

7. Fatal harvest: old and new dimensions of the ecological tragedy of modern agriculture

Miguel A. Altieri

INDUSTRIAL AGRICULTURE AND BIODIVERSITY

Agriculture implies the simplification of nature's biodiversity and reaches an extreme form in crop monoculture. The end result is the production of an artificial ecosystem requiring constant human intervention. In most cases, this intervention is in the form of agrochemical inputs which, in addition to boosting yields, result in a number of undesirable environmental and social costs (Altieri, 1995).

Global threats to biodiversity should not be foreign to agriculturalists, since agriculture, which covers about 25–30 per cent of the world land area, is perhaps one of the main activities affecting biological diversity. It is estimated that the global extent of cropland increased from around 265 million hectares in 1700 to around 1.5 billion hectares today, predominantly at the expense of forest habitats (Clay, 2003). Very limited areas remain totally unaffected by agriculture-induced land use changes (McNeely and Scherr, 2003).

Clearly, agriculture implies the simplification of the structure of the environment over vast areas, replacing nature's diversity with a small number of cultivated plants and domesticated animals. In fact, the world's agricultural landscapes are planted with only some 12 species of grain crops, 23 vegetable crop species, and about 35 fruit and nut crop species; that is no more than 70 plant species spread over approximately 1440 million ha of presently cultivated land in the world. This is in sharp contrast with the diversity of plant species found within one hectare of a tropical rainforest which typically contains over 100 species of trees. Of the 7000 crop species used in agriculture, only 120 are important at a national level. An estimated 90 per cent of the world's calorie intake comes from just 30 crops, a small sample of the vast crop diversity available (Jackson and Jackson, 2002).

The process of ecological simplification associated with industrial agriculture can affect biodiversity in various ways:

- Expansion of agricultural land with loss of natural habitats
- Conversion into homogenous agricultural landscapes with low habitat value for wildlife
- Loss of wild species and beneficial agrobiodiversity as a direct consequence of agrochemical inputs and other practices
- Erosion of valuable genetic resources through increased use of uniform high-yielding varieties

As the industrial model was introduced into the developing world, agricultural diversity has been eroded as monoculture has started to dominate. For example, in Bangladesh the promotion of Green Revolution rice led to a loss of diversity including nearly 7000 traditional rice varieties and many fish species. Similarly in the Philippines, the introduction of HYV rice displaced more than 300 traditional rice varieties. In the North similar losses in crop diversity are occurring. Eighty-six per cent of the 7000 apple varieties used in the US between 1804 and 1904 are no longer in cultivation; of 2683 pear varieties, 88 per cent are no longer available. In Europe thousands of varieties of flax and wheat vanished following the take-over by modern variants (Thrupp, 1998; Lipton and Longhurst, 1989).

MODERN AGRICULTURE, GENETIC HOMOGENIZATION AND ECOLOGICAL VULNERABILITY

Modern agriculture is shockingly dependent on a handful of varieties for its major crops. For example, in the US two decades ago, 60 to 70 per cent of the total bean acreage was planted with two to three bean varieties, 72 per cent of the potato acreage with four varieties, and 53 per cent with three cotton varieties (National Academy of Sciences, 1972). Researchers have repeatedly warned about the extreme vulnerability associated with this genetic uniformity. Perhaps the most striking example of vulnerability associated with homogenous uniform agriculture was the collapse of Irish potato production in 1845, where the uniform stock of potatoes was highly susceptible to the blight *Phytophthora infestans infestans*. During the nineteenth century in France, wine grape production was wiped out by a virulent pest, *Phylloxera vitifoliae*, which eliminated 4 million hectares of uniform grape varieties. Banana monocultural plantations in Costa Rica have been repeatedly seriously jeopardized by diseases such as *Fusarium*

oxysporum and yellow sigatoka. In the USA, in the early 1970s, uniform high-yielding maize hybrids comprised about 70 per cent of all the maize varieties; a 15 per cent loss of the entire crop by leaf blight occurred in that decade (Thrupp, 1998). Uniform commercial potato crops in western industrial nations are currently threatened by late potato blight, the same fungus that caused the potato famine in Ireland. Late blight is jeopardizing the \$160 billion potato industry in the USA, and is causing losses of up to 30 per cent in Third World potato areas, and especially in those where potato diversity has been lost. A worrisome trend is the recent expansion of transgenic maize and soybean monocultures with a narrow genetic base and which reached about 70 million hectares worldwide in 2004.

Modern agroecosystems are unstable, and breakdowns manifest themselves as recurrent pest outbreaks in most cropping systems. The worsening of most pest problems has been experimentally linked to the expansion of crop monoculture at the expense of vegetation diversity. This diversity is a key landscape component providing crucial ecological services to ensure crop protection through provision of habitat and resources to natural pest enemies (Altieri, 1994). Ninety-one per cent of the 1.5 billion hectares of cropland worldwide are under annual crops and planted with mostly monocultures of wheat, rice, maize, cotton and soybeans. One of the main problems arising from the homogenization of agricultural systems is an increased vulnerability of crops to insect pests and diseases, which can be devastating if they infest a uniform crop, especially in large plantations. To protect these crops, copious amounts of increasingly less effective and selective pesticides are injected into the biosphere at considerable environmental and human costs. These are clear signs that the pesticide-based approach to pest control has reached its limits. An alternative approach is needed; one based on the use of ecological principles in order to design more sustainable farming systems that take full advantage of the benefits of biodiversity in agriculture.

THE EXPANSION OF MONOCULTURE IN NORTH AMERICA

Today, monoculture has increased dramatically worldwide, mainly through the geographical expansion of land devoted to single crops and year-to-year production of the same crop species on the same land. Available data indicate that the amount of crop diversity per unit of arable land has decreased and that croplands have shown a tendency toward concentration. There are political and economic forces influencing the trend to devote large areas to monoculture and, in fact, such systems are rewarded by

economies of scale and contribute significantly to the ability of national agricultures to serve international markets.

