ARTICLES

Defining and Using the Concept of Sustainable Agriculture

Ray R. Weil*

ABSTRACT

Sustainability has recently become a buzzword for agricultural programs in education, extension, research, and government policy. For effective communications among those teaching, studying, and practicing agriculture, it is essential that there be some agreement as to the definition of the term *sustainable agriculture.* The definition should be general enough to accommodate the wide range of agricultural situations in which it will be applied, yet specific enough to provide criteria by which the sustainability of alternative systems may be judged. To allow the greatest combination of utility and flexibility, the definition should be "ends oriented" rather than "means oriented." This article presents one such definition, discusses several definitions proposed by others, and attempts to clarify some concepts such as "low-input" often associated with the sustainability issue.

WIDESPREAD INTEREST in the concept of sustainable agriculture is a relatively recent phenomenon. Government, academic, and business entities that ignored nonconventional systems a decade ago are now actively promoting the concept of sustainability in their programs. Many universities have recently offered new courses to address the issue of agricultural sustainability, while several have even developed a degree program in sustainable agriculture (Howell, 1989).

Sustainability has become an educational and political buzzword, but one that means different things to different people. For effective communications among those teaching, studying, practicing, regulating, or patronizing agriculture, it is essential that there be some agreement as to the meaning of the term *sustainable agriculture.* Otherwise, government and private programs developed with the aim of promoting or subsidizing research on, and farmer transition to, sustainable agriculture might end up just promoting old standard practices under a new name. Likewise, without a suitable definition, students and instructors will not share a common understanding of what types of agricultural systems and approaches are appropriate for inclusion in courses addressing the subject. The definition must be general enough to accommodate the wide range of agricultural situations in which it will be applied, yet specific enough to provide criteria by which the sustainability of a proposed system may be judged. This article presents one such definition, discusses several others, and attempts to clarify some concepts often associated with sustainable agriculture.

Agronomy Dep., Univ. of Maryland, College Park, MD 20742. Contribution from the Dep. of Agronomy, Univ. of Maryland, College Park. Received 16 Oct. 1989. *Corresponding author.

Published in J. Agron. Educ. 19:126–130 (1990).

BASIC CONSIDERATIONS

The adjectives *biological, ecological, alternative, regenerative,* and *low-input* are commonly used to refer to seemingly similar concepts of agricultural systems. The term *sustainable agriculture* is herein defined broadly enough to include all of these concepts to some degree, and also address a specific set of criteria.

In authorizing $3.9 million for research on sustainable/low-input agriculture in 1987–1988, the U.S. Congress specified two such criteria: that this agriculture should lower costs (thus presumably improve farm profits) and reduce negative impacts on soil and water resources (Madden and O'Connell, 1989). To these criteria, Francis et al. (1987) adds the goal of at least sustaining the current level of agricultural production. Three schools of thought on sustainability were noted by Lowrance et al. (1986) as being concerned with: food self-sufficiency, land stewardship, and preservation of rural communities. It could be argued, in addition, that to be sustainable in the long term, agriculture must provide society with quality food high in nutrition and taste value and free from potentially toxic pesticide residues. Authors such as Knorr and Vogtmann (1983) and Clancy (1990), therefore focus on food quality and human health as issues of sustainability.

Thus, three broad areas of concern seem to underlie the concept of sustainable agriculture: (i) *economic* concerns over economic justice, the survival of owner-operated farms, and the long-term profitability of agriculture; (ii) *environmental* concerns over adverse impacts of agriculture on land, water, and wildlife resources; and (iii) *public welfare* concerns over food quality and human exposure to toxic chemicals.

The degree of integration also sets the sustainable agriculture approach apart from more conventional approaches. A sustainable agriculture integrates all components of a system in the horizontal, vertical, and time dimensions. In the horizontal dimension, field-scale systems must be analyzed for their implications at the farm, watershed, regional, and national levels . . . and vice versa (i.e., national policies must be evaluated in terms of their regional and farm-scale impacts, etc.). Lowrance et al. (1986) suggest that different types of considerations will predominate at different levels—agronomic at the field-scale, micro-economic at the farm-scale, ecological at the regional scale, and macro-economic at the national scale. In any case, the sustainability of a practice or program applied at one level must be judged in the context of its impacts at the more broad and narrow levels. For example, introducing cattle (*Bos taurus*) into a grain-based system at the whole farm level will result in changes in crop rotations and manure input at the field level, as well as changes in land-use patterns and nutrient cycles at the watershed and regional levels. Vertically, field-scale systems must be integrated with input supply, marketing, consumption, and disposal/recycling . . . and vice versa. Likewise, systems must be projected in the time dimension over entire rotations, and long-term (decades, centuries) resource and social cycles. In recognition of this, F.E. Hutchison, in opening an International Conference on Sustainable Agriculture at Columbus, OH, in 1988, remarked that the concept of sustainability "simply adds a long-term time dimension to discussions on farming systems."

