Technologies for Meeting Future Global Demands for Food

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Abstract

Food can be produced under a number of technological conditions. Some observers hold that modern crop production technologies, typified by those embodied in the Green Revolution, are so intensive in the use of external inputs that they damage the environment and so are not sustainable. Those observers argue that "alternative" technologies that use fewer, safer external inputs mark the path toward agricultural sustainability. But the question arises: will those alternative technologies permit increases in global food production on the required scale? In this paper, we address this question and the conflicting arguments regarding the answer.

Key Words: agriculture, environment, green revolution, research and development, technology

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Pierre Crosson and Jock R. Anderson[1]

1. Introduction

Recent reports from the International Food Policy Research Institute (IFPRI) (Pinstrup-Andersen and Cohen 1999) indicate that, between 1993 and 2020, global demand for cereals is expected to increase by 40%; for meat the expected increase is 65%; and for roots and tubers it is 40%. In the developing countries the expected increases in demand over the period are 59% for cereals, 120% for meat and 58% for roots and tubers. The average annual percentage rates of increase in the developing countries are 1.7% for cereals, 3.0% for meat and 1.7% for roots and tubers. The expected increases are greater in developing countries because most future population growth is expected to be in those countries. In addition, rising per capita income in those countries is expected to stimulate increases in demand for food because present consumption levels are low.

A study by the Food and Agriculture Organization (FAO 1996) estimated that demand for food would have to increase 2.4 times in Asia from 1990 to 2050 to provide all the people in that region an adequate diet by the latter date. In Latin America and the Caribbean the increase in that period would have to be 1.9 times; in Africa a five-fold increase would be required. The average annual percentage rates of increase in the regions over the 60-year period are 1.5% for Asia, 1.1% in Latin America and the Caribbean, and 2.7% for Africa.

The IFPRI projections and those for FAO (1996) are not directly comparable for two reasons. First, IFPRI and FAO cover different time periods: 1993-2020 and 1990-2050, respectively. Also, the IFPRI projection is for economic demand, reflecting both population

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growth and rising per capita income in the developing countries. FAO projects the level of consumption that would be required to ensure an adequate diet. Although they are not directly comparable, they concur in showing that if per capita income in Asia and Latin America continues to grow at something like recent rates and African countries can turn their economies around, demand for food in developing countries will increase substantially over the next several decades.

We address the question, what technologies would make it possible to meet future demands for food in the developing countries under sustainable conditions. Definitions of sustainable agriculture vary widely and are neither right nor wrong, only more or less useful. We define sustainable agriculture as a production system that indefinitely meets demands for food and fiber at socially acceptable economic and environmental costs, and also satisfies certain equity criteria.

Two questions are immediately posed: what are “socially acceptable” economic and environmental costs and what are satisfactory equity criteria? Clearly there are no precise answers to these questions. What constitutes acceptable costs and satisfactory equity criteria inevitably is to some extent in the eye of the beholder. Yet many countries around the world have legislation to contain economic and environmental costs, which suggests that a rough social consensus does emerge about acceptable levels of these costs.

Equity criteria are more elusive. We will assert here that in developing countries sustainability in agriculture requires that the income of poor farm families rise enough to permit significant improvements in nutrition for all members of the family and to health and educational services. Of course, there is a supply dimension that could limit access to these services. Particularly in rural areas of developing countries, public investments in educational and health facilities have lagged so much that rural people might have limited access to such services even if their incomes were substantially higher than they are now. In other words, the welfare of people in these areas is conditioned not only by their income-earning capability but also by the overall level of economic and political development in their respective countries.

2. Technological Choices

The focus here is on the capacity of two different technological systems to sustainably meet future demands for food in developing countries. One we call the "conventional" system, which includes the kinds of technologies making up the Green Revolution (GR). For the most part these are still the main focus of research institutions in the Consultative Group on International Research (CGIAR) and in the national agricultural research systems (NARSs). These technologies rely heavily on higher-yielding crop cultivars and other inputs purchased by farmers, particularly inorganic fertilizers to provide the nutrients needed for higher yields, and pesticides for control of insects, weeds and disease. The GR technologies usually are combined with irrigation, which would continue to play a role, albeit diminished, in the adoption of future conventional technologies. The principal objective of using these technologies is to increase production by increasing crop yields.

We call the other kind of technology the alternative system. The word "alternative" here is used to distinguish the system from the conventional system. Alternative technologies do not reject the use of higher-yielding cultivars, but consider them less important than the conventional system does. The major difference between the alternative and conventional systems is that the former seeks to minimize the use of purchased inputs. To do this while maintaining satisfactory yields, the alternative system puts major emphasis on the use of rotations, mixed cropping (growing more than one crop on the same piece of land), and mixed crop-livestock systems. In general, although there are many exceptions, alternative systems are more management-intensive than the conventional system (Pretty 1995, p. 19). Proponents and practitioners of the alternative system are not indifferent to its yield characteristics, but producing higher yields is not the prime objective for the systems. Some advocates of the alternative system like it also because, in their judgment, it promotes a more equitable distribution of income and political power in the countryside (e.g., Altieri 1995).[2]

We begin with an assessment of how the conventional system has performed since the early 1960s with respect to the sustainability criteria of economic and environmental costs and

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[2]This description conveys the general characteristics of the alternative system. However, there are many variations. To get a more complete sense of the characteristics of the alternative system see Altieri (1995), the various chapters in Altieri and Hecht (1990), Altieri, Rosset and Thrupp (1998), and Pretty (1995).

equity. Then we assess the relative merits of the two systems in their ability to sustainably respond to future demands for food in developing countries.

3. Performance of the Conventional System to Date

Production growth: in developing countries and worldwide. Data compiled by the United Nations indicate that, on a global scale, per capita production of food increased almost 20% between 1960 and 1990. In developing countries, per capita food supplies increased 27% from the early 1960s to the late 1980s despite rapid population growth in those countries. Some of the increased food supply in developing countries came from imports from more developed countries (MDCs), but most of it came from higher production in the developing countries themselves. Increased production in those countries was driven not only by population growth but also by substantial increases in per capita income. According to the World Bank, per capita Gross Domestic Product (GDP) in those countries after adjustment for inflation rose by an average of 162% from 1960 to 1990, an average annual rate of 3.3%, which is substantially greater than income growth in the MDCs.

Production performance since 1960 has not been uniformly favorable around the world. Data collected by the FAO show that in Asia, per capita food production increased by one-third from 1961-65 to 1989-91, but in Africa per capita production declined 16% in that period. In Latin America per capita production was up 13%.

