Agricultural sustainability: an overview and research assessment

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Agricultural sustainability has different meanings, depending on the context. But many people share a concern that the current, highly productive agricultural system has become so dependent on agrichemicals that problems have emerged affecting the environment, food safety, farm-worker safety, and production costs. There are hindrances to change, however, and research on low-energy-input farming is still developing. A broad approach is required, taking into consideration not only the farm production system but also the need to "sustain" society as a whole.

"Sustainable" is used by resource managers to refer to the maximum harvesting of forests or fisheries consistent with the maintenance of a constantly renewable stock. The same concept applies to the optimal use of a groundwater aquifer. Sustainability is the steady state in which what is being used (harvested) is continually replaced.

Sustainability has been defined by population biologists in terms of carrying capacity—the maximum population size that the environment can support on a continuing basis.

Agricultural sustainability is sometimes referred to as alternative, regenerative, low-input, ecological, environmentally sound, and even organic agriculture. These terms are used by people interested primarily in alternative systems of farming that will feed expanding populations while minimizing potential negative effects. Defining the negative effects essentially separates or categorizes the various proponents of sustainable agricultural systems. Some groups put primary emphasis on minimizing environmental damage and degradation; sustainability becomes almost synonymous with stewardship of the earth. Others want mainly to perpetuate a rural community system. Still others equate agricultural sustainability with food self-sufficiency while minimizing costs. Some advocate an energy-conservation agriculture, measuring efficiency of the system exclusively in terms of energy use. Other proponents argue that, because people require safe food and water, an agricultural system is needed that can operate forever with only meager dependence on inputs external to the farm.

Just as "sustainability" has different meanings in various contexts, the agricultural counterpart has social, ecological, economic, and emotional connotations.

The current agricultural system

A succession of new technologies has helped transform societies over the last few centuries from predominantly rural to urban. The heavy plow, the harness, and the nailed horseshoe doubled agricultural productivity with horses over that with oxen, according to historian L. White, Jr. Mechanical power replaced the horse early in this century, resulting in further productivity gains and releasing vast amounts of land for food production formerly used to produce animal feed. Over the last half century, the revolution in productivity for the developed, and to a lesser extent the developing world, has been from the chemical technologies applied to agriculture. The next technological revolution is expected to come from biotechnology, particularly recombinant DNA.

Since the turn of the century, a dramatic downward trend has occurred in the use of nonpurchased farm inputs—those produced on the farm—while purchased inputs, such as fertilizers, pesticides, equipment, machinery, and hired labor, have increased. Total production expenses in the United States have grown since 1900 from 45% to over 80% of gross farm income. Between 1950 and 1985, manufactured inputs, interest, and capital-related expenses as a share of total production cost almost doubled (from 22% to 42%), while labor and farm-origin input expenses declined from 52% to 34%. Similar trends are found in other developed regions and in the developing countries with the greatest productivity gains. If farming systems are to be "sustainable" in that they minimize the use of external inputs and maximize internal inputs already existing on the farm, a way must be found to reverse these nearly century-old trends.

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Relative prices are important in farmers' decisions to shift to or from energy-intensive production. A U.S. Department of Agriculture study shows that, during most of the last four decades, both farm wage rates and the price of farm machinery increased at a faster rate than the cost of farm chemicals, making fertilizers and pesticides relatively inexpensive factors to substitute for other inputs. Price incentives have thus contributed importantly to increased chemical use in the postwar years; these high chemical application rates have been only slightly moderated recently, in part because of their increased cost.

This agricultural system in the United States and other developed countries, which relies heavily on energy-intensive, purchased inputs, is without a doubt a success story in terms of traditional measurements of output and productivity. Agricultural abundance is now seen also in parts of the underdeveloped world. Many developing countries are participating in the global expansion of agricultural output. India, China, Bangladesh, and Indonesia have experienced dramatic turnabouts in production. The "green revolution," accompanied by applications of biotechnology to plant and animal agriculture, promises more.