The technologies which have facilitated the shift toward monoculture are mechanization, the improvement of crop varieties, and the development of agrochemicals to fertilize crops and control weeds and pests. Government commodity policies these past several decades have also encouraged the acceptance and utilization of these technologies. As a result, farms today are fewer, larger, more specialized and more capital-intensive. At the regional level, the increase in monoculture farming has meant that the entire agricultural support infrastructure (that is research, extension, suppliers, storage, transport, markets, and so on) has become more specialized.

From an ecological perspective, the regional consequences of monoculture specialization are manifold:

- a. Most large-scale agricultural systems exhibit a poorly structured assemblage of farm components, with almost no linkages or complementary relationships between crop enterprises and among soils, crops and animals.
- b. Cycles of nutrients, energy, water and wastes have become more open, rather than closed as in a natural ecosystem. Despite the substantial amount of crop residues and manure produced in farms, it is becoming increasingly difficult to recycle nutrients, even within agricultural systems. Animal wastes cannot economically be returned to the land in a nutrient-recycling process because production is geographically remote from other systems which would complete the cycle. In many areas, agricultural waste has become a liability rather than a resource. Recycling of nutrients from urban centers back to the fields is similarly difficult.
- c. Part of the instability and susceptibility to pests of agroecosystems can be linked to the adoption of vast crop monocultures, which have concentrated resources for specialist crop herbivores and have increased the areas available for immigration of pests. This simplification has also reduced environmental opportunities for natural enemies. Consequently, pest outbreaks often occur with the simultaneous occurrence of large numbers of immigrant pests, inhibited populations of beneficial insects, favorable weather and vulnerable crop stages.
- d. As specific crops are expanded beyond their 'natural' ranges or favorable regions to areas of high pest potential, or with limited water or low-fertility soils, intensified chemical controls are required to overcome such limiting factors. The assumption is that human intervention and the level of energy inputs that allow these expansions can be sustained indefinitely.

- e. Commercial farmers witness a constant parade of new crop varieties as varietal replacement due to biotic stresses and market changes have accelerated to unprecedented levels. A cultivar with improved disease or insect resistance makes a debut, performs well for a few years (typically 5–9 years) and is then succeeded by another variety when yields begin to slip, productivity is threatened, or a more promising cultivar becomes available. A variety's trajectory is characterized by a take-off phase when it is adopted by farmers, a middle stage when the planted area stabilizes, and finally a retraction of its acreage. Thus, stability in modern agriculture hinges on a continuous supply of new cultivars rather than a patchwork quilt of many different varieties planted on the same farm.
- f. The need to subsidize monoculture requires increases in the use of pesticides and fertilizers, but the efficiency of use of applied inputs is decreasing and crop yields in most key crops are leveling off. In some places, yields are actually in decline. There are different opinions as to the underlying causes of this phenomenon. Some believe that yields are leveling off because the maximum yield potential of current varieties is being approached, and therefore genetic engineering must be applied to the task of redesigning crops. Agroecologists, on the other hand, believe that the leveling off is because of the steady erosion of the productive base of agriculture through unsustainable practices.

MODERN SCIENCE, THE GREEN REVOLUTION AND PEASANT CROP DIVERSITY

Perhaps the greatest challenge to understanding how traditional farmers maintain, preserve and manage biodiversity is to acknowledge the complexity of their production systems. Part of this complexity involves the recognition that crop genetic resources are more than just a collection of alleles and genotypes of native crops and wild relatives. They also include ecological interactions such as gene flow via cross-pollination among crop populations and species, as well as human selection and management guided by systems of knowledge and practice associated with genetic diversity, especially complex folk taxonomies and selection about adaptation to heterogeneous environments. Today it is widely accepted that indigenous knowledge is a powerful resource in its own right and is complementary to knowledge available from Western scientific sources. Agronomists, other scientists and development consultants have struggled to understand the complexities of local farming methods and their underlying assumptions. Unfortunately, more often than not, they have ignored traditional farmers'

rationales and imposed conditions and technologies that have disrupted the integrity of native agriculture (Shiva, 1991). This was prophetically stated by Berkeley geographer Carl Sauer after visiting Mexico at the invitation of the Rockefeller Foundation in the wake of the Green Revolution:

A good aggressive bunch of American agronomists and plant breeders could ruin native resources for good and all by pushing their American commercial stocks. . . . And Mexican agriculture cannot be pointed toward standardization on a few commercial types without upsetting native economy and culture hopelessly. The example of Iowa is about the most dangerous of all for Mexico. Unless the Americans understand that, they'd better keep out of this country entirely. This must be approached from an appreciation of native economies as being basically sound. (Jennings, 1988)

Part of the problem arises from the fact that the association of genetic diversity with traditional agriculture is perceived in development and scientific circles as negative, and thus linked to underdevelopment, low production and poverty. Many people involved in international agriculture view on-farm conservation of native crop diversity as the opposite of agricultural development (Brush, 2000). The proponents of the Green Revolution assumed that progress and development in traditional agroecosystems inevitably required the replacement of local crop varieties by improved ones. They also assumed that the economic and technological integration of traditional farming systems into the global system is a positive step that enables increased production, income and social well-being (Wilkes and Wilkes, 1972). But, as evinced by the Green Revolution, integration also created several negative impacts (Tripp, 1996; Lappe et al., 1998):

- The Green Revolution involved the promotion of a package that included modern varieties (MVs), fertilizer and irrigation, marginalizing a great number of resource-poor farmers who could not afford the technology.
- In areas where farmers adopted the package stimulated by government extension and credit programs, the spread of MVs greatly increased the use of pesticides, often with serious health and environmental consequences.
- Enhanced uniformity caused by sowing large areas to a few MVs increased risk for farmers. Genetically uniform crops proved more susceptible to pests and diseases; and improved varieties did not perform well in marginal environments where the poor live.
- Diversity is an important nutritional resource of poor communities, but the spread of MVs was accompanied by a simplification of traditional agroecosystems and a trend toward monoculture which

affected dietary diversity, thus raising considerable nutritional concerns.

- The replacement of folk varieties also represents a loss of cultural diversity, as many varieties are integral to religious or community ceremonies. Given this, several authors have argued that the conservation and management of agrobiodiversity may not be possible without the preservation of cultural diversity.