Trends in real food prices. Data compiled by the World Bank indicate that global inflation-adjusted prices of wheat, maize, and rice declined by 47%, 50%, and 56%, respectively from 1960/62 to 1995. The price of each commodity then rose from 1995 to 1996 by 23% (wheat), 42% (maize) and 10% (rice), reflecting the widely prevalent weather-induced deterioration in growing conditions. From 1996 to 1998 weather improved, production increased, and relative to 1995, 1998 prices were down 18% for wheat and 5% for maize. Rice prices in 1998 were 9% higher than in 1995, but for all three crops 1998 prices were well below 1960/62 levels (Donald Mitchell, World Bank, personal communication).

These price declines reflect increases in productivity generated by the spread in much of Asia and Latin America of the Green Revolution and related technologies. Despite the large increases in global and developing-country demand for food, the productivity gains were so large that production growth outpaced demand growth, forcing prices down. In the world as it has existed since the end of World War II, changes in agricultural prices over long periods of time reflect changes in economic costs of production. The price behavior observed since the early 1960s thus indicates that over the past 35 years, global and developing-country agriculture has met reasonable economic criteria for sustainability.

Changes in nutritional status in developing countries. The FAO defines undernourished people as those whose average food energy consumption over the course of a year is insufficient to maintain body weight and support light activity. By this standard, and according to the FAO, 36% of the population of the developing countries was undernourished in 1969/71 compared with 26% in 1979/81 and 20% in 1988/90. In numbers of people these percentages translate into 940 million, 845 million and 780 million in each of the three-year periods, respectively. As in the case of per capita food production, this performance in reducing undernutrition was not spread evenly among the main developing-country regions. The most dramatic improvement was in East Asia, where the percentage of the undernourished fell from 44 in 1969/71 to 16 in 1988/90. In South Asia, the decline was from 34% to 24%, and in Latin America it was from 19% to 13%. In Sub-Saharan Africa, however, the situation deteriorated, the percentage of the undernourished rising from 35 to 37 over the 19 years, and the number of undernourished people from 94 million to 175 million.

Because undernourished people generally are poor people, improved nutrition in developing countries since the late 1960s—with the important exception of Africa—implies that tens of millions of the poor in those countries benefited from general economic growth and agricultural development in particular. In the developing countries, agricultural development in that period was driven mainly by the development and spread of the Green Revolution technologies. This suggests that the income distribution consequences of the GR benefited the poor substantially. This does not mean that the poor were favored more than or even as much as the rich, but that the poor, at least in Asia and Latin America, enjoyed substantial increases in income, which is implicit in the marked improvement in nutrition among people in those areas.[3]

Because the poor spend proportionally more than the rich on food, the decline in prices of wheat, rice, and maize must have differentially favored the poor, both in urban and rural areas.

Other evidence on income distribution consequences. Studies specifically aimed at investigating the income and employment consequences of the GR point in the same direction. Hazell and Ramasamy (1991) studied the income-distribution consequences of the GR among small-scale farmers in southern India. They found that both small-scale rice farmers who adopted the new technology and landless farm laborers enjoyed income increases on the order of a doubling. The income of landless laborers rose because of increased demand for their services.

David and Otsuka (1994) undertook in-depth studies of the income-distribution impact of the rice GR in Thailand, Indonesia, the Philippines, Bangladesh, India, China, and Nepal. They found that the main determinant of adoption of the GR technologies in these countries was the availability of irrigation. Adoption was not strongly influenced by farm size or land tenure arrangements in most regions. In Bangladesh and Thailand small-scale farmers adopted faster than large-scale farmers. Only in China, where rice hybrids are important, did "large-scale" farmers adopt more rapidly.

Adopting farmers in all countries achieved higher yields, because of the higher yield potential of the improved varieties and through more intensive use of the land permitted by the GR technologies. Yields, hence farm income, increased more in more favored environments than in those less favored. Consequently, income differences between more and less favored regions increased. David and Otsuka found that this effect was compensated to some extent because in the better-endowed regions' demand for labor rose with adoption of the GR technologies, which provided rising job opportunities for landless laborers and

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[3] Let it be noted that the Green Revolution has not happened in Africa.

marginal farmers in the less-favored regions. Labor markets thus acted to ease the interregional differences in income promoted by adoption of the GR technologies.

Thus there is strong evidence that the Green Revolution technologies have not only met the economic cost criterion for sustainability, but also, if they did not quite reach it, made a strong move toward satisfying the equity criterion as well.

Trends in environmental costs. Strictly speaking, environmental costs of agriculture are those that farmers impose on others in the society as a result of farm operations under institutional conditions such that those bearing the costs cannot extract compensation from the farmers. However, much of the discussion in the literature also treats losses of on-farm productivity (because of land degradation) as environmental costs. To keep this discussion relevant to that literature, we treat land degradation-induced losses of on-farm productivity as environmental costs.

Land degradation losses of on-farm productivity: On a global scale. Dregne and Chou (1992) estimated the spatial extent and productivity effects of land degradation in dry areas in most countries of the world. Dry areas are those in arid, semi-arid, and dry sub-humid climatic zones. The estimates are for three kinds of agricultural land use: rainfed cropland, irrigated land, and rangeland. Drawing on data provided by the FAO, Dregne and Chou found 5.1 billion hectares of dry land in the three uses, 88% of it in range, 9% in rainfed crops, and 3% in irrigated crop production. Degradation of rainfed cropland is mainly by water and wind erosion. Irrigated land is degraded mainly by salts carried and deposited by irrigation return flows, and rangeland is degraded mainly by overgrazing, which promotes increased erosion and decline in the quality of vegetation for animal forage.

Dregne and Chou classified the land they considered by its degree of degradation: slight, moderate, severe, and very severe. They assigned percentage losses of productivity (measured by yields) to each category, ranging from 0-10 for slightly degraded to >50 for very severely degraded land. The losses are cumulative over some period that Dregne and Chou do not specify, but presumably it dates from the beginning of the land's present use.

Crosson (1995) weighted the percentages of productivity loss using the amount of land in each category of degradation for each of the three kinds of land use. He found the following percentages of cumulative loss:

Irrigated land	11%
Rainfed cropland	13%
Rangeland	43%

Dregne and Chou also estimated the per hectare values of each of the three kinds of land use, in prices around 1990: $625 for irrigated land, $95 for rainfed cropland, and $17.50 for rangeland. Obviously, the degradation-induced loss of a unit of irrigated land imposes a higher social cost than the loss of a unit of rainfed cropland, which imposes a higher cost than the loss of a unit of rangeland. Crosson (1995) used these three per hectare values to calculate the weighted average cumulative loss of productivity on the three kinds of land together. The loss was 12%, and over three decades, the average annual rate of loss would be 0.4%.

