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The need for a systems approach to sustainable agriculture

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Abstract

Differences between conventional and sustainable paradigms of agriculture are much more a matter of differences in farming philosophy than of farming practices or methods. The conventional model of agriculture is fundamentally an industrial development model which views farms as factories and considers fields, plants, and animals as production units. The goal of industrial development is to increase human well-being by increasing production of material goods and services and simultaneously increasing aggregate employment and incomes. The underlying assumption of the industrial model is that a higher quality of life can be derived from increases in income and consumption of goods and services. A fundamental strategy for industrial development has been to specialize, routinize, and mechanize agricultural production in order to achieve the economic efficiencies that are inherent in large-scale industrial production. New technologies are designed to remove physical and biological constraints to production and, thus, make unlimited progress possible. Sustainable agriculture, on the other hand, is based on a holistic paradigm or model of development which views production units as organisms that consist of many complex interrelated suborganisms, all of which have distinct physical, biological, and social limits. People are viewed as part of the organisms or systems from which they derive their well-being. Quality of life is considered to be a consequence of interrelationships among people and between people and the other physical and biological elements of their environment. Fundamental strategies for sustainable development include diversification, integration, and synthesis. Whole systems have qualities and characteristics that are not contained in their individual parts or components. The same set of components or parts may be rearranged spatially or sequentially resulting in a unique system or whole for each new arrangement. People increase their well-being by using information and knowledge to manage or rearrange the components of systems, resources, processes, and technologies in ways that enhance the productivity or 'well-being' of those systems. Human progress is limited only by our ability to enhance the social, biological, and physical systems of which we are a part. Sustainable agriculture requires a holistic systems approach to farm resource management. A component approach focusing on individual farming practices, methods, and enterprises may have been appropriate for the era of agricultural industrialization. However, a systems approach which focuses on knowledge-based development of whole farms and communities will be required to address the environmental, economic, and social challenges of the post-industrial era of agricultural sustainability.

Introduction

The primary public mandate or social agenda for US agriculture throughout this century has been to increase production efficiency in order to reduce

consumer food costs, to free farm families for more rewarding occupations, and to free rural resources for other uses. Government programs for agriculture, including publicly funded research and education, have been focused on development and implementation of new technologies that would enhance agricultural productivity and reduce the need for farm labor.

Agricultural development strategies of the past have been highly successful in reducing the proportion of the nation's resources devoted to food production. For example, the 1895 Yearbook of Agriculture indicated that 42% of people in the US were employed on farms in 1890 (US Department of Agriculture (USDA), 1895). This compares with less than 2% of the total US population living on farms a century later. In addition, those living on farms today earn more than half of their income from non-farm sources (USDA,1990). US consumers now spend less than 12% of their income on food. Farmers get only about 25 cents out of each dollar spent for food, and about half of that goes to pay for purchased inputs.

Agriculture has fulfilled its public mandate of the past, but public priorities are changing. Until now, the negative side-effects of the twentieth-century agricultural policies and technologies on the ecological and social environment of rural areas have been largely ignored (National Research Council, 1989), but growing environmental and social equity concerns of the general public are raising questions that must be addressed by all sectors of the US economy, including agriculture. People are increasingly concerned about the negative environmental impacts of modern farming methods and the deteriorating quality of life in rural communities. These concerns have already resulted in changes in agricultural policies and programs at the national level. Additional fundamental changes could well be forthcoming.

Society appears to be giving agriculture a new, much broader public mandate. This new mandate is to develop a food and fiber system that is still efficient and productive, but in addition is ecologically sound, economically viable, and socially acceptable. This new mandate may well dictate a new paradigm or model for US agriculture.

