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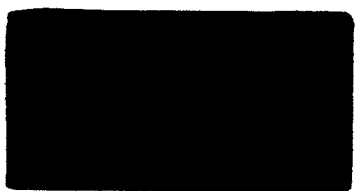
Poetry, Policy and Science

by

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SUSTAINABLE GROWTH IN AGRICULTURAL PRODUCTION: Poetry, Policy and Science*

Vernon W. Ruttan**

Contemplation of the world's disappearing supplies of minerals, forests and other exhaustible assets has lead to demands for regulation of their exploitation. The feeling that these products are now too cheap for the good of future generations that they are being selfishly exploited at too rapid a rate, and that in consequence of their excessive cheapness they are being produced and consumed wastefully has given rise to the conservation movement (Hotelling, 1931).

In this paper I review the evolution of the sustainability concept. This is followed by a description of three "classical" systems of sustainable agriculture. None of these systems were or are capable of generating growth of output consistent with modern rates of growth in demand. I then turn to three unresolved analytical issues that continue to divide the conventional resource economics and the sustainable development communities. In a closing section I argue sustainable growth in agricultural production should be viewed as a research agenda rather than as a package of practices that is available to producers whether in developed or developing countries.

When confronted with the task of defining sustainable agriculture one's natural inclination is to finesse. David Hopper, formerly World Bank Vice President for the South Asia Region, insisted, "I don't think I can define it (sustainability) without unduly

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constraining the free flow of my thoughts" (Hopper, 1987, p. 5). Hopper's inclination to avoid the issue of definition reflects the fact that sustainability has emerged as an umbrella under which a large number of movements with widely disparate reform agendas have been able to march while avoiding confrontation over their often mutually inconsistent agendas.

Definitions of Sustainability

In spite of the advantages of avoiding defining a term which has apparently been adopted precisely because of its ambiguity it is useful to trace the evolution of the concept. The term was first advanced in 1980 by the International Union for the Conservation of Nature and National Resources (IUCN; Lele, 1991). Prior to the mid-1980s the term had achieved its widest currency among critics of what was viewed as "industrial" approaches to the process of agricultural development (Harwood, 1990, pp. 3-19). Proponents had traveled under a number of rhetorical vehicles such as biodynamic agriculture, organic agriculture, farming systems, appropriate technology and, more recently, regenerative and low-input agriculture (Dahlberg, 1991).¹

Writing in the early 1980s, Gordon K. Douglass identified three alternative conceptual approaches to the definition of agricultural sustainability (Douglass, 1984, pp. 3-29). One group defined sustainability primarily in technical and economic terms - in terms of the capacity to supply the expanding demand for agricultural commodities on

¹Sandra Batie regards the concept of sustainable development "as the latest step in along evolution of public concern with respect both to natural resources and to the environment . . . Prior to World War II those concerns . . . emphasized technically efficient development of such resources for use as commodities. After World War II, the emphasis shifted to the aesthetic and amenity use of natural resources." (Batie, 1989, p. 1083).

resource economists, the long-term decline in the real prices of agricultural commodities has represented evidence that the growth of agricultural production has been following a sustainable path. In contrast a sustained rise in the real prices of agricultural commodities would be interpreted as raising serious concern about sustainability.

Douglass identified a second group that regards agricultural sustainability primarily as an ecological question - "for its advocates an agricultural system which needlessly depletes, pollutes, or disrupts the ecological balance of natural systems is unsustainable and should be replaced by one which honors the longer-term biophysical constraints of nature" (Douglass, 1984, p. 2). Among those advancing the ecological sustainability agenda there is a pervasive view that present population levels are already too large to be sustained at present levels of per capita consumption (Goodland, 1991).²

A third group traveling under the banner of "alternative agriculture," places its primary emphasis on sustaining not just the physical resource base but a broad set of community values (Committee on the Role of Farming Methods in Modern Production Agriculture, 1989). This third group draws substantial inspiration from the agroecological perspective. But it often views conventional science based agriculture as an assault, not only on the environment, but on rural people and rural communities. Its adherents take as a major objective the strengthening or revitalization of rural culture and rural communities guided by the values of stewardship and self-reliance and an

²This view stems in part from a naive carrying capacity interpretation of the potential productivity of natural systems. (Raup, 1964).

integrated or holistic approach to the physical and cultural dimensions of production and consumption.