Oldeman (1992) with colleagues from Wageningen Agricultural University in the Netherlands found that on a global scale there are currently some 8.7 billion hectares in crops, permanent pasture, forest and woodlands. Oldeman (1992) reported that the amount of this land that has been degraded between the end of World War II and 1990 was 2.0 billion hectares. Of the 2 billion, 33% was lightly degraded, 45% was moderately degraded, and 22% was strongly degraded. Eighty-four percent of the land in these three categories had been degraded by soil erosion.

Oldeman (1992) did not estimate the percentage losses of productivity on the degraded land. Crosson (1995) assumed that the losses were the same as those estimated by Dregne and Chou (1992) for the same categories of degree of degradation, that is, lightly degraded land had lost 0–10% of its productivity and so on. Crosson then calculated the weighted average cumulative percentage loss of productivity to be 4.6% on the 8.7 billion hectares of land in crops, permanent pasture, forest and woodland. This percentage is bound to be low because Oldeman estimated that 77% of the 8.7 billion hectares suffered no degradation, hence must have lost no productivity.

These estimates of global degradation-induced losses of land productivity are much smaller than others found in the literature (e.g., Brown 1984; Pimentel et al. 1995). Both Dregne and Chou (1992) and Oldeman (1992) emphasize the many weaknesses in their data. Nevertheless, in our judgment, their estimates are the best available. We believe they indicate that on a global scale, cumulative degradation-induced losses of land productivity are small. This, in turn, suggests that conventional agricultural technologies used by farmers worldwide have not significantly damaged the capacity of the land to support global agricultural production.4

Land degradation losses of on-farm productivity: Asian rice and wheat. The estimates of Oldeman (1992) and Dregne and Chou (1992) as manipulated by Crosson, suggest that on a global scale, land degradation has not seriously compromised agricultural production capacity. The evidence is strong, however, that the Green Revolution technologies used in irrigated rice production and rice-wheat rotations in Asia have significantly impaired the productivity of the land. The evidence is considered and summarized in Pingali and Rosegrant (1998). They show that by the 1990s intensive monocultural systems of rice production were predominant throughout South and Southeast Asia, and that the rice-wheat rotational system occupied some 12 million hectares in the Indo-Gangetic plain between Pakistan and Bangladesh. Pingali and Rosegrant show that rice yield growth declined from 2.8% annually in the 1970s to 1.4% in the decade beginning in 1986. Yield growth of wheat in Asia showed a similar declining trend, although the decline was less marked than that for rice.

Pingali and Rosegrant (1998) attribute some of the decline in the percentage rates of growth in Asian rice and wheat yields to the decline in prices of the two crops, which has caused a fall-off in investment in irrigation infrastructure and in rice and wheat research. They argue, however, that much of the decline in yield growth is owed to the negative land productivity impacts of the Green Revolution technologies used to produce the two crops. Pingali and Rosegrant put it this way (p. 4): “Declining productivity trends can be directly associated with the ecological consequences of intensive rice monoculture systems, such as

[4] Studies indicate that in regions of Uganda (Lindblade et al. 1998) and Kenya (Tiffen and Mortimore 1992) , agricultural land use over periods of several decades has shifted strongly toward more land conservation despite strong population growth. These findings are consistent with that of Scones (1994) concerning African pastoral lands.

buildup of salinity and waterlogging, declining soil nutrient status, increased soil toxicities and increased pest buildup, especially of soil pests. Many of the above degradation problems are also observed in the irrigated lowlands where wheat is grown after rice in a long term rotation …"

Of special interest here is the argument Pingali and Rosegrant make with respect to the negative effects of the GR technologies on soil nutrient status and pest management. With respect to the former, they assert that the most important impact on production under both the rice and rice-wheat rotation systems is the declining yield response per unit of nitrogen fertilizer applied. In continuous rice harvesting, the problem arises because the flooding that is an integral part of the production system results in chemical changes in soil organic matter and reduces the level of microbial activity (Pingali and Rosegrant 1998, p. 8). Something similar happens to soil in the rice-wheat rotation. Because of these changes, the soil's capacity to provide nitrogen to the plant declines. To maintain yields under this condition requires increasing per hectare amounts of nitrogen fertilizer.

With respect to pest management, Pingali and Rosegrant note that continuous cropping of cereals with GR technologies has increased the incidence of weed, insect, and disease problems (p. 10). These problems have become more serious in continuous rice production than in wheat production. With respect to wheat, Pingali and Rosegrant assert that insecticides are not much used and that fungus diseases have been largely controlled by development of disease-resistant varieties.

The emergence of insect and disease problems in rice has been encouraged by excessive uses of pesticides, which in turn has been stimulated by government policies to subsidize these materials. These subsidies in large part reflect the widespread perception of policymakers that rice production with GR technologies inevitably results in yield-threatening buildups of insects that can only be controlled by increasing use of insecticides. These subsidies, according to Pingali and Rosegrant (p. 11), resulted in "Pesticide mismanagement, disruption of the pest-predator balance, and increased pest losses …"

Pingali and Rosegrant note that insect- and disease-resistant varieties of major cereals are widely available, which has the effect of reducing the profitability of current pesticide practices, even with the policies promoting the use of pesticides. The good news is that the existence of insect- and disease-resistant varieties means that eliminating the subsidies would not reduce the profitability of current practices. Indeed, profitability could be increased because more limited and judicious use of pesticides would reduce, if not eliminate, the problems arising from excessive use. The bad news is that educating policymakers about the fact that pesticide subsidies are not only unnecessary, but that they actually impose costs on the production system, is no easy task. Pingali and Rosegrant point out that nitrogen fertilizers also have been widely subsidized in Asia, and that at least some of the problems of providing adequate soil nutrient supplies in rice and rice-wheat production systems would be eased by elimination of these subsidies.

