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Policy Forum

Introduction: Farming the Garden of Eden

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Guest editors

The second part of this special issue on agroindustrialization, development and the environment is a policy forum based on an article from *The Economist* news magazine on the current and prospective environmental pressures induced by changes in agricultural technology. Global demand for food and other agricultural products will inevitably grow considerably over the course of this century, due to growth in both population and incomes. At the same time, farming's share of the economically active population will fall sharply, necessitating increased commercialization of agriculture so as to increase productivity to meet the growing demands of urban and non-agricultural rural consumers. Yet there is little room to expand agricultural production beyond lands currently cultivated or in pasture without incurring additional economic and environmental costs. Nor is there a great surplus of water with which to irrigate more crops. Meanwhile, current farming practices are leading to alarming rates of soils degradation and inorganic and organic water pollution.

The pressing question thus facing future agroindustrialization and development is how best to stimulate increased agricultural production to satisfy burgeoning commercial consumer demand without further degrading the natural environment. The resulting debate over such expansion is concerned with three distinct technological developments available today: 1 'Green Revolution' methods of agricultural intensification based on irrigation, use of inorganic fertilizers, increasingly precise machinery, and chemical pesticides; 2 so-called 'agroecological' approaches based on traditional methods of intercropping, fallows and rotations, agroforestry, crop-livestock integration, green manure cover crops, and integrated pest management; and 3 genetically engineered cultivars designed to increase resistance to pests and drought and to increase yields, or some combination of these three means. The conflict is not merely one over science, it is also about distributional politics. For some, the debate revolves around scales of production, with advocates for peasant farmers commonly objecting to Green Revolution methods for which there appear to be minimum efficient scales of operation. In other circles, the contest is over how to balance the competing demands of urban consumers wanting safe, attractive, and nutritious foods grown in environmentally benign ways against those of farmers looking to increase yields and reduce costs. There are additionally macro-level issues of sovereignty related to national food self-sufficiency objectives and to the enforcement of intellectual property rights originating in foreign legal systems and cultural traditions. In sum, multiple economic, political, and scientific fault lines exist in the debate over the future of farming in an era of inevitable agroindustrialization.

Reactions to this article were invited from a number of distinguished scholars engaged in this debate. While their optimism regarding the relative merits of agroecological, genetic engineering, and Green Revolution approaches varies considerably, their responses nonetheless evince a common belief that there is considerable latent complementarity among these approaches. Realizing the potential synergies remains a great challenge, however. Most of the commentators point to the need for institutional innovations to foster improved resolution of the externality problems inherent to agriculture–environment interactions. Perhaps the most central institutional challenge revolves around private–public cooperation. Where public sector research sparked the last great leap in developing-country agriculture, perhaps especially in south and southeast Asia private agro-industry may well have to lead the next agricultural transition. Private firms, both domestic and multinational, indeed seem poised to play an unprecedentedly active role in global agricultural development in the twenty-first century if genetic engineering or advances along Green Revolution lines play a major role. Ujjayant Chakrovorty notes that increasing private sector leadership in agriculture brings with it vertical integration and globalization, a fundamental reorganization of the agricultural sector to which there remains predictable resistance. To what extent can increased private investment in biotechnology complement or even induce greater public investment in crops and methods offering little commercial promise?

Scott Swinton emphasizes the continued crucial role of public investment in any effective strategy of agroindustrialization in the low-income world, where corporate profitability remains minimal. The public sector in low-income countries is resource starved, however. Distributional and environmental tradeoffs exist among resources put into developing marketing infrastructure to improve farmer access to Green Revolution inputs and commercial markets, versus alternative uses in laboratory work in genetic engineering or in promotion of a dense network of farmer field schools to identify and disseminate effective local management methods. Allen Blackman points out that the appropriateness of policy interventions to promote more environmentally benign agroindustrialization depends heavily on local context. Quite aside from the economic and ecological issues, new scientific methods raise ethical and risk management questions that must be resolved within the prevailing mores of quite heterogeneous sociopolitical systems.

There also seem to be limits to the complementarities between the three technological options. For example, agroecological and genetic engineering methods generally appear more knowledge intensive than Green Revolution techniques, with the notable exception of precision agricultural machinery that will remain beyond the means of most developing-country farmers for many years. This knowledge intensity raises important questions as to who will fund, generate, and disseminate such knowledge. The Green Revolution was launched largely with public research, especially on improved hybrid cereals. Biotechnology offers technological answers embodied in a product, seed or livestock genetic material, whose value added can be captured through monopoly rents generated by patent protection. So biotechnology knowledge generation has to date largely been concentrated in a few large multinational firms. Agroecological approaches, by contrast, exploit indigenous knowledge to identify context-appropriate processes that farmers must learn and master. As Norman Uphoff suggests, the agroecological approach thus demands a fundamental recasting of the relationship among scientists and farmers as a partnership, quite a different model than that of lab-based biotechnology or Green Revolution advances. Carlos Seré also emphasizes this distinction, noting that widespread commercial interest in genetic engineering has thus far been targeted more toward the aesthetic and environmental concerns of consumers in wealthy countries than toward the food security and poverty challenges confronting developing countries.

Peter Hazell emphasizes regional differences in the nature of the environmental challenge posed by agroindustrialization. Where Green Revolution farming systems have brought soil and water degradation to much of Asia and most of the industrialized world, the environmental problems of Africa and much of Latin America have more to do with the absence of Green Revolution intensification. Because current and impending potential and challenges are so very different across various regions and levels of income, the right approach almost surely varies as well. Complementarity at the global scale may mask appropriate concentration on one or another approach to agricultural intensification and agroindustrialization within specific regions or countries.

As the world gathers in Johannesburg in 2002 for the Rio+10 conference on environment and development, the issue of how to satisfy impending food demands in an environmentally responsible manner occupies center stage. Where a century ago, humanity had relatively few avenues open for feeding a larger and wealthier population, several pathways seem viable today. Economists have a central role to play in discerning whether the economic and environmental costs associated with each of these paths, including their effects on global food security, will mean that their net benefits to humankind will diverge or converge over the course of the twenty-first century.

Farming the Garden of Eden

There are few more powerful reminders of the fragility of human endeavour than a storm which sweeps away half a country. In October 1998, Hurricane Mitch roared through Honduras, Nicaragua, and Guatemala, taking with it 10,000 lives and $5.5 billion-worth of the regions' economy. Agriculture was hard hit, but not all farmers suffered in equal measure. 'Conventional' farms, using the industrial model of chemical-intensive monoculture had 60–80 per cent more soil erosion, crop damage, and water loss than those that practised 'traditional' methods, such as crop mixing, biological pest control, water conservation, and agroforestry.

Proof positive that agriculture defies nature at its peril? Not quite. Agriculture is inherently unnatural, tethering the land to a single purpose, but some forms are more unnatural than others. Since the Second World War, agriculture in the developed world has become increasingly intensive, relying heavily on machines, chemicals, irrigation, and selectively bred plants and animals to coax more output from each unit of land. This system has spread widely across the third of the world's land given over to agriculture. It is the dominant model in North America, Europe, and Australia, and sits uncomfortably alongside traditional farming practices in sub-Saharan Africa, Asia, and Latin America. The model has been remarkably successful in what it set out to do: to produce more abundant, less-expensive food. But such productivity has come at a price, much of it paid for in four kinds of environmental damage.

Soil degradation Almost two-thirds of all the world's agricultural land is degraded to some degree, according to Stanley Wood at the International Food Policy Research Institute in Washington, DC. Its sorry state is due to compaction from running machinery over it, water and wind erosion, and depletion of minerals and organic matter through overplanting and overgrazing.