Growing concerns with industrialization of agriculture

The industrial model of agriculture "treats the farm like a factory, with inputs and outputs, and considers fields and animals to be production units" (Kirschenmann, 1991). Industrial farming systems have relied primarily on specialization and mechanization to achieve physical and economic efficiencies through large-scale production. However, these same strategies that have increased past agricultural productivity have now begun to raise significant environmental and economic concerns. There is no general agreement among scientists at present regarding the extent to which these concerns reflect actual

threats to long-term agricultural sustainability. None the less, there can be no doubt that the public is in fact concerned.

First, there are growing concerns regarding the continued effectiveness of the inputs and technologies which support these large-scale, specialized systems. Increased concentration of a single crop within a geographic region increases pest pressures on that crop. In addition, insects and weeds are becoming resistant to pesticides and require higher rates of application or new, more costly pesticides for control. Previously fertile soils in some areas have lost organic matter and natural fertility through monocropping, conventional tillage, and removal of crop aftermath year after year. Lower organic matter has meant less microbial activity, less ability to hold water, and less availability of nutrients in root zones, meaning lower yields from a given level of water and fertilization or higher fertilizer and irrigation costs to maintain yields.

Questions of natural resource stewardship are also confronting modern agriculture. Water tables in some of the major irrigated areas are declining as rates of irrigation surpass rates of natural regeneration of aquifers. Irrigation supports some of the largest of the large farming operations. Salinization of soils has also become a major concern in some irrigated farming regions. Soil conservation rose to the top of the political agenda in 1985 primarily because of rising soil erosion rates. Soil losses went up as farmers abandoned forage grass and legume-based crop rotations in the 1960s and rose still further as farmers intensified row crop production for growing export markets during the 1970s.

Other costs of specialization are beginning to show up in the environment of farm families, farm workers, and rural residents. Health risks in handling pesticides, for example, have become a major issue in farm safety. Risks of chemical contamination of drinking water and risks of pesticide residues in food are important public perceptions, regardless of the facts concerning actual risk levels. Nitrate leaching into ground water may be attributed to organic sources, such as livestock waste and crop residues, as well as the use of commercial fertilizer. However, this issue, as much as any other, has increased awareness in rural areas of the potential environmental hazards of chemically dependent farming.

The industrialization of agriculture has also changed rural landscapes. Farmers planted 'fence row to fence row' during the 1970s and many tore down the fences and plowed out the fence rows. Farming areas were no longer patchworks of fields, meadows, grassy hills, and valleys separated by rows of trees. Rural landscapes became field after field of corn, soybeans, wheat, and cotton across the hills and valleys. Timber was cleared to make room for cow herds. Livestock feeding and poultry production became concentrated in large feed lots in animal producing factories.

Larger, more specialized farming operations have meant fewer farming families. Fewer people are needed on farms with industrial farming technol-

ogies. Not only have purchased inputs been substituted for land and climate, but machines have been substituted for labor and technology has been substituted for management. The unneeded human resources have been squeezed out of agriculture as a natural economic consequence of the substitution of technology-based inputs for resources.

Technological advances reduced the costs of production and provided incentives for expanded production which, in turn, reduced market prices and ultimately reduced farm incomes. Attempts to mitigate the effects of surplus production through export expansion have instead created a system that is even more dependent on new technologies to remain competitive in global markets. Only those farmers who were among the first to adopt new technologies have realized profits. Those who lagged behind were forced to adopt to the new technologies in order to survive. Those who could not adopt or adapt quickly enough were forced to sell out to their more 'progressive' neighbors.

The continual repetition of this process over time has ensured that the economic returns to those remaining in agriculture were kept well below those of growing economic sectors. This process was an economic necessity to move unwilling people and resources out of agriculture and into other uses within the economy. But there were costs associated with this migration out of agriculture. These costs have included "social disorganization, shrinking rural economic bases, declining rural communities and institutions, and the specter of a permanent underclass in the cities" (Glover, 1988).