Because agriculture involves site and situation specific processes, it is probably not possible to define sustainable agriculture in terms of specific sets of *practices*. Also, because sustainability is dependent on social, political, and economic factors, these factors cannot be divorced from the definition of sustainable agriculture (Altieri, 1986). By its biological and social nature, agriculture is not static. A sustainable agriculture must be capable of continually evolving, while preserving the social and natural resources upon which it is based.

DEFINITION AND CRITERIA

It may be of less importance to assess the sustainability of a system as currently practiced, than to assess the sustainability of changes proposed in the system. The underlying basis of the definition proposed here is that it is easier to judge the *direction* in which a new technology or policy will move an agriculture system than it is to judge the absolute sustainability of a system as it is. In December 1988 at the Annual Meetings of the American Society of Agronomy, Soil Science Society of America, and Crop Science Society of America, I had the privilege of facilitating a discussion group of about 250 agronomists that developed a definition of sustainable agriculture that could serve this purpose:

"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" (Anon., 1989).

Another definition proposed here, which is modified from Weil (1988), sets forth three sets of criteria by which the direction, toward greater or less sustainability, may be judged. To be judged sustainable, changes to the current system should be an improvement over present practice and policy by *all three sets of criteria*. The definition is as follows:

An agricultural program, policy, or practice contributes to agricultural sustainability if it:

1. Enhances, or maintains, the number, quality, and long-term economic viability of farming and other agricultural business opportunities in a community or region.
2. Enhances, rather than diminishes, the integrity, diversity, and long-term productivity of both the managed agricultural ecosystem and the surrounding natural ecosystems.
3. Enhances, rather than threatens, the health, safety, and aesthetic satisfaction of agricultural producers and consumers alike.

Using this definition, certain inputs or practices may be judged "sustainable" in one situation but not in another, or at one point in the evolution of a system, but not at a later point. Such a definition treats sustainable agriculture as a dynamic system and is operational despite our imperfect knowledge of the system. It can hopefully serve to guide agriculturalists and policy makers in their efforts to make agriculture more sustainable.

It should be noted that both the ASA definition and that proposed here involve *ends* rather than *means*. A means-oriented definition would require prejudgment of certain types of practices (e.g., use of nitrogen fertilizers) and policies (e.g., price supports), hence would stifle creativity in government, in the marketplace and among individual farmers. Ideas for changes in policy and practice should be judged, on an ad hoc basis, by how well they meet the goals or "ends" laid out in the above definitions.

THE LOW INPUT ISSUE

The term *low input* is not found in these definitions because it is a means to the ends of economic viability, resource conservation, and environmental protection, but not necessarily the only or best means to those ends. This is not to say that the low input concept does not have a place in agricultural sustainability; reducing the use of many purchased inputs would, in many cases, enhance sustainability by the above criteria.

As the recently coined acronym LISA (Low Input Sustainable Agriculture) associated with a USDA research grants program implies, excessive use of off-farm purchased inputs may jeopardize sustainability by squeezing farmer profits, disrupting ecosystems with off-target effects, and depleting nonrenewable resources. Indeed, in many cases reduction or elimination of certain off-farm inputs may be an important component of strategies to increase sustainability. Low input is not an appropriate basic criterion of sustainability, however. Rather it is one of several possible *means* of achieving the ends of sustainability. For example, where soils are depleted of mineral reserves and being farmed destructively with little or no off-farm inputs, a modest *increase* in inputs in the form of lime or phosphate may be necessary to establish a sustainable system. The use of the term low-input is also rendered nearly meaningless when considered in the light of the level of inputs of fossil fuel and industrially manufactured equipment employed on *sustainable* grain and cattle farms, in different parts of the world, e.g., one a 200-ha mechanized organic farm in Ohio, and the other a sustainable farming system for peasants in a country like Tanzania.

Low input in the pursuit of sustainability does not necessarily mean an overall reduction in inputs, but rather a switch away from inputs that derive from nonrenewable resources (fossil fuels, fertilizers, pesticides, paleo-groundwater, etc.) or inputs that have negative side effects on the health of ecosystems and people (toxic herbicides, insecticides, excessive nitrate-producing manure or fertilizer applications, etc.) toward inputs that enhance or do not deplete the resource base and have positive rather than negative side effects (release of natural predators of pests, legumes crops that supply N in rotations, knowledge of weed and insect life-cycles, and, in some cases, labor).