Impetus to change

Despite the impressive gains and the hopes for continued or even expanded growth, the rate of increase in food productivity has been diminishing (table 1). Some question whether this portends some approaching capacity limits to productivity gains. At the same time, other concerns about current farming technologies are being raised:

Groundwater contamination. In some areas, agricultural chemicals and by-products have leached into underground aquifers used as a source of drinking water. In the United States, residues of 17 different pesticides have been detected in groundwater in 23 states, according to the U.S. Environmental Protection Agency. U.S. Economic Research Service economists Elizabeth Nielsen and Linda K. Lee found that about one-third of all U.S. counties are vulnerable to groundwater contamination by pesticides. In 1986, California voters passed Proposition 65, the Safe Water and Toxic Enforcement Act, which holds industries, including agriculture, directly accountable for their use of chemicals that can cause cancer, birth defects, or sterility.

Food safety/pesticide residues. Consumer attitude surveys have revealed that pesticide residues on agricultural commodities are judged to be a serious hazard to health. In fact, many consumers tend to be more worried about pesticides than about hazards that food safety experts feel are much more serious, such as fats, cholesterol, and microorganisms. There has recently been a spate of publications on the subject, including *Leaching Fields, Regulating Pesticides in Food: The Delaney Paradox, Pesticide Alert, The Invisible Diet.* The UC Agricultural Issues Center sponsored a year-long study of the ways agricultural chemicals find their way into our food supply, what the risks are, and what should be done about it.

Health and safety of farm workers. Many argue that worker safety is of higher priority than food safety in reference to agricultural chemical usage. Quoting Donald Kennedy, President of Stanford University, at a UC Agricultural Issues Center Conference: "...a careful look at the problems of occupational health and problems of consumer health reveals that they are not the same. Persistence is an important feature of pesticide risk to consumers; but the occupational threats to production workers, applicators, and agricultural field workers relate much more to immediate toxicity. Thus the organophosphate insecticides, if proper reentry times are not observed, constitute major occupational hazards—but, owing to their rather quick degradation, they are not the major problems for consumers."

Effects on wildlife. Environmental contamination from agricultural chemicals has in some areas caused direct harm to certain wildlife species. It has indirectly affected others preying on those that tend to accumulate residues in their tissue. Some tie a large part of an observed decrease in wildlife populations directly to increased use of agricultural chemicals. Legislation restricting agricultural chemical use in known habitats of endangered species has been enacted.

Dwindling supplies of resources. The energy crisis in the early 1970s drew attention to scarcity and capacity limits of important nonrenewable resources and to agriculture's increasing dependence on energy-intensive inputs.

Other environmental concerns. Recently, in the face of mounting commodity surpluses, U.S. farm legislation has taken a conservation posture. The 1985 Food and Security Act included provisions for a conservation reserve program, a conservation compliance requirement, and sodbuster and swampbuster programs, all aimed primarily at reducing soil erosion. The World Bank is also bringing environmental concerns to the center of its policy-making agenda with the creation of a new Environmental Department overseen by the vice president of policy, planning, and research.

Increasing production costs. The severe recession farmers experienced in the first half of the 1980s has accentuated the need for cost-reducing technologies to decrease reliance on purchased farm inputs. In California, costs of pesticide purchases and application for specialty crops may be as much as 20% of total direct costs for a season. Ed Sills, a California grower who has turned to organic farming, reported at the UC Agricultural Issues Center conference: "...it appeared to me that we were spending a lot of money to produce crops that were in oversupply, and using a great deal of high-priced chemicals to do so. In rice and almond weed control, it seemed that I was selecting for the weed that was hardest to kill, and invariably that last weed required the highest priced herbicide to control it." Pest resistance to chemicals that worked well in the past is an increasingly serious problem.

Research

The number of experimentally designed, replicated studies on sustainable or low-energy-input farming systems is still limited compared with those on current methods. Ten years ago information was almost nonexistent.

Research and extension activity dealing with these systems has been increasing in nearly every agricultural research institution. Many studies are comparative analyses, some using replicated experiments, whole farms, and side-by-side field comparisons. Farming practices in the eastern and midwestern United States have received the greatest attention nationally, with relatively little work done in specialty crops in the irrigated West. Requirements for any farming system, including low-energy-input, vary between countries, between regions, and even from farm to farm. Much of the research so far on alternative farming systems is based on case studies over limited periods. These only suggest possible outcomes and make generalization difficult. Tailoring a system to unique on-farm conditions requires time and considerable management skill.