It is important to point out that indigenous/traditional farmers are not totally isolated from industrial agriculture and many appear to be more than willing to experiment with MVs, adopting them when they fulfill complex criteria that include not only higher yield, but also local adaptation and cultural value. Once tested, farmers may integrate some MVs into the group of local landraces as done by farmers in Cuizalapa, in the state of Jalisco, Mexico. In this case, rather than displacing local cultivars, exotic varieties occupy a small proportion of the area planted to maize, but local landraces continue to dominate the agroecosystem. Introduced varieties more often have uses and modes of management that are complementary, rather than substitutable for those of the dominant local cultivars (Brush, 2000).

THE FIRST WAVE OF ENVIRONMENTAL PROBLEMS

The specialization of production units has led to the image that agriculture is a modern miracle of food production. Evidence indicates, however, that excessive reliance on monoculture farming and agroindustrial inputs, such as capital-intensive technology, pesticides and chemical fertilizers, has negatively impacted the environment and rural society. Most agriculturalists had assumed that the agroecosystem/natural ecosystem dichotomy need not lead to undesirable consequences, yet, unfortunately, a number of 'ecological diseases' have been associated with the intensification of food production. They may be grouped into two categories: (1) diseases of the ecotope, which include erosion, loss of soil fertility, depletion of nutrient reserves, salinization and alkalization, pollution of water systems, loss of fertile croplands to urban development; and (2) diseases of the biocoenosis, which include loss of crop, wild plant and animal genetic resources, elimination of natural enemies, pest resurgence and genetic resistance to pesticides, chemical contamination, and destruction of natural control mechanisms. Under conditions of intensive management, treatment of such 'diseases' requires an increase in the external costs to the extent that, in some agricultural systems, the amount of energy invested to produce a desired yield surpasses the energy harvested (Altieri, 1995).

The loss of yields due to pests (reaching about 20–30 per cent in most crops), despite the substantial increase in the use of pesticides (about 500 million kg of active ingredient worldwide) is a symptom of the environmental crisis affecting agriculture. It is well known that cultivated plants grown in genetically homogenous monocultures do not possess the necessary ecological defense mechanisms to tolerate the impact of outbreaking pest populations. Modern agriculturists have selected crops for high yields and high palatability, making them more susceptible to pests by sacrificing natural resistance for productivity. On the other hand, modern agricultural practices negatively affect pests' natural enemies, which in turn do not find the necessary environmental resources and opportunities in monocultures to effectively suppress pests by natural biological means.

The lack of natural pest control mechanisms in monocultures makes modern agroecosystems heavily dependent on pesticides. In the past 50 years the use of pesticides in agriculture has increased dramatically worldwide and now amounts to some 2,56 million tons of pesticides per year. In the early twenty-first century the annual value of the global market was US\$ 25 billion (Pretty, 2005). In the US approximately 324 million kg of 600 different types of pesticides are used annually at a cost of no less than \$4.1 billion (Pimentel and Lehman, 1993; Pretty, 2005). The indirect costs of pesticide use to the environment and public health have to be balanced against their benefits. Based on the available data, the environmental costs (impacts on wildlife, pollinators, natural enemies, fisheries, water and development of resistance) and social costs (human poisonings and illnesses) of pesticide use reach about \$8 billion each year (Pimentel et al., 1980). What is worrisome is that pesticide use is on the rise. Data from California shows that from 1991 to 1995, pesticide use increased from 161 to 212 million pounds of active ingredient. These increases were not due to expansion in planted acreage, as statewide crop acreage remained constant during this period. Crops such as strawberries and grapes account for much of this increased use, which includes toxic pesticides, many of which are linked to cancers. On top of this, 540 species of arthropods have developed resistance against more than 1000 different types of pesticides which have been rendered useless to control such pests chemically (Bills et al., 2003). During the 1990s there was a 38 per cent increase in products to which one or more arthropod species is now resistant and a 7 per cent increase in arthropod species that are resistant to one or more pesticides.

Pesticides in groundwater, surface waters and drinking water have become a serious and increasingly environmental side-effect of pesticide use. In the US, some 9900 wells out of 68 800 tested between 1971 and 1991 had pesticide residues exceeding EPA standards for drinking water (Pretty,

2005). Among the residues found are DDT, chlordane, dieldrin and PCBs – all persistent pesticides.

Fertilizers, on the other hand, have been praised as being closely associated with the increase in food production observed in many countries. National average rates of nitrate applied to most arable lands fluctuate between 120–550 kg N/ha. But the bountiful harvests created at least in part through the use of chemical fertilizers, have associated, and often hidden, costs. A primary reason why chemical fertilizers pollute the environment is due to wasteful application and the fact that crops use them inefficiently. The fertilizer that is not recovered by the crop ends up in the environment, mostly in surface water or in groundwater. Nitrate contamination of aquifers is widespread and at dangerously high levels in many rural regions of the world. In the US, it is estimated that more than 25 per cent of the drinking water wells contain nitrate levels above the 45 parts per million safety standard (Conway and Pretty, 1991). Such nitrate levels are hazardous to human health, and studies have linked nitrate uptake to methaemoglobinemia in children and to gastric, bladder and oesophageal cancers in adults (Conway and Pretty, 1991).

Fertilizer nutrients that enter surface waters (rivers, lakes, bays, and so on) can promote eutrophication, characterized initially by a population explosion of photosynthetic algae. Algal blooms turn the water bright green, prevent light from penetrating beneath surface layers, and therefore kill plants living on the bottom. Such dead vegetation serves as food for other aquatic micro-organisms which soon deplete water of its oxygen, inhibiting the decomposition of organic residues, which accumulate on the bottom. Eventually, such nutrient enrichment of freshwater ecosystems leads to the destruction of all animal life in the water systems. In the US it is estimated that about 50–70 per cent of all nutrients that reach surface waters are derived from fertilizers. Chemical fertilizers can also become air pollutants, and have recently been implicated in the destruction of the ozone layer and in global warming. Their excessive use has also been linked to the acidification/salinization of soils and to a higher incidence of insect pests and diseases through mediation of negative nutritional changes in crop plants.