Salt, too, is building up through over-irrigation and poor soil drainage. Roughly 20 per cent of the world's irrigated land suffers from salinization, which makes it less productive. The most dramatic evidence of the perils of excessive irrigation is the Aral Sea, where the water level has fallen by two-thirds over the past 40 years, causing large-scale environmental destruction and human misery. The recipient of its watery wealth – an 8m-hectare expanse of irrigated cotton in Central Asia – is losing fertility because of growing salinization.

Pollution Although the use of synthetic fertilizer has declined in the developed world over the past decade, the world still spreads 135m tonnes a year, most of it in developing countries. The problem is not just how much is used, but how it is applied. Much of it runs off to contaminate aquifers, rivers, and lakes.

The use of pesticide is running at roughly 2.5m tonnes a year, more than double the figure 30 years ago. The use of a group of pesticides including

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aldrin and DDT, known as the 'dirty dozen', is restricted in many countries, but they are still liberally applied in parts of the developing world. Such persistent organic pollutants both linger and concentrate throughout food chains, causing reproductive, developmental, and immune-system problems in both man and beast. And resistance to chemical pesticides is growing among the organisms they are designed to kill.

Nor is it just synthetic chemicals that are a problem. Manure from intensive livestock rearing which makes its way into soil and water is just as damaging. Just look at the algal blooms now choking America's Chesapeake Bay, largely thanks to nitrogen and phosphorus leaking into groundwater from farms in Delaware, Maryland, and Virginia. Even organic agriculture is less innocent than it looks. Although it does without synthetic pesticides and fertilizers, some of its 'natural' alternatives, such as copper sulphate, can be equally harmful.

Water scarcity Roughly 40 per cent of the world's food comes from the 5 per cent of the agricultural land that is irrigated. But the water is running out. According to Sandra Postel, director of the Global Water Project based in Amherst, Massachusetts, water is being pumped out of the ground faster than it can be replenished, mainly because of the farmland thirst of America, North Africa, and the Arabian Peninsula, as well as China and India. Much of this water is wasted through inefficient use, and agriculture is finding it increasingly difficult to compete with new urban and industrial demands.

Biodiversity loss The rich mix of creatures that make up ecosystems is often irrevocably shaken up by intensive agriculture. According to the Food and Agriculture Organisation, at least 13m hectares of forest – providing control of watersheds and a repository of potentially useful industrial and medicinal compounds in plants, animals, and micro-organisms – is lost to agriculture every year in developing countries.

Intensive monoculture also reduces genetic diversity. Some 7,000 crop species are available for cultivation, but 90 per cent of the world's food comes from only 30 of them. Breeding programmes for much of the past half-century have concentrated on high-yielding, pest-resistant, fast-growing crop varieties, which now dominate over half of all the land planted to rice, maize, and wheat. The story is much the same in animal breeding, where over a sixth of the 3,800 breeds of domestic animal that existed a century ago have disappeared. This narrows the room for manoeuvre if disease strikes and different strains are needed.

A quick fix The tension between agriculture and ecology shows up clearly in the current debate over transgenic crops. In 1999, about 40m hectares of genetically engineered crops were grown by a dozen countries, a 44 per cent increase on the previous year. Most of the crops were bred to resist herbicides, such as Monsanto's Round-up®, or to produce insecticidal proteins, known as *Bacillus thuringiensis*, or *Bt* toxins. Such genes are now found in a variety of commercial crops, such as soyabeans, maize, canola (oil seed rape), and cotton, increasingly put together in one plant. Their corporate purveyors promised higher yields with better pest control and lower expenditure on chemicals.

The technology has yet to deliver on all its promises, but has provided enough benefit to keep farmers planting. Four years after their launch, these crops have been taken up by farmers far more rapidly than the previous wonder, hybrid corn. Whether the inbuilt chemical protection of such genetically modified crops has reduced the use of pesticide is high contested. A new study by Leonard Gianessi and Janet Carpenter at the National Centre for Food and Agricultural Policy in Washington, DC, seems to bear out both the hopes of farmers and the fears of environmentalists. It finds that in 13 American states that have been growing transgenic soyabeans, herbicide applications per acre have fallen by 9 per cent, but 14 per cent more herbicide is being used in total because acreages have expanded as well. And genetic modification has not increased yields.

'Post-emergence' herbicides such as Round-up®, also known as glyphosate, work by killing all the plants in the field, both weed and crop: the point of the genetic modification is to make the crop plants resistant to the chemical. This should eliminate the need for tillage, thus reducing mechanical damage to the soil. Gordon Wassenaar, who has been growing soyabeans in Iowa since the 1950s and remembers the bad old days of the highly toxic pestkiller DDT, is puzzled by the objections to GM crops. Like other farmers, he finds glyphosate much safer. 'It beats me how to please these environmentalists. As soon as we meet one bar, another goes up.'

Ecologists such as Margaret Mellon at the Union of Concerned Scientists worry that genetic modification not only perpetuates the problems of intensive agriculture but also adds new ones. They fret about the dominance of one 'broad-spectrum' herbicide that both reduces biodiversity in a field by killing all the plants and causes a few hardy weeds to develop resistance. They also fear, not unreasonably, that the added gene might be transferred from the crop plant to relatives in the field.

American maize farmers like *Bt* plants, crediting them with keeping levels of their chief pest, the European corn borer, so low as to benefit both GM and unmodified varieties. But such transgenic crops are even more troubling to environmentalists who fear they will also make pests more resistant. Last year, the news that pollen containing one of the *Bt* genes can stunt or kill Monarch caterpillars enraged butterfly enthusiasts around the world. The equally lethal effect on green lacewings got much less publicity, yet these insects do a useful job by feeding on the corn borer. Researchers have also shown that *Bt* toxins of the sort produced by the transgenic plants stay in the ground longer than expected, and may kill local insects and soil organisms. But these experiments were carried out in a laboratory. Real-life results are less alarming, but more tests are needed.

Some of agriculture's most serious environmental problems – such as lack of water – can be eased with technical solutions. Parched countries like Israel have mastered a number of neat tricks – such as using a continuous drip of salt or waste water – to make crops grow better. But how to encourage others to adopt such practices?

Most countries have relied on a mixture of regulation and prohibition to deal with environmental offences, such as taxing pesticides, penalising the discharge of manure, and removing fertilizer subsidies. Both the European Union and America make direct payments to promote the use of less intrusive forms of cultivation and the setting aside of land. This is designed to cut production but has welcome environmental side effects. On the whole, however, carrots for good ecological behaviour are less common than sticks for bad.

An exception is water marketing. Irrigation water is rarely priced at its real value, but without a price tag is often waste. In Chile, Mexico, and California, however, farmers are able to trade 'water rights' – allocated by the state – to those in need, such as industry. This seems to encourage farmers to invest in water-saving technologies so they can sell some of their rights, rather than quit altogether.

Having it all

Many ecologists, not content with improvements in conventional farming, would like to see completely new ways of farming adopted. Or, rather, old ways, going back to the traditions of half a century ago, when yields in the industrialized West depended more on nature and labour, and less on artificial aids. A mix of crops, trees, and ground cover, rather than monocultures, helped buffer pest infestations and severe weather. Nutrients were recycled from livestock to crops. Nitrogen was introduced into the soil by rotating the main field crops with pulses. Rotations also helped keep down insects, weeds, and diseases by breaking their life cycles. This kind of farming caused less environmental degradation than today's intensive, highly specialised agriculture, which produces much higher yields but may prove hard to sustain in the long term.

