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THE ECONOMICS OF SUSTAINABLE AGRICULTURAL SYSTEMS IN DEVELOPING COUNTRIES

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ABSTRACT

This paper is written from the perspective that sustainable agricultural growth in the LDCs is related to both agricultural and non-agricultural policies in the developed as well as the developing world. Most economists view sustained agricultural growth as a necessary but not a sufficient condition for economic development. But in an era of rapid population growth, sustained agricultural growth is achieved not by sustaining, but rather by changing agricultural systems, and by creating a viable market economy that can serve the needs of urban as well as rural consumers.

The rapid growth in agricultural production in Asia in the past two decades, as a consequence of the introduction of "green revolution" technology, was confined largely to the irrigated areas. Such a growth rate could not have been achieved without a long history of institutional and infrastructure investment. Much of the potential of the "green revolution" technology has been exploited, and investments in irrigation and agriculture have been declining. Whether the growth rates of the past two decades can be sustained in the future is open to question.

The sustainability of African agriculture is far more problematic. Population is growing at almost twice the rate of food production. Africa is poorer than Asia, not only in terms of natural resources, but also in terms of the institutions and infrastructure needed for rapid growth in agricultural production. We argue that it will take decades of investment in institutions, infrastructure, and human capital at very low rates of return to lay the foundation for sustainable growth in African agriculture.

The major long term threat to the sustainability of agricultural production in the developing country comes from the policies and practices of the developed countries. Consumer demand for energy in the developed countries is depleting resources and polluting the environment at an alarming rate. Global environmental problems due to fossil energy and chemicals, and the limited nature of world petroleum resources both imply the need for reduced dependency on fossil-fuel based energy and on agricultural chemical use. However, none of the presently available alternatives are cost effective. While biotechnology offers some promise for reducing the dependence on agricultural chemicals, major gains from biotechnology are still decades away.

Declining world grain prices and the financial constraints of the developing countries have tended to discourage investment in agriculture in the short run. However, the future holds many uncertainties, and sustaining agricultural growth in the long term is likely to require a higher level of investments than in the past.

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History records the decline and disappearance of earlier civilizations who were unable to sustain agricultural production (Douglas, 1984). Since the time of Malthus, we have been repeatedly warned about the "limits to growth", first by economists (economics gained an early reputation as the dismal science) and more recently by environmentalists. However, scientific progress and new technology have always postponed the day of reckoning (Barnett and Morse, 1962).[1] There is now a faith among many that science and new technology will continue to remove the environmental constraints to growth. Like the story of the boy who cried "wolf", there is a danger that we will discover too late that the wolf has already arrived.

In this paper, we address this issue from an economist's perspective. In so doing we must come to grips with the central theme of this conference, what

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1.One of the most comprehensive investigations of this issue was conducted by Barnett and Morse, (1962). The authors state that: "Malthusian scarcity, no doubt has characterized many relatively primitive societies which possessed limited knowledge and skill. They not only failed to develop cultural taboos which stabilized population but also were able to extract only a small portion of services available in their natural resources. Thus the limits of their resources were quickly reached.... Under primitive conditions of isolation a relevant question is whether it is the limited availability of natural resources or the limited stock of knowledge which produces diminishing returns and inhibits economic growth.... Recognition of the possibility of technological progress clearly cuts the ground from under the concept of Malthusian scarcity." pp. 6-7.

constitutes a sustainable agricultural system. We address this issue from a macro perspective, because sustainable agricultural systems must be viewed in the context of national, regional, and world agricultural development.

Douglas, writing on the "Meanings of Sustainability", distinguishes between sustainability as "food self-sufficiency" (an economic perspective), "stewardship" (as ecological perspective), and "community" (a sociological perspective) (Douglas, 1984). Our discussion is concerned principally with the first area, the balance between food production and food demand. However, we should emphasize that achieving food self sufficiency is itself an illusive concept definitionally. Furthermore, meeting demand for major food crops is for most economies in the developing world often a necessary but not a sufficient condition for take-off to sustained economic development. For example, in the mid-1980s India actually exported food grains, while millions of her citizens lacked the purchasing power to meet minimum basic needs.

In the section which follows, we present a perspective on sustainable agriculture. Next we discuss sustainable agricultural systems in the context of the recent Asian experience. We then ask the question, under what conditions is African agriculture sustainable? Finally, using nitrogen fertilizer as an example, we discuss the impact of developed country policies on the sustainability of agriculture in the developing countries.

Sustainable Agricultural Systems: A Perspective

Sustainable development in a world economy implies a stable and satisfactory relationship between agricultural production and consumption. It implies a world population level or growth rate that is supportable on a long term basis. It implies that negative products such as hazards from pesticides are controlled. Sustainability requires sufficient equity in access to production capacity and distribution to insure political stability.

Agricultural sustainability has extraordinarily different implications in today's world than in even the recent past. Some traditional systems were able to sustain growth rates in agricultural production of one percent per year (Hayami and Ruttan, 1985). Prior to World War II, Japan was among the first countries to make use of chemical fertilizers. However, between 1918 and 1940 rice output in Japan grew at less than one percent, although growth rates of around 2 percent were achieved in the Japanese colonies, Korea and Taiwan. Agricultural production, slowed by the great depression and the drought in the 1930s, grew at 1 percent per annum in the United States between the two World Wars.