Rural communities are as much the victims of a more productive agriculture as are displaced farm families. Rural America has lower levels of income, education, employment, health, nutrition, and community service than urban America, and the agricultural technology treadmill has been a major contributor to this. Today, about one-quarter of the US population lives in rural areas, but only about 8% of all rural residents are farmers. About 75% of total agricultural income comes from the largest 25% of all farming units. Only about one-third of all farmers consider farming to be their principal occupation. About 75% of farmers' incomes come from off-farm sources (Hyman, 1990). Thus, most people who live in rural areas are not farmers, most farmers are not large producers or even full-time farmers, and most farm families depend more on non-farm income than on farming for a living.

These statistics reflect the indirect effects of the forced migration of families out of farming. Farmers have been reluctant to leave their local communities even though they no longer have an economic future in farming. Many have been willing to work in their home town for lower wages than they would be willing to accept elsewhere. Other farm families have been able to continue to farm, but they can no longer make an adequate living from farming alone. In these cases, one or more family members have taken a part-time or full-time job off the farm at lower wages than they might be willing to accept if they had to give up farming. Off-farm employment has allowed many to re-

main on the land that otherwise have been forced to leave their communities. However, the need for off-farm employment of farmers has added to the oversupply of rural labor and thus has contributed to chronically depressed rural labor markets.

However, the problem is not with agriculture in general but with an industrial, input-dependent agriculture. Today, the sustainability of industrial farming systems is being questioned. The ability of industrial systems to compete in the information age of the twenty-first century is also being questioned. The answers to these questions could well have significant implications both for the future of agriculture and of rural communities.

A new paradigm for agriculture

A sustainable agriculture must be capable of maintaining its productivity and usefulness to society indefinitely (Ikerd, 1990). Such an agriculture must use farming systems that conserve resources, protect the environment, produce efficiently, compete commercially, and enhance the quality of life for farmers and society overall.

Systems which fail to conserve and protect their resource base degrade its productivity and eventually lose their ability to produce. Such systems are not physically sustainable. Systems which fail to protect their environment eventually produce more harm than good; they lose their usefulness to society and, thus, are not socially sustainable. Farming systems which fail to provide the people with adequate supplies of safe and healthful food at reasonable costs and otherwise enhance the quality of life are not politically sustainable. Agricultural systems of Communist Europe were prime examples of such systems. Systems that are not commercially competitive will not generate the profits necessary for financial survival or an acceptable quality of life for producers and, thus, are not economically sustainable.

The industrial model of farming may or may not be sustainable over time. No one can possibly know the future with certainty. It may be possible to fine-tune, refine, or redesign the industrial model, resulting in a new model that will meet the ecological and social standards required to sustain long-term productivity without changing the fundamental approach to farming. On the other hand, an approach to or philosophy of farming that is fundamentally different from the industrial model may be required. Such an alternative agricultural model has evolved, and is being further developed, to address the economic, ecologic, and social balances required for long-term sustainability. This alternative to the industrial model of agriculture is commonly called sustainable agriculture. However, only time will tell which, if any, of our current models of farming are actually sustainable.

The new sustainable paradigm "treats the farm like an organism consisting of many complex, interrelated suborganisms, all of which have distinct bio-

logical limits" (Kirschenmann, 1991). Economic performance is dependent on the achievement of the total organism and, thus, requires a holistic systems approach to farm resource management. The sustainable agriculture model relies more on management of the internal resources of the farm and less on purchased commercial inputs in attempting to reduce negative ecological impacts while maintaining economically viable farms. Such an approach was characterized by the National Research Council (1989) in outlining the goals for alternative agriculture as involving:

(1) greater reliance on natural processes such as nutrient cycling, nitrogen fixation, and pest–predator relationships in the production process;
(2) reduction in use of off-farm inputs with the greatest potential to harm the environment or the health of farmers and consumers;
(3) greater productive use of the biological and genetic potential of plant and animal species;
(4) improved matching of cropping patterns and the productive potential and physical limitations of agricultural lands to ensure long-term sustainability of production levels;
(5) profitable and efficient production with greater emphasis on farm resource management and conservation of soil, water, energy, and biological resources.