It is clear then that the first wave of environmental problems is deeply rooted in the prevalent socioeconomic system which promotes monoculture and the use of high input technologies and agricultural practices that lead to natural resource degradation. Such degradation is not only ecological in nature, but also a social and political-economic process. This is why the problem of agricultural production cannot be regarded as only purely technological. While agreeing that productivity issues represent part of the problem, attention to social, cultural and economic issues that account for

the crisis is crucial. This is particularly true today where the economic and political domination of the rural development agenda by agribusiness has thrived at the expense of the interests of consumers, farm workers, small family farms, wildlife, the environment and rural communities.

THE SECOND WAVE OF ENVIRONMENTAL PROBLEMS

Despite the fact that awareness of the impacts of modern technologies on the environment has increased, as we have traced pesticides in food chains and crop nutrients in streams and aquifers, there are those who still argue for further intensification to meet the requirements of agricultural production. It is in this context that supporters of 'status-quo agriculture' celebrate the emergence of biotechnology as the latest magic bullet that will revolutionize agriculture with products based on nature's own methods, making farming more environmentally friendly and more profitable for the farmer. Clearly, certain forms of non-transformational biotechnology hold promise for an improved agriculture. However, given its present orientation and control by multinational corporations, it holds more promise for environmental harm, for the further industrialization of agriculture, and for the intrusion of private interests too far into public interest sector research.

What is ironic is the fact that the biorevolution is being brought forward by the same interests (such as Monsanto, Novartis, DuPont, and so on) that promoted the first wave of agrochemically-based agriculture. By equipping each crop with new 'insecticidal genes', they are now promising the world safer pesticides, reduction of chemically-intensive farming and a more sustainable agriculture. As long as transgenic crops follow closely the pesticide paradigm, however, such biotechnological products will do nothing but reinforce the pesticide treadmill in agroecosystems, thus legitimizing the concerns that many scientists have expressed regarding the possible environmental risks of genetically engineered organisms.

So far, field research as well as predictions based on ecological theory indicate that the major environmental risks associated with the release of genetically engineered crops can be summarized as follows (Rissler and Mellon, 1996; Marvier, 2001):

- The intent of agrocorporations is to create broad international markets for a single product, thus creating the conditions for genetic uniformity in rural landscapes. History has repeatedly shown that a huge area planted to a single cultivar is extremely vulnerable to a new matching strain of a pathogen or pest;

- The spread of transgenic crops threatens crop genetic diversity by simplifying cropping systems and promoting genetic erosion;
- There is potential for the unintended transfer to plant relatives of the 'transgenes' and unpredictable ecological effects. The transfer of genes from herbicide resistant crops (HRCs) to wild or semi-domesticated relatives can lead to the creation of super weeds;
- It is likely that insect pests will quickly develop resistance to crops with *Bacillus thuringiensis* (Bt) toxin. Several Lepidoptera species have been reported to develop resistance to Bt toxin in both field and laboratory tests. Major resistance problems are likely to develop in Bt crops where the continuous expression of the toxin create a strong selection pressure;
- Massive use of Bt toxin in crops can unleash potential negative interactions affecting ecological processes and non-target organisms. Studies conducted in Scotland suggest that aphids are capable of sequestering the toxin from Bt crops and transferring it to its coccinellid predators, in turn affecting reproduction and longevity of the beneficial beetles (Hilbeck et al., 1998);
- Bt toxins can also be incorporated into the soil through leaf materials and litter, where they may persist for 2–3 months, resisting degradation by binding to soil clay particles while maintaining toxic activity. This negatively affects invertebrates and nutrient cycling;
- A potential risk of transgenic plants expressing viral sequences derives from the possibility of new viral genotypes being generated by recombination between the genomic RNA of infecting viruses and RNA transcribed from the transgene;
- Another important environmental concern associated with the large scale cultivation of virus-resistant transgenic crops relates to the possible transfer of virus-derived transgenes into wild relatives through pollen flow.

Although there are many unanswered questions regarding the impact of the release of transgenic plants and micro-organisms into the environment, it is expected that biotechnology will exacerbate the problems of conventional agriculture and, by promoting monoculture, will also undermine ecological methods of farming such as crop rotations and polyculture. Transgenic crops developed for pest control emphasize the use of a single control mechanism which has proven to fail over and over again with insects, pathogens and weeds. Thus transgenic crops are likely to increase the use of pesticides and to accelerate the evolution of 'super weeds' and resistant insect pest strains (Altieri, 2000). These possibilities are worrisome, especially when considering that during the period 1986–1997,

approximately 25 000 transgenic crop field trials were conducted worldwide on more than 60 crops with 10 traits in 45 countries. The biotech industry and their research allies celebrated in 2004 the continual expansion of biotech crops for the ninth consecutive year at a sustained double-digit growth rate of 20 per cent, compared with 15 per cent in 2003. The estimated global area of approved biotech crops for 2004 was 81.0 million hectares in 22 countries, although most are concentrated in the USA, Canada and Argentina.

In most countries, biosafety standards to monitor such releases are absent or are inadequate to predict ecological risks. In the industrialized countries from 1986–1992, 57 per cent of all field trials to test transgenic crops involved herbicide tolerance pioneered by 27 corporations including the world's eight largest pesticide companies. As Roundup and other broad spectrum herbicides are increasingly deployed on croplands, the options for farmers for a diversified agriculture will be even more limited.

THE POTENTIAL IMPACTS OF TRANSGENIC CROPS ON SMALL-SCALE AGRICULTURE IN THE DEVELOPING WORLD

Concerns have been raised about whether the introduction of transgenic crops may replicate or further aggravate the effects of MVs on the genetic diversity of landraces and wild relatives in areas of crop origin and diversification and therefore affect the cultural thread of communities. The debate was prompted by a controversial article in *Nature* reporting the presence of introgressed transgenic DNA constructs in native maize landraces grown in remote mountains in Oaxaca, Mexico (Quist and Chapela, 2001). Although there is a high probability that the introduction of transgenic crops will further accelerate the loss of genetic diversity and indigenous knowledge and culture through mechanisms similar to those of the Green Revolution, there are some fundamental differences in the magnitude of the impacts. The Green Revolution increased the rate at which modern varieties replaced folk varieties without necessarily changing the genetic integrity of local varieties. Genetic erosion involves a loss of local varieties, but it can be slowed and even reversed through *in situ* efforts which conserve not only landraces and wild-weedy relatives, but also agroecological and cultural relationships of crop evolution and management in specific localities. Examples of successful *in situ* conservation have been widely documented.