Following World War II, advances in medicine, health care, and nutrition greatly reduced mortality leading to a population explosion in the developing world. Population growth rates of 2 to 3 percent became normal. The annual increase in food demand now ranges from 2 to over 4 percent. This unprecedented expansion in food demand was met by expanding cultivated land and land under irrigation, and by increasing yield per hectare. Increases in yield per hectare in the order of 2 to 3 percent were made possible only through the rapid increase in use of purchased inputs, particularly chemical fertilizers. Not all of the developing world could achieve these growth rates. Some countries, particularly in Africa, have become increasingly dependent on food imports as production per capita has declined.

The situation that the world now faces with respect to sustaining growth in agricultural production is described by Ruttan as follows: (Ruttan, 1987)

"We are during the closing decades of the twentieth century, approaching the end of the most remarkable transition in the history of agriculture. Before the beginning of this century almost all increases in agricultural production occurred as a result of increases in the area cultivated. By the end of this century there will be few significant areas where agricultural production can be expanded by simply adding more land to production. Agricultural output will have to be expanded almost entirely from more intensive cultivation in areas already being used for agricultural production."

Sustainable agricultural systems are those systems which support sustainable development in a world economy. Today we hope to develop flexible agricultural systems with the capacity incorporate new knowledge and increase yield per hectare at two percent or more, but a system which maintains both the quality and production potential of the physical environment. At present, we are capable of achieving these growth rates only by exploiting non-renewable resources. While we look for a more sustainable long-run alternative, we must not destroy the production potential of the environment. At the same time, we must invest enough in research to insure that the technology is on hand to provide continuous gains in yield.

As with all processes of development, the question is one of balance in investments. There is always the danger that the effort to satisfy short-run demand will do irreparable damage to long run agricultural production potential. This threat to the environment comes in the developing world from farmers in the less favorable areas struggling to meet basic needs, from those who exploit forest, land, and water resources for short-run profits, and from farmers in the more favorable areas using modern inputs to sustain high growth in yields; it comes in the developed world, from consumers whose energy demands are depleting resources and polluting the environment at an alarming rate. All of these factors are considered in the following sections of the paper.

The Asian Experience

The predominant food grain in Asia is rice. The wetbed paddy rice culture practiced throughout Asia today had its origins in China and South Asia centuries ago (Barker and Herdt, 1985, pp. 15-16). Irrigation was widely practiced in China in the second and third century B.C. Manuring and transplanting were practiced in the early Christian era. Many of the tools used today, such as the combtooth harrow, were developed in the 8th to the 12th century. With the expansion of irrigation during the colonial period, the paddy rice culture spread widely. These technologies combined with the development of irrigation permitted Chinese farmers between the 14th and mid-20th centuries to raise grain output in more or less equal measure by expanding the cultivated acreage and by raising yield per acre (Perkins, 1969, p.13). But population grew at less than one half of one percent per annum.

The rice culture practiced throughout Asia today is remarkable in both its longevity and degree of homogeneity. With the exception of East Asia (Japan, South Korea, and Taiwan) and other pockets of Asia which are largely mechanized, cultivation practices differ very little. Land is puddled with animal power, and rice transplanted, cultivated, and harvested by hand using similar technologies.

Adding new seed varieties and chemical fertilizers to this ancient system has made it possible to raise growth in yield per hectare from less than 1 percent to 2 to 3 percent in many countries. While similar success has been achieved with wheat and a limited number of other crops, in terms of geographic coverage, the so-called modern rice technology (making relatively minor management changes to a traditional system) has had the biggest impact in Asia.

However, for this seemingly simple technological achievement in rice to succeed, much more was needed. It was necessary to distribute seeds and fertilizer, to provide credit, to provide irrigation facilities, to provide transportation, storage and stable grain markets for the large increases in marketable surplus. All of these inputs are part and parcel of Asia's sustainable rice system.

The case of Indonesia illustrates the problems that can occur with the growing dependency on agricultural chemicals in a developing country. Indonesia is regarded as one of the recent success stories in agriculture. In the late 1970s Indonesia imported 1.5 million metric tons of rice per year, but in 1985 exported one-half a million metric tons. Rice production grew at 5 percent per year between 1968 and 1984, but roughly half of that growth is attributable to improved financial incentives generated by massive fertilizer subsidy (Timmer, 1988). Farm gate fertilizer prices were less than half of world prices, and fertilizer consumption grew at 25 percent per year.

Farmers in Indonesia also paid only 10 to 20 percent of the cost for pesticides, and the extremely low price lead to widespread and heavy application (Repetto, 1985). The high rates of application in Java caused serious damage to the 1986 rice crop and created serious ecological problems, poisoning the breeding grounds for fish and shrimp in the coastal waters.[2] Furthermore, the

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2 International Rice Research Institute, News Release, "Indonesia Backs Beneficial Insects," Los Banos, Philippines: International Rice Research Institute, Jan. 1987. The brown planthopper was said to have reached epidemic proportions in Central Java resulting in a rice harvest shortfall of an estimated 100,000 tons.