When held up to the criteria in the definition proposed above, inputs that favor sustainability are often found to be those that are internal to the farm or to the local agricultural community (such as soil, labor, management, savings, natural enemies of pests, etc.) as opposed to those that are external and not controlled by the farmer and the local community (purchased chemicals, loans, government subsidies, purchased machinery, etc.). Although the distinction between internal and external resources (a concept developed by Rodale, 1988) is a useful one, external resource use cannot be condemned out-of-hand. The distinction between external and internal is not always clear-cut. Each case should be judged by the criteria of sustainability. Genetically engineered pest resistance in crop seeds and research-generated information are examples of external resources that may become internalized.

When the conventional agriculture of the past several decades is held up against the criteria of sustainability, it is clear that there is much room for reduced inputs. Most state soil test labs report that the number of farm fields testing high or very high in P increased dramatically from the 1950s to the 1980s. The widespread occurrence of excessively high P soil tests indicates that P fertilizers (or in some cases animal manures) have been over-applied. Phosphorus is a very costly input derived from a nonrenewable resource and, when washed into lakes and streams with eroded soil, causes algal blooms and eutrophication. Therefore, restriction of P fertilizer application to moderate rates applied only on soils that can be demonstrated to be economically responsive to P would be a good example of lower-inputs leading to greater sustainability. Other technologies that might be pursued to achieve some of the same goals with respect to P might include more efficient recycling of this nutrient through crop residues, manures, sewage sludges, and biological pumping from deep substratum reserves by deep-rooted crops, as well as improvements in mycorrhizal symbiosis with crop plants.

Nitrogen fertilizers (and manures, in some cases) present a similar record of over-use, the reduction of which would often lead to greater sustainability by all of the above criteria. Nitrogen that finds its way into groundwater in agricultural watersheds represents application of this inherently expensive (though sometimes artificially cheap) input in excess of crop needs. The environmental consequences of excessive N application are potentially very serious indeed, ranging from the formation of carcinogens in drinking water to eutrophication of estuaries, to accelerated depletion of the stratospheric ozone layer by catalytic gases formed from N in soils.

Although it may not be possible to provide enough readily available N in soils for high corn (*Zea mays* L.) yields without some leaching losses, concentrations of two to three times the USEPA drinking water standard for NO_3 are typical under cropland in many regions and are indicative of excessive or poorly timed applications. This is true where the source of N is commercial fertilizer as well as where the source is animal manures. In fact, in many regions the worst cases of excessive nitrate-N contamination of groundwater are associated with concentrated livestock operations. Nitrogen soil tests for corn production (Beegle et al., 1989) and tissue tests for wheat (*Triticum aestivum* L.) production (Alley, 1989) currently under development in several states promise to provide important tools for rationalizing N use on these crops.

Other areas abound in which the concept of lower inputs could contribute to sustainability. The application of pesticides according to spray schedules rather than as a last recourse in response to pest populations demonstrated to exceed economic thresholds, is a case in point: imposing unnecessary costs and posing unnecessary risks to farm workers, wildlife, and consumers alike. The concept of integrated pest management (IPM) has a major role to play in enhancing agricultural sustainability, specifically with regard to insect pests (to which the great majority of the effort has been applied to date), weeds (which have received relatively little IPM attention), and plant and animal diseases. Still another area in which inputs have often been excessive is that of farm machinery, with the need to make payments on larger and newer-than-necessary tractors and combines, which drive over-capitalized farmers to push for maximum yield and short-term profits, at the expense of good husbandry.

Based on theoretical calculations, it is often suggested that low per-unit costs of production, and therefore high profits, require high levels of inputs to achieve high yields. The levels of inputs considered most profitable are typically based on quadratic production function curves. The most profitable input rate is extrapolated from that point on the curve where the last dollar spent on the input results in just one additional dollar of output.

Recommendations based on such calculations are unrealistic, in that at a much lower rate of input use the returns would become low enough that the farmer could better invest the next dollar in some other input or enterprise with a greater rate of return. Add to this the high degree of risk associated with the tremendous year-to-year variations in these production functions and in commodity prices, and it is obvious that the true economic optimum rate of input use may be far below that recommended. That this is the case was supported by a recent study by the USDA Economic Research Service (Glaze and Ali, 1988). They reported that, among the commercial wheat producers surveyed, those with the highest costs of production per bushel were also those with the heaviest use of fertilizers and agricultural chemicals. If these statistics are representative, they bear important implications, not only for the role of "low-input" farming in the viability of individual farm enterprises, but also for the sustainability of American agriculture in a competitive world market. The latter would become especially relevant should there be a general elimination of agricultural subsidies through the upcoming General Agreements on Trade and Tariffs (GATT) negotiations.