Some of the alternative, low-energy-input methods being analyzed include: use of natural enemies or biological control agents; appropriate field selection; changes in land preparation, irrigation, tillage, and sanitation; improved timing of planting; and choice of resistant varieties. Attempts are made to substitute renewable sources of soil nutrients such as manures and legumes for chemical fertilizers partially or in total. Any of these changes must be considered in the context of the entire farming system. Case studies show that, under particular conditions, low-energy-input systems can produce economic returns close or equal to those from conventional farming methods. In most cases, the farmer is substituting land, labor, and especially management for chemical inputs. The extra management and experience required for "low-input"

TABLE 1. Growth rates for agricultural production

Region*	1951-60	1961-70	1971-80	1980-84
	%/year			
Developed countries	2.5	1.9	1.8	1.1
Developing countries	3.1	2.7	3.2	3.0
Latin America	3.3	2.7	3.5	0.0
Mexico	5.3	4.0	2.8	-1.0
Brazil	5.1	2.7	4.4	1.7
Argentina	2.0	2.1	4.4	0.5
Middle East	4.2	3.0	3.8	-0.6
South Asia	3.3	2.5	1.8	1.5
India	3.4	2.1	2.4	2.4
Southeast Asia	2.8	4.2	4.6	2.3
East Asia	5.1	4.4	4.7	-0.2
Indonesia	2.9	1.7	4.2	4.2
People's Republic of China	1.7	2.0	1.9	5.2
Africa°	2.9	3.0	1.1	1.6
Sub-Saharan Africa°	3.1	2.2	1.5	1.7

SOURCE: U.S. Department of Agriculture, Economic Research Service, *World Indices of Agricultural and Food Production*, Statistical Bulletin No. 669, 1981 and Statistical Bulletin No. 730, 1985.
* Country groupings are as defined by the U.S. Department of Agriculture.
° Excluding South Africa.

systems suggest that if farmers switched abruptly from chemical-intensive to certain kinds of sustainable farming methods, their yields would probably decline sharply at first.

Studies of sustainable farming methods often emphasize the costs and benefits of adopting a particular method as they relate to a specific enterprise—for example, rotation effects on corn yield. Proponents of sustainable systems contend that the effective "system" boundary usually includes the entire farm or management unit, its crop and animal mix, the crop rotation or sequence, and the flow of materials through the system over time. William Liebhardt, director of the UC Agricultural Sustainability Program, points out that a systems analysis is required that considers not only the inputs and outputs of the agricultural process but also the environment at large (physical, economic, institutional) and the interaction among these components. Few studies of this nature are yet available.

Integrated pest management

IPM is a low-input approach that has achieved notable success in numerous regions and crops. The strategy is to use a combination of biological, physical, and chemical controls, habitat modification techniques, and "whatever works" to monitor the system, economically reduce pest damage, and minimize chemical use. Nationwide, programs have been developed for corn, cotton, alfalfa, soybeans, grapes, apples, almonds, peanuts, and tobacco, to mention a few.

In many cases, farmers are able to reduce and sometimes eliminate pesticide applications that would routinely be used under conventional systems. IPM practices are usually profitable, particularly when properly applied to cropping systems and regions where high rates of pesticides have normally been used. As with other low-input practices, IPM calls for careful multidisciplinary analysis at the research level, as well as more sophisticated, skilled management and more information at the farm level, than is required for other farming systems.

A systems approach to research

Liebhardt lists the many factors that determine the specific type and amount of pesticides needed for a particular crop, in a particular field, in a particular season: (1) genetic (crop species, variety, pest resistance, and chemical resistance); (2) environmental (location, climate, year-to-year changes, soil, water, pest population and inoculum levels, beneficial organisms); (3) agronomic (cropping pattern, planting date, irrigation method, field selection, tillage); and (4) economic/policy (management system on farm, consumer demand and market structure, relative costs of control practices, regulations and farm programs, farmer beliefs and attitudes). Therefore, analysis requires the joint effort of researchers and extension specialists in, for example, agronomy, soil and water sciences, entomology, animal science, engineering, and agricultural economics. Much individual consultation with users will also be required. Since most agricultural universities are organized around disciplinary departments, considerable reorganization may be needed to mount a serious research and extension effort to understand and apply low-energy-input agricultural systems.