The emphasis on policies that subsidize pesticides and nitrogen fertilizers is key to the Pingali/Rosegrant analysis of the ecological problems plaguing use of GR technologies in rice and rice-wheat systems in Asia. They write (p.17):

> While resource base degradation is increasingly observed in the intensively cultivated lowlands of Asia, *intensification per se is not the root cause of environmental and ecological damage.* Severe environmental degradation in intensified agriculture occurs mainly when incentives are incorrect due to bad policy or lack of knowledge of the underlying processes of degradation. … The problem of sustaining productivity growth comes about because of inadequate attention to understanding and responding to the physical, biological and ecological consequences of agricultural intensification. *The focus of research and policy ought to be on shifting away from a fixation on 'increasing the pile of grain' to a holistic approach to the long-term management of the agricultural resource base.* (Italics added for emphasis.)

Despite the documented negative impacts on the soil resource base with current GR technologies in rice and rice-wheat production in Asia, the impacts have not yet shown up in rising economic costs of production. But if demand for rice and wheat continues to grow as projected by Pinstrup-Andersen and Cohen (1999), economic costs will likely rise unless corrective policy measures, such as those described by Pingali and Rosegrant, are widely adopted. Absent these measures, it seems clear that production practices in rice and wheat production in Asia will fail to meet the economic cost criterion for sustainability.

"True" environmental costs of agriculture. As noted earlier, most economists argue that environmental costs are costs that some actors in the society impose on other actors under institutional conditions in which the latter cannot exact compensation from the former. We consider these "true" environmental costs here. From a policy perspective, environmental costs of agriculture are important in two ways. One is that farmers have no incentive to control them because they do not bear them. If the costs are to be held within socially acceptable limits, policies and institutional innovations must be devised that could achieve that objective. Second, typically the costs are not priced, so there are no good quantitative measures of them, unlike the situation with economic costs. The absence of objective measures means that it is difficult to reach consensus on the importance of environmental costs, a necessary component in effective policymaking.

Environmental costs are not priced because of the difficulty of establishing clear and enforceable property rights in environmental resources. Absent property rights, markets for the services of environmental resources do not emerge, hence we have no prices for the services. The most important environmental resources that might be affected by agriculture are ground and surface water, wildlife habitat, the atmosphere, and the biological diversity embodied in wild plants and animals. Much ground water is open access property, meaning that it underlies the property of many farmers, all of whom have equal access to it. Consequently, no farmer has incentive to conserve the resource because he has no assurance that, if he does, others will also. Whatever groundwater is not pumped to the surface today may not be available to him tomorrow.

Any particular farmer should have incentive to protect the groundwater from pollution by nitrogen fertilizers and pesticides if his or her family drinks the water. But if they do not, as when their drinking water is supplied by a municipal system, the incentive is weakened. Surface water in streams moves, often across long distances, which makes it practically impossible for any individual or even groups of individuals to establish an enforceable property right in it. The same applies to the atmosphere and, in general, to biological diversity.

The main environmental costs of agriculture, not necessarily in order of importance, are the following: clearing and draining land to plant a crop, which may harm plant and animal wildlife habitat and, more broadly, impose losses of socially valuable biological diversity; damages to surface water quality from sediment from farmers' fields, which increase the costs of cleaning water used for residential and urban purposes; cleaning rivers and harbors to facilitate shipping; the costs of losses of recreational values because of muddy water; possible public health costs from nitrogen fertilizer in ground-water used for drinking; and pesticides in both ground and surface waters, which may threaten human health as well as the value of ecosystems.

A recent study (Crosson 1998) suggested that in the United States, the most important environmental cost of agriculture since the end of World War II probably was the loss of wildlife habitat values because of drained wetlands and changes in agricultural technology that removed much habitat-friendly vegetation on farms. Arguably the next most important cost was the loss of the recreational value of surface waters due to sediment from farmers' fields. By comparison, human health and ecological costs of fertilizers and pesticides in ground and surface waters were less important. The evidence with respect to losses of biological diversity was too thin to support a judgment.

It is worth noting that U.S. agriculture uses far more fertilizers and pesticides per hectare and per person than most developing countries. But in general, one cannot compare experiences in the United States to that in developing countries. The United States is a rich country, and evidence suggests that people in rich countries put more value per unit on environmental resources than people in poor countries. The situation in developing countries must be investigated on its own merits.

The major obstacle to investigating environmental costs in developing countries is that it is harder to determine such costs in these countries than in the United States. There is much concern that agricultural practices, particularly in tropical regions, have destroyed extensive areas of forest, resulting in losses of plant and animal biodiversity. Deforestation also can cause increased erosion and severity of floods, but we have found no reliable documentation of these consequences. It is important to mention, however, that the agricultural practices with these adverse environmental effects are mostly a slash and burn type of agriculture. The practices embodied in GR technologies are mostly aimed at increasing crop yields, and hence are land conserving. (The case of GR rice and wheat in Asia is an exception). Whatever the environmental impacts of these technologies may be, those resulting from deforestation are not typically among them.

Compared to alternative technologies, the GR practices involve relatively large amounts of pesticides. It was noted above that these can contaminate ground and surface waters, with potentially negative impacts on human health and ecosystem values. Antle (1994) studied the effects of pesticides used in rice production in the Philippines on the health of farm workers using these materials. He found adverse impacts sufficient to reduce the productivity of the affected workers.

Pingali and others studied the environmental impacts of insecticides to control insect pests in rice across a number of countries in Asia. Much of this research is summarized in Pingali and Gerpacio (1997). They report (as noted above in the discussion of Pingali and Rosegrant (1998)) that the rapid spread of GR technologies in rice production in Asia led to an increase in indiscriminate use of insecticides in many places, which resulted in disrupted pest-predator relationships, pest outbreaks, and yield losses. The adverse consequences of these practices on the environment, paddy ecology, and human health have been well documented. Some examples are health impairment, contamination of ground and surface waters, the transmittal of insecticide residues through the food chain, an increase in insect resistance to insecticides, and the destruction of populations of beneficial macro and micro fauna.

The research reported by Pingali and Gerpacio (1997) shows that the current trend is for more discriminating use of insecticides in rice production, nonetheless most farmers still use prophylactic methods to control insects. The appeal of insecticides reflects the farmers' perceptions that the insect threat to rice yields is high. Much evidence has accumulated, however, indicating that the perception is incorrect (Pingali and Gerpacio 1997). Leaf-eating insects are common in rice production, and the damage they do is highly visible. But studies show that the effects of these insects on crop yields is small, and that the use of insecticides to control them generally is not cost-effective. Yet 80% of the insecticides applied to rice in Asia is aimed at controlling leaf-eating insects (Pingali and Gerpacio 1997 p. 110). These authors argue for a “minimum insecticide strategy” that would rely heavily on natural predators for insect control. They note that the success of such a strategy would require (p. 114) “in-depth farmer knowledge of the pest-predator ecology and frequent monitoring of field conditions by the farmer. In this regard, natural control can be considered the ultimate goal of an IPM [integrated pest management] program and farmers who are well-versed in IPM techniques would converge towards it. Therefore continued investments in IPM training would be essential for the successful adoption” of a minimum insecticide strategy.