In addition to the low input concept, there are numerous other means that are generally, but not always, relevant to achieving greater agricultural sustainability. To save space, I will list several of these with only very brief discussion.

1. *Biological diversity.* Species diversity is usually a sign of ecological stability. A diversity of crop and animal enterprises on a farm also often lends economic stability.
2. *Crop rotations.* Along with increasing diversity, crop rotations are known to reduce soil erosion, ameliorate pest problems, improve soil fertility (especially if legumes are included in the rotation), and also produce an additional, unaccounted for 10 to 15% increase in crop yields.
3. *Animal integration.* Plant and animal production are so complimentary that integration of animals into farming systems often seems essential to developing a sustainable system. Concentration of livestock production separate from crop production makes it difficult to justify the kinds of rotations that enhance sustainability. It also makes manure a serious waste disposal problem instead of a valuable on-farm resource.
4. *The soil as biological system.* An understanding of this concept leads to the use of management practices designed to enhance the viability and diversity of soil organisms (microbes, arthropods, earthworms, etc.) and biological functions (organic matter and nutrient cycling, etc.). Formal research on the application of this concept is sparse, but its role in successful, stable, low input farm operations is often acknowledged by researchers and farmers alike.
5. *Knowledge-based farming.* Sustainable agriculture will probably depend increasingly on sophisticated information on weather prediction, pest life cycles, soil processes, markets, and the like, melded into a holistic understanding of the agro-ecosystem and the agricultural community. An important aspect of this arena is the ability of the individual farmer to assimilate and, in many cases, to generate the information and insights needed to allow him or her to adapt to changing circumstances. Sustainability implies a dynamic, self-adjusting system.
6. *Human scale farm size.* There is no simple answer to how big is too big for sustainability, but the trend of the past few decades toward ever larger farms, operated by ever fewer farmers who are ever more remote from their fields is one that does not stand up well to the criteria of sustainability, both in terms of substituting management for nonrenewable resources, and in terms of sustaining the numbers of economic opportunities in farming.
7. *Minimal dependence on nonrenewable resources.* Agriculture has been practiced for thousands of years and will continue to be needed as long as large numbers of humans populate the Earth. The basic resources of agriculture are *sunlight, air (carbon and oxygen), water, soil (including the nutrient elements therein), germplasm (of animals, plants and microbes), and farmers (with their skills, knowledge and labor).* These resources are renewable and can sustain agriculture in perpetuity, if managed well. An agriculture cannot be sustained in the long run if it depends on the one-way, dead-end street of nonrenewable resources use; e.g., burning fossil fuels, dispersing pesticides made from fossil fuels, or mining nutrients and dispersing them without recycling. Soil can only be considered renewable if not allowed to erode away faster than it forms.

SUSTAINABILITY AS A PIVOTAL CONCEPT FOR AGRICULTURAL POLICY, EDUCATION, AND RESEARCH

The concept of sustainability is meant to integrate economic, social, and environmental dimensions of agriculture. This is not merely an artificial construct. Rather it is a recognition of the fact that all these aspects are interconnected. Policies and practices will not meet the test of sustainability unless they satisfy all three sets of criteria given in the definition. Although it might be fine to have a particular piece of legislation or research project devoted to such components of sustainability as soil conservation or low-input farming technology, sustainability requires that *all* government policies and *all* agricultural research meet the three criteria of sustainability. Otherwise, the overall government programs will become riddled with inconsistent provisions working at cross-purposes, and research will solve isolated problems without generating integrated systems, with the net result being little or no progress toward a more sustainable agriculture. It must also be asked "does this provision or project move agriculture in the direction that we want it to go during the next 10 or 100 yr?" If continued, movement down the road laid out would seem to lead inevitably to undesirable consequences, then the direction should be altered now.

The commodity price-support programs are a good example to consider. It has become clear to many people that these programs, intended to put a floor under farmer incomes, have had far-reaching impacts on many aspects of the agricultural system. The abandonment of diverse crop rotations in the Corn Belt can be partially attributed to disincentives provided by the base acreage provisions of that program. Price supports, in general, also tend to take some of the risk out of heavy investments in production inputs and probably contribute to higher levels of fertilizer and pesticide usage than would be the case without them. The price support program also encourages the concentration of production on certain commodities (often those produced in surplus).