Those who advocate going back to agriculture's roots argue that their approach – known as agroecology – is just as scientific as the latest GM technology, because it relies on a detailed understanding of the complex interactions between soil, water, plants, and animals. Miguel Altieri, an agroecologist at the University of California at Berkeley, points out that this is not the same as much of modern organic agriculture, which still largely relies on monoculture.

But in a world of industrialized farming, agroecology is hard to put into practice, if only because of the vested interest of the agribusiness. One company that is easing itself towards encouraging this kind of agriculture is Unilever. For the past two years the Anglo-Dutch giant has been running pilot projects with growers to spread expertise around the world. It has found, for example, that natural forest left among its Kenyan tea plantations harbours insects that keep nasty bugs in check and acts as a windbreak, as well as providing fuel for the locals. This technique is now being passed on to the firm's plantations in India. Producers venturing into agroecology hope that it will lower their costs in the long run. But conversion is expensive, and although consumers say they want 'clean, green, and pristine' agriculture, they are not always willing to pay a higher price for it.

Obstacles to a doubly green revolution

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Increasingly, conventional wisdom dictates that agrarian policy in developing countries should foster a 'doubly green revolution' that both protects the environment and boosts output (Conway, 1997). While the conservation ethic reflected in the article, 'Farming the Garden of Eden' is a necessary first step towards this goal, it is far from sufficient. A doubly green revolution will require convincing millions of poor small-scale farmers to adopt new agricultural practices, such as agroforestry, soil conservation, and integrated pest management. As a result, it will have to overcome a host of well-documented barriers to technological change in developing-country agriculture: pervasive shortages of credit needed to cover fixed set-up costs, missing or thin markets for critical inputs like labor and water, farmers' risk aversion, tenurial arrangements that create disincentives for technological change, and distorted output markets that lower returns to investment (Feder, Just, and Zilberman, 1985). Despite these barriers, efforts to diffuse improved crop varieties – the (first) green revolution – have had considerable success (Lipton and Longhurst, 1989). But a new transformation emphasizing environmental protection may have difficulty replicating this success. The reason is that many environmentally friendly agricultural practices differ from conventional green revolution technologies in a number of ways that make them less apt to diffuse quickly.

First, environmentally friendly practices are often advocated partly because they have important off-farm and non-farm benefits. For example, policy makers may promote agroforestry partly because it preserves biodiversity and prevents siltation of rivers and irrigation canals. But in deciding whether to adopt new technologies, farmers are overwhelmingly concerned with on-farm benefits. This divergence between the interests of policy makers and farmers has been less of an issue with conventional green revolution technologies which have been explicitly designed to raise yields and/or to reduce yield variability, benefits internalized by individual adopters.

Second, in many developing countries, the policy environment favors the use of input-intensive technologies – including many green revolution technologies – and is biased against environmentally friendly alternatives. For example, fertilizer subsidies discourage investments in soil conservation (since farmers use fertilizer to offset productivity losses due to soil degradation), pesticide subsidies discourage investments in integrated pest management, and irrigation subsidies discourage water conservation.

Third, many environmentally friendly agricultural practices entail significant fixed set-up costs as well as delayed payoffs. For example, agroforestry meant to supply cash crops and timber requires farmers to acquire, plant, and cultivate seedlings which are not harvested for a number of years (Scherr, 1995). Similarly, soil conservation measures such as diversion ditches and terraces are somewhat costly to build but may not provide significant on-farm benefits (in terms of prevented yield losses due to soil degradation) for several years (Lutz, Pagiola, and Reich, 1994). Payoff streams such as these are particularly unappealing to smallholders who – as a result of credit constraints, poverty, and lack of tenure security – have notoriously short planning horizons (Holden, Sheiferaw, and Wik, 1998). By comparison, high-yielding crop varieties entail smaller fixed set-up costs and generally provide more immediate returns.

Fourth, a number of environmentally friendly agricultural technologies entail significant economic irreversibilities that discourage adoption. For example, soil conservation investments like terraces are not fully recoverable unless adopters can sell their plots in well-functioning land markets.

Finally, it may bear noting that the adoption of environmentally friendly technologies undoubtedly will be patchy for the same reason that the adoption of many conventional agricultural technologies has been piecemeal: the private profitability of adopting depends critically on farm- or region-specific characteristics. For example, many soil conservation practices are only attractive when soil degradation causes serious productivity losses. This depends, among other things, on slopes and soil characteristics, such as depth and structure. Hence, soil conservation practices will diffuse slowly in areas where farms have deep soils, even when erosion is occurring at a rapid rate (Lutz, Pagiola, and Reich, 1994). Agroforestry provides a second example. Farmers are only apt to adopt it when tree products, such as fuelwood and poles, are in short supply (Scherr, 1995). Finally, some agroforestry and integrated pest management practices are labor intensive and are unlikely to be adopted by farmers who do not have easy access to farm labor (Ramirez and Schultz, 2000).

In light of the obstacles to the diffusion of conventional environmentally friendly agricultural practices, some have pinned hopes for more sustainable farming in poor countries on innovations in biotechnology. Already some transgenic crops have the potential to reduce chemical pesticide and fertilizer use. Also, some advocates argue that by raising yields, transgenic crops can reduce agricultural extensification that leads to deforestation and the cultivation of ecologically fragile lands. As discussed in the *Economist* article, there are legitimate concerns about whether the potential environmental hazards associated with transgenic crops outweigh the benefits. Even if they do not, however, there are at least two well-known obstacles to the widespread diffusion of such crops in poor countries (Spillane, 2000).

First, although many conventional green revolution technologies were developed by public sector research institutions for the express purpose of improving the lot of small- and medium-scale farmers in developing countries, most agricultural biotechnology has been developed by a relatively small number of private Western companies and is primarily marketed in industrialized countries. At present, agricultural biotechnology companies face strong incentives to continue to ignore poor farmers in poor countries. Greater profits are to be had from selling biotechnology products to large-scale farmers growing cash crops than to small-scale farmers growing subsistence crops. Also, biotechnology companies are concerned about the limited willingness and/or ability of many developing countries to enforce intellectual property restrictions.

Second, like most agricultural technologies, transgenic crops are location-specific, that is, they need to be adapted to particular agroclimactic and sociocultural environments. In most developing countries, however, agricultural research and extension institutions with the expertise in biotechnology required for such adaptation are lacking, as are institutions needed to assess risks associated with transgenic crops and to take the appropriate regulatory action.

The purpose of this comment is not to dismiss the idea of a shift towards more environmentally friendly agriculture in poor countries or to deny that 'win-win' opportunities exist that can facilitate this shift. Rather the purpose is simply to make the point that the first green revolution may serve as an overly optimistic model for this transformation. Policy prescriptions for addressing the challenges listed above are frequently mentioned in the literature. With regard to conventional environmentally friendly practices, policy makers can eliminate market distortions such as fertilizer subsidies that dampen incentives to adopt, and they can strengthen tenure security where its absence is a significant impediment to adoption. In addition, they can subsidize fixed adoption costs where there are clear incentives for the continued use of environmentally friendly practices, and they can encourage rural communities that would capture the off-farm and non-farm benefits of such practices to work cooperatively to speed adoption. Finally, to accommodate heterogeneity across potential adopters, rather than promoting selected technologies, they can provide extension services for a range of different technologies. With regard to agricultural biotechnology, institutions and incentives must be developed to coax private companies to focus their efforts on poor developing-country farmers. Proposals include: favorable tax and foreign exchange considerations for biotechnology multinationals operating in developing countries, public–private sector joint ventures, creating 'honest-broker' institutions to mediate partnerships between private and public sector institutions, strengthening intellectual property regimes, and subsidizing targeted research.