The sustainable model implies greater reliance on human resources, in terms of the quality and quantity of labor and management, and relatively less reliance on land and capital. Thus, sustainable farming systems may require more farm operators, more farm laborers, and more farm families than do conventional farming systems. In addition, operators of sustainable farmers are motivated by a new mix of objectives. Social considerations are balanced with environmental and economic concerns. Social concerns may cause such farmers to show a preference for local markets and local input supply sources if this preference does not threaten their economic survival.

A fundamental shift in the balance of returns to people versus land and capital must be brought about, by one means or another, if more families are to be able to farm successfully. Disproportionately large quantities of land and capital are often controlled by a few individuals. Thus returns to human resources, to people, tend to be more egalitarian in nature. Government farm policies of the past have undervalued rural resources by failing to recognize the long-term social cost of resource depletion and degradation and even by subsidizing their short-term exploitation. Changes in government farm policies will be required to remove past government subsidies of large-scale, specialized farming. However, smaller diversified farms will become commercially competitive with larger specialized farms, only if human resources can be economically substituted for other resources and commercial inputs.

By implication, diversified sustainable farmers of tomorrow must be more knowledgeable, more creative, and more skilled workers. They cannot expect to earn a larger return for their labor and management, reducing their reliance on land and commercial inputs, unless they possess superior labor and management skills.

Sustainability: a systems concept

Differences between sustainable and industrial models of farming reflect differences in farming philosophy. In fact many individual farming practices, methods, or components used in industrial systems may be useful in sustainable systems. Farmers with different philosophies, however, may choose to integrate the same basic components quite differently in the process of developing farming systems. Differences in philosophy cannot be subjected to scientific analysis. Thus, some scientists have concluded that comparisons of conventional and sustainable systems fall outside the realm of science (Council of Agricultural Science and Technology, 1988). However, all scientific inquiry begins with at least two basic value judgments. How does the world work? What is the basic purpose of human activity? Science is incapable of providing definitive answers to either of these questions.

Agroecology provides a philosophical foundation for the sustainable agriculture concept. Agroecology is a synthesis of agriculture and ecology (Altieri, 1983). Agriculture, by its very nature, represents an attempt to enhance the productivity of nature in ways that favor humans relative to other species. However, the discipline of ecology views humanity as only one component of essentially interrelated ecosystems that include all people as well as the other biological species and physical elements of the biosphere. The concept of agroecology implies a right of humans to shift the ecological balance in favor of humans relative to other elements of the ecosystem. However, attempts to shift the balance too far or too fast in favor of humans relative to other species, in favor of some people relative to others, or in favor of the current generation relative to later generations, may destroy the critical ecological balance upon which the survival of humanity ultimately depends. Quality of human life is a product of relationships among humans and between humans and non-human elements of the biosphere. The humanistic and egocentristic elements of agroecology are constrained in that human well-being is dependent upon the well-being of other species and individual well-being is dependent on the well-being of society.

Actions taken in any part of an ecosystem have consequences for all other parts of the ecosystem, both now and in the future. Agroecologists contend that agricultural technologies must ultimately enhance nature rather than replace nature and must work with nature rather than attempt to conquer nature. The constraints of nature on humankind can be moved but not removed.

The techno–industrial philosophy of agriculture views humans as having dominion over all other species and over the biosphere in general. The quality of human life is a product of bringing this dominion under human control. The purpose of agriculture is to serve humanity, and in this philosophy, any constraints to productivity imposed by nature can be removed by future technology and, thus, are viewed as temporary obstacles to overcome. The purpose of technological development is to replace limited natural resources and limited natural production processes with technology-based industrial alternatives. The implicit assumption is that technology can ultimately remove all constraints to human progress.

