Sustainable Agriculture and the Environment

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Abstract

Sustainable agriculture will continue indefinitely and will supply the world's food, fiber and esthetic needs of its citizens. Issues involving the environment are central to sustainable agriculture. Recorded history has many examples of civilizations and nations that suffered or even disappeared because their agriculture was not sustainable. Today, many aquatic and terrestrial ecosystems are showing stress because of agriculture practices that are not in harmony with the environment. Erosion, salinization, desertification, water pollution and climate change are affecting agricultural productivity in many nations. The agricultural practices identified with environmental degradation include overgrazing, poor irrigation practices, excessive row cropping leading to erosion, overuse or misuse of agricultural chemicals, and bringing land into production that is too fragile to grow crops. Corrective actions leading to a sustainable agriculture are necessary soon before the growing and more demanding world population requires food and fiber at levels that cannot be supplied with current agricultural systems. This will require major changes in the world's food growing patterns and approaches. Needed changes include research to find more appropriate crops and practices and using holistic principles in the development of agricultural systems. While free trade promises to raise living standards, benefits must accrue to all the population for agriculture to be sustainable. Otherwise, environmental degradation will continue as the poor gather firewood and water and use unstable lands for food. Developed nations have an obligation to help stabilize the environment by supporting policies and research that will lead to a more sustainable agriculture in all nations.

Introduction

The high demands on sustainable agriculture (and on sustainable development) and the problems that sustainability has had fitting into the short-term political and economic agendas of developed and developing nations and international conglomerates, have made sustainability a controversial and poorly understood concept (Pretty *et al.*, 1996; Harremoes, 1996). At the World Summit in Rio, for example, sustainable agriculture was a major item in Agenda 21 (Ryan, 1992), but there is little chance that the items in Agenda 21 will be implemented in the near future. Many assessments of current and future world food needs such as those by Ruttan (1991), Crosson (1993) and Pretty (1996) project that by 2030 world population will have risen to about 8.5 billion and that food demand will be at least doubled the present needs. Lester Brown (1995), in his controversial book "Who Will Feed China?," compares food needs and development of several Pacific Rim countries that have developed strong ex-

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port economies. His analysis suggests that high grain demands in the future will be accompanied by lower production in developing Asian countries, particularly China, because of: (a) land degradation, (b) water pollution and lack of water to distribute between agriculture and urban areas, and, (c) diversion of productive lands for housing and industry. These same trends are underway in many other countries, including developed countries such as the United States. The pessimistic view of Brown and others is that increased food production by use of technology will not be able to keep up with the production loss to the above factors, leading to a greatly increased demand and cost of grain worldwide. A different view is presented by Bender (1996). He proposes alternate strategies to address growing demand for food including improving food processing and delivery efficiencies, and change of diet that would keep the need for food in line with increased worldwide production.

Most predict that population will not stabilize for 30 to 50 years. This critical period comes at a time when the knowledge of agricultural production and its environmental consequences are greatly expanded (Ruttan, 1991; Crosson, 1993; Hatfield and Keeney, 1993). There are many views on how to reach the elusive goal of a sustainable society. Their suggestions range from a change in ethics from anthropocentric to ecocentric views and actions (Harremoes, 1996) to intensification of agricultural inputs and productivity worldwide on the world's prime farm lands (Avery, 1997). Harremoes (1996) in his philosophical discussion, defines the two main components of sustainability:

"Society should use its resources such that the society can continue its mode of operation without exhausting its resources." and "Society should protect the environment against irreversible damage, including protection of unique species and habitats." He identifies water quantity and quality as the most important environmental compartments to protect. I would also include soil quality as a key component (Keeney and Cruse, 1997).

Sustainable agriculture defined

There seems to be a general consensus that sustainable development refers to the need to meet the needs of the present without compromising the ability to meet needs of future generations (e.g., Harremoes, 1996). However, the literature indicates that little agreement has been attained on operational definitions of sustainability (Cocklin, 1995). In essence the debate swirls around what is being sustained, for whom, and for how long. The term has social, environmental and economic dimensions, leading few to hope for consensus in the near future. The social, environmental and economic triumvirate is the reason for so many disagreements on sustainability concepts. Pretty *et al.* (1996) suggest a more sustainable agriculture that pursues a more thorough incorporation of natural processes, minimal use of external and non-renewable inputs that harm the environment or health of farmers and consumers, more participation of farmers, environmentalists, industrialists and consumers in problem analysis and development of solutions, equity in access of productive resources and opportunities, use of local knowledge, resources and opportunities, and greater self-reliance among farmers and rural communities. Notably, Pretty *et al.* (1996) involved human resources, concerns and indigenous knowledge in their discussion.