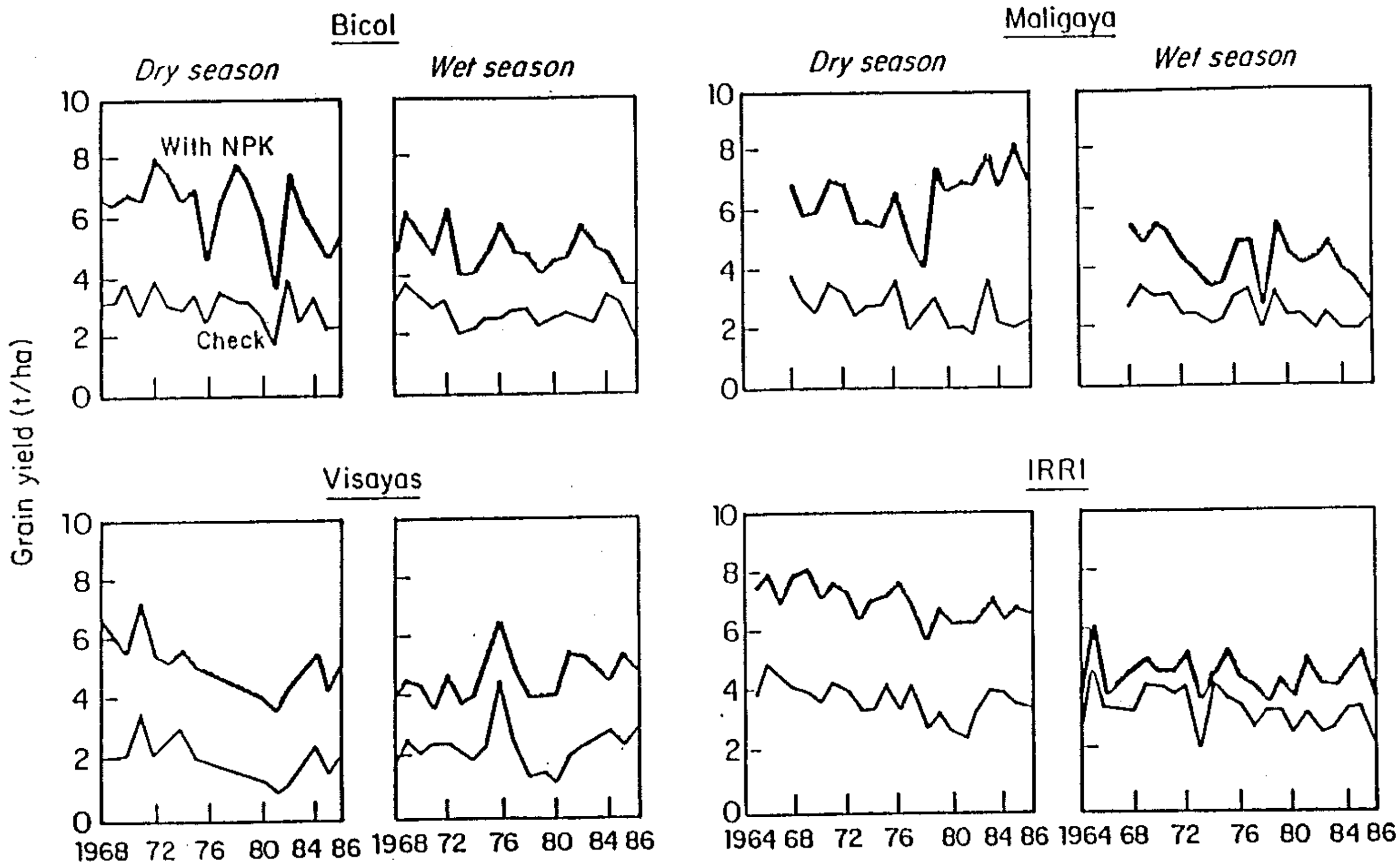
heavy application of chemicals promoted the build up of brown planthopper by destroying the predators of the planthopper and by encouraging the development of new planthopper biotypes.

The problems in Indonesia came as no surprise to rice scientists in Asia who for more than two decades have been breeding for varieties resistant to insects and diseases, and who since the energy crisis in the mid-1970s have been researching ways to make more efficient use of chemical fertilizers and to find alternative sources for nitrogen. In fact much of the research at the International Rice Research Institute and elsewhere is described as "maintenance research" designed to sustain the recent gains in productivity.

Despite the achievements of the past, the future of the Asian rice economy remains more uncertain than is commonly recognized. First, sustaining the current yield levels is not enough. Figure 1 shows the long term yields of rice under experimental conditions in four locations in the Philippines. In all four locations experimental yields over a period of two decades have been either constant or declining. With the exception of hybrid rices which are now widely grown in China, there has been no significant breakthrough in the yield ceiling in Asia since IR8 was first released in 1966. There are already signs that in parts of China and other intensively cultivated areas such as Central Java we may be approaching these yield ceilings.

Another mainstay of output growth in Asia has been the expansion of irrigation. The downward trend in world grain prices, due in no small measure to surpluses generated through subsidized production in the developed countries, has been a major factor discouraging investments in irrigation. Table 1 and Figure 2 show the sharp decline in the 1980s in the growth in new area irrigated and in

Figure 1. Changes in Yield Response to NPK with Successive Croppings of Improved Rice Varieties Grown for 23 years (1964-86) at IRRI and 19 years (1968-86) at Bicol, Maligaya, and Visayas Experiment Stations.



Source: De Datta, Gomez, and Descalsota, 1988.

Table 1. Compound Growth Rates of Net Irrigated Area - World.

Period	Rate[a] (%)	
	World	Asia
1965-84	2.0	1.6
1965-69	2.2	2.5
1970-74	2.3	2.1
1975-79	2.5	1.9
1980-84	0.9	0.7

[a] Computed from table 1 using semi-log regression techniques.