Science can neither prove nor disprove the correctness of any philosophy. Intelligent people, including scientists, differ with respect to their philosophies regarding the relationships between people, agriculture, nature, and the fundamental purpose of developing new agricultural technologies. Those concerned with the sustainability of agriculture tend to lean more toward an agroecological viewpoint while those who see little relevance of the sustainability issue tend to lean toward the techno–industrial viewpoint. Lacking the ability to prove that one view is right and the other is wrong, scientists should be willing to pursue knowledge and to develop technologies that are consistent with both.

Agroecology implies a systems approach to farming, integrating technology, and natural processes to develop productive systems. All systems are in fact components of still larger systems and all components of systems are in fact systems made up of still smaller components. The first step in a systems approach to management is to identify the boundaries of the system to be managed (Bird et al., 1984). The purpose in establishing boundaries is to separate those things which can be managed and, thus, are a part of the management system from those things which cannot be managed and are thus a part of the external environment. Those things in the external environment may affect, and be affected by, those things within the system. Thus, systems boundaries do not imply mutual independence between things inside and outside them. On the contrary, the boundaries serve to sharpen the perception of interdependence between systems and their external environment.

The system under the management control of a farmer is the economic unit typically called a farm. A farm may include owned or rented land in several different geographic locations and all related buildings, equipment, and financial assets that are managed. In the case of a part-time farm, the economic unit may include off-farm as well as on-farm enterprises. A farming system also includes people: the principal farm operator, hired farm workers, and in the case of farming families, all members of the family who are considered part of the farming operation. The key concept in defining the boundaries of a farming system is to separate those things that can be managed, or directly influenced, from those things that cannot. A systems approach to farm man-

agement then implies that each decision will be evaluated in terms of its impact on the performance of the system as a whole.

Sustainable agriculture is fundamentally a systems approach to farm planning and decision making. The National Research Council (1989) defines a farming practice as a way of carrying out a discrete farming task such as preparing a seed bed, applying fertilizer, or spraying pesticides. A farming method is defined as a systematic way of accomplishing a basic farming function such as establishing, protecting, or feeding a crop that is achieved by integrating a number of complementary farming practices. A farming system, however, must be defined in terms of an overall approach to farming derived from a farmer's goals, values, knowledge, available technologies and opportunities, and is constructed by integrating a number of complementary farming methods.

A given set of farming practices or methods is not inherently more or less sustainable that any other set of practices or methods. Sustainability depends on the nature of whole farming systems. The goals and values of long-term sustainability must be reflected in combinations of practices and methods that are consistent with an individual farmer's unique set of resources, including his or her knowledge base, technical know-how, and farming opportunities. Sustainable farming systems are very much individual farmer and farm-site specific. Sustainability is determined by the system, considered as a whole, not by its individual components.

Synergism: the key to sustainability

Farming for sustainability requires a holistic approach to farm planning and management. Whole systems have qualities and characteristics not present in any of their constituent parts; therefore, one must seek to understand the greater whole in order to understand its parts, not vice versa (Savory, 1988). Systems take on values in and of themselves through the process of synergism. The essence of the whole of something is the arrangement of its parts. Arrangement is not a characteristic of the parts arranged but rather of the whole. Time, place, form, and possession are the fundamental sources of utility or economic value. Thus, creation of value is not a simple matter of changing the form of things through the physical processes of production. Value can also be produced by rearranging the various forms of things so as to affect their dimensions of time, place, and individual possession. Synergism then is the process by which resources and inputs are rearranged spatially, temporally, physically, and individually in order to create more valuable wholes.

Some simple examples may serve to illustrate the basic nature of potential synergistic gains from holistic management of farming systems in general. The time, space, form, and possession characteristics of production systems are

obviously interrelated and are treated separately in these examples only for purposes of illustration.