The problem with the introduction of transgenic crops into regions characterized by diversity is that the spread of characteristics of genetically altered grain to local varieties favored by small farmers could dilute

the natural sustainability of these races. Many proponents of biotechnology believe that unwanted gene flow from GM maize may not compromise maize biodiversity (and therefore the associated systems of agricultural knowledge and practice along with the ecological and evolutionary processes involved) and may pose no worse a threat than cross-pollination from conventional (non-GM) seed. In fact, some industry researchers believe that DNA from engineered maize is unlikely to have an evolutionary advantage, but if transgenes do persist, they may actually prove advantageous to Mexican farmers and crop diversity. But here a key question arises: can genetically engineered plants actually increase crop production and, at the same time repel pests, resist herbicides, and confer adaptation to stressful factors commonly faced by small farmers? Thermodynamic considerations suggest they cannot; traits important to indigenous farmers (resistance to drought, food or fodder quality, maturity, competitive ability, performance on intercrops, storage quality, taste or cooking properties, compatibility with household labor conditions, and so on) could be traded for transgenic qualities which may not be important to farmers (Jordan, 2001). Under this scenario, risk will increase and farmers will lose their ability to adapt to changing biophysical environments and their ability to produce relatively stable yields with a minimum of external inputs while supporting their communities' food security.

Most scientists agree that teosinte and maize interbreed. One problematic result from a transgenic maize-teosinte cross would be if the crop-wild relative hybrids become more successful by acquiring tolerance to pests (Ellstrand, 2001). Such hybrids could become problem weed upsetting farmers' management but also out-competing wild relatives. Another potential problem derived from transgenic crop-to-wild gene flow is that it can lead to extinction of wild plants via swamping and outbreeding depression (Stabinski and Sarno, 2001).

The impacts of transgenic contamination of landraces may not be limited to introgression mediated changes in the fitness of native crops or wild relatives. Introduction of transgenic crops could also affect the biological balance of insect communities within traditional agroecosystems. In the case of Bt maize, it is known that natural enemies of insect pests could be directly affected through inter-trophic level effects of the Bt toxin. The potential of Bt toxins to move through insect food chains has serious implications for natural biocontrol in agricultural fields. Recent evidence shows that the Bt toxin can affect beneficial insect predators that feed on insect pests present on Bt crops. Studies in Switzerland show that mean total mortality of predaceous lacewing larvae (*Chrysopidae*) raised on Bt-fed prey was 62 per cent compared to 37 per cent when raised on Bt-free prey. These

Bt prey fed *Chrysopidae* also exhibited prolonged development time throughout their immature life stage (Hilbeck et al., 1998).

These findings are of concern to small farmers who rely on the rich complex of predators and parasites associated with their mixed cropping systems for insect pest control (Altieri, 1994). Inter-trophic level effects of the Bt toxin raise serious concerns about the potential for the disruption of natural pest control. Polyphagous predators that move throughout the crop season within and between mixed crops cultivars subjected to transgenic pollution will surely encounter Bt-containing, non-target prey. Disrupted biocontrol mechanisms may result in increased crop losses due to pests or to increased use of pesticide by farmers, with potential consequent health and environmental hazards.

Still, the negative environmental effects are not limited to crops and insects. Bt toxins can be incorporated into the soil through leaf materials when farmers plow under transgenic crop residues after harvest. Toxins may persist for two to three months, resisting degradation by binding to clay and humic acid soil particles while maintaining toxin activity. Such active Bt toxins that end up and accumulate in the soil and water from transgenic leaf litter may have negative impacts on soil and aquatic invertebrates and nutrient cycling processes. The fact that Bt retains its insecticidal properties and is protected against microbial degradation by being bound to soil particles, persisting in various soils for at least 234 days, is of serious concern for poor farmers who cannot purchase expensive chemical fertilizers. These farmers rely instead on local residues, organic matter, and soil microorganisms for soil fertility (key invertebrate, fungal or bacterial species), which can be negatively affected by the soil-bound toxin. By losing such ecological services, poor farmers can become dependent on fertilizers, with serious economic implications (Altieri, 2000).

CREATING SAFEGUARDS AGAINST TRANSGENIC HOMOGENIZATION

In today's globalized world, technological modernization of small farmers, through monoculture, new crop varieties and agrochemicals is perceived as a critical prerequisite for increasing yields, labor efficiency and farm income. As conversion from subsistence to a cash agricultural economy occurs, the loss of biodiversity in many rural societies is progressing at an alarming rate. As peasants directly link to the market economy, economic forces increasingly favor a mode of production characterized by genetically uniform crops and mechanized and/or agrochemical packages. As adoption of modern varieties occurs, landraces and wild relatives are progressively abandoned,

becoming relics or extinct. The greatest loss of traditional varieties is occurring more in lowland valleys close to urban centers and markets than in more remote areas (Brush, 2000). In some areas, land scarcity (resulting mostly from uneven land distribution) has forced changes in land use and agricultural practices. The result has been the disappearance of habitats that formerly maintained useful non-crop vegetation including wild progenitors and weedy forms of crops (Altieri et al., 1987).

This situation is expected to be aggravated by the evolution of agriculture based on emerging biotechnologies whose development and commercialization has been characterized by concentration of ownership, control by a small number of corporations, and the decreased presence of the public sector as major provider of research and extension services to rural communities (Jordan, 2001). The social impacts of local crop shortfalls, resulting from genetic uniformity or changes in the genetic integrity of local varieties due to genetic pollution, can be considerable in the margins of the developing world. In the extreme periphery, crop losses mean ongoing ecological degradation, poverty, hunger and even famine. It is under these conditions of systemic market failure and lack of public external assistance that local skills and resources associated with biological and cultural diversity should be available to rural populations to maintain or recover their production processes.