Sustainable agriculture and environmental concerns

A major agenda of sustainable agriculture is related to environmental protection and enhancement (Keeney, 1990, 1993, 1997). Table I summarizes the concerns I feel must continually be addressed by agriculture through research, development and application of technologies to food and fiber production. Nonpoint source pollution involves human and animal pathogens, nitrate and pesticides in ground and surface water, phosphorus and other nutrients in surface water, and sediment loads in water. A related issue is wind-blown sediment and other pollutants from dry uncovered soils, Other concerns include food safety (in particular presence of toxins, heavy metals and pesticides in foods), food quality, air quality including odors, greenhouse gases and acid rain.

Table 1 Environmental concerns associated with agriculture

Nonpoint source water pollution
Drinking water:
Nitrate, Pesticides, Disease organisms
Surface water quality
Nitrogen, Phosphorus, Organic matter, Sediment
Atmosphere
odir, Dust, Greenhouse gases
Landscape concerns
Soil erosion
Soil quality
Biodiversity
Water pollution

Modification of a natural landscape for agricultural, industrial or urban uses will modify the ecosystem from what it was in the pristine state. Many of these problems have resulted from use of land in a manner that leads to its abuse, in other cases to modification of the landscape in ways that destroy natural drainage patterns, and in other cases to overuse of nitrogen and pesticides. Relatedly, the increased desire of people for cheap meat and dairy products has led to intensification of grain production, disturbance of natural pest control systems, reliance on pesticides, and over-application of animal-derived nutrients in manure, especially from intensive animal operations.

1 Nitrogen in the environment

There are numerous health and environmental issues associated with excess N in the environment. Health issues center around nitrate in drinking water (methemoglobinemia), while environmental issues concern productivity of fresh water bodies, estuaries and natural ecosystems, greenhouse gases, ozone destruction, acid rain, leaching of bases from soils and acceleration of losses in biodiversity (Vitousek *et al.*, 1997 ; Keeney, 1997).

2 Environmental accumulation of nitrogen

Nitrogen from anthropogenic sources, including fertilizers, biological N fixation and combustion, and activities that bring N from long-term storage pools such as forests have been estimated by several groups to be close to the same order of magnitude as the N from natural (preindustrial) sources (Vitousek *et al.*, 1996) (Table 2). This doubling of the available N pool worldwide has many implications. While most N issues are local and thus the global N cycle would not seem applicable, many issues have regional or global implications.

Table 2 Estimates of global nitrogen fixation

Source	1960	1990
	—millions of metric tons of N—	
Legume crops	30	40
Fossil fuel	10	15
Fertilizer	20	80
Total	60	145
Natural N fixation	80 to 130	80 to 130

Extrapolated from Vitousek *et al.* 1997.

Numerous studies, summarized by Hallberg (1989), Keeney (1986) and Hallberg and Keeney (1993) have documented the large increase in nitrate in groundwater in the US relative to pre-industrial levels. Natural background levels commonly are less than 2 mg nitrate-N/L while agricultural areas often exhibit seasonal levels greater than 10 mg/L. The numerous sources and sinks of nitrate make evaluation and control of sources difficult and hence establishment of policies and groundwater protection goals are controversial and often unproductive. Hallberg's (1989) review points out the interaction of ground and surface water systems, particularly those that impact shallow groundwater. Vitousek *et al.* (1996) summarize accumulation of nitrogen in surface waters, particularly riverine systems but also estuaries. For example Howarth *et al.* (1996) , cited in Vitousek *et al.* (1996), estimated that riverine fluxes from lands surrounding the North Atlantic Ocean have increased from pre-industrial times by 2- to 20-fold.

3 Methemoglobinemia

The health problems associated with high nitrate in drinking water have been discussed (Keeney, 1986 ; Canter, 1997). The 10 mg/L nitrate-N standard seems to have stood the test of time and is widely accepted, even though many drinking water supplies greatly exceed this limit. It is perhaps the most difficult issue to address, because evidence indicates that current agricultural systems often lose sufficient nitrate through leaching to the groundwater so that this standard is difficult to reach (Keeney, 1986). Most control efforts will involve the use of fertilizer and animal wastes in the most efficient and timely manner (Keeney, 1986 ; Canter, 1997)

4 Hypoxia

The large increase in nitrate flux to estuaries has been linked with greatly increased phytoplankton growth and subsequent drop in dissolved oxygen and in water quality (hypoxia) in numerous shallow ocean areas around the world (Keeney, 1997), including the Chesapeake

Bay and the Gulf of Mexico (Rabalias *et al.*, 1996). The Gulf of Mexico receives water from the Mississippi River basin which drains over 40% of the land area in the contiguous United States and includes some of the most productive farmlands in the world. Monitoring studies have shown that nitrogen contributions by the Mississippi River to the Gulf have more than doubled since 1960 and that about 60% of this nitrogen is derived from the so-called "corn belt" states, far removed from the Gulf. The economic and environmental effects of hypoxia in the Gulf of Mexico are hotly debated. Lessening of inputs will be difficult given the large land area involved, the numerous sources of nitrogen (Table 3), and the type of crop production practices involved (Keeney, 1997). Hallberg (1996) also emphasizes the slow change in nitrate concentrations in groundwater over time, even when significant lowering of N inputs has occurred. He notes no significant trends in water quality in the past decade in Iowa.