In addition to such investments, some argue (Pingali and Gerpacio 1997; Pingali and Rosegrant 1998) that subsidies to pesticides should be removed so that farmers have to face the full economic cost of using them. This policy and others related to insecticides were implemented in Indonesia, with impressive results in reducing insecticide use in rice production with little loss of yield. Imposition of a tax on insecticides could be justified to reflect the environmental costs of using them. Antle and Pingali (1994) showed that a 100% tax on insecticides could actually increase rice productivity through the beneficial effects on farmer health.

The story that Pingali and Garpacio (1997) tell provides insights to the process of agricultural development generally and to understanding the Green Revolution in particular. They demonstrate the importance of research that follows the path of development of new technologies and analyzes both the technology’s environmental and production consequences. And the story strongly suggests that such research can provide the basis for policies to control the environmental and other social costs of the technologies that are not revealed in markets.

Conclusion about the sustainability of the conventional system. The declining trends in prices for wheat, rice, and maize over the past 50 years despite substantial increases in demand for these commodities strongly suggests that the Green Revolution technologies have met the economic cost criterion of sustainability. Substantial improvements in the nutrition of people in Asia and Latin America and studies of the favorable income-distribution consequences of the technologies suggest that they have also moved strongly toward meeting the equity criterion.

There is not enough evidence to determine the environmental consequences of the technologies, thus the costs of the consequences cannot be accurately ascertained. It is plausible to believe that the substantial increase in agricultural production based on GR technologies has resulted in an increase in at least some of the various environmental costs of agriculture, because farmers have little incentive to keep the costs under control. But specific information is scarce. The land-conserving nature of the technologies indicates that the various environmental costs of land clearing, including the loss of biodiversity, must have been less than they otherwise might have been. However, the relatively high dependence of the technologies on pesticides has had some negative human health and ecological impacts. The research reported by Pingali and Gerpacio (1997) on insecticide use on rice in Asia indicates that these adverse effects can be controlled; but to do so takes investments in research to understand the problems and intelligent use of the research to formulate effective control policies.

4. Can Conventional and Alternative Systems Meet Future Demands?

There is a broad consensus among students of the world food situation that most future increases in production must come from increasing yields rather than from cultivating additional land (e.g., Crosson and Anderson 1992; Alexandratos 1995). The consensus rests on evidence suggesting that both the economic and environmental costs of production would rise to unacceptable levels if the main pattern of production growth were to involve increasing land use rather than toward increasing yields.

The issue discussed here, then, is the relative advantages and disadvantages of the conventional and alternative systems in meeting future demands for food at sustainable economic and environmental costs and equity conditions. We begin by considering the conventional system.

The Conventional System

Future sustainability. Although to date the conventional system appears to have met the economic cost criterion of sustainability, there now is widespread concern about whether it can continue to do this in the future. This is prompted by evidence that the annual percentage rate of increase in crop yields with the conventional system is faltering. We noted above the sharp decline in the percentage rate of increase in rice yields between 1981/83 and 1988/90 and between 1988/90 and 1996/98. These declines were attributed in good part—not exclusively—to degradation of the rice-land resource (Pingali and Rosegrant 1998).

The more general perceived problem, as one writer put it, is that "the [global] surge in demand [for food] will occur even as evidence suggests that the Green Revolution is petering out. In recent years grain yields have stopped rising as fast, and plant scientists agree that they are facing physical limits as they try to coax plants to produce ever more of their weight in grain" (Mann 1997, p. 1038). Mann cites Kenneth Cassman, head of the agronomy department at the University of Nebraska, and other agricultural scientists in support of his assertion (p. 1038) that to maintain adequate yield growth,"scientists will have to bring modern agricultural methods to areas where they are not now used, as [Nobelist Norman] Borlaug and others [e.g., the World Bank] are trying to do in Africa."

The discussion of rates of increase in crop yields is always in terms of annual average percentage rates. Table 1 shows these rates over two periods for rice, wheat, and coarse grains (mostly maize and sorghum).

Table 1. Average Annual Percentage Rates of Yield Growth for Rice, Wheat, and Coarse Grains in Developing Countries

Year range	Rice	Wheat	Coarse grains
1972/76 to 1994/98	2.1	3.0	2.2
1983/87 to 1994/98	1.4	2.0	2.2

Source: USDA (1999)

By the mid-seventies the Green Revolution was in full swing, which is why this comparison begins with that period. Table 1 shows that from the mid-eighties to 1994/98 the average annual percentage rate of growth of yields for rice and wheat was, indeed, lower than in the period from the mid-seventies. Yield growth for coarse grains, however, was undiminished.

Perhaps it is time to question the practice of stating average annual rates of yield growth as percentages when making judgments about the adequacy of future yield growth. The United Nations's projections of population growth in the developing countries (FAO 1996, p.19) show steadily declining percentage rates from 1990/95 through 2045/50. For Africa the projected rate falls from 2.8% in 1990/95 to 2.1% in 2020/25 to1.1% in 2045/50. The corresponding rates for Latin America are from 1.8% to 1.0% to 0.5% ; for Asia the rates are 1.6% to 0.9% to 0.4%.

These projections suggest that demand for food in developing countries will also increase at diminishing percentage rates. Indeed, the declines in percentage demand growth probably will be even more pronounced as more and more of the developing countries achieve levels of per capita income high enough that additional increases add little if anything to per capita demand for food.

It is relevant, therefore, to consider recent yield experience expressed in terms of absolute annual growth relative to the trend rate of growth, also expressed in those terms. Table 2 permits such a comparison.

The data in Table 2 do not suggest that yield growth of the three crops, expressed in annual absolute amount, has declined over the past decade relative to the trend of yields established over the period 1960-1998. Furthermore, recognizing that *percentage* rates of increase in demand for the three crops in developing countries almost surely will decline in the next several decades, the recent yield experience of these crops does not appear to be as negative as the current view among many agricultural scientists . If this is true, then the likelihood that the conventional technologies can continue to meet the economic cost criterion of sustainability is stronger than many now believe.