This is not to imply that only applied research is needed. The search for effective reduced-chemical alternatives requires the full spectrum of basic to applied research. For example, years of basic research are needed before a microbial pesticide or an insecticide-resistant parasite can be brought to the marketing stage.

Most attention has centered on the feasibility of adopting low-energy-input technology at the farm level. Questions about the larger effects a widespread switch would have on the economy (farm income, exports, consumer food prices, structure of the agricultural sector) have been largely ignored. At this stage, so little is known about expected yields and costs in most U.S. cropping situations, and about associated price and structural effects, that any conclusions must be viewed with caution. For one thing, new (even profitable) technologies usually require a considerable transition period. Therefore, the move to low-energy-input farming will probably be associated with a gradual adjustment in prices and resource use.

Impediments to change

The structure that has evolved based on cheap energy inputs (fuel, fertilizer, and pesticides) helps explain farmers' reluctance to adopt low-input or sustainable methods. Farms in the United States, and in other developed countries, tend to be highly specialized. But multiple cropping and even multiple crop-livestock systems are the hallmark of most low-input farms. The heavy investment in equipment and machinery, and the debt load, of existing high-input farms means that a switch to alternative farming systems could require a formidable disinvestment. Also, considerable retraining of farm managers and the work force might be necessary.

Government programs that provide incentives for high-input farming were devised in a cheap energy era and remain largely intact. The food processing and distribution system has evolved to complement the current production system and to meet the needs of masses of people in metropolitan areas. For example, the premium put on fruits and vegetables that are cosmetically appealing to consumers makes it difficult to produce and market profitably without chemicals.

In many developing countries, reliance is placed on family labor, integrated crop-livestock operations, and polyculture—all components of sustainable systems. Moreover, farmers are on small holdings of marginal land with limited access to capital, credit, and markets, prerequisites for conventional agricultural operations. Yet the current trend is toward more rather than less use of agricultural chemicals in the developing world. Fertilizer application rates are up; the largest gains in Asia, where rates doubled between 1974-76 and 1981-83. The value of pesticide imports to Asia more than tripled in constant dollars between 1971-73 and 1983-85. Apparently, in such areas, the pressure to boost food productivity and turn a profit means a shift toward the chemically intensive practices of the developed world.

An agenda for change

In conclusion, I make two observations. First, I would argue that our area of inquiry for considering change should be broader than the farm production system that has received most of the emphasis. It is society and the people within it that we want to sustain over time. As important as the agricultural production system is to that goal, it should not be considered as an end in itself or independent of other aspects that come together to define "quality of living" in its broadest sense. It makes little sense to make decisions at the production level affecting the quality of the product if that product cannot be profitably marketed because of constraints in another part of the food chain. Agriculturists must give primary attention to the total food system—production, processing, and distribution. That is, we want to consider changes in the total food system that can meet the growth in food demand and be consistent with societal long-run food safety and environmental goals.

Second, chemical use and any alternatives to chemical use at whatever level of the food system must be viewed and analyzed in a benefit/cost framework. These costs and benefits are those not only to the farmers using chemicals, but to consumers and society as a whole. Benefits to farmers from use of agricultural chemicals include increased yields and reduced pest damage; costs are the additional outlays for the chemicals and possible hazards in applying them. Similarly, benefits and costs can be calculated for whatever chemicals or additives are used by food processors, wholesalers, and retailers. It is usually possible to assess the cost/benefit of conventional practices because of their impact through the marketplace.

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meet the shortage number would additional registration be announced. If the top-priority group were from 1 to 50,000 smaller than the shortage number, applications would be accepted only from aliens currently residing in the United States whose qualifying agricultural work was in SAS. If the difference were greater than 50,000, all eligible aliens residing in the United States could apply. At a difference greater than 200,000, registration would be extended to all eligible aliens, including those living outside the United States.

The lists of denied SAW applicants and additional registrants would be randomly ordered, except that spouses and unmarried children of aliens legalized under IRCA would have priority within each group. Aliens would be invited to interview and petition for RAW status in the order in which they appeared on the resulting master list. If the proposed registration priority is sustained in the final rule, RAW-eligible aliens who have remained illegally in the United States will be higher on the list, ironically, than those who left when they became ineligible for employment.