Table 3 Estimated sources and amounts of N inputs to and contributions from the Mississippi River basin to the Gulf of Mexico by the Mississippi River basin (Goolsby and Battaglin, 1995)

Total N input, 11 million metric tons per year (1987-1992 average)
Commercial fertilizer, 6.3 million tons (57%)
Animal manures, 2.8 million tons (25%)
Legumes, 2.8 million tons (17%)
Domestic and municipal waste, 0.9 million tons (8%)
Atmospheric deposition, 0.5 million tons (4%)
Nitrate-N contributed to the Gulf per year
1955-1969 average, 320,000 metric tons
1980-1995 average, 900,000 metric tons
1993 (high flow), 1.4 million metric tons
Total N contributed per year, 1980-1995 average, 1.5 million tons
Nitrate-N, 60%
Dissolved organic N, 26%
Particulate N, 13%
Total P contributed per year, 1980-1995 average, 110,000 metric tons
Orthophosphate P, 35%
Particulate P, 65%

5 Role of pesticides in sustainable agriculture

Pesticides, including herbicides, insecticides and fungicides, are fundamental tools for modern production agriculture. However, they have also caused considerable environmental damage ranging from extinction of species, human and animal health effects, and development of target species resistant to the action of the particular pesticide (Benbrook, 1996). One might ask the question: what is the true price of pesticides? Often market prices of pesticides do not reflect the social and environmental costs. For example, rice has been highly subsidized in Japan, causing farmers to receive high prices relative to the world market. This has encouraged high-yield technologies including pesticides, and Japan has by far the highest pesticide use (kg per hectare) in the world. Pesticides fit well into the intensive high-yield concepts promoted by "feed-the-world" advocates such as Avery (1995), but many studies have shown that they do not necessarily increase net income over the long-term and that they have long-term effects, not the least is a change in the structure of farming towards what is termed industrial agriculture. There are many sustainable agriculture systems available to reduce or eliminate pesticide use in particular crops, ranging from rotations, managing weeds according to ecological principles, and use of ecologically-based integrated pest management (Buhler, 1997; Benbrook, 1996). However, widespread adoption is not likely in the short term because of lack of research opportunities to develop low pesticide use systems, and the strong marketing efforts of the pesticide industry.

Sustainable agriculture technologies will continue to emphasize appropriate use of pesticides. However, current trends in agriculture favor even more reliance on chemicals as research probes increasingly high yield technologies, and as biotechnology places more emphasis on the development of herbicide-crop packages that require use of one herbicide for broad spectrum weed control. Nevertheless, there are situations where pesticides no longer will effectively control the target pest and ecologically based pest management principles must be employed (Benbrook, 1996).

6 Soil quality

Perhaps the most important long-term issue in sustainable agriculture is the quality and conservation of soil (Keeney and Cruse, 1997). The Soil Science Society of America (1995) defines soil quality as "The capacity of a specific kind of soil to function, within the natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation." Similarly, the Natural Resources Conservation Service (1995) defines soil quality as "The capacity of a soil to function for specific land uses or within ecosystem boundaries. This capacity is an inherent characteristic of a soil and varies from soil to soil. Such indicators as organic matter content, salinity, tilth, compaction, available nutrients, and rooting depth help measure the health or condition of the soil-its quality-in any given place". Importantly this definition also recognizes the concept of soil health/soil condition as a part of soil quality.

Soil quality is closely related to issues of soil conservation, and sustainable agriculture (Karlen *et al.*, 1990; NRC, 1993; Larson and Pierce, 1994; Warkentin, 1995). The 1993 report by the Board on Agriculture Committee on Long-Range Soil and Water Conservation (National Research Council NRC, 1993) has brought new awareness to this concept and to the relation of the soil to the environment and to the long-term sustainability of the soil resource. Soil quality concepts cover issues central to environmental soil science including soil compaction, soil salinization, soil organic matter as well as associated biological factors. Closely related are the factors such as soil structure, soil erosion index, and water infiltration.