Diverse agricultural systems and genetic materials that confer high levels of tolerance to changing socioeconomic and environmental conditions are extremely valuable to poor farmers, as diverse systems buffer against natural or human-induced variations in production conditions (Altieri, 1995). Impoverished rural populations must maintain low-risk agroecosystems that are primarily structured to ensure local food security. Farmers at the margins must continue to produce food for their local communities in the absence of modern inputs, and this can be achieved by preserving *in situ*, ecologically-intact, locally-adapted agrobiodiversity. For this, it will be necessary to maintain pools of genetic diverse material, geographically isolated from any possibility of cross fertilization or genetic pollution from uniform transgenic crops. These islands of traditional germplasm within specific agroecological landscapes will act as safeguards against the ecological failure derived from the second green revolution imposed at the margins.

One way to isolate traditional varieties from exposure to transgenic crops is to declare a country-level moratorium on the field experimentation and commercial release of biotech crops. But this may not provide sufficient safeguards, as many developing countries receive food aid which is a major entry point for transgenic seeds. In 2001, the United States donated 500 000 tons of corn and corn products for international aid programs, and former

president Clinton assigned US\$ 300 million for a program called 'Global food for education', through which 680 000 metric tons of soybean, corn, wheat and rice surplus would be exported to Latin America, Africa, Asia and Oriental Europe.

THE IMPACTS OF ROUND-UP-READY SOYBEAN IN BRAZIL AND ARGENTINA

In Argentina and Brazil the expansion of soybean is driven by prices, government and agroindustrial support and importing countries' demand. China, the world's largest importer of soybean and soybean products, has a market that encourages rapid proliferation of soybean production. Soybean expansion is accompanied by massive transportation infrastructure projects that unleash a chain of events leading to destruction of natural habitats over wide areas and deforestation directly caused by soybean cultivation. In Brazil soybean profits justified improvement or construction of 8 industrial waterways, 3 railway lines and an extensive network of roads to bring inputs and take away produce. These have attracted private investment in logging, mining, ranching and other practices with severe impacts on biodiversity not accounted for by any impact assessment study (Fearnside, 2001). In Argentina, the agroindustrial cluster area for transformation of soybean into oils and pellets is concentrated in the Rosario region on the Parana River, turning it into the largest soy transformation area of the world, with all the associated infrastructure and environmental impacts that this entails (Pengue, 2005).

Deforestation

In Brazil, the area of land in soybean production has grown at an annual rate of 3.2 per cent, and soybean today occupies the largest area of any crop in Brazil with 21 per cent of the total cultivated land. The area planted to soybean has increased by 2.3 million hectares since 1995 for an average increase of 320 000 hectares per year. Since 1961, soybean acreage has increased 57 times and production volume has increased 138 times (Fearnside, 2001). In Paraguay soybeans are planted on more than 25 per cent of all agricultural land in the country, and in Argentina soybean acreage reached almost 15 million hectares in 2000, producing 38.3 million metric tons. All this expansion is occurring dramatically at the expense of forests and other habitats. In Paraguay much of the Atlantic forest is being cut (Clay, 2003). In Argentina 118 000 hectares of forests have been cleared to grow soybean: in Salta about 160 000 hectares and in Santiago del Estero

a record of 223 000 hectares. In Brazil, the Cerrado and the savannas are falling victim to the plow at a rapid pace (Pengue, 2005).

Soil Degradation

Soybean cultivation has always led to soil erosion, especially in areas where soybeans are not part of a long rotation. Soil loss reaches an average of 16 t/ha in the US Midwest, a rate that is still greater than is sustainable, and it is estimated that in Brazil and Argentina soil losses average between 19–30 t/ha depending on management, slope and climate. No-till agriculture can reduce soil loss, but with the advent of herbicide-resistant soybeans, many farmers now cultivate in highly erodible lands. Farmers wrongly believe that with no-till systems there is no erosion, but research shows that despite improved soil cover, erosion and negative changes in soil structure can still be substantial in highly erodible lands if weed cover is reduced (Pengue, 2005).

Large scale soybean monocultures have rendered Amazonian soils unusable. In areas of poor soils, within two years of cultivation, fertilizers and lime have to be applied heavily. In Bolivia, soybean production is expanding toward the east and many such soybean growing areas are already compacted and soil degradation is severe; 100 000 hectares of land with soils exhausted due to soybean were abandoned for cattle grazing, which in turn further degrades the land. As soils are abandoned, farmers move to other areas to once again plant soybeans and thus repeat the vicious cycle of soil degradation (Clay, 2003).

AGROECOLOGY: AN ALTERNATIVE STRATEGY

Third World Agroecological Initiatives

Since the early 1980s, hundreds of agroecologically-based projects have been promoted by NGOs throughout the developing world, incorporating elements of both traditional knowledge and modern agricultural science. A variety of projects feature resource-conserving yet highly productive systems, such as polycultures, agroforestry, the integration of crops and livestock, and so on. Such alternative approaches can be described as low-input technologies, but this designation refers to the external inputs required. The amount of labor, skills and management that are required as inputs to make land and other factors of production most productive is quite substantial. So rather than focus on what is not being utilized, it is better to focus on what is most important to

increase food output: labor, knowledge and management (Uphoff and Altieri, 1999).

Agroecological alternative approaches are based on using locally available resources as much as possible, though they do not totally reject the use of external inputs. However, farmers cannot benefit from technologies that are not available, affordable or appropriate to their conditions. Purchased inputs present special problems and risks for less-secure farmers, particularly where supplies and the credit to facilitate purchases are inadequate.

The analysis of dozens of NGO-led agroecological projects shows convincingly that agroecological systems are not limited to producing low outputs, as some critics have asserted. Increases in production of 50 to 100 per cent are fairly common with most alternative production methods. In some of these systems, yields for crops that the poor rely on most (such as rice, beans, maize, cassava, potatoes and barley) have been increased by several times. This process relies on labor and know-how more than on expensive purchased inputs, and capitalizes on processes of intensification and synergy.