By the mid-1980s the sustainability concept was diffusing rapidly from the confines of its agro-ecological origins to include the entire development process. The term had been appropriated by the broader development community. A sampling of the definitions that have been advanced in support of particular agendas are listed in Appendix 1. The definition that has achieved the widest currency was that adopted by the Bruntland Commission:

"Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs."
(World Commission on Environment and Development, 1987, p. 43).

The Bruntland Commission definition raises the possibility that it may be necessary for those of us who are alive today, particularly those of us living in the more affluent societies, to curb our level of material consumption in order to avoid an even more drastic decline in the consumption levels of future generations. This is not a welcome message to societies that have found it difficult to discover principled reasons for the contemporary transfer of resources across political boundaries in support of efforts to narrow the level of living between rich and poor nations or rich and poor people (Ruttan, 1989).

Our historical **experience**, at least in the West, often causes us to be skeptical about our obligations to **future** generations. It was less than a generation ago that Robert Solow, one of our leading growth theorists, noted in his Richard T. Ely address

to the American Economic Association: "We have actually done quite well at the hands of our ancestors. Given how poor they were and how rich we are, they might properly have saved less and consumed more" (Solow, 1974, p. 9). In most of the world the ancestors have not been so kind! This suggests that the future may be too important to be left to either market forces or historical accident - even for the more affluent societies.

In spite of its challenge to current levels of consumption in the developed countries it is hard to avoid a conclusion that the popularity of the Bruntland Commission definition is due, at least in part, to the fact that the definition is so broad that it is almost devoid of operational significance. The sustainability concept has undergone what has been referred to as "establishment appropriation" (Buttel and Gillespie, 1988). It is now experiencing the same "natural history" as earlier reform efforts. Initially a "progressive" rhetoric is advanced by critics as a challenge to the legitimacy of dominant institutions and practices. If the groups and symbols involved are sufficiently threatening to the dominant institutions, these institutions will attempt to respond to these challenges by "appropriating" or embracing the symbol themselves. "In so doing these dominant institutions - such as the World Bank and the agricultural universities - are typically able to demobilize the movement" (Buttel, 1991, p. 7).

Buttel argues that sustainability has been embraced both by radical reformers and neo-conservatives because it removes the focus from achieving greater participation of the poor in the dividends from economic growth to protecting an impersonal nature from the destructive forces of growth (Buttel, 1991, p. 9). Runge (1992) presents a more

positive perspective on the move by the traditional agricultural and development communities to embrace the sustainability concept. He visualizes sustainability as an integrative concept that can facilitate the synthesis of the research and policy agendas of the environmental, agricultural and development communities.

Sustainable Agricultural Systems in History

It is not uncommon for a social movement to achieve the status of an ideology while still in search of a methodology or a technology. If the reform movement is successful in directing scientific and technical effort in a productive direction it becomes incorporated into normal scientific or technical practice. If it leads to a dead end it slips into the underworld of science often to be resurrected when the conditions which generated the concern again emerge on the social agenda.

Research on new uses for agricultural commodities is one example. It was promoted in the 1930s under the rubric of chemurgy and in the 1950s under the title of utilization research as a solution to the problem of agricultural surpluses. It lost both scientific and political credibility because it promised more than it could deliver. It emerged again in the late 1970s and early 1980s in the guise of enhancing "value added." Integrated pest management represents a more fortunate example. This term emerged in the 1960s as an alternative to chemical intensive pest control strategies and was appropriated in the 1970s as a rhetorical device to paper over the differences between ecologically oriented and economically oriented entomologists (Palladino, 1989). At the time the terminology was adopted there were few pest control technical packages that could credibly be regarded as either technologically or economically viable "integrated"

pest control technologies. After two decades of scientific research and technology development there are now packages of practice which come closer to meeting the definition of integrated pest management as visualized by those who had coined the terminology.

In the case of sustainable agricultural systems we are able to draw on several historical examples of systems that proved capable of meeting the challenge of achieving sustainable increases in agricultural production. One example is the forest and bush fallow (or shifting cultivation) systems practiced in most areas of the world in pre-modern times and today in many tropical areas (Pingali et al., 1987). At low levels of population density, these systems were sustainable over long periods of time. As population density increased, short fallow systems emerged. Where the shift to short fallow systems occurred slowly, as in Western Europe and East Asia, systems of farming that permitted sustained growth in agricultural production emerged. Where the transition to short fallow has been forced by rapid population growth the consequence has often been soil degradation and declining productivity.