This somewhat brighter conclusion is, however, not grounds for complacency about the prospects for the conventional technologies. There are two reasons for this, both rooted in current trends in agricultural research. One has to do with the *quantity* of such research, and the other has to do with the *direction* of the research.

Table 2. Trend vs. Actual Yields of Rice, Wheat, and Coarse Grains in Developing Countries, 1988-1998
(metric tons per hectare)

	Rice		*Wheat*		Coarse grains	
	A	T	A	T	A	T
1988	2.19	2.16	2.16	2.13	1.59	1.63
1989	2.27	2.20	2.20	2.18	1.58	1.66
1990	2.32	2.24	2.24	2.23	1.75	1.69
1991	2.34	2.28	2.32	2.29	1.75	1.72
1992	2.35	2.32	2.40	2.34	1.82	1.75
1993	2.40	2.35	2.43	2.39	1.86	1.78
1994	2.39	2.39	2.43	2.44	1.83	1.82
1995	2.44	2.43	2.50	2.59	1.88	1.85
1996	2.47	2.47	2.56	2.55	2.00	1.88
1997	2.50	2.51	2.71	2.60	1.87	1.91
1998	2.47	2.55	2.57	2.65	1.98	1.94

Notes: A = actual yields; T = trend yields. Actual yields same as or greater than trend yields: 9 out of 11 years for rice, although actual was less than trend in each of the past 2 years, 8 of 11 years for wheat, and 8 of 11 years for coarse grains.
The yield trend is linear in the actual data and is established on the 39 years, 1960 through 1998.

Source: USDA (1999)

Quantity of research. The increase in crop yields with conventional technologies over the past 3 or 4 decades reflect an enormous increase in publicly funded investments in agricultural research, mostly in developed countries and in the international agricultural research institutions included in the Consultative Group on International Agricultural Research (CGIAR), but also in a number of the larger developing countries in Asia and Latin America.

But the *average annual percentage rate of increase* in these research investments declined sharply in 1981/91 relative to the rate in 1971/81 (Alston, Pardey, and Roseboom 1998). Philip Pardey, one of the co-authors, tells us in a personal communication that recent studies of publicly funded global agricultural research investments are no longer available. In 1971/81 these investments increased at an average annual rate of 6.4% in the developing countries. In 1981/91 the rate declined to 3.8%. In Africa, a region particularly in need of new agricultural knowledge, the rate declined from 2.5% to 0.8%; and in Latin America and the Caribbean the rate actually turned negative, going from 7.2% to -1.1%. The rate in the developed countries declined from 2.7% to 1.7%.

The rate of increase in spending in the CGIAR institutions also declined dramatically over the past couple of decades. The most prominent of these institutions, the International Center for Improvement of Maize and Wheat in Mexico and the International Rice Research Institute in the Philippines, were primarily responsible for the research that produced the GR in wheat and rice production. Alston, Pardey and Roseboom (1998) show that, in constant 1993 dollars, research spending by CGIAR institutions increased from an annual average of $88 million in 1972/75 to $244 million in 1981/85 to $314 million in 1991/94 to $317 million in 1995, a figure not really different from the 1991/94 average.

Private investments in agricultural research increased sharply over the past couple of decades. In 1993 they made up half of total global private and public spending on such research (Alston et al. 1998). However, Alston et al. found that only about 12% of the privately funded research is aimed at improving on-farm productivity. Most of the rest is focused on increasing productivity of the agricultural system beyond the farm gate.

The sharply declining rates of public investment in agricultural research is worrisome. If it continues, the likelihood that conventional technologies will meet the economic criterion of sustainability in the future will become increasingly problematic. The worry is heightened by some evidence, albeit inconclusive, that the efficiency of agricultural research spending is declining. That is, it may be that an additional dollar of such spending buys a smaller increase in on-farm productivity than in the past.

The reasons for the declining rate of increase in publicly funded agricultural research are not clear, but evidence suggests that declining rates of return to such research is not one of the reasons. On the contrary, studies over the past several decades indicate that rates of return to investments in agricultural research have consistently been high, with no tendency to fall. These returns, on average, are substantially higher than the average for investments in the economy generally (Alston et al., 2000;Pardey and Beintema, 2001).

One possibility for the decline in research investments is “donor fatigue.” This has some plausibility because much of the funding in the developing countries, and nearly all of it in the CGIAR, is from donors in the more developed countries. Whatever the reasons, the declining trend raises serious questions about the future economic viability of the conventional technologies.

Direction of research. Similar questions can be raised about the ability of these technologies to meet the sustainability criterion for environmental costs. Strong evidence indicates that, as per capita income increases, people increase their demands for environmental services. If per capita income in the developing countries increases as current projections indicate, demands for environmental services in those countries could rise. As noted above, the services of the land, water, wildlife habitat, and biological diversity could be particularly affected by agricultural production. Unless the supplies of these services can be increased in step with demand, the costs of providing the services will rise, probably to unacceptable levels in time. As indicated above, problems of providing adequate supplies of environmental services reflect failures of the institutions involved in the management of environmental resources. Difficulties in establishing clear and enforceable property rights in these resources are the root cause of the failure.

Dealing with the problem requires more research to develop new institutions or to correct the failure of existing institutions. The existing national and international agricultural research institutions are not well-equipped by tradition and structure to do the research needed for this task. Their mission has always been to develop the technologies needed to increase on-farm productivity. As we have noted, they have done an outstanding job in accomplishing this mission. But management of natural resource and environmental resources only recently has become an important element in the research agenda of these institutions. We question whether institutions have the organizational and intellectual resources necessary to do the required institutional research (Crosson and Anderson 1993). If they do not, conventional technologies in the future will not likely meet the environmental cost criterion for sustainability.

The Alternative System

Future Sustainability. The general characteristics of alternative systems were given above. These systems are sometimes called “sustainable” (Pretty 1995) or “agroecological systems” (Altieri 1995), but all of these names describe the same set of production practices.

As noted previously (p. 4), the single most important difference between the alternative system and the conventional system is that, in the former, producers rely mainly on resources internal to the farm or in the immediate local area. (e.g., Altieri 1995, p. 11; Francis 1990, p. 140; Pretty 1995, p. 8). The rationale for this emphasis on the use of internal inputs is variable. Some (e.g., Altieri 1995) argue that this characteristic of the alternative system promotes local and regional economic and political autonomy, hence favors a more equitable distribution of economic and political power in the countryside.