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Globalization and the agriculture–environment relationship

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The focus of this comment is to place the agriculture–environment relationship in the larger context of economic reforms, international competitiveness, and the general trend of consolidation in the agriculture industry. It is well known to observers of agricultural development that the structure of agriculture is changing rapidly both in the developed and the developing countries. These changes are being caused by demand-side effects, such as changes in income and population and shifts in tastes, as well as supply-side factors, such as market deregulation, technological change, and the limited availability of land, water, and other factors of production. These changes are not only affecting how business is traditionally conducted on the farm, but the very core of the agriculture–environment relationship.

As *The Economist* article suggests, modern agricultural practices are one of the major contributors to the degradation of the natural resource base (e.g., soils and water) upon which rests the future productivity of our planet. However, in a world that is rapidly becoming urbanized, agriculture is also valued as a source of open spaces, clean air and water, and as a preserver of the traditional way of life. In many developed economies, such as Israel, Switzerland and the United States, the high opportunity cost of land and water in alternative uses has largely rendered farming an uneconomical proposition. In fact, current farm subsidies and tariffs on imported agricultural products can be potentially justified as a subsidy for the above positive externalities created by the farming sector.

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Although a movement from traditional to chemical-intensive modern agricultural practices has created a host of environmental problems, this shift must be seen in a global context, where the comparative advantage of countries and regions is rapidly shifting, especially in a dynamic sense. For instance, with globalization and the gradual demolition of tariff barriers, large-scale intensive agricultural systems may shift out of the developed countries into developing countries. This in turn may lead to a reduction in environmental problems in the developed economies and a concomitant increase in impacts in the developing economies. The second factor is the advent of biotechnology with its huge potential for breeding crops that are not only high yielding and pest and disease resistant but individually tailored to local agroecological conditions and the tastes and preferences of the consumer (e.g., low cholesterol foods). This would dramatically increase the efficiency of agriculture, and could free up land for alternative uses.

A shift of agriculture from the north to the south will imply that the developing countries will bear the brunt of environmental and resource degradation in the near future. However, this group again is not homogenous. One would need to look into specific countries and regions because of variations in capital and resource endowments and government policies that are resulting in quick shifts in comparative advantage over time. For instance, two of the biggest developing countries, China and India, will likely become net importers of food in the near future, since their economies are rapidly moving towards specialization in high-quality manufacturing and information technology, respectively. In the case of China, it is likely that unskilled and semi-skilled labor will shift out of agriculture into manufacturing, raising the cost of farming and reducing the country's competitiveness in the international agricultural market. Preliminary evidence in the livestock and other industries suggests that this is already happening. In the case of India though, there are plentiful supplies of low-skilled labor which do not compete with demands from newly emerging sectors such as information technology. However, the problem may lie in the high cost of increasing irrigation capacity in the non-Green Revolution areas.

A recent Worldwatch Institute study found that in the next two years, a quarter of the farms in the US breadbasket states of Iowa and Nebraska will go out of business as will millions of farms in countries ranging from Sweden to the Philippines. The report also points out that this is part of a general trend towards vertical integration in agriculture, with giant firms such as Novartis and ConAgra extending their operations across the food chain from research and production of inputs to sales and marketing. This wave of consolidation and integration of the farming sector will lead to economies of scale and an accelerated process of technological change that will lead to a 'paradigm shift' in the farming sector, just like the one we saw during the Green Revolution. However, the increases in production efficiency achieved in this second phase will far outstrip the magnitude of gains from the previous shift from subsistence agriculture to mechanization.

Biotechnology specialists suggest that there is enormous potential for a whole new set of genetically engineered farm products that take into account heterogeneity in human physiology and tastes in the human population. The increased productivity through technological change and an already evident flattening of global population growth and, therefore, food demand would mean that derived demand for land, water, and chemicals might decline in the future. As *The Economist* points out, there is some evidence that herbicide applications have fallen in the case of transgenic soyabeans, although the reductions have been compensated by acreage increases. However, acreage increases would imply that transgenic crops are being substituted for traditional varieties, which in turn suggests that overall input use must decline in the absence of significant positive demand shocks.

The consolidation of farming activity among a small number of multinationals may be a good thing simply because environmental regulation becomes a less complex task, and, given the global reach of these companies, the negative consequences of being branded an 'environmental pariah' are high. One only need to look at the extent to which Ford went to try to contain the recent Firestone/Bridgestone tire controversy or the Coke fiasco in Europe in the summer of 1999 to understand the magnitude of reputation effect that affects a global multinational. Regulatory institutions in the developing world are weak enough, and the task of ensuring environmental compliance by thousands of small farms practicing chemical-intensive agriculture will prove to be extremely difficult.

The Economist article tends to promote the classic 'tradition is good, modern is bad' argument that fails to recognize economic realities being faced by the agriculture sector. Part of the fear of 'genetic engineering' stems from the fear of any new technology (since the days of the steam locomotive), since it displaces the traditional way of growing crops. Although it is true that modern agriculture is more chemically intensive, the environmental issues that have merged under the Green Revolution have a lot to do with inappropriate economic policies and rent seeking and not the technology *per se*. For instance, the water logging and salinity that has rendered large tracts of fertile agricultural land unproductive in the Punjab in India and Pakistan is a direct result of overuse of subsidized water. Pricing reforms that will charge farmers the marginal cost of water will reduce water use, decrease runoff into groundwater aquifers, as well as release water for alternative uses. Most governments are loath to increase water prices for fear of political retribution from an active farm lobby. This is true not only in the developing countries but also in the developed countries in Europe, Japan, and the US. However, the effect of price reforms that increase input prices closer to their true opportunity costs on the farming community may be much lower than generally expected, because of the substitution effects. During the California drought of 1987–92, a University of California study found that while, water supplies were reduced by 50 per cent during the drought, farm revenue declined by only 20 per cent, as farmers switched out of low-valued crops, such as alfalfa, that are only viable when water supplies are cheap and abundant. The magnitude of improvements in water-use efficiencies through pricing and institutional reforms is likely to be much larger in the developing countries simply because the baseline efficiency there is much lower than in the developed countries. Water prices are generally unrelated to water use, and volumetric and other pricing principles are rarely implemented. Water pollution from the use of fertilizers and pesticides is also primarily caused by input subsidies.

In this sense, the twin goals of economic efficiency and environmental conservation are intertwined. It is only economic reform that will lead to the adoption of conservation measures and technological change in the agricultural sector. This in turn, will free up limited land and water resources for use as amenity resources. Twenty years ago, the fight over water, for example, was mainly between the agriculture and urban sectors. The justification given for improving efficiency in water use was that water needs to be made available for higher-valued urban and industrial uses. In recent years, there is a new actor in this game, and that is the hyperactive environmental sector. In many countries, new laws and regulation promoted by an active environmental lobby has led to an earmarking of water resources for preservation of marine and other aquatic ecosystems, so that the agricultural and urban sectors now have access to much less water than before. Hence the urgent need to improve economic efficiency and reduce resource use per capita output.

The adoption of agroecological techniques may be somewhat similar to organic farming. Consumers who prefer organically grown products pay a premium relative to standard supermarket produce. With increases in GDP per capita, consumers will slowly shift into pricier environmentally friendly farm products. This has already happened in the developed countries and is happening in the developing countries, but at extremely slow rates. A niche market may develop over time, but it may not be enough to overcome the serious environmental problems associated with modern agriculture. Genetic engineering, economic reforms, and industry-wide consolidation may have a more profound effect in the near term.

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I would like to thank Joy Mazumder for valuable comments.