A second example can be drawn from the agricultural history of East Asian wet rice cultivation (Hayami and Ruttan, 1985). Traditional wet rice cultivation resembled farming in an aquarium. The rice grew tall and rank; it had a low grain-to-straw ratio. Most of what was produced, straw and grain, was recycled in the form of human and animal manures. Mineral nutrients and organic matter were carried into and deposited in the fields with the irrigation water. Rice yields rose continuously, though slowly, even under a monoculture system.

A third example of sustainable agriculture was the system of integrated crop-animal husbandry that emerged in Western Europe in the late middle ages to replace the medieval two- and three-field systems (Van Bath, 1963; Boserup, 1965). The "new husbandry" system emerged with the introduction and intensive use of new forage and green manure crops. These in turn permitted an increase in the availability and use of animal manures. This permitted the emergence of intensive crop-livestock systems of production through the recycling of plant nutrients in the form of animal manures to maintain and improve soil fertility.³

The three systems that I have described, along with other similar systems based on indigenous technology, have provided an inspiration for the emerging field of agroecology. But none of the traditional systems, while sustainable under conditions of slow growth in demand, has the capacity to respond to modern rates of growth in demand generated by some combination of rapid increase in population and in growth of income. Some traditional systems were able to sustain rates of growth in the 0.5-1.0 percent per year range. But modern rates of growth in demand are in the range of 1.0-2.0 percent per year in the developed countries. They often rise to the range of 3.0-5.0 percent per year in the less developed and newly industrializing countries. Rates of

³In his study of sustainable agriculture in the middle ages Jules N. Pretty notes that "Manorial estates survived many centuries of change and appear to have been highly sustainable agricultural systems. Yet this sustainability was not achieved because of high agricultural productivity - indeed it appears that farmers were trading off low productivity against the more highly valued goals of stability, sustainability and equitability. These were promoted by the integrated nature of farming; the great diversity of produce, including wild resources; the diversity of livelihood strategies; the guaranteed source of labor; and the high degree of cooperation." (Pretty, 1990, p. 1).

growth in demand in this range lie outside of the historical experience of the presently developed countries!

In the presently developed countries the capacity to sustain the necessary increases in agricultural production will depend largely on our capacity for institutional innovation. If our capacity to sustain growth in agricultural production is lost, it will be a result of political and economic failure. It is quite clear, however, that the scientific and technical knowledge is not yet available that will enable farmers in most tropical countries to meet the current demand their societies are placing upon them nor to sustain the increases that are currently being achieved. Further, the research capacity has not yet been established that will be necessary to provide the knowledge and the technology. In these countries, achievement of sustainable agricultural surpluses is dependent on advances in scientific knowledge and on technical and institutional innovation (TAC/CGIAR, 1989).

The Technological Challenge to Sustainability

One might ask why concern about the sustainability of modern agricultural systems has emerged with such force toward the end of the 21st century? The first reason is the unprecedented demands that growth of population and income are imposing on agricultural systems. We are in the process of completing one of the most remarkable transitions in the history of agriculture. Prior to the beginning of this century almost all increases in food production were obtained by bringing new land into production. This process of growth in agricultural production within the framework of what has been termed the "resource exploitation" model clearly is no longer sustainable.

By the first decades of the next century almost all increases in food production must come from higher yields - from increased output per hectare. In most countries of the world the transition from a resource - based to a science-based system of agriculture is occurring within a single century. In a few countries this transition began in the 19th century. For most of the presently developed countries it did not begin until the first half of this century. Most of the countries of the developing world have been caught up in this transition only since mid-century. Among developing countries this transition has proceeded further in South and Southeast Asia than in Latin America or Africa.

Historical trends in the production and consumption of the major food grains could easily be taken as evidence that one should not be excessively concerned about the capacity of the worlds farmers to meet future food demands. World wheat prices have declined since the middle of the last century. Rice prices have declined since the middle of this century. These trends suggest that productivity growth has been able to more than compensate for the rapid growth in demand arising out of growth in population and income, particularly during the decades since World War II. But the past may not be an effective guide to the future. The demands that the developing countries will place on their agricultural producers arising out of population growth and the growth in per capita consumption will, until well into the middle of the next century, be exceedingly high.