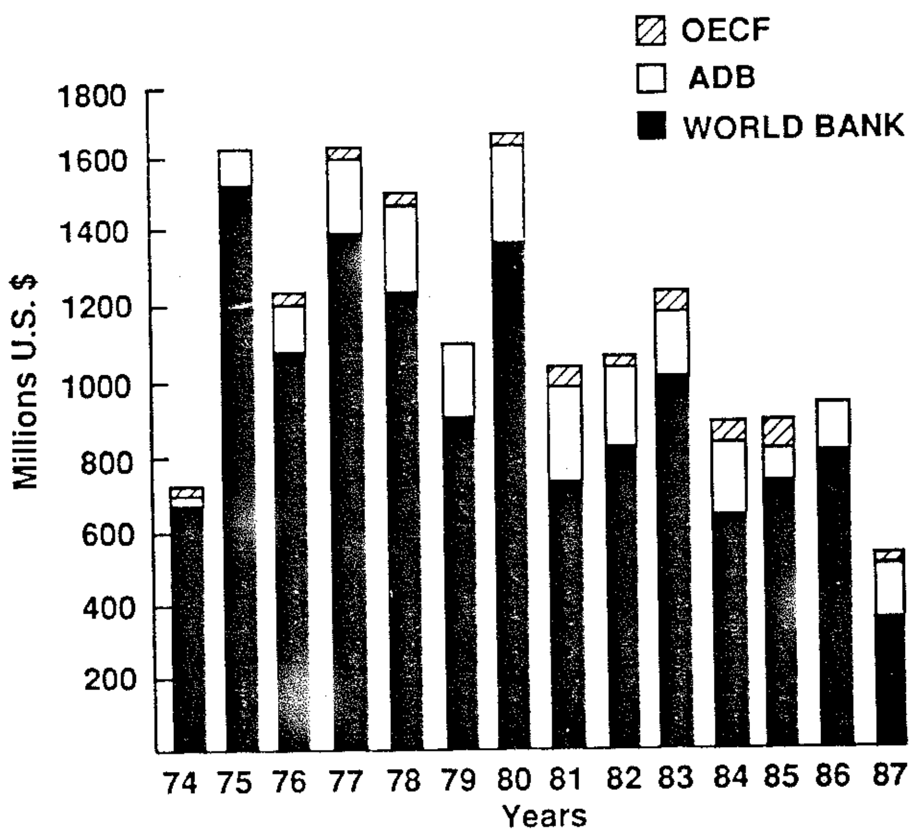


Figure 2. World Bank, ADB and OECF irrigation loans M. East, South and Southeast Asia, (1980 Prices)

irrigation investments by the World Bank and other major international lending institutions.

The sustainability of Asia's rice production systems depends on a healthy irrigation system. The past emphasis on investment in physical structures (hardware) as opposed to management (software) means that many systems are not operated efficiently. Increased siltation due to loss of tree cover in the catchment areas reduces production potential in many irrigation systems. Waterlogging and salinity threaten the sustainability of agriculture in the Indus Basin.

While the focus of the above remarks is on sustaining growth in the favorable areas, there are major regions of Asia which have benefited little if at all from the "green revolution." Of particular concern are the heavily populated, rice-dependent areas of Eastern India and Bangladesh. In most of these areas of uncontrolled water, constant flooding, poor drainage, and even drought, rice yields have remained at about 1.5 t/ha for almost three decades. Of this region, Gilbert Etienne writes as follows: (Etienne, 1985, p. 147).

> "The advanced districts which are already highly productive cannot feed India for ever. The future battles will increasingly be fought in the eastern plains where the untapped potential is enormous."

Yet the battle has scarcely been joined. The rivers that flow from the Himalayas are short, frequently change course, and are extremely difficult to harness. Massive investments are needed for the development of ground water and the control of flooding. There is a chronic shortage of power for operating pumps. Any comprehensive, long-term plan for the development of the Ganges-Brahmaputra basin will require the cooperation of the governments of India, Bangladesh, and Nepal.

The Sustainability of Sub-Saharan African Agricultural Systems

Population growth in Africa has been more rapid than growth in food crop production (Table 2). The result has been a decline in staple food production per capita and a sharp rise in food imports to hold food consumption per capita almost constant. It would be necessary to double Africa's annual rate of growth in food production to attain regional self-sufficiency (Eicher, 1988).

It would be presumptive to suggest that we can pinpoint the reasons for this problem, or to indicate precisely how this rate can be doubled. There would appear to be a complex of factors involved. In this section we will highlight some key issues, and draw some contrasts with the Asian experience.

If one compares regions of Africa with the upland or non-irrigated areas of much of Asia, the problems in raising agricultural production appear to be very similar. For example, prior to the 15th century and the spread of paddy rice, a tree crop, root crop culture predominated in Southeast Asia. Today the vestiges of that culture can still be found in the marginal and upland areas and in the islands of the South Pacific. The shifting cultivation crop rotations are remarkably similar to those of West and Central Africa. A crop or two of upland rice or maize is followed by cassava or sweet potato and then several years of fallow. The problems faced by farmers, controlling emparada weed, shortening the fallow, and maintaining soil fertility without access to chemical fertilizers, are virtually the same in both regions. In Asia as well as in Africa food production has not increased rapidly in these areas.

One of the most convincing arguments for the failure of the of farmers in Sub-Saharan Africa to adopt modern varieties and purchased inputs is advanced by

Table 2. Africa Growth of Food Production, Consumption and Trade.