In a recent study of 208 agroecologically-based projects and/or initiatives, Pretty and Hine (2000) documented clear increases in food production over some 29 million hectares, with nearly 9 million households benefiting from increased food diversity and security. Promoted sustainable agriculture practices led to 50–100 per cent increases in per hectare food production (about 1.71 tonnes per year per household) in rain-fed areas typical of small farmers living in marginal environments; that is, an area of about 3.58 million hectares cultivated by about 4.42 million farmers. Such yield enhancements are a true breakthrough for achieving food security among farmers isolated from mainstream agricultural institutions.

More important than just yields, agroecological interventions raise total production significantly through diversification of farming systems, such as raising fish in rice paddies, growing crops with trees, or adding goats or poultry to household operations. Agroecological approaches increased the stability of production as seen in lower coefficients of variance in crop yield with better soil and water management (Francis, 1986). Data from agroecological field projects shows that traditional crop and animal combinations can often be adapted to increase productivity when the biological structuring of the farm is improved and labor and local resources are efficiently used (Altieri, 1999). In general, data shows that over time agroecological systems exhibit more stable levels of total production per unit area than high-input systems; produce economically favorable rates of return; provide a return to labor and other inputs sufficient for a livelihood acceptable to small farmers and their families; and ensure soil protection and conservation as well as enhanced biodiversity.

Organic Farming

Organic agriculture is practiced in almost all countries of the world, and its share of agricultural land and farms is growing. The total organically managed area is more than 24 million hectares worldwide. Australia/Oceania holds 42 per cent of the world's organic land, followed by Latin America (24.2 per cent) and Europe (23 per cent). Oceania and Latin America concentrate much of the land under organic management, but this is due to the fact that extensive organic livestock systems dominate in Australia (about 10 million hectares) and in Argentina (almost 3 million hectares). Europe and Latin America have the highest numbers of organic farms, and in Asia and Africa organic farming is growing and both regions are characterized by small farms.

In Europe organic agriculture is increasing rapidly. In Italy there are about 56 000 organic farms occupying 1.2 million hectares. In Germany alone, there are about 8000 organic farms occupying about 2 per cent of the total arable land, and in Austria about 20 000 organic farms account for 10 per cent of total agricultural output. In the UK the organic market is displaying growth rates of 30–50 per cent per annum.

Although in the USA organic farms occupy 0.25 per cent of the total agricultural land, organic acreage doubled between 1992 and 1997, and in 1999 the retail organic produce industry generated \$6 billion in sales. In California, organic foods are one of the fastest-growing segments of the agricultural economy, with retail sales growing at 20–25 per cent per year for the past six years.

Research has shown that organic farms can be as productive as conventional ones, but without using agrochemicals. They also consume less energy and save soil and water. A strong body of evidence suggests that organic methods can produce enough food for all – and do it from one generation to the next without depleting natural resources or harming the environment. In 1984 the National Research Council wrote up case studies of eight organic farms that ranged from a 400-acre grain/livestock farm in Ohio to 1400 acres of grapes in California and Arizona. The organic farms' average yields were generally equal to or better than the average yields of the conventional high-intensity farms surrounding them – once again showing they could be sustained year after year without costly synthetic inputs (NRC, 1984).

Several recent long-term studies have been conducted, such as the Farming Systems Trial at the Rodale Institute, a non-profit research facility near Kutztown, Pennsylvania. Three kinds of experimental plots have been tested side by side for nearly two decades. One is a standard high-intensity rotation of corn and soybeans in which commercial fertilizers and

pesticides have been used. Another is an organic system in which a rotation of grass/legume forage has been added and fed to cows, whose manure is then returned to the land. The third is an organic rotation in which soil fertility has been maintained solely with legume cover crops that have been plowed under. All three kinds of plots have been equally profitable in market terms. Corn yields have differed by less than 1 per cent. The rotation with manure has far surpassed the other two in building soil organic matter and nitrogen, and it has leached fewer nutrients into groundwater. The 10-year period from 1988–1998 included five years in which the total rainfall from April to August was less than 350mm (compared with 500mm in average years). Average corn yields in those dry years were significantly higher (28 per cent to 34 per cent) in the two organic systems: 6938 and 7235kg per ha in organic-animal and organic-legume systems compared with 5333kg per ha in the conventional system. During the extreme drought of 1999 (total rainfall between April and August only 224mm), the organic animals system had significantly higher corn yields (1511kg per ha) than either the organic legume (421kg per ha) or the conventional (1100kg per ha). Crop yield in the organic legume was much lower in 1999 because the high biomass of the hairy vetch winter cover crop used up a large amount of the soil water. During the 1999 drought soybean yields were 1400, 1800 and 900kg per ha for organic animal, organic legume and conventional. Economic comparison of the organic corn–soybean rotation with conventional corn–soybean systems from 1991–2000 showed that without price premiums for the organic rotation, the annual net returns for both were similar: \$184 per ha for conventional, \$176 per ha for organic legume (Pimentel et al., 2005).

In what must be the longest-running organic trial in the world – 150 years – England's Rothamsted Experimental Station (also known as the Institute of Arable Crops Research) reports that its organic manured plots have delivered wheat yields of 1.58 tons per acre, compared to synthetically fertilized plots that have yielded 1.55 tons per acre. That may not seem like much, but the manured plots contain six times the organic matter found in the chemically treated plots (Stanhill, 1990). FIBL scientists in Central Europe conducted a 21-year study of the agronomic and ecological performance of biodynamic, organic and conventional farming systems. They found crop yields to be 20 per cent lower in the organic systems, although input of fertilizer and energy was reduced by 31 to 53 per cent and pesticide input by 98 per cent. Enhanced soil fertility and higher biodiversity found in organic plots rendered these systems less dependent on external inputs (Mader et al., 2002).