A second reason for concern about sustainability is that the sources of future productivity growth are not as apparent as we move toward the early years of the 21st century as they were a quarter century ago. It seems apparent that the gains in agricultural production required over the next quarter century will be achieved with

much greater difficulty than in the immediate past (Ruttan, 1989; 1993). The incremental responses to the increases in fertilizer use has declined. Expansion of irrigated areas has become more costly. Maintenance research, the research required to prevent yields from declining, is rising as a share of research effort (Plucknett and Smith, 1976). The institutional capacity to respond to these concerns is limited, even in the countries with the most effective national agricultural research and extension systems. And during the 1980s there had been considerable difficulty in many developing countries in maintaining the agricultural research capacity that had been established in the 1960s and 1970s (Cummings, 1989; Eicher, 1993).

It is possible that within another decade, advances in basic knowledge will create new opportunities for advancing agricultural technology that will reverse the urgency of some of the above concerns. Institutionalization of private sector agricultural research capacity in some developing countries is beginning to complement public sector capacity (Pray, 1987). Advances in molecular biology and genetic engineering are occurring rapidly. But the date when these promising advances will be translated into productive technology appears to be receding.⁴

It is only a slight overstatement to note that advances in crop yields have come about primarily by increasing plant populations per hectare and the ratio of grain to straw. Advances in animal feed efficiency have come about primarily by decreasing the proportion of feed consumed that is devoted to animal maintenance and by increasing

⁴For an argument that the results of genetic engineering can be expected to undermine sustainable methods of farming see Richard Hindmarsh (1991).

the proportions devoted to the production of usable animal products. There are severe physiological constraints to continued improvement along these conventional paths. These constraints are most severe in the areas that have already achieved the highest levels of productivity as in Western Europe, North America and parts of East Asia. Advances in conventional technology will be inadequate to sustain the demands that will be placed on agriculture as we move beyond the second decade of the next century.

It seems reasonable to anticipate, however, that advances in molecular biology and genetic engineering will release the constraints on productivity growth in the major food and feed grains. But advances in agricultural technology will not be able to eliminate what some critics tend to view as a "subsidy" from outside the agricultural sector. Transfers of energy in the form of mineral fuels, pathogen and pest control chemicals, and mineral nutrients from outside the agricultural sector will continue to be needed to sustain growth in agricultural production - and in much larger quantities - until well into the middle of the next century. Until population and total demand growth rates fall below one percent per year, energy transfers can be expected to continue to expand. Over the very long run scarcity, reflected in rising real prices, of phosphate fertilizer and fossil fuels are likely to become the primary resource constraints on sustainable growth in agricultural production (Chapman and Barker, 1991; Desai and Gandhi, 1990).

This leads to what appears, in my reading of the evidence, to what ought to be the primary concern about the sustainability of growth in agricultural production. This third set of concerns is with the environmental spillover from agricultural and industrial

intensification. The spillover effects from agricultural intensification include the loss of soil resources due to erosion, water-logging and salinization, surface and groundwater contamination from plant nutrients and pesticides, resistance of insects, weeds and pathogens to present methods of control, and the loss of landraces and natural habitats (Conway and Pretty, 1991). If agriculture is forced to continue to expand into more fragile environments because of lack of technical progress in more robust soil resource areas, problems such as soil erosion and desertification can be expected to become more severe. Additional deforestation will intensify problems of soil erosion, species loss, degradation of water quality and contribute to the forcing of climate change.

The sustainability of agricultural production will also be influenced by the impact of continued intensification of industrial and transportation systems. There can no longer be much doubt that the accumulation of carbon dioxide (CO₂) and other greenhouse gases - principally methane (CH₄), nitrous oxide (N₂O) and chlorofluorocarbons (CFC's) has set in motion a process that will result in a rise in global average surface temperature over the next 30-60 years. There continues to be great uncertainty about the temperature and rainfall changes that can be expected to occur at any particular date or location. But these changes can be expected to impose substantial adaptation demands on agricultural systems. The systems that will have the least capacity to adapt will be in countries with the weakest agricultural research and natural resource management capacity - principally in the humid and semi-arid tropics (Ruttan, 1992). The effects of industrial intensification can also be expected to impose substantial health burdens on agricultural producers and consumers. The effects of

heavy metal contamination has already affected the quality of crops and of animal and human health in a number of areas.

Sustainability is Not Enough

It should be apparent that a major issue over the next half-century for most developing countries, including the formerly centrally planned economies, will be how to generate and sustain the advances in agricultural technology that will be needed to meet the demands that these societies will place on these agricultural sectors. This objective appears to be in direct conflict with the world view of many of the leading advocates of sustainable development.