It also is argued that the purchased-input-minimizing characteristic of the alternative system makes it natural-resources saving and environmentally friendly, hence sustainable (Altieri 1995; Toledo 1990, p. 53). In contrast, the conventional system is said to be unsustainable because of its alleged natural resource and environmentally damaging characteristics.

Among proponents of the alternative system, its minimization of purchased inputs is also favored because it makes farmers less dependent on fluctuations in national and international markets (Francis 1990, p. 138). Avoidance of purchased inputs is also favored by some (e.g., Gliessman, 1990 p. 13; Altieri, 1990, p. 117), because these inputs are believed to be more costly than those available on the farm or locally.

However, the references cited do not present much evidence to support the arguments for the benefits of minimizing purchased inputs. Altieri (1995), for example, simply assumes that the conventional system is not sustainable; Francis (1990) simply assumes that increased dependence of farmers on national and international markets is undesirable; and Gliessman (1990) and Altieri (1990) assume that purchased inputs are more costly than on-farm or locally available inputs. Gliessman and Altieri ignore the fact that it is the relative costs of the various inputs *in relation to their respective productivities* that determines which is most economical for the farmer. In short, in the literature we have surveyed, the arguments in support of the low purchased-input characteristic of the alternative system have been asserted, not made.

The literature is unclear on the question of how much land the alternative system would require for a given amount of production relative to the conventional system. The fact that the alternative system relies on systems of crop rotations to provide nutrients and manage pests suggests that the system would require more land to produce a given amount of output than the conventional system. That is, it would appear that crop yields with the alternative system ought to be less than with the conventional system. In this case, widespread adoption of the alternative system when demands for food increases would require more land clearing and draining, and questions would have to be asked about the economic and environmental costs of this pattern relative to those of the conventional system.

Pretty (1995), however, contradicts this position. He states (p. 2) that with the alternative system there "is less need for expansion into non-agricultural areas, so ensuring that wild plant and animal species are not lost." Pretty does not explain how this assertion is consistent with the reliance of the alternative system on rotations to maintain nutrient supplies and control pests.

Apart from the statement by Pretty, we found no specific treatment of the land-use issue in the literature. Much of it argues, however, that in fact crop yields with the alternative system are often equal to and in some cases superior to those of the conventional system (e.g., Gliessman 1990; Pretty, 1995; Uphoff and Fernandes 1999). All of this evidence about yields with the alternative system relative to those of the conventional system is anecdotal. We found no systematic comparisons of yields under the same soil and climatic conditions and over wide areas. Such comparisons are essential in carefully assessing the yield characteristics of the two systems and answering the question, which system would require more land in responding to future global and developing country demands for food?

In fact, much of the literature about the alternative system does not address whether the system could meet these demands. Uphoff and Fernandes (1999) are an exception. They specifically cast their analysis of the alternative system in the context of meeting future global demands for food. And Gliessman (1990, p. 13) asserts that the alternative system satisfies local needs “together with a significant contribution to demands on a larger scale.”

In his treatment of small-scale agriculture in Southeast Asia, Marten (1990) does not explicitly address the issue of meeting future demand, but he emphasizes that agricultural modernization “is a fact of life” (p.183) in the region, and that farmers there have clearly demonstrated that they are sensitive to market opportunities. By implication, therefore, Marten discusses the alternative system in the context of market demand.

Much of the literature, however, either does not address the issue of supplying demand on a large scale or argues that orienting developing country agriculture toward national and international markets would be a mistake. Toledo (1990, p. 58), for example, asserts that, with the alternative system: “Local and regional subsistence and not commercial production should be the first productive goal in any rural development policy, especially in those areas characterized by high eco-geographical complexity and high biological and genetic richness.” Altieri (1990, p. 116) argues that, in the search for alternative systems, the first goal is to improve “the production of basic foods at the farm level to enhance the family nutritional intake.” Francis (1990, p. 138) states that “the family that produces either a food or non-food crop for sale and becomes dependent on the international export market for guaranteed sales is highly vulnerable to changes in the international trading systems. It is desirable both for families and countries to become as self-sufficient as possible in food production, especially in basic grains and root crops.”

For Toledo, Altieri, and Francis the question of the capability of the alternative system to meet future global and developing country demands for food appears to be irrelevant. But for assessment of the ability of the alternative system to widely complement, if not substitute for, the conventional system, the question is, in fact, highly relevant.

Pretty (1995) argues that the alternative system has high potential in developed countries, in countries where the Green Revolution has already been widely adopted, and in those developing countries still engaged in traditional agriculture. With respect to meeting future global and developing country demands for food, however, Pretty takes a profoundly pessimistic position without seeming to realize that he is doing it.

The alternative system in the developed countries. Pretty argues that the alternative system now is economically viable in these countries, although general adoption of it would involve "stabilized or lower yields" (Pretty 1995, p. 206). He asserts that this yield result would not be a problem because these countries already must contend with agricultural surpluses. The yield penalty would eliminate these surpluses, and adoption of the alternative systems would provide more natural-resource and environmental benefits than the conventional system would displace.

Pretty cites a small amount of evidence from the United Kingdom for this argument, but the argument rests almost entirely on his analysis of present U.S. agriculture. He cites a substantial amount of literature supporting the argument that the alternative system now is economically viable in the United States. As far as it goes, this literature seems to support Pretty's argument, but the cited literature is quite limited. One source, a report by the U.S. National Research Council (1989), accounts for 5 of 10 cases Pretty uses to support his argument. (See Pretty, Table 7.1, p. 207). Those cases were for one farm each in the states of Ohio, Virginia, and Pennsylvania, and two farms in Iowa. The other five cases were from different sources and were for 20 farms in the states of Iowa, Illinois, Missouri, Nebraska and Minnesota (one case), one farm each in Washington State and California, and two farms in Nebraska. We are skeptical that such limited evidence can support general statements about the widespread economic viability of alternative systems.

Other studies, not cited by Pretty (they were published after his book appeared), are similarly limited to a small number of farms, and are ambiguous about the economic viability of the alternative system relative to the conventional system. Dobbs and Smolik (1996) compared the profitability of "conventional" and "alternative" farms on the western edge of the Cornbelt between 1985-1992. They found that over this period the conventional farm was more profitable when price premiums were excluded from the earnings of the alternative farm.

Smolik, Dobbs, and Rickerl (1995) compared the profitability (and other characteristics) of alternative and conventional farms at two agricultural experiment station sites in northeastern South Dakota over the years 1986-1992. Each farm consisted of 216 tillable hectares. Over the seven-year period the alternative farm was substantially more profitable than the conventional farm at one site and somewhat less profitable at the other.