	Annual Growth Rates in Percent
Production of all major food crops (1961-80)	+1.7
Cereals production (1961-80)	+1.8
Total human consumption of staple food	+2.5
Population growth rate	+2.6
Staple food production per capita	-0.9
Staple food consumption per capita	-0.1
Food exports (1966/70-1976/80)	-7.1
Food imports (1966/70-1976/80)	+9.2

Source: Staatz, 1988.

Binswanger and Pingali (1988). The person/land ratios in Africa have usually been lower than in Asia, invalidating the focus on high yields per acre as these farmers have sought high yields per farmer.

However, this situation is changing rapidly. In papers presented at this conference, Bede Okigbo and Natalie Hahn describe how some farming systems in Africa have been able to achieve sustainability under intense population pressure[3]. Goldman and other colleagues at the International Institute of Tropical Agriculture are conducting research to understand how the process of adjustment to population pressure takes place.

Goldman (1988), lists the ways in which the farming systems of the high density acid soil regions of Imo State in Southeastern Nigeria have adapted to the problems of generating increased food and income:

(1) Extending the margins of cultivation to previously unused land.

(2) Shortening the fallow period: increasing the intensity of land use overtime.

(3) Soil amendments to increase the productivity during the period.

(a) enhanced recycling of soil nutrients in vegetation, crops, etc.

(b) import of soil nutrients.

(4) Differentiation of fields in relation to soil and crop management.

(5) Creation of high intensity production niches.

(a) compound farms.

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3. See Bede N. Okigbo, "Sustainable Agricultural Systems in Tropical Africa," and Natalie Hahn, "Compound and Household Farming: A Sustainable System of African Agriculture," papers prepared for International Conference on Sustainable Agricultural Systems, Ohio, Sept. 19-23, 1988.

(b) wetland development.

(6) Crop changes; adoption of crops less sensitive to existing soil conditions.

(7) Management of fallow vegetation; enhancing regeneration of soil productivity during the fallow period.

(8) The transfer of land use entitlements; diffusion of intensified land use.

(9) Food imports from other areas.

(10) Increasing non-farm activities for income generation.

(11) Out migration from the area; seasonal or permanent.

The above list is extremely useful because it is readily generalizable to other areas, and because it allows us to systematically examine for a given farming system, region, or country, the opportunities and constraints for expanded food production.

In much of the humid tropics where soils are notoriously infertile, migration has been a major form of adjustment to growing population pressure. Migration to urban areas has been encouraged by the lack of investment in rural infrastructure and the subsidization of cheap food imports for urban consumers. The unfavorable climate matched by unfavorable policies for rural development makes it impossible to generate the marketable surplus to feed the rapidly growing (6% per annum) urban population. It is estimated that by the year 2010 approximately half of Africa's population will reside in the cities (IITA, 1988; p. 11).

Recognizing that rapid growth in food production has been achieved with the use of chemical inputs, scientists in both Africa and Asia have attempted this approach on the non-irrigated lands of the humid tropics hoping to find an alternative for shifting cultivation or at least to shorten the fallow period. At the experiment station at the International Institute of Tropical Agriculture, where neither capital nor access to purchased inputs is a constraint, researchers beginning in 1967 cleared the land and practiced conventional plow, harrow, seed-bed preparation with contour farming, hoping to maintain fertility with chemical fertilizers.[4] Since 1974 ever increasing areas have been planted no-till until by 1985 only the root crops received conventional seed-bed preparation. The replacement of mechanical weed control with chemical weed control resulted in a dramatic decrease in soil erosion. However, despite improved soil conservation, a decline in crop yields continued due to inadequate organic matter levels and soil compaction. Around 1980 it was decided to adopt a rotation planting the legume, mucuna pruriens, every second or third year. From 1980 onward experimental yields of both cassava and maize have remained fairly constant, but have shown no tendency to increase (Table 3). Furthermore, yields reported have not been adjusted for the fallow period.

Over a period of two decades much has been learned. However, whether the practices currently being followed at IITA are a viable alternative to the shifting cultivation widely practiced in this area is still open to question.

The mixture of trees with annual crops has been a traditional feature of farming systems in the humid tropics.[5] Alley farming with the use of leucaena

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4. The remainder of the paragraph is based on " the Ibadan Farm as a Research Resource" a note prepared for management by the Farm Management Unit, International Institute of Tropical Agriculture in 1987.

5. For an excellent review of alley farming, see B. T. Kang, L. Reynolds, and A. N. Atta-Krah, "Alley Farming". This publication prepared by scientists from the International Institute of Tropical Agriculture and the International Livestock Center for Africa in 1988 is still in draft form.

Table 3. Yields of Cassava and Maize Varieties from Experiment Conducted at IITA, 1972-1987.[a]

Year	Cassava Variety TMS30572	Year	Maize Varieties TZB	
			TZB	TZ5RW
1973-74	66.2	1972	4.3	
1974-75	54.1			
1975-76	35.2			
1976-77	22.5			
1977-78	40.5			
1978-79	24.6	1978	3.1	
1979-80	30.7	1979	6.7	4.4
1980-81	15.6	1980	3.6	3.7
1981-82	19.0	1981		3.8
1982-83	18.4			
1983-84	21.8			
1984-85	20.1			
1985-86	17.1	1985	4.9	5.0
1986-87	20.4	1986	3.7	4.8

Source: Cassava data: Root and Tuber Improvement Program, IITA, Ibadan, Nigeria.