"Sustainable development" is a concept that implies limits, both to the assimilative capacity of the environment and to the capability of technology to enhance human welfare. To the sustainable development community the capacity of the environment to assimilate pollution from human production and consumption activity is the ultimate limit to economic growth" (Batie, 1989, p. 1085). But this is not a problem that has emerged only during the second half of the 20th century.⁵

I differ in one fundamental respect from those who are advancing the sustainability agenda. It seems clear to me the capacity of a society to solve either the

⁵"Man has throughout history been continuously challenged by the twin problems of (a) how to provide himself with adequate sustenance and (b) how to manage the disposal of what in recent literature has been referred to as "residuals." Failure to make balanced progress along both fronts has at times imposed serious constraints on societies growth and development. The current environmental crisis represents one of those recurring times in history when technical and institutional change in the management of residuals has lagged relative to progress in the provision of sustenance, conceived in the broad sense of the material components of consumption. Furthermore, in relatively high income countries the demand for commodities and services related to sustenance is low and declines as income continues to rise, while the income elasticity of demand for more effective disposal of residuals and for environmental amenities is high and continues to rise. This is in sharp contrast to the situation in poor countries where the income elasticity of demand is high for sustenance and low for environmental amenities." (Ruttan, 1971, p. 707).

problem of sustenance or the problems posed by the production of residuals is inversely related to population density and the rate of population growth and is positively related to its capacity for innovation in science and technology and in social institutions (Ruttan, 1971, p. 788). I am exceedingly concerned that the bilateral and multilateral assistance agencies, in their rush to allocate resources in support of a sustainability agenda derived more from developed country than developing country resource and environmental priorities, will fail to sustain the effort needed to build viable agricultural research institutions in the tropics.

Africa, in particular, has been the victim of a succession of donor enthusiasms-- integrated rural development, farming systems research, agro-forestry programs and others-- for which program rhetoric has preceded the technical and institutional knowledge and capacity necessary for program implementation. Sustainable development is now high on the agenda of many donor agencies. Yet it is clear that the technology does not exist in most African agro-ecological regions to assure sustainable growth in agricultural production at the rates of growth in demand, arising out of population and income growth, that most African societies are imposing on their farmers. Within Africa the technologies necessary to achieve sustainability will vary spatially and temporally (Spencer and Polsong, 1991; Webb et al., 1991; Matlon and Adesina, 1991). One of the most difficult problems, particularly in humid and sub-humid Africa, is how to supply and maintain adequate organic matter on the ground and in the topsoil in those areas where intensive animal agriculture is not feasible. Elements of sustainable systems are available from traditional systems. Others are becoming available from the

national and international research systems in the region. These include such practices and components as (a) leguminous cover crops, (b) ally farming with leguminous trees; (c) biological pest control, (d) host plant resistance to disease, and (e) improved maize, cassava, cowpea, plantain and other cultivars. While some of the new practices and technologies are technically viable they are often not economically viable. Inadequate physical and institutional infrastructure - transport and markets, for example - often impose a severe burden on use of even the most viable sustainable practices.

Three Unresolved Analytical Issues

In this section I identify three unresolved analytical issues that must be confronted before a commitment to sustainability can be translated into an internally consistent reform agenda.

The Issue of Substitutability

One area where our knowledge is inadequate is with respect to the role of technology in widening the substitutability among natural resources and between natural resources and reproducible capital. Economists and technologists have traditionally viewed technical change as widening the possibility of substitution among resources - of fertilizer for land, for example (Solow, 1974; Goeller and Weinberg, 1976). The sustainability community rejects the "age of substitutability" argument. The loss of plant genetic resources is viewed as a permanent loss of capacity. The elasticity of substitution among natural factors and between natural and man-made factors is viewed as exceedingly low (James et al., 1989; Daly, 1991). When considering the production of a

particular commodity-for example the substitution of fertilizer for land in the production of wheat-this is an argument over the form of the production function. But substitution also occurs through the production of a different product that performs the same function or fills the same need-of fiber optic cable for conventional copper telephone wire or of fuels with higher hydrogen to carbon ratios for coal, for example.