Agriculture and the environment

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We do need to be concerned about the environmental problems that blight many farming areas around the world. But in our pre-occupation with

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these issues and the search for solutions, we should not ignore 1 the dramatic improvements to food security that science-based agricultural advances have brought to most countries, 2 the virtual impossibility of going back to 'old time' technologies that never did all the things that modern proponents would have us believe, and 3 the very different agricultural and environmental problems facing undeveloped regions in poor countries where most of the rural poor now live. Solutions to agriculture's environment problems can be found, but they will involve a mix of appropriate technology, policy, and institutional approaches. Moreover, industrial countries have more options for solving these problems than most developing countries.

Past successes

Food scarcities have always haunted mankind. In earlier centuries, few technological breakthroughs increased yields and the food needs of growing populations had to be met by expanding cultivated area. As the most fertile land became scarce, further expansion meant bringing lower-yielding land into cultivation. By the eighteenth century pessimism had grown about the possibility of feeding ever-larger populations, as exemplified by the writings of Thomas Malthus. The task seemed even more daunting as advances in medicine and public health led to longer life expectancies and higher fertility rates.

Massive public investments in modern scientific research for agriculture led to dramatic yield breakthroughs in the twentieth century. The story of English wheat is typical. It took near 1,000 years for wheat yields to increase from 0.5 to 2t/ha by the Second World War, but only 40 years to climb from 2 to 6t/ha. Most industrial countries had achieved sustained food surpluses by the second half of the twentieth century.

These advances in plant breeding, agronomy, fertilizers, and pesticides were much slower to reach today's developing countries. Colonial powers had invested little in the food production systems of these countries, and populations in the colonies were growing at historic highs by the time they gained independence. By the mid 1960s, there was widespread hunger and malnutrition, especially in Asia, with growing dependence on food aid from the rich countries. This was not a time of agrarian bliss and harmony with Mother Nature.

In response, a small consortium of donors established two international agricultural research centers to help transfer and adapt available scientific advances to conditions in developing countries. The first investments were made in rice and wheat research, two of the most important food crops for the developing world. The breeding of improved varieties combined with the expanded use of fertilizers, pesticides, and irrigation led to dramatic yield increases in the late 1960s. This development was coined the Green Revolution in 1968 by USAID Administrator William. S. Gaud.

The adoption of the improved varieties occurred quickly, reaching about 70 per cent of the wheat and rice area in developing countries by 1990. With faster growing varieties and irrigation, farmers grew more crops on their land each year. Moreover, as international agricultural research centers were established to work on other crops (there are now 16 centers in the CGIAR system), improved varieties of other major food crops were soon developed and widely adopted.

These changes more than doubled cereal production in Asia between 1970 and 1995, while population increased by 60 per cent. Instead of widespread famine, cereal and calorie availability per person increased by nearly 30 per cent, and wheat and rice became cheaper (Rosegrant and Hazell, 2000). There were also similar gains in Latin America. Unfortunately, the Green Revolution proved unsuitable for much of Africa and had only modest impact on food production there.

Overall, modern agricultural technologies have transformed the global food situation to one in which there is more than enough food for everyone were it more equitably shared. Moreover, this has been achieved with little increase in the cropped area: in Asia; for example, the doubling of cereal production since 1970 has been achieved with only 4 per cent more cropland. This was a dramatic departure from historical trends.

No going back

To produce today's food output with 1950 yields would require more than twice the total crop area farmed today. This would require massive deforestation around the world, and conversion of many fragile hillsides and drylands to cropping for which they are environmentally unsuitable. Moreover, most Asian countries would not have nearly enough land to feed their current populations, leaving billions of people dependent on world food markets in a scenario in which world food prices would skyrocket. The 'going back' scenario requires that either large numbers of people must starve to bring the world back to a Malthusian equilibrium, or somehow the more traditional low-external input (LEI) technologies that predominated in earlier times could miraculously achieve the same kinds of yields as modern farming today. Moreover, since another 1.5 billion people are already in the works for 2020, then any alternative agriculture must also provide for the continuing 2–3 per cent annual yield growth needed to keep up with growing food needs. Can agroecologists meet this challenge, or will it take further intensification of modern agriculture?

Contrasting environmental problems

It is important to distinguish between two types of environmental problems associated with agriculture. On the one hand, are the intensive irrigated and high-potential rainfed areas where high levels of fertilizers and agri-chemicals are used. These areas include the Green Revolution areas in developing countries and large swathes of farming in the industrial countries. They are the bread basket areas that feed the world's urban populations. The problems here largely relate to the excessive and inappropriate use of fertilizers and pesticides that pollute waterways and upset ecosystems, irrigation practices that lead to salt build up and eventual abandonment of good farming lands, decline of groundwater levels, and loss of biodiversity.

On the other hand, an enormous amount of environmental degradation in rural areas has little to do with modern farming systems. A great deal of deforestation and land degradation (including soil erosion and soil fertility loss) has occurred in undeveloped areas that did not benefit from the modern farming revolution. This degradation is not driven by excessive intensification; quite the reverse, it is driven by insufficient agricultural intensification relative to population growth. As more and more people seek to eke a living out of these areas, they crop land in unsustainable and erosive ways, and fail to replenish the soil nutrients that they remove. Much of the same problem is happening in Africa on a larger scale because farmers are too poor or do not have access to the fertilizers that are key to maintaining yields and sustaining soil fertility.

These two contrasting environments require very different solutions.

High-potential areas

The management of intensive farming systems in irrigated and high-potential rainfed areas requires better management of modern inputs. Their current misuse in developing countries is hardly surprising, as millions of largely illiterate farmers have only recently begun to use them for the first time, but the problem has been exacerbated by inadequate extension and training, an absence of effective regulation of water quality, and input pricing and subsidy policies that made modern inputs too cheap and encouraged excessive use. Rich countries have not escaped these problems either, again in part because of government support policies that made highly intensive farming more profitable than it should have been and because of the same problems of regulating water quality and use as in developing countries. Policy and institutional reforms that correct inappropriate incentives can and are making an important difference. Improved technologies, such as precision farming, ecological approaches to pest management, pest resistant varieties, and improved water management practices can even increase yields while they reduce chemical use.

Can ecological farming substitute for modern agriculture in these breadbasket areas? There is tested and documented evidence from a very small number of farms (e.g. just a few dozen in the US) that competitive yields can sometimes be obtained at the plot level. But the approach requires more labor, mixed farming (including crop rotations and crop–livestock integration), and use of fallow and green manures to generate organic matter and nitrogen. These methods are expensive; wages are higher in better-developed regions, and mixed farming and fallows have high opportunity costs because part of the land is kept out of its most profitable uses. Moreover, without use of some external inputs, especially phosphate, potassium, and lime, yields cannot be sustained under these farming systems.

In rich countries with abundant food supplies, there is the option of labeling foods produced as 'organic' or 'ecologically friendly', and charging a price premium to offset their higher costs. However, if this type of farming were to spread on a significant scale it would have broader market impacts. Diverting some of the best land into fallow, rotations, and livestock production would reduce aggregate cereal output, while at the same time leading to a greater glut of livestock products. Unfortunately, the diversification needs of ecological farming do not necessarily match the kinds of agricultural diversification that the market wants and is willing to

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pay for. Even so, the resulting price changes may not be unbearable for most people, and their governments could afford to subsidize food for the needy and farm incomes where needed.

Taking this same approach in many developing countries would be disastrous, aggravating poverty and malnutrition for hundreds of millions. They simply do not have the option of moving to farming systems that reduce total foodgrain output, or which lead to production of other kinds of foods that their people cannot afford.