Welsh (1999) studied the results of seven case studies of the profitability of conventional and organic farms in Iowa, Minnesota, Nebraska, Kansas and South Dakota. (Organic farming is a special case of alternative systems). Four of the seven studies were based on experiment station projects, and three were of actual operating farms. All of the studies covered a number of years, typically from the mid-1980s to the early 1990s, but they were not the same years in all studies. In four of the seven studies the conventional system was more profitable than the organic system. (See Welsh 1999, Table 10, pp. 38-39).

The evidence provided by Pretty and in the other studies just cited indicates that in some places in the U.S. alternative systems can be more profitable than the conventional system; in other places it is less profitable. All of the studies cited are limited to one or a few farms, and many of them are based on experiment station projects, not actual operating farms. As indicated in connection with Pretty's work, we find the evidence with respect to the profitability of alternative and conventional systems in the United States to be far too skimpy to support Pretty's argument that the general economic viability of the alternative system has been adequately demonstrated.

Apart from whether Pretty is right on this issue, we question his conclusion that the stabilization or decline in yields in developed countries occasioned by adoption of the alternative system is not important for future world food supplies. As Pretty puts the argument, the yield experience in these countries clearly would result also in no increase in or an actual decline in total production. With the world facing steadily rising demands for food, especially in developing countries, the idea that the most agriculturally productive countries in the world should shift to a system that would, at most, stabilize and possibly reduce production makes no sense.

The alternative system in Green Revolution countries. Pretty (1995, p. 211) asserts that Green Revolution areas "are the current 'bread basket' for many Third World countries, supporting some 2.3-2.6 billion people." However, despite good natural resource and marketing conditions in these areas, "the hope that they will be the source of future agricultural growth is being undermined by emerging evidence of stagnating yields coupled with increasing environmental and health costs . . . If, as seems likely, the micro-environments for crops are being disrupted by the high input regimes, then a more realistic hope would be to stabilize yields in these areas while reducing environmental impacts" (p. 211).

We showed above that yields of rice, maize, and wheat in developing countries have continued to increase through 1998 in step with the arithmetic yield trend established from 1960 through 1998. Pretty's statement that these yields are stagnating is incorrect. With respect to his argument that in Green Revolution areas environmental and health costs of these technologies are rising, his evidence is no more robust than what we cited above, which is to say not robust at all.

But apart from whether he is right or wrong on the question of environmental and health costs, the curious aspect of Pretty's argument about the potential in Green Revolution areas is that he is quite prepared to accept a situation in which no further yield increases are likely in areas that now, as he states, support 2.3-2.6 billion people. Either these people (of whom there surely will be more over the next several decades) attempt to import more food to meet future demands, or they turn to more land-using, environmentally destructive production practices. But importing more food would prove to be very costly, because in Pretty's scenario, production, hence export capacity, in developed countries would not have increased and may be reduced. In Pretty's scenario these 2.3-2.6 billion people (and counting) would find themselves in a very unpleasant box. Pretty is astonishingly complacent about this.

The alternative system in traditional agricultural areas. According to Pretty (1995, p. 2) some 1.9-2.2 billion people live in these areas. These people reside in poorer countries with little foreign exchange to buy external inputs and live in areas largely untouched by modern technology. "Their agricultural systems are complex and diverse, and are in the humid and semi-humid lowlands, the hills and the mountains, and the drylands of uncertain rainfall. They are remote from services and roads, and they commonly produce one-fifth to one-tenth as much food per hectare as farms in the industrialized and Green Revolution lands."

It is in these areas that Pretty finds considerable potential for the alternative system to increase yields and total production. He supports this argument with evidence from 20 case studies in 12 developing countries of yield and production consequences of adopting the alternative system.

Pretty is properly circumspect in the claims he makes about the generality of the results from these case studies. In fact he makes no general statements beyond saying that the evidence suggests that the alternative system has potential for increasing yields and production in regions with poor resources. He does not deal with the potential limitations to generalizing the system implied by the remoteness of these areas from roads and services (See Pretty's quotation above).

We find Pretty's argument profoundly pessimistic because it is quite explicit that the only areas that could potentially increase yields and production are poor in natural resources, inaccessible to markets, and presently home to only 1.9 to 2.2 billion of the world's 6 billion-plus people. In Pretty's scenario, the likelihood that wide adoption of the alternative system would provide a sustainable response to rising global and developing-country demands for food is small.

Our (by no means complete) review of the literature dealing with the alternative system leaves us unconvinced that complementing, if not totally substituting, the conventional system with the alternative system would lead to a sustainable supply response to future demands for food.

Is There Something in Common Between the Conventional and Alternative Systems?

There is a strand in the alternative system literature suggesting that the distinction between the two systems is not as sharp as the material discussed above might indicate. That strand concerns the critical importance of agricultural research in the search for a sustainable production response to rising global and developing country demands for food. The key role of research in maintaining the sustainability of the conventional system has already been emphasized above. Much of the literature on the alternative system also places much importance on research.

Pretty, for example (1995, p. 19), asserts that "farmers do not get more output from less input. They have to substitute knowledge, labor and management skills to make up for the forgone added value of external inputs." Francis (1990, p. 142) also implies that research is important. He states, "If we can combine some of the best and lowest cost components of improved technology … with the conventional wisdom of farmers about their environment and crops which grow well, we can work together to design alternative systems which will work and improve agriculture for small farmers."

Kirkby (1990, pp. 178-9) makes it clear that research must be undertaken to overcome the problems of insufficient rainfall and low-fertility soils imposed on farmers in much of Sub-Saharan Africa. With respect to Southeast Asia, Marten (1990, p. 183) writes, "It is a responsibility of agricultural scientists to provide farmers with new technologies that offer not only higher yields and higher incomes but also sustainable yields and prudently low levels of environmental degradation and social disruption."

These various statements could also apply to the conventional system. To be sure, the lines of research that would be pursued under the rubrics of the two systems would not be identical. For example, Uphoff and Fernandes (1999) argue that future agricultural research should put more emphasis on technologies that tap the dynamics of biology, a line indicated by alternative systems, and less on systems that "rely principally on strategies that emphasize chemistry, engineering and breeding," the strategies that have guided research on the conventional system.

We are pleased to find that advocates of both the conventional and alternative systems give importance to research. This suggests that scientists in agricultural research institutions will find themselves following paths that combine the best features of each system, thus increasing the likelihood of achieving a sustainable response to future global and developing country demands for food.

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