The argument about substitutability, while inherently an empirical issue, is typically argued on theatrical or philosophical grounds. It is passable that historical experience or advances in futures modeling may lead toward some convergence of perspectives. But the scientific and technical knowledge needed to fully resolve disagreements about substitutability will always lie in the future. Yet the issue is exceedingly important. If a combination of capital investment and technical change can continuously widen opportunities for substitution, imposing constraints on present resource use could leave future generations less well off. If, on the other hand, real output per unit of natural resource input is narrowly bounded -cannot exceed some upper limit which is not too far from where we are now -then catastrophe is unavoidable.

Obligations Toward The Future

The second issue is one that has divided traditional resource economists and the sustainability community. That is the issue of how to deal analytically with the obligations of the present generation toward future generations. The issues of intergenerational equity is at the center of the sustainability debate (Pearce et al., 1990; Solow, 1991). Environmentalists have been particularly critical of the approach used by resource and other economists in valuing future benefit and cost streams. The

conventional approach involves the calculation of the "present value" of a resource development or protection project by discounting the cost and benefit stream by some "real" rate of interest - an interest rate adjusted to reflect the costs of inflation. It is World Bank policy (but not always practice) to require a 10-15 percent rate of return on projects. These higher rates are set well above long term real rates of interest (historically less than 4 percent) in order to reflect the effect of unanticipated inflation and other risks associated with project development and implementation. An attempt is made in this way to avoid unproductive projects.

The critics insist that this approach results in a "dictatorship of the present" over the future. At conventional rates of interest the present value of a dollar of benefits fifty years into the future approaches zero. "Discounting can make molehills out of even the biggest mountain" (Batie, 1989, p. 1092). Solow has made the same point in more formal terms. He notes that if the marginal profit - marginal revenue less marginal cost - to resource owners rises slower than the rate of interest resource production and consumption is pushed nearer in time and the resource will be quickly exhausted (Solow, 1973, p. 3; Lipton, 1991).

A question that has not been adequately answered is if, as a result of the adoption of a widely held sustainability "ethic," the market determined discount rates would decline toward the rate preferred by those advancing the sustainability agenda.⁶ Or will

⁶The question of the impact of the use of a positive discount (or interest) rate on resource exploitation decisions is somewhat more complex than often implied in the sustainability literature. Simply lowering the discount rate to favor the natural resource sector will not assure slower exploitation of natural resources if the market rate of interest remains high. Recipients of the lower interest rates may transfer the revenue from resource exploitation to investments that have higher rates of return rather than reinvesting to sustain the flow of resource benefits. Furthermore, high rates of resource exploitation can be consistent with either

it be necessary to impose sumptuary regulations -constraints on current consumption- in an effort to induce society to shift the income distribution more strongly toward future generations? It is clear, at least to me, that in most countries efforts to achieve sustainable growth in agricultural production must involve some combination of (a) higher contemporary rates of saving - that is deferring present in favor of future consumption, and (b) more rapid technical change - particularly the technical changes that will enhance resource productivity and widen the range of substitutability among resources.⁷ But will this be enough? I suspect not! What should be done given the inability of economic theory to provide satisfactory tools to deal analytically with obligations toward the future? My own answer is that we should take a strategic approach to the really large issues - how much should we invest to reduce the probability of excessive climate change, for example. We should continue to employ conventional cost benefit analysis to answer the smaller questions, such as when to develop the

high or low interest rates. In the case of forest exploitation, for example, a low discount rate favors letting trees grow longer and the planting of trees which take longer to grow. In the other hand a low discount rate will make it profitable to invest in mineral exploitation, land and water development or other investment projects, that might otherwise be unprofitable. That is why, in the past, resource economists and environmentalists have argued in favor of higher interest rates on public water resource projects. (Norgaard, 1991; Price, 1991; Graham-Tomasi, 1991). As an alternative to lower discount rates, Mikesell (1991) suggests taking resource depletion into account in project cost benefit analysis. For a useful commentary on the debate about the effects of high and low interest rates on sustainability see Lipton (1991).

⁷Norgaard and Howarth (1991) and Norgaard (1991) argue that decisions regarding the assignment of resource rights among generations should be made on equity rather than efficiency grounds. When resource rights are reassigned between generations interest rates will change to reflect the intergenerational distributions of resource rights and income. I interpret these arguments as saying that if present generations adopt an ethic that causes them to save more and consume less the income distribution will be tilted in favor of future generations. This is, however, not the end of the story. A decline in marginal time preference has the effect of lowering the rate of interest. Improvement in investment opportunities resulting, for example, from technical change will have the effect of increasing the demand for investment and thus raising interest rate (Hirschleifer, 1970, pp 113-116).

drainage systems needed to avoid excessive build-up of water logging and salinity in an irrigation project.