Less-favored areas

In many undeveloped regions and much of Africa, the answer to environmental degradation lies in the greater use of irrigation and modern inputs to achieve higher yields. Current input use is very low in these areas (e.g. fertilizer use in Africa averages 11.6 kg of NPK nutrients per hectare of cropland compared to 158.4 kg in Europe and 265 kg in East Asia (Wood, Sebastian, and Scherr, 2000)) and greater use could help restore soil fertility and increase yields without becoming an environmental threat. Unfortunately, because many of these undeveloped areas have limited infrastructure and market access, greater use of modern inputs is difficult and often unprofitable, and farmers must find alternative ways to increase yields.

Ecological and LEI farming may actually have an important role to play in these regions, at least until such time as infrastructure and markets are better developed. The greater labor intensity of LEI technologies is not necessarily a problem in some of these labor abundant regions unless there is seasonal bunching of tasks. However, allocating land to fallow, green manures, rotations and livestock that would otherwise be in crop production may not be feasible for many small-scale farms, nor may the use of composts and manures for soil replenishment where these compete for more pressing household energy needs.

Although more skillful management of traditional farming systems offers some promise for raising food production in many less-favored lands, the extravagant claims made by some grass roots development agencies for their LEI approaches is not substantiated by any rigorous testing with experimental controls. Nor is it clear that these successes scale up to larger areas of farmland, particularly to areas where poor soils and limited rainfall constrain possibilities for generating much organic matter without some use of inorganic fertilizers.

If the world is to meet its food needs in an environmentally sustainable way, then we need less polarization in approaches and better integration of traditional, ecological and scientific approaches to agriculture. Ecological approaches to pest management in combination with the judicious use of pesticides (so-called 'integrated pest management') are proving very successful in some intensively farmed areas, raising yields and drastically reducing environmental problems. Perhaps it is an example of what might be achieved if there was less ideology and a greater willingness amongst agriculturalists to work together.

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Farming the Garden of Eden: a comment

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In the Bible, Cain and Abel are reported to have had serious conflicts: one was a shepherd, the other a crop producer. Today's agriculture hosts a range of such conflicts: Northern producers against developing-country competitors, traditional small farmers versus agribusinesses, environmental concerns of consumers versus competitiveness concerns of producers and governments.

In our globalized Garden of Eden changes driven by technology, global trade, increasing awareness of the externalities, both environmental and social, have in the past decade exacerbated the range, complexity, and scale of these conflicts. While the Green Revolution and the development of the CGIAR were an effective response to the Malthusian drama of food production lagging behind population growth, the present context clearly requires a far more sophisticated holistic approach to deal simultaneously with issues of cheap but safe food production, environmental management, fight against poverty, migration, and others.

Both responses surveyed in *The Economist*'s article – biotechnology and agro-ecology – have in common their substantial knowledge requirements to address societies food needs. However, the nature of the required knowledge and its use are quite contrasting. This does not imply that the approaches are necessarily incompatible. In fact, it seems more likely that the future needs of our societies will require to combine the best of both approaches. What this note does is to highlight their respective knowledge systems implications, and to identify the emerging challenges for the policy and research organizations (national and international) that are expected to contribute to the sustainable development of agriculture to meet human needs.

In the case of biotechnology, the knowledge that it requires to develop refers largely to molecular biology. A large share of this knowledge is presently produced and sold to farmers by the private sector, with the known implications in terms of intellectual property rights (companies' rights, farmers' and indigenous communities rights over traditional knowledge, etc.). While some of the issues have been around for some time, the solutions are not always obvious and certainly they are not neutral in terms of the distribution of wealth and incomes. Moreover, the existing economic and social structures at a given point in time, and the expectations about their change, have a decisive effect in terms of what production problems attract the greatest attention and resources from private investors. These need not be the same crops or problems that would be the priority from the angle of fighting poverty and hunger, or more generally raising living standards for a larger share of the population.

Agro-ecology requires a deep understanding of the functioning of ecosystems. It relies largely on traditional knowledge as a starting point, using the trial and error of thousands of years of agriculture. Rapid change of the context in which agricultural systems operate, both biophysical and more importantly economic and social, have made these approaches frequently not competitive. By its very nature, the agro-ecology approach does not attract private sector investment. This is largely public non-proprietary knowledge, which is not easy to embody in saleable inputs, as is the case for hybrid or genetically manipulated seed or plant material. It is public research institutions that have been investing significant amounts of resources in understanding the underlying principles and using these principles to adapt the systems to today's world. Part of the needed knowledge refers to a practical understanding of the social arrangements that make agro-ecological solutions more or less likely to succeed, and not just the technological knowledge on which type of seed produces the best yield under what soil and weather conditions.

Predictably, the impacts and constraints of both paths to more and better food are therefore quite distinct. The biotechnology path is largely private sector driven, operates in commercial systems, and can produce relatively fast responses, but it requires collective decisions about risks and ethical issues with which mankind have not been confronted before (Wolfenbarger and Phifer, 2000). These social/ethical aspects and the perceptions of risks are major constraints, which will take some time to come to grips with.

Given the required fine tuning of the diversity of local conditions, the knowledge involved in the development and implementation of agro-ecological solutions has to be in the minds and hands of those actually doing the farming. Therefore, to be competitive, these systems require an educated population of farmers and efficient approaches for knowledge sharing and scaling up. In many countries this is a serious bottleneck hindering this and other development processes. This bottleneck implies that diffusion and adoption processes tend to be slower and sometimes costlier.

Both approaches are presently being pursued independently, in different institutional settings, and knowledge is exchanged insufficiently across this divide. Future farming systems will most probably entail a range of combinations of outputs of biotechnology research and of better understanding of the agro-ecology (Swaminathan, 1999). There is a need to create spaces for the discussion of the combinations of approaches suitable for specific societies and ecologies. In this discussion, ways must be found to consider and weight social goals that are not normally part of private sector investment decisions.

At the same time research and discussion needs to take place on the ethical issues and risks to be managed in dealing with the outputs of biotechnology. A better understanding of the ecological and social implications of genetically modified organisms is needed, and this points to differential roles for public and private research systems. Economic, social, and political research are also needed to make the trade-offs clearer, so that those who will make policy choices on behalf of societies at least have a fuller picture of what is at stake. While it is salutary that the main stakeholders have a chance to articulate their claims and policy proposals in technical terms, there is a need for more and better 'public good' research to illuminate open policy debates. This will be a continuous process as the technological frontiers evolve and social conditions change. International trade between societies with diverging perceptions on these issues will keep posing new challenges to WTO negotiations.

These combination of traditional knowledge, understanding of the underlying ecology and the socially acceptable use of biotechnology will have to be produced in a very decentralized way around the world and will require widespread sharing of knowledge through networks. This view has significant implications for the institutions which will be required to support the continuous evolution of the farming systems. This recognition comes at a time when public funding for agricultural research is being reduced in most developed and developing countries. The special case of agriculture and the global ecosystem has to be pleaded for. But this public research has to evolve significantly from what it used to do in the past. It has to address the new agenda including the ethical/risk issues of biotechnology, the biotechnology for crops and ecosystems which are socially critical but are not appealing to commercial interests, the better understanding of the environmental and social externalities of diverse farming options, and the formulation of policy options for globally acceptable trade-offs. Thus the increased private investment in agricultural research in the North cannot lead to a prescription for less public investment, but must on the contrary lead to more, but different public research investment globally to ensure that socially acceptable approaches are developed and implemented.

This scenario presents a number of complex research policy issues for public Southern agricultural research managers:

1. The establishment of the most efficient allocation of scarce public research funds to different crops and production issues. While Southern countries are confronted with daunting social problems, they also are endowed with the weakest research systems and government budgets. They are, therefore, the ones in greater need of judicious choices, since they cannot afford the luxury to duplicate efforts, and they need to maximize the payoff from the limited resources they can invest.