Conclusion

For the first two years of IRCA implementation, the new legalization programs and hiring rules diverted most attention from the law's other major provisions affecting farm labor supply. With possible admission of replenishment agricultural workers only a few months away, farm employers and government administrators are facing the formidable task of gearing up for the RAW program. They are generating and processing a tremendous amount of labor market information.

Determinations of how many RAWs to admit each year, from fiscal 1990 through 1993, will rely heavily on data provided by employers to the USDA, DOL, and Committee for Employment Information on Special Agricultural Workers. Even imperfect compliance with the new reporting obligation and uneven participation in the voluntary surveys will greatly enrich the stock of information about farm employment and the influence of legal status on occupational choice. As concern mounts about future farm labor supplies and the impact of IRCA on California agriculture, data collected for RAW program administration will hold great interest for agricultural employer and labor groups as well as the research community.

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differences in grading. Water penetration was shallowest in the wheel track positions, and intermediate at the interrow center position.

Conclusions

The increases in infiltration quantity and water penetration depth resulting from all of the calcium-added treatments were encouraging, but certainly not of great magnitude and less than we had hoped for in this experiment. We had hoped for 100% increases. Two related factors may have contributed to the lack of a greater difference between control and calcium treatments. One is the relatively steep grade, 0.4%, of the border checks, and the other is the length of set, 14 hours. A gentler grade and a longer set, allowing a longer opportunity time for infiltration, perhaps would have magnified the difference between control and calcium treatments. Even with the 0.4% grade, a cutback of water application at some point and extension of the length of set might have provided more infiltration and deeper penetration, particularly at the lower end of the checks.

Among the calcium treatments, the surface-spread gypsum surprised us by remaining effective for several irrigations after it had apparently all been dissolved. This finding implies that high concentrations in the early irrigations are not as wasteful as it would first appear. They may have a favorable effect on soil structure that deteriorates only slowly after the gypsum is gone, as long as the soil surface remains undisturbed.

The gypsum-dissolving machine worked well in adding approximately 3 milliequivalents per liter to the irrigation water. The calcium nitrate solution was easily prepared and applied, but more research is needed to determine if this substantial nitrate addition (180 pounds nitrogen per acre) is equivalent to conventional fertilization. Runoff flows should be recycled to prevent environmental pollution by nitrate.

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However, calculation of costs and benefits for low-input systems not yet in full operation is much more difficult.

Consumer benefits of chemical use within the food system include (possibly) increased quality and quantity of food, lower prices, and increased availability of perishable foods over longer periods. An example is the health benefits of having a year-round supply of fruits and vegetables available in many parts of the world. Costs to society may include consumer health risks from residues on crops, exposure of farm workers to contaminants, degradation of underground aquifers and waterways. Quantification of these effects is difficult, since both market and nonmarket evaluations are involved.

Further, we need to understand what policies are appropriate when social benefits do not exceed or equal social costs. The impacts of any regulation usually extend far beyond its intended purpose. And conflicting regulations currently plague the food industry in the United States.

Increasingly, we are receiving signals that our high-technology, energy-intensive agricultural system has not only not sustained productivity, but is causing troublesome environmental problems and exerting pressure on the resource base. These concerns have not been translated into quick action and change. Legislation in the United States has been passed at the state and federal level aimed mainly at some of the environmental issues without consideration of the total problem. Many farmers express interest in adopting low-input practices, but so far change has not been widespread for a variety of reasons—lack of knowledge, risk of decreased profitability, fixity in existing investments. Farmers can't be expected to bear all the costs when they can claim only a share of the perceived environmental benefits.

In summary, there is considerable interest—even deep concern by some groups—and support is growing for action and change. Agricultural academic institutions and the U.S. Department of Agriculture are making a good beginning in researching sustainable agriculture. Every indication is that the pace will be accelerated in the near future. But we don't have sufficient information on farm, regional, or global impacts of the changes that will ensue. The current agricultural system evolved over considerable time, and with some "nudging and pulling," we can eventually tilt it in a different trajectory. However, the rhetoric vastly exceeds our knowledge at this time.

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