Incentive Compatible Institutional Design

A third area where knowledge needs to be advanced is on the design of institutions that are capable of internalizing--within individual households, private firm and public organization--the costs of actions that generate the negative spillover effects - the residuals - that are the source of environmental stress. Under present institutional arrangements important elements of the physical and social environment continue to be undervalued for purposes of both market and non-market transactions. Traditional production theory implies that if the price to a user of an important resource is undervalued it will be overused. If the price of a factor, the capacity of groundwater to absorb pollutants for example, is zero it will be used until the value of its marginal product to the user approaches zero. This will be true even though it may be imposing large social costs on society.

The dynamic consequence of failure to internalize spillover costs are even more severe. In an environment characterized by rapid economic growth and changing relative factor prices failure to internalize resource costs will bias the direction of technical change. The demand for a resource that is priced below its social cost will grow more rapidly than in a situation where substitution possibilities are constrained by existing technology. As a result "open access" resources will undergo stress or depletion more rapidly than in a world characterized by a static technology or even by neutral (unbiased) technical change.

The process is clearly apparent in agriculture. In the United States federal farm programs encourage farmers to grow a small group of selected program crops, to grow these crops on a continuous basis, and to use more chemical intensive methods in production (General Accounting Office, 1990). Over the long-run one effect of U.S., EC and Japanese agricultural commodity programs has been to bias the direction of technical change by making land more expensive. Until very recently the capacity of the environment to absorb the residuals from crop and livestock production has been treated as a free good. As a result, scientific and technical innovation in both the public and private sectors has been overly biased toward the development of land substitutes - plant nutrients and plant protection chemicals and management systems that reflected the overvaluation of land and the undervaluation of the social costs of the disposal of residuals from agricultural production processes. In retrospect it seems apparent that the same biases in factor prices have led to underinvestment in technological effort directed toward pest and soil management systems consistent with the social value of environmental services (Runge et al., 1990).

The design of incentive compatible institutions - institutions capable of achieving compatibility between individual, organizational and social objectives - remains at this stage an art rather than a science. The incentive compatibility problem has not been solved even at the most abstract theoretical level.⁸ This deficiency in institutional design capacity is evident in our failure to design institutions capable of achieving contemporary

⁸The concept of incentive compatibility was introduced in a 1972 paper by Hurwicz (1972). In that paper he showed that it was not possible to specify an informationally decentralized mechanism for resource allocation that simultaneously generates efficient resource allocation and incentives for consumers to honestly reveal their true preferences. For the current state of knowledge in this area see Groves et al. (1987).

distributional equity, either within countries or among rich and poor countries. It impinges with even greater force on our capacity to design institutions capable of achieving intergenerational equity.

An Uncertain Future

In closing I would like to emphasize how far we are from being able to design either an adequate technological or institutional response to the issue of how to achieve sustainable growth in agricultural production - or in the sustainable growth of both the sustenance and the amenity components of consumption.

At present there is no package of technology that is available to transfer to producers that can assure the sustainability of growth in agricultural production at a rate that will enable agriculture, particularly in the developing countries, to meet the demands that are being placed on them.⁹ Sustainability is appropriately viewed as a guide to future agricultural research agendas rather than as a guide to practice (Ruttan, 1988; Graham-Tomasi, 1991). As a guide to research it seems useful to adhere to a definition that would include: (a) the development of technology and practices that maintain and/or advance the quality of land and water resources, and; (b) the improvement in the performance of plants and animals and advances in production

⁹There is a large literature in agronomy, agricultural economics and related fields that reports on research designed to develop or transfer sustainable agricultural practices. some of this research is reported in the papers in this volume. For other examples see Board on Agriculture, National Research Council (1991); Board on Agriculture and Board on Science and Technology for Development (1992). See also the bibliography by Rosenberg and Eisgruber (1992). Much of the evidence presented in such studies represents progress reports on preliminary results from experiments or trials that are, of necessity, long term in nature. The value I place on such studies is consistent with my comments above that in the absence of clarity about the concept of sustainable agricultural development it is important that we "approach the issue of technological and institutional design pragmatically."

practices that will facilitate the substitution of biological technology for chemical technology. The research agenda on sustainable agriculture needs to explore what is biologically feasible without being excessively limited by present economic constraints.