In the absence of sustainability criteria, the emphasis of applied research at Land Grant Institutions has tended to be influenced by such factors as gifts and small grants from private industry, the academic pressures on individual researchers to focus solely on their narrow specialty, and the desire of extension personnel for easily recommended, widely applicable technical fixes for specific production problems. As a result, non-product-oriented, interdisciplinary systems research has been almost nonexistent. Perusal of almost any extension guide to pest control will reveal the tremendous imbalance between ecologically based information and specific chemical fixes. Such a guide typically contains more than 100 pages of tables listing what chemical to use for which weed or insect at what rate. Only a few sentences are devoted to the general idea of cultural controls and cropping system management, with few, if any, specific suggestions for effective mechanical weed control, rotations, etc.

An overall sustainability standard could help broaden research and extension approaches to better deal with whole systems and the concept of maximizing farmer self-reliance for information and other inputs. The 2-year-old LISA research grants program is a small, though exemplary start in this direction. Given the extremely modest funds available (<$0.1 million per state), it is amazing how great an effect this new program is having on the kinds of research projects being undertaken, on the development of interdisciplinary linkages, and on the farmer involvement in research and technology development.

In education the holistic approach to sustainability would suggest that there be more interweaving of ecological and social considerations in technical agronomy courses and that standard practices running counter to the criteria of sustainability be discussed more as stop-gap measures than permanent management approaches. Even with this kind of emphasis on sustainability throughout the curriculum, it might be useful to create a capstone course that focuses on integrating a wide range of technical material into holistic, sustainable agricultural systems.

The holistic nature of sustainability suggests that in all policy and program areas, those options that would tend to increase the number of farming and related agricultural jobs in a community and improve the working conditions in those jobs should be favored over those that would not. Those options that would tend to encourage further specialization and concentration should be rejected in favor of other options that would not do so. Programs should be favored that tend to promote the integrity of the agro-ecosystem, its homeostasis and self-regulating, self-supporting ability. Programs that promote the use of chemicals toxic to humans and/or other nontarget organisms should be replaced whenever possible with programs that lessen the toxic load in the environment. Thus, as far as possible, the criteria of sustainability should help shape all farm policies, research programs, and curricula. In this way it may be possible to empower students and farmers to control their own destinies, to provide proper stewardship for our nations natural resources, and provide a future for rural communities.

REFERENCES

Alley, M. 1989. Help customers make wise, efficient use of N fertilizer applications on wheat. Solutions. January 1989, p. 20–24.

Altieri, M.A. 1986. Agroecology: The scientific basis of alternative agriculture. 2nd ed. Div. of Biol. Control, Univ. of California, Berkeley, CA.

Anonymous. 1989. Decision reached on sustainable ag. Agronomy News. January, p. 15.

Beegle, D., R. Fox, and G. Roth. 1989. Nitrogen soil test for Pennsylvania. Agron. Facts no. 17. Agronomy Dep., Pennsylvania State Univ., State College, PA.

Clancy, K. 1990. Agriculture and human health. *In* C.A. Edwards et al. (ed.) Sustainable agricultural systems. Soil and Water Conserv. Soc., Akeny, IA.

Francis, C.A., D. Sanders, and A. Martin. 1987. Search for a sustainable agriculture: Reduced inputs and increased profits. Crops Soils 39(9):12–14.

Glaze, D., and M. Ali. 1988. Distribution of cost and production for wheat farms. Agricultural income and finance: Situation and outlook report. AFO-31. Econ. Res. Service, USDA, Washington, DC.

Howell, D. 1989. Organic agriculture: What the states are doing. Center for Science in the Public Interest, Washington, DC.

Knorr, D., and H. Vogtmann. 1983. Quality and quality determination of ecologically grown foods. p. 352–381. *In* D. Knorr (ed.) Sustainable food systems. AVI, Westport, CT.

Lowrance, R., P.F. Hendrix and E.P. Odum. 1986. A hierarchical approach to sustainable agriculture. Am. J. Altern. Agric. 1:169–173.

Madden, P. and P. O'Connell. 1989. Early results of the LISA program. p. 1–10. *In* Agric. Libraries Information Notes. Vol. 15 (6/7). USDA, Beltsville, MD.

Rodale, R. 1988. Agricultural systems: The importance of sustainability. National Forum 58(3):2–6.

Weil, R.R. 1988. Developing an operational definition of sustainable agriculture. p. 121. *In* Abstracts Intl. Conf. on Sustainable Agric. Systems, Columbus, OH. 19–23 Sept. Ohio State Univ., Columbus, OH.