2. The need to define to what extent public biotechnology research should be pursued. The issues of 'orphan crops' (those that are socially critical but uninteresting to the private sector), strategic national interests, or international competitiveness, are some of those that have to be weighted by public research managers in deciding whether, and how much, to invest in public biotechnology research.
3. The creation of a domestic capacity to deal with the impacts of biotechnology on trade, food safety, property rights, etc., involving research and policy advise. Due to the globalized nature of agricultural systems, this capacity is required even if the country is not actively promoting domestic biotechnology research or the use of genetically modified organisms in agriculture.
4. The need to develop institutional approaches to cost effectively undertake agro-ecological research. Less-developed countries have to find ways to develop agro-ecological solutions that are location specific, with research resources that will not allow them to cover each and every ecosystem in their territories. This may require greater international knowledge-sharing and research coordination.

These challenges, particularly for smaller and poorer countries, can easily lead to slower than possible progress in agriculture. Presented with new technologies and solutions that raise new issues they are not prepared to tackle, public bureaucracies may choose to delay the measures that would facilitate their dissemination. More and better interdisciplinary public research and policy dialogue may thus be as important to the future of the Garden of Eden as plain technological research. International cooperation can significantly contribute to global welfare by facilitating the sharing of knowledge in these critical areas that will shape agriculture's contribution to human well-being in the future.

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More avenues for boosting agricultural productivity than just biotechnology

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The Economist's survey on 'Agriculture and Technology' (25 March 2000) portrays a dismal future for agricultural sustainability in developing countries. Faced with soil degradation, water pollution and biodiversity loss, the survey points to biotechnology as the embattled savior. As an afterthought, it notes that agro-ecology, offers a folksy approach 'going back to the traditions of half a century ago' that 'is hard to put into practice' and would confront consumers with higher prices.

Missing from the survey are two key points:

1. Basic agronomic management practices can contribute dramatically to raising yields in developing countries – especially in Africa – but only if the institutional setting is right, and
2. Knowledge-based agricultural management need not be embodied in the high-cost equipment of rich nations' 'precision agriculture'.

Economic institutions as the greenhouse of the Green Revolution

If conventional plant breeding was the seed of the Green Revolution, then good agronomic management was the gardener that made it grow. High-yielding, fertilizer-responsive rice varieties require fertilizer to achieve their potential; they often require irrigation or drainage as well.

But fertilizer cannot be applied where it cannot be bought. Irrigation is infeasible where water supplies are unavailable. Agricultural production beyond subsistence verges on the pointless where product markets are remote and costly to reach. Long-term investments in land productivity offer little promise if land tenure is not assured. Incentives are what unify these four points.

Incentives motivate farmers to manage for higher productivity. If agronomic management made the Green Revolution grow, then sound public institutions provided the greenhouse environment that made the sunlight and water available for the gardener. Public institutions (governmental and non-governmental organizations alike) shape the incentive environment. They build the roads that give farmers cheaper fertilizer and more remunerative farm-gate sales. Public institutions drill the boreholes and maintain the irrigation canals that make water available when needed. Governments and social norms shape the land tenure regimes that determine how far ahead farmers will risk investing in higher productivity.

The potential for institutional changes to boost agricultural productivity

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remains great, especially in sub-Saharan Africa. In a continent wracked by economic retrenchment and civil war during the past two decades, public services have declined across the board. The collapse of rural infrastructure and public services for agricultural research, credit, and extension has raised daunting barriers that prevent African farmers from using markets and modern technology to raise their productivity (Collier and Gunning, 1999). Programs like the Sasagawa-Global 2000 experience have shown again that African farmers can raise crop yields given access to fertilizers and pesticides (Howard *et al*., 1999). But for farmers to get timely access to those inputs is often difficult. The institutional change and public investment required to make farm input markets function sustainably remains a challenge in many countries.

Dismal as the picture may appear, bright spots glow in areas where public services are present that enable markets to work. Malian cotton farmers apply fertilizer to their cereal crops because the cotton marketing infrastructure makes inputs available along with the cash income to buy them (Kelly *et al*., 2000). Peruvian crop farmers with access to the Lima market invest in more productive farming practices while farmers in the same river valley who are remote from markets disintensify and emigrate (Wiegers *et al*., 1999). In those favored locales where the public infrastructure and institutions offer the right incentives, farmers have shown that they will respond.

Farmer knowledge for low-cost precision management

Opportunities for increased agricultural productivity are not restricted to external investments and genetic innovation. As biologists learn better how crops and livestock interact with their environment, they find new opportunities to educate farmers on making timely interventions – both in boosting yields and in reducing wasteful agrochemical use. *The Economist*'s survey characterizes agricultural information technology as embodied in $10,000 yield monitors using satellite positioning. In focusing exclusively on capital-intensive information technologies, it misses the quiet expansion of biological information to substitute for cash inputs among poorer farmers.

The best examples of biological information substituting for cash inputs in developing-country agriculture come from integrated pest management (IPM). IPM typically uses information about the life cycles of crops and their pests to diagnose the likely severity of pest problems. It uses that information to determine the type and degree of crop protection needed. In developing countries, IPM has offered two principal benefits; better crop protection that boosts harvested yields and input savings that cut production costs and excess pesticide use. For example, improved understanding of the potato tuber moth's life cycle in Tunisia cut potato storage losses, stabilizing supplies and reducing pesticide use and storage costs (Fuglie, 1995).

In capital-poor rural areas, IPM and similar knowledge-based farm management practices show promise. As a result, the World Bank has recently chosen to expand its investment in farmer field schools, most focusing specifically on IPM education. More initiatives like this one will be needed if farm information management is to achieve its potential to raise agricultural productivity.

In sum, the avenues open to developing country farmers for enhancing their productivity reach well beyond the biotechnology 'quick fix' offered by *The Economist*'s survey of agriculture and technology. Two leading avenues for productivity gains are: 1 the alleviation of institutional constraints to public infrastructure and land tenure, and 2 the diffusion of better biological knowledge and information management.

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Expanding opportunities with agroecological approaches

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The Garden of Eden was left a long time ago, and population pressure on the land then was minimal, to say the least. In this twenty-first century AD, we have long ago lost our innocence about agriculture, and we now have serious population pressures to contend with, even if they are not evenly distributed. The natural resource base from which we must find ways to feed the world's still-growing population is not only taxed to its limit in

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many places; it is contracting and degrading, often where people can least afford the loss of productive capacity. Half of the world's six billion population are undernourished according to the World Health Organization.

The Economist has done the world a service by addressing these issues so thoughtfully in its 25 March 2000 commentary. Since 1990, when I became responsible for directing an institute devoted to finding solutions to problems of sustainable agricultural and rural development, I have had to get immersed in these issues. 'Farming the Garden of Eden' provides a well-selected set of facts that everyone who is concerned with continued economic expansion and well-being – or with the less-glamorous alleviation of poverty and staving off of environment decline – has to reckon with. (However, the statistic on the share of food produced on irrigated land is wrong; about one-third of our food is produced on the one-sixth of our arable area that is irrigated.)

The Cornell International Institute for Food, Agriculture and Development (CIIFAD) in its various collaborative programs in Latin America, Africa, and Asia has seen that agroecological approaches, while not an entire solution to problems of agricultural development and food security, offer more promise than acknowledged thus far by conventional agricultural research and development programs. We have been working with innovations in agroforestry, use of organic inputs in tropical soils, integrated pest management and other strategies that benefit both farmers and the environment.