The NRC (1993) report relates the impacts of soil quality on water and air quality, as well as on the efficiency of crop production practices. The report also considers the relationship of agricultural policies on soil quality. Soil quality issues overlap many of the issues of sustainable agriculture. This is, I feel, one of the most important interfaces of soil science to sustainable agriculture. As understanding of soil quality and the soil and crop management that affects soil quality is gained, the interaction with sustainable agriculture will become much clearer. However, even now a clear intuitive relationship between a healthy soil and a long-term productive agriculture must be acknowledged.

The NRC (1993) report recommends (p. 201) that the soil quality concept should be used to guide the recommendations for the use of conservation practices and for federal targeting of programs in resources conservation. It also emphasizes the importance of a holistic approach to the policy recommendations. The development of policies and technologies that expand production of row crops such as corn on highly erodible lands is a good example of our economic system rewarding operators for using unsustainable farming systems. Abler and Shortle (1995) point out that these innovations can reduce marginal cost and increase output demand because of lower prices. If crop production increases sufficiently, the total use of potentially polluting inputs as well as the amount of soil eroded would actually increase. Thus, the current push for more efficient technologies needs to be viewed cautiously. Rapidly developing technologies that must be considered with regard to their impacts on soil conservation and on sustainable agriculture include precision farming and biotechnology. Current policies that may decrease soil quality include the strong emphasis on exports (moving erodible land into production, use of non-conserving practices to maximize yield), emphasis on research and technology to increase grain production rather than on alternate crops and profitable crop rotations, and emphasis on chemical rather than on management alternatives for pest control.

The concept of designing agricultural practices for the landscape is not particularly new. The failure of in-field approaches to solve environmental problems (example, conservation tillage) has opened opportunities for a strong interface between sustainable agriculture and soil conservation when the landscape is considered. Landscape approaches include use of conservation easements for highly erodible land, vegetated buffer strips, strip intercropping, placement of livestock production areas to minimize water pollution and odor problems, and wetlands to remove contaminants from runoff. The combination of good science and a land use policy dedicated to environmental improvement and economical crop production offers widespread benefits. These include water quality enhancement, improved soil quality, ecotourism, and higher returns on land best suited for crop production. While much is promised from the landscape planning concept, delivery on the promises will require diligent effort. There are many hindrances, first and foremost the political and property rights issues which make landscape planning difficult at best. And, as well-stated by Stanley (1994), application of science or technology to solve ecosystem level resources or conservation problems often is difficult to impossible because of the human-based objectives of management. However, Peterson *et al.* (1993) have demonstrated the power of an agroecosystem approach to soil and crop management research at the landscape level without losing the ability to detect cause and effect, while providing technology transfer from the researcher to the user.

Soil quality likely offers the most promise for close linkage of the principles of soil conservation and sustainable agriculture principles. Therefore, exploratory and adaptive research in soil quality should be encouraged. Importantly, the landscape basis of soil quality enhancement should be evaluated and the socioeconomic and farmer assessment of soil quality must be placed in context with the agronomic aspects (Romig *et al.*, 1995). Warkentin (1995) puts it well "The exciting work of using soil quality concepts for sustainable production and environmental protection has just begun".

The future

As it evolves, sustainable agriculture will have much to offer regarding environmental protection. It will use the latest technologies consistent with a sustainable agriculture, and over time will be the agriculture accepted as conventional agriculture. Many new technologies are currently being developed for sustainable agriculture. One is managed intensive grazing, which allows beef and dairy to be produced without heavy reliance on grain, while maintaining erosion control with grass species; precision farming (also called site-specific farming) which permits management of production factors on a very small land area, allowing this area to be treated as a separate unit (Christensen and Krause, 1995). Plant breeding is another technology that offers much promise. New crops bred to provide season-long soil cover may be able to mesh soil conservation and sustainable agriculture. Improved fiber crops and perennials are also possible. However current industrial application of plant breeding, including biotechnology, appears to be concentrating on improved food and feed varieties of cultivated crops, particularly those that provide a strong profit to the industry (Duvick, 1991). Ecologically based pest management technologies fit well with the systems where pesticide options have grown too expensive, or where the consumer desire foods grown without pesticides (Benbrook, 1996).

New and improved technologies must be designed with the landscape, including the people, in mind. The development of sustainable systems must involve people, particularly those who own and manage the land, if sustainable agriculture is to be achieved. Therefore, to achieve success, research institutions, industry and government organizations must become learning organizations. Technologies must emphasize environmental protection on the landscape or ecosystem scale. Research needs are cross-disciplinary. Team approaches will be necessary and will need support from a wide array of technical and social sciences as well as end-users and policymakers. Most research will be long-term, high-risk research and development, something that is not easily supported by conventional organizations.

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