Maize data: Farm Management Unit, IITA, Ibadan, Nigeria.

a Data should be interpreted with caution. Experiments are not conducted at the same location on the farm each year. Beginning around 1980, mucuna is planted every second or third year to nuture soil organic matter, and yields have not been adjusted for this.

has been widely publicized in both Africa and Asia as a "new" technology with great potential for raising crop productivity. It has been tested in the experiment station and in farmer's fields with mixed results. The fast growing <u>leucaena</u>, with its high demand on labor and management, appears to be an appropriate technology for only a small fraction of the farmers. <u>Leucaena</u> is very sensitive to acid soils, and in many other areas where labor is in short supply it has the potential of becoming an unwanted weed.

The wide range of differences in climates, soils, and labor in Sub-Saharan Africa, and in upland Asia, leads to a variety of farming systems. Technology strategies must take into account local differences. At present, for example, the moist savannahs offer more potential than the humid tropics for creating the needed food surpluses. However, in these more favorable ecologies, inadequate transportation, markets, and facilities for supplying both inputs and credit constrain the growth of agriculture. Eicher states the issue as follows: (Eicher, 1988; p. 19).

> "Food policy analysts must, by necessity, include both food demand and supply issues in their analyses instead of assuming that Africa's food gap can be closed by action on the supply side, i.e. stepping up food production. More research is urgently needed on food consumption, marketing, and food systems."

In summary, we observe that growth of food production in the non-irrigated areas of Africa and Asia has been extremely slow, too slow to keep pace with a growth in food demand of 2 to 4 percent. Asia, however, has extensive areas of irrigation representing an investment in land infrastructure that has occurred over centuries. Africa is poorer, not only in terms of natural resources, but also in terms of the institutions and infrastructure needed for rapid growth in agricultural production. It is likely to take at least a half century of major investments at extremely low rates of return (internal rates of return that the World Bank would find unacceptable), under a relatively stable political situation with favorable policies toward the rural areas to lay the foundation for a truly productive African agriculture.[6] There are already signs in countries such as Ivory Coast, Cameroon, and Kenya that programs of this nature can have a high long-run payoff. Is such a long-term plan for Africa feasible? How will Africa feed itself in the mean time? Are these not the issues we must address as we consider the sustainability of African agriculture?

Impact of Developed Country Policies

The policies and practices of the developed countries with respect to resource use represent probably the greatest long-term threat to sustainability of developing country agricultural systems. One such policy is the tendency of developed countries to subsidize agricultural production, treating the agriculture much like a utility, or in other words regarding a high level of

[6]The fact that many essential investments are unlikely to payoff in the short-run or even in 10 to 20 years, raises questions about the relevance of widely practiced benefit-cost studies for judging the feasibility of projects. Even within the World Bank those who develop African projects recognize that some form of "creative" project development is required to get project approval. But the results is often projects with faulty design. For example, in the early 1980s a very comprehensive study of the Gambia River Basin was accomplished by the University of Michigan for the U. S. Agency for International Development and the Gambia River Basin Development Organization. See The University of Michigan, Gambia River Basin Studies. For the irrigation feasibility study, the internal rate of return was projected to be 4 percent. The Gambia River Basin Development Organization rejected the report, and hired a new consultant who raised the estimated internal rate of return primarily by increasing the potential irrigable area and the yield of rice to unrealistically high levels. Whether the project should be undertaken is an open question which probably should not be judged on the basis of the internal rate of return. But if the project is designed on the basis of the assumptions used by the second consultant it is almost sure to fail.

national "self-sufficiency" as necessary and desirable. The effect on the developing countries is to destroy potential export markets and encourage greater dependency on developed-country surplus food grain exports. This slows the growth of agriculture and threatens the viability of developing-country agricultural economies.

Of more widespread concern at present is the potential impact of the so-called "greenhouse effect" due largely to the emission of gases into the atmosphere largely through vehicular and utility fuel consumption in the developed countries. A report released by the United Nations (Jaeger, 1988; pp. 7-18), in April of this year (prior to any awareness of the magnitude of this years drought), states that the impact of "greenhouse gases" is expected to be greatest in three general areas: (1) semi-arid regions of Africa where the hotter days would aggravate famine and drought, (2) humid, tropical parts of Asia where higher sea levels would increase risk of flooding, and (3) high latitudes of Alaska, Canada, and Scandinavia, where more extensive ice thaws would complicate everything from marine transportation to construction practices.

In the remainder of this section, we will discuss yet a third area where developed country policies and practices may have a substantial impact on the sustainability of agricultural systems in the developing countries. We have noted earlier that in both the developed and the developing world we are moving rapidly toward dependence on increases in yield per hectare as the major source of growth in food production. This means a growing dependency, at least in the immediate future, on nitrogen fertilizer as the single largest category of energy use. Developed countries rely almost exclusively on chemical fertilizers, and chemical fertilizers are rapidly replacing organic fertilizers in developing countries. In fact, agricultural systems that have been able to sustain growth rates of 2 to 4 percent per annum over a period of two to three decades have all relied on purchased chemical fertilizers as a major source of output growth.

Agricultural production itself uses a modest 1 percent of the US total annual energy consumption of 75 Q.[7] With world energy consumption at 300 Q, global agricultural energy consumption is probably much smaller than 3 Q. Why then should we be concerned?