A crop rotation represents a temporal sequence of farming methods and practices within a given spatial context. A particular sequence of crops may result in increased yields, reduced commercial pesticide and fertilizer requirements, and reduced soil erosion. A cropping sequence may break biological pest cycles, fix nitrogen from the air, and keep the ground covered during periods of heavy rainfall. In other words, crops grown continuously in separate fields may result in higher total costs, greater environmental risks, lower production, and less profit than would the same crops grown in a logical rotation or cropping sequence. The added benefits come from the temporal arrangement.

The spatial matching of crop and livestock enterprises to particular climate and soil characteristics is a critical factor in determining both economic and ecologic results. Most crop and livestock species have natural comparative advantages in production in particular regions of a country. Cotton, peanuts, rice, and tobacco, for example, are more common in the southern US because historically they have had comparative advantages under warm, moist growing conditions. When crops and livestock are grown in regions for which they are not particularly well adapted, the natural environment must be modified.

Relatively cheap and effective commercial pesticides, fertilizers, fossil fuels, and irrigation water have allowed commercially competitive production of many commodities outside their range of previous comparative advantage. However, the increased use of these particular inputs and resources is now a primary source of concern regarding environmental risks and resource depletion. Environmental risks are not inherent characteristics of plants or animals, nor even inherent to particular chemicals. Risks and returns, in many cases, are determined by the location of production, or spatial arrangement, among regions of production or even among fields on a farm.

The basic function of agriculture is to convert solar energy into an energy form that will provide human food, clothing, and shelter. Over time, however, US farmers have changed from being basic producers of food and fiber to being primarily converters of purchased inputs into raw materials. However, some farmers now have begun to try to reverse this trend. They are expanding their operation vertically rather than horizontally. They are producing some of their own inputs and substituting resource management for others. They are adding value to their products by integrating some or all of the traditional form-changing processing functions into their farming operations. Many successful niche farmers also tailor the form of output of each production process to fit the input requirement of the next process. In addition, they may utilize wastes from one stage of production as inputs in another in order to reduce costs and environmental risks. Their success may depend more on gains from their unique vertical arrangement of form changing processes than

from either their market niche or the individual processes considered separately.

The utility or value of possession or ownership is an individualistic concept. Different individuals have different tastes and preferences which determine the value they place on given goods or services. Thus, the value of a given kind of good or service, at a given place and time, may not be the same for any two individuals. Different individuals also have different sets of skills, knowledge, and other resources that they can use to produce something of value to other people. Thus, the efficiency with which any two people are able to produce a given good or service may be quite different. Consequently, the cost of providing a given kind of good or service may be different depending on the individual(s) involved in the production process. The key to creating value through individualization is to match people, as producers, with other people, as consumers, so that people are producing the things they can produce best for people who value those things most.

In reality, the dimensions of time, space, form, and ownership are inseparable. Thus, a holistic systems approach to farming is a matter of managing the temporal, spatial, physical, and individual arrangements of interrelated sets of markets, resources, inputs, products, people, and processes. Holistic management is complex, but within this complexity lies the potential for synergistic gains. Such gains come from management, the process of choosing arrangements, and not from a given endowment of land, labor, or capital resources.

Knowledge: the key to systems management

Many of the past gains in productivity of agriculture have resulted from applying industrial production and business principles to farming. Likewise, many of the current threats to agricultural sustainability are associated with these same industrial systems of farming, but the industrial era may be coming to an end in the general economy. Thus, the industrialization of agriculture could be nearing an end as well. Further attempts to apply the industrial model in farming may result in declining economic benefits at increasing economic costs. Thus, the era of input-intensive farming, and its associated environmental and social costs, may be coming to an end, with or without a new environmental and social agenda for agriculture. The new public policy agenda will still have an important role in ensuring that agriculture in the post-industrial era is environmentally sound and socially acceptable as well as productive and profitable.