At present the sustainability community has not been able to advance a program of institutional innovation or reform that can provide a credible guide to the organization of sustainable societies. We have yet to design the institutions that can assure intergenerational equity. Few would challenge the assertion that future generations have rights to levels of sustenance and amenities that are at least equal to those enjoyed (or suffered) by the present generation. They also should expect to inherit improvements in institutional capital - including scientific, and cultural knowledge - needed to design more productive and healthy environments.

My conclusion with respect to institutional design is similar to that which I have advanced in the case of technology. Economists and other social scientists have made a good deal of progress in contributing the analysis needed for "course correction." But capacity to contribute to institutional design remains limited. The fact that the problem of designing incentive compatible institutions - institutions capable of achieving compatibility between individual, organizational and social objectives - has not been solved at even the most abstract theoretical level means that institutional design proceeds in an ad hoc trial and error basis - and that the errors continue to be expensive. Institutional **innovation** and reform should represent a high priority research agenda.

**"Had we but world enough, and time,
defining sustainable development, Professor,
were no crime" John Donne,
"To my coy mistress," (adapted by James Winpenny)**

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Appendix 1

Definitions of Sustainability

Ecological Sustainability

1. "Sustainable agriculture is both a philosophy and a system of farming. Sustainable agricultural systems rely on crop rotations, crop residues, animal manures, legumes and green manures, off farm organic wastes, appropriate mechanical cultivation and mineral bearing rocks to maximize soil biological activity, and to maintain soil fertility and productivity. Natural, biological and cultural controls are used to manage pests, weeds and diseases . . . We can no longer go on pretending that the energy dependent, environmentally destructive systems of the past can be passed on as sustainable agriculture" (Hill, 1990, quoted in Loyns and MacMillan, 1990).
2. "Alternative agriculture is any system of food or fiber production that systematically pursues the following goals: more thorough incorporation of natural processes such as nutrient cycles, nitrogen fixation, and pest-predator relationships into the agricultural production process; reduction in the use of off farm inputs with the greatest potential to harm the environment or the health of farmers and consumers; greater productive use of biological and genetic potential of plant and animal species; improvement of the match between cropping patterns and the productive potential and physical limitations of agricultural lands to ensure long-term sustainability of current production levels; and profitable and efficient production with emphasis on improved farm management, conservation

of soil, water, energy and biological resources." (Committee on the Role of Alternative Farming Methods in Modern Production Agriculture, 1989, p. 4).

3. A sustainable system is "...a system that can be maintained almost indefinitely in the same site, that over the long term enhances the environment and quality of life for farmers and society, and does not negatively affect the environmental system." (Gomez-Pompa et al., 1991).
4. "Sustainability should be treated as a dynamic concept, reflecting changing needs, especially those of a steadily increasing population . . . The goal of a sustainable agriculture should be to maintain production at levels necessary to meet the increasing aspirations of an expanding world population without degrading the environment. It implies concern for the generation of income, the promotion of appropriate policies, and the conservation of natural resources" (TAC/CGIAR, 1989).

Developmental Sustainability

5. "Sustainable development is not a fixed state of harmony but rather a balanced and adaptive process of change . . . Sustainability takes for granted a balance between economic development - all quantitative and qualitative changes in the economy that offer positive contributions to welfare - and ecological sustainability - all quantitative and qualitative environmental strategies that seek to improve the quality of an ecosystem and hence also have a positive impact on welfare" (Nijkamp et al., 1990, p. 156).

6. "Sustainability has assumed particular importance because (of) the sharp drop in living standards that has accompanied adjustment programs in many countries . . . We term real output growth sustainable if it exceeds population growth" (Faini and de Melo, 1990, p. 496).
7. Project sustainability . . . (is) the maintenance of an acceptable net flow of benefits from the projects' investments after its completion - after the project ceased to receive both financial and technical support" (Cernea, 1987, p. 118).
8. "Sustainability can be introduced into CBA (cost benefit analysis) by setting a constraint on the depletion and degradation of the stock of natural capital. Essentially the economic efficacy objective is modified to mean that all projects yield net benefits should be undertaken subject to the requirement that environmental damage (i.e. natural capital depreciation) should be zero or negative. However, applied at the level of each project such a requirement would be stultifying. Few projects would be feasible. At the programme level, however...it amounts to saying that netted out across a set of projects the sum of individual damages should be zero or negative." (Pearce et al., 1990, pp. 58, 59).