The supply relationship for energy use in agriculture depends on non-agricultural consumption of energy. The question is particularly important for petroleum. In 1987, proven world reserves were 700 billion barrels. In addition to proven reserves, recent geological estimate of as-yet undiscovered oil are about 450 billion barrels.[8] At a world consumption of 20-25 billion barrels per annum, the supply of 1.2 trillion barrels would last about 50 years. Figure 3 shows one solution to the problem of pricing remaining oil resources and related depletion of reserves (Chapman, 1987). With stable world population and no effect of rising third world income level on demand, prices would stay near present levels (in real dollars) for many years, and begin rising sharply in the next century (Figure 3a).

Most countries strive to emulate the high living standard in the U.S. which is sustained with an annual per capita oil consumption of 24 barrels, most of it burned in transportation. If the current population of 5 billion were to obtain

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7. A Q is a quadrillion Btu, or 252 trillion kcal. The one percent estimate is by Heady and Christiansen, 1984, p. 237. International data are published in U.S. Energy Information Administration, International Energy Annual. Energy is used to process, transport, refrigerate, and cook food is much greater than the conventional energy used in on-farm production. For corn, farm production is only one-seventh of the total energy requirement.

8. Proven reserve data are published in year-end issues of the Oil and Gas Journal. Geological estimates of yet undiscovered oil and gas are from Charles Masters, 1985.

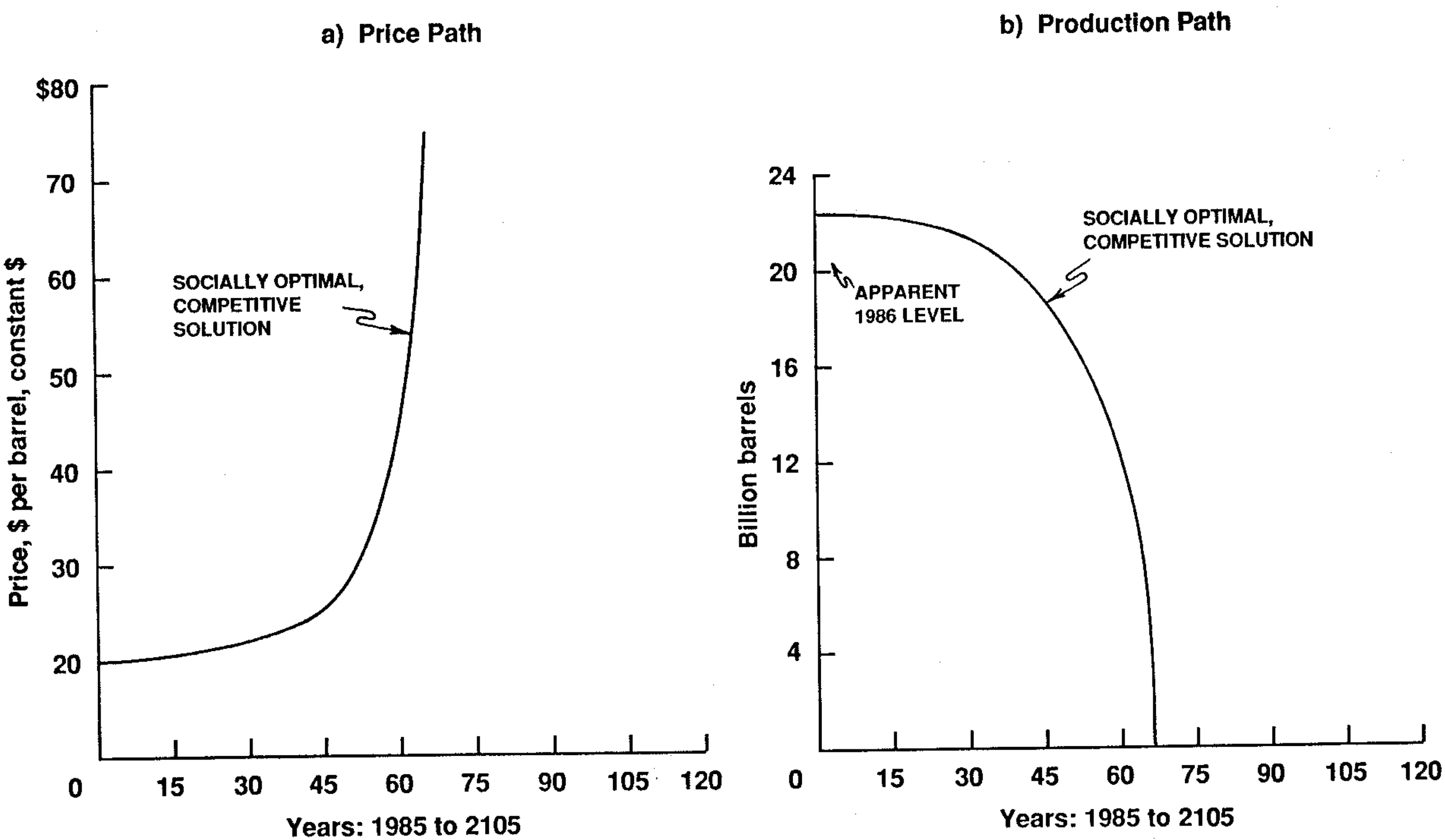

Figure 3. Competitive World Oil Market

only half the U.S. consumption level, the global use would be 60 billion barrels annually, and the supply would last only 18 years. Depending on the actual future rate of population and income growth, oil reserves are likely to become scarce resources in than the fifty years as suggested in Figure 3b.