Toffler (1990) contends that knowledge will be the key to economic and political power in the future. He argues that the smoke-stack era in which power was associated with control of capital and the physical means of production is passing. He suggests that power in the future will belong to those

who know how to access and synthesize data and information into value-added knowledge. Information and knowledge must be translated into value through the act of decision making. Value from knowledge results from decisions concerning arrangements of things, not from the things available to be arranged. Value created on farms in the future may result much more from the application of knowledge than from the possession of either resources, capital, or production technology. Knowledge is not a characteristic of the components or parts of a system. Knowledge is embodied in the arrangements which are characteristics of wholes.

He summarizes his hypotheses concerning the new system of wealth creation with twelve basic characteristics of a future knowledge-based system.

(1) The new system for wealth creation is increasingly dependent on the data, information, and knowledge.
(2) The new system of flexible, customized, 'de-massified' production will turn out products at costs approaching those of mass production.
(3) Conventional factors of production — land, labor, raw materials, and capital — become less important as knowledge is substituted for them.
(4) Capital becomes extremely fluid and the number of sources of capital multiplies.
(5) Goods and services are modular and configured into systems.
(6) Slow-moving bureaucracies are replaced by 'ad-hocratic', free-flowing information systems.
(7) The number and variety of organizational units multiply.
(8) The most powerful wealth-amplifying tools are inside workers' heads, giving them a critical share of the 'means of production'.
(9) The new heroes are the innovators who combine imagination with action.
(10) Wealth creation is recognized to be a circular process, with wastes recycled into inputs for the next cycle of production.
(11) Producer and consumer, divorced by the industrial revolution, are reunited in cycles of wealth creation.
(12) The new wealth creation system is both local and global, doing things economically on a local basis but with functions which spill over geographic boundaries.

These same basic characteristics can be associated with sustainable farming systems. Sustainable farming systems:

(1) are management-intensive and knowledge-dependent;
(2) are individualistic and site specific;
(3) substitute knowledge and information for inputs;
(4) may require capital from non-traditional sources;
(5) may produce composite products for specific niche markets;
(6) depend on free-flowing information from multiple sources;

(7) tend to be smaller and more varied in size and character;
(8) combine functions of thinking and doing in family operations;
(9) rely on innovative arrangements of parts within whole systems;
(10) utilize wastes and on-farm inputs in production processes;
(11) connect production with consumption, producing for market niches;
(12) rely more on local resources but may produce for global market niches.

Toffler (1990) contends that the smoke-stack industries lack the necessary flexibility to adapt to accelerated changes in needs and desires of society in the twenty-first century. Power in the future will accrue to those who have the knowledge needed to translate resources, inputs, and raw data into goods, services, and information tailored to narrowly segmented markets. He suggests that pursuit of economic power, rather than environmental protection or conservation, may be the primary motivation for adopting these knowledge-based systems of production.

In the post-industrial era, egocentric motives may support more sustainable systems of economic development in much the same sense that profit motives supported more productive development strategies during the industrial era. The industrial model, with its inherent environmental and social costs, may well become economically obsolete. However, public policies will still be required to protect the long-term interests of society in cases where they inevitably conflict with short-term interests of businesses and individuals.

Knowledge-based systems of farming could reduce, if not eliminate, many of the existing capital constraints to future agricultural productivity while conserving the natural resource base and protecting the environment. Knowledge is infinitely expandable since there is essentially no limit to how much we can create or use once it is created. The same knowledge can be used by many people at the same time and is more likely to be expanded than expended through simultaneous use. Knowledge can be created, in principle at least, just as effectively by the weak and poor as by the strong and rich. An economy based on knowledge rather than capital can provide greater equity of opportunity among all people.

Sustainable farming systems are fundamentally knowledge-based systems of farming. Holistic management of the physical, biological, and financial components of farming systems, oriented toward a goal of long-term sustainability, may be a classic example of knowledge-based systems of resource development. The ability of farmers to participate successfully in the era of knowledge-based development may well depend on the ability of the public research and education community to move from an industrial agriculture paradigm, designed to increase productivity, to a knowledge-based paradigm designed for long-term economic, environmental, and social sustainability.

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