Several years before Hurricane Mitch hit Honduras in October 1998, CIIFAD together with NGOs and the Panamerican School of Agriculture at Zamorano began working with farmers on the hillsides there. We saw for ourselves how the use of cover crops and mixed farming methods resisted the damage of torrential rainfall and rapid runoff caused by Mitch. While agriculture may be 'inherently unnatural', as *The Economist* article suggests, it can come much closer to natural conditions than most practices do now.

Certain experience in Madagascar has given us greater confidence that agroecological methods – capitalizing on better methods of managing plants, soil, water, and nutrients in integrated and synergistic ways – can give higher yields than at present and with fewer purchased inputs. Agroforestry methods, for instance, we find well suited to reversing the loss of forest resources, while improving farmers' incomes in Madagascar.

A system of rice intensification (SRI) developed in that country in the 1980s by Fr. Henri de Laulanié is particularly innovative, almost revolutionary. This methodology, being popularized by a Malagasy NGO, Association Tefy Saina (ATS), can raise rice yields far above the national average of 2 tons/hectare. It does this by changing practices, such as timing, spacing and weeding; it does not require new varieties of seed or chemical fertilizers, just compost.

The environmental impacts of SRI are quite beneficial. It requires only about half as much irrigation water as usually applied because paddy soils are kept well-drained instead of saturated, thereby also reducing methane gas emissions. The healthy plants that result with SRI methods have more natural resistance to pests and diseases, so agrochemicals are not needed.

The farmers around Ranomafana National Park with whom ATS and CIIFAD have worked since 1994 have averaged over 8 rice tons per hectare. Many get yields in the 10–15 ton range, and a few get yields even higher – on some of the poorest soils in the world (Uphoff, 1999).

This sounds too good to be true, but significantly higher yields have been obtained with SRI methods elsewhere in Madagascar as well.[1] In the past year we have had confirmation of the benefits of this alternative method for managing rice production from Bangladesh, China, Cambodia, Indonesia, Philippines, Sri Lanka, and the Gambia.

Another example, suggested by my Cornell colleague David Pimentel, is an agroforestry system in Central America where maize is interplanted with a leguminous tree, resulting in nearly doubled yield. Not only are maize yields increased, but soil erosion is reduced nearly 30-fold compared to conventinal monocrop cultivation. The system provides also significant wood fuel for cooking, sparing existing forests and improving biodiversity.

There are good reasons for continuing experimentation with genetic improvements of plants and animals, provided that there are adequate safeguards. More drought-tolerant varieties, for example, would be a great boon to the world's more marginal farmers if this innovation can be accomplished. Some of the best SRI yields are attained with new high-yielding rice varieties.

But as suggested in *The Economist* article, much present biotech research is oriented toward increasing the profitability of agriculture, with selective benefits, rather than to raising its productivity with widespread benefits. About 40 per cent of current research is focused on herbicide tolerance. While this reduces the cost of weed control, through the equivalent of 'clear-cutting' all plant species except the protected one, it does little to increase crop yields.

It is not sensible or necessary to choose *between* the improvement of genetic endowments and of management practices because the contributions of both will be needed to meet the awesome challenge of doubling food production in the next three to four decades. But it makes sense to invest more in research and application of agroecological approaches that capitalize on the *interaction* between genetic potentials and growing environments made more favorable by different and better management practices. The SRI case indicates that there remains considerable genetic potential to be tapped.

This process is not just a technical one. Fifteen case studies presented at a conference on sustainable agriculture that Miguel Altieri and I organized and chaired at the Rockefeller Foundations' international conference center at Bellagio, Italy in April 1999, gave impressive evidence of large productivity increases with various methods broadly characterized as agroecological.

[1] Yields with SRI methods averaging 7.9–9.2 tons per hectare on the high plateau, a very different agroclimatic zone, are reported in Hirsch (2000). Yields with peasant methods averaged 2.2–2.5 t/ha, and with government-recommended improved methods, 3.6–4 t/ha.

Production increases of 50, 100, 200 per cent or more were achieved with few or no outside inputs under environmental conditions far from ideal: eroding hillsides of Central America, high barren plateaus of the Andes, semi-arid areas in the West African Sahel, exhausted lands in eastern and southern Africa, the edge of Madagascar rainforests, heavily populated areas of Malawi, crowded flood plains of Bangladesh, sloping areas in the Philippines, remote forest margins in Indonesia, even within the war zone in Sir Lanka.[2]

The cases also showed that success depends on a participatory approach in which farmers are not seen as the recipients and adopters of new technology but rather are *partners* in the development and testing of new practices and altered farming systems. Such an approach helps to upgrade the human resources of rural communities, enabling people to continue the process of innovation on their own or with reduced external support.

Because external conditions are continually changing, especially as the forces of 'globalization' gain momentum, farmers need to be always testing, adapting, and changing their agriculture. No technology is in itself sustainable since sustainability is not something intrinsic to a given technology; rather it is a function of the technology's 'fit' with the physical, economic, social and institutional environment.

Given the hazards of simply expanding present modern technologies on an ever-greater scale, described well in *The Economist* article, researchers and policy makers should be thinking about how to transform farming to create closer and more symbiotic links between people and their environment through practices that are better attuned to ecological dynamics.

Since 1950, the application of nitrogen fertilizers worldwide has gone up more than 35-fold, and the use of pesticides, herbicides, and other agrochemicals has increased even more. Yet overall agricultural yields have only about tripled. These are sharply diminishing returns. Achieving another doubling of yields by such methods becomes dubious if we consider their implications in terms of environmental and human health, apart from their economic cost when petrochemical products become more costly in the future. Can we countenance another 10 to 15-fold increase in the use of agrochemicals?

This is not to propose that we can or should abandon present fossil-fuel-based production methods. They will continue to be necessary for many years to come. The knowledge base for more extensive and effective agroecological production is still being built up. Under some environmental and economic conditions there is no real alternative to agricultural production based primarily on engineering and chemical applications. But we will be better served in the future by approaching agriculture more explicitly and creatively as the biological enterprise that it is.

We need to harness more fully the power of genetic inheritances to meet

[2] *Alternatives to Conventional Modern Agriculture for Meeting World Food Needs in the Next Century*. Report of a Conference on Sustainable Agriculture: Evaluation of New Paradigms and Old Practices, April 26–30, 1999, Bellagio, Italy. Available from CIIFAD, Box 14, Kennedy Hall, Cornell University, Ithaca, NY 14853. An edited book with papers and learning from the conference is nearly completed.

world food needs. While this power can be assessed through biotechnology and genetic engineering, it can also become available through better understanding and application of principles of agroecology. Not only can agriculture be made more sustainable in terms of soil and water resources, but it can help to conserve biodiversity. One current estimate is that about 90 per cent of the world's biodiversity exists on the 70 per cent of land that is under some form of human management.

Following these principles could be made to seem like a return to the Garden of Eden. But previous knowledge and practices are not always the best. Nor are they always right, as seen in the case of SRI, which changes four practices that farmers growing irrigated rice have followed for millennia. There were some 'rational' reasons for those practices, which were thought to minimize risk. Unfortunately they have had the effect of inhibiting yield, by reducing root growth, by suppressing tillering, and by making the correlation between tillering and grain filling negative, when biologically it can be made positive.

We should be looking ahead rather than back – to a new commonwealth rather than to an old Eden. More progress is likely to be achieved where farmers and researchers work together than by continuing the linear, one-direction strategy where researchers discover or develop innovations by themselves, and then these innovations are transmitted to farmers through an extension service, with 'adoption of recommendations' regarded as a mark of success. Agroecological approaches should be evaluated and developed to enhance the quality of life for rural populations, involving them actively in creating better technologies, at the same time that these approaches preserve and improve the quality of natural resources.

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