation, but are not stochastic in the sense of accounting for variability. Resilience has not yet been defined in an integrated manner. The assumptions about future variability and disturbances necessary for resilience to be predictive and stochastic are avoided in discussions of its use for characterizing sustainability. Simulated farm survivability is the only approach reviewed that incorporates all of the elements listed.

CONCLUSIONS

There is widespread consensus about the importance of sustainability and its desirability as a goal for agriculture. However, its potential as a criterion for guiding agriculture as it responds to change has not been realized. Characterization is a prerequisite to using the concept of sustainability as a basis for guiding change. Logical inconsistencies limit the usefulness of characterization based on interpretations of sustainability as an ideological or management approach to agriculture. Interpreting sustainability as an ability to meet a diverse set of goals suggests measuring sets of system indicators consistent with those goals. However, these measurements have proven difficult to integrate and interpret in a manner that identifies constraints and focuses research.

Literal interpretations of sustainability as an ability to continue into the future suggest measurable, integrated criteria for its characterization. However, applications of these criteria — time trends and resilience — have neglected or misinterpreted important aspects of system performance that influence sustainability. Criteria are needed that relate levels, trends and variability of long-term systems performance to the needs and goals of farmers and of society.

In order for sustainability to be a useful criterion for guiding change in agriculture, its characterization should be literal, system-oriented, quantitative, predictive, stochastic and diagnostic. These elements identify weaknesses in existing and proposed approaches, suggest directions for future development of approaches and together constitute a systems approach for characterizing sustainability of agricultural systems. The tools of systems analysis and simulation must be part of approaches that incorporate all of these elements.
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