An important generalization follows: energy intensive high technology agriculture can continue to expand, perhaps for several decades. At some point in the next century, accelerating energy prices will require a new direction in production technology. What are the alternatives?

Can today's alternative energy technologies provide substitutes for conventional oil and gas? Synthetic gas from coal will cost $16 tp $20 per 1,000 cubic feet. Synthetic gasoline from coal is equally costly, in the range of $2 plus per gallon production cost. (Chapman, 1983, Chapter 14).

Can biomass energy substitute for oil and gas in agriculture? Again the cost seems prohibitive. Brazil has demonstrated that sugar can be the fuel basis for automotive transportation. But we cannot visualize technically an economy wherein tractors and trucks are manufactured with biomass energy, and these vehicles are used on biomass farms with biomass fuel to produce liquid fuels for general non-agricultural use. The most widely used U.S. process today requires one gallon of conventional petroleum to produce one gallon of biomass ethanol (Chapman, 1983, p. 286). Brazil's debt problem is in part caused by the massive subsidies necessary to support its sugar-based ethanol program.

Can coal or nuclear power replace oil and natural gas as an energy source for agricultural inputs? The answer is not clear. Increased global coal use may create global environmental problems with respect to climate change, upper atmosphere ozone depletion, lower atmosphere ozone pollution, and acid deposition. Nuclear power in the 1980s is much more costly than conventional electricity sources or conservation investment.

In summary, global environmental problems due to use of fossil energy and chemicals, and the limited nature of world petroleum resources both imply the need for reduced dependency on fossil-fuel based energy and on agricultural chemical use. However, none of the alternatives mentioned above are at present cost effective.

One conclusion from the above is that agricultural research will need to focus on obtaining high yields with less dependency on conventional oil and natural gas. Recent advances in the biological sciences offer the greatest hope for developing the needed technologies. This kind of research, including basic and applied aspects, is typically termed "biotechnology." In the broad generic sense it includes such areas as tissue and anther culture, biocontrol, and wide crossing with related species, as well as recombinant DNA. Advances in biotechnology might make it possible to reduce the use of pesticides, enhance the nitrogen fixing capacity of plants as a substitute for chemical fertilizers, improve the tolerance of certain plant species to stresses such as drought or cold temperature, and increase the biomass or yield potential of plants. But major gains from biotechnology are still decades away and will require substantial investment in research.

Conclusions

The sustainability of agricultural systems in developing countries must be viewed from a macro or world-economy perspective. Population growth rates are projected to decline only gradually in the decades ahead. We are becoming increasingly dependent on yield per hectare as the major source of added food output growth.

Asian agriculture has grown at an extraordinarily rapid rate since World War II. The capacity of Asian farmers to effectively utilize modern technology (seeds, fertilizer and chemicals) is based on centuries of development of land infrastructure and institutions. Nevertheless, the capacity to sustain these growth rates in the future is less certain than generally recognized. Furthermore, there are major regions of Asia where agricultural productivity has grown slowly if at all. For Asian agriculture to continue to grow at past levels will require greater investment in research and infrastructure than in the past.

The situation in Africa is even more problematic. The evidence shows that the rate of growth of African agriculture would have to be doubled to achieve sustainability as we have defined it. Achieving such growth is not simply a matter of taking steps to increase food production. Markets and transportation networks must also be improved. Achieving a sustainable African agriculture will require major investments in research, infrastructure, and institutions over a period of at least half a century.

A major long-term threat to sustainability of developing country agricultural systems comes from the developed country consumers whose energy demands are depleting resources and polluting the environment at an alarming rate. Because fossil fuels supplies are limited, and because these energy sources do perhaps irreparable damage to the environment, we will have to look for alternative energy sources. At present there are no cost-effective alternatives.

The transition to a heavy reliance on purchased chemical inputs as a major source of output growth, as has already occurred in much of Asia, threatens the environment in terms of pollution and health hazards. In seeking ways to maintain productivity growth in these more favorable environments, we need to understand more clearly the nature and magnitude of problems associated with the increased use of purchased inputs.

In the less favorable agroclimatic regions, where modern inputs cannot be effectively used, farmers are reducing the production potential of the environment in their efforts to meet food demands in the short run. More research is needed to assist farmers in finding ways to sustain or enhance the production potential of these environments in the face of increasing population pressure. There may also be opportunities for enhancing environmental protection by a change in ownership of resources eg. transferring public lands to private ownership. (This is what economists refer to as "internalizing the externalities").

Consumers in developed countries are becoming increasingly aware that the growing demand for energy poses a serious long-term threat to the global environment. Yet given the potential magnitude of the problem, the research effort in this area is still very modest.

In conclusion, sustaining agricultural systems in the developing countries requires a greater commitment to long-term investment in research, infrastructure, and institution building on the part of both the developed and the developing countries. Unfortunately, however, declining world grain and oil prices in the short run have discouraged such investments. The energy crisis in the 1970s and this year's drought serve to remind us of the tenuousness of our situation. But our memories are short, and our thinking about development dominated by short-run project analyses, and the search for quick solutions to development problems. As Schultz (1987, p. 16) states:

> "The adverse consequences of the short view in economic policy carry a high price. Though theoretical elaboration of the short view is being made by economists with increasing subtlety, refinement, and elegance, it is nevertheless a structure built upon shifting sand."

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