In North America and Europe, researchers have convincingly demonstrated that it is possible to provide a balanced environment, sustained

yields, biologically-mediated soil fertility and natural pest regulation through the design of commercial diversified agroecosystems and the use of low-input technologies (Altieri and Rosset, 1996). Many alternative cropping systems have been tested, such as double cropping, strip cropping, cover cropping and intercropping. More importantly, concrete examples from real farmers show that such systems lead to optimal recycling of nutrients and organic matter turnover, closed energy flows, water and soil conservation and balanced pest–natural enemy populations. Such diversified-organic farming exploits the complementarities that result from the various combinations of crops, trees and animals in spatial and temporal arrangements. In orchards and vineyards, the use of cover crops improves soil fertility, soil structure and water penetration, prevents soil erosion, modifies the microclimate and reduces weed competition. Entomological studies conducted in orchards with ground cover vegetation indicate that these systems exhibit lower incidence of insect pests than clean cultivated orchards. This is due to a higher abundance and efficiency of predators and parasitoids enhanced by the rich floral undergrowth. The challenge consists in assembling a functional biodiversity in each farm in order to initiate synergies which subsidize agroecosystem processes through the provision of ecological services such as activation of soil biology, recycling of nutrients, enhancement of beneficial arthropods and antagonists, and so on. Today there is a diverse selection of practices to achieve this purpose readily available to small, medium and large-scale farmers.

SCALING UP ALTERNATIVE AGRICULTURAL APPROACHES

Throughout the developing and industrialized world there are thousands of agroecological initiatives that have demonstrated a positive impact on the livelihoods of small farming communities (Pretty, 1995). Success is dependent on the use of a variety of agroecological improvements. In addition to farm diversification favoring a better use of local resources, they also emphasize human capital enhancement and community empowerment through training and participatory methods as well as greater access to markets, credit and income-generating activities. In most cases, farmers adopting agroecological models achieved significant levels of food security and natural resource conservation. Given the benefits and advantages of such initiatives, a key question that emerges is how to scale up these initiatives to enable wider impact and diffusion of benefits to more farmers.

Scaling up strategies must capitalize on mechanisms conducive to the spread of knowledge and techniques, such as:

- Strengthening producers' organizations through alternative marketing channels. The main idea is to evaluate whether the promotion of alternative farmer-led markets constitutes a mechanism to enhance the economic viability of the agroecological approach and thus provides the basis for the scaling-up process.
- Developing methods for rescuing/collecting/evaluating promising agroecological technologies generated by experimenting farmers and making them known to other farmers for wide adoption in various areas. Mechanisms to disseminate technologies with high potential may involve farmer exchange visits, regional-national farmer conferences, and publication of manuals that explain the technologies for use by technicians involved in agroecological development programs.
- Training government research and extension agencies in agroecology so they can include agroecological principles in their extension programs.
- Developing working linkages between NGOs and farmers' organizations. Such alliance between technicians and farmers is critical for the dissemination of successful agroecological production systems emphasizing biodiversity management and rational use of natural resources.

Other important requirements for the scaling up of agroecological innovations include more effective farmers' organizations, research-extension institutional partnerships, exchanges, training, technology transfer and validation in the context of farmer-to-farmer activities, enhanced participation of small farmers in niche markets, and so on. From their worldwide survey of sustainable agriculture initiatives, Pretty and Hine (2000) concluded that if sustainable agriculture is to spread to larger numbers of farmers and communities, then future attention needs to be focused on:

1. ensuring the policy environment is enabling rather than disabling;
2. investing in infrastructure for markets, transport and communications;
3. ensuring the support of government agencies, in particular, for local sustainable agricultural initiatives; and
4. developing social capital within rural communities and between external agencies.

The main expectation of a scaling-up process is that it should expand the geographical coverage of participating institutions and their target

agroecological projects while allowing an evaluation of the impact of the strategies employed. A key research goal should be that the methodology allows for a comparative analysis of the experiences learned, extracting principles that can be applied in the scaling up of other existing local initiatives, thus illuminating other development processes.

REFERENCES

- Altieri, M.A. and L.C. Merrick (1987), 'In situ conservation of crop genetic resources through maintenance of traditional farming systems', *Economic Botany*, **41**, 86-96.
- Altieri, M.A. (1994), *Biodiversity and Pest Management in Agroecosystems*, New York: Harworth Press.
- Altieri, M.A. (1995), *Agroecology: the Science of Sustainable Agriculture*, Boulder: Westview Press.
- Altieri, M.A. (1999), 'Applying agroecology to enhance productivity of peasant farming systems in Latin America', *Environment, Development and Sustainability*, **1**, 197-217.
- Altieri, M.A. (2000), 'The ecological impacts of transgenic crops on agroecosystem health', *Ecosystem Health*, **6**, 19-31.
- Altieri, M.A. (2004), *Genetic Engineering in Agriculture: the Myths, Environmental Risks and Alternatives*, Oakland: Food First Books.
- Altieri, M.A. and P. Rosset (1996), 'Agroecology and the conversion of large-scale conventional systems to sustainable management', *International Journal of Environmental Studies*, **50**, 165-85.
- Bills, P.S., D. Mota-Sanchez and M. Whalon (2003), *Background to the Resistance Data base*, Michigan State University, at www.cips.msu.edu/resistance.
- Brush, S.B. (2000), *Genes in the field: on-farm conservation of crop diversity*, Boca Raton, FL: Lewis Publishers.
- Clay, Jason (2003), *World Agriculture and the Environment: A Commodity-by-commodity Guide to Impacts and Practices*, Washington: Island Press.
- Cleaveland, D.A. and S.C. Murray (1997), 'The world's crop genetic resources and the rights of indigenous farmers', *Current Anthropology*, **38**, 477-92.
- Conway, G.R. (1997), *The Doubly Green Revolution*, London: Penguin Books.
- Conway, G.R. and J.N. Pretty (1991), *Unwelcome Harvest: Agriculture and Pollution*, London: Earthscan Publications.
- Denevan, W.M. (1995), 'Prehistoric agricultural methods as models for sustainability', *Advanced Plant Pathology*, **11**, 21-43.
- Donald, P.F. (2004), 'Biodiversity impacts of some agricultural commodity production systems', *Conservation Biology*, **18**, 17-37.
- Ellstrand, N.C. (2001), 'When transgenes wander, should we worry?', *Plant Physiology*, **125**, 1543-5.
- Fearnside, P.M. (2001), 'Soybean cultivation as a threat to the environment in Brazil', *Environmental Conservation*, **28**, 23-8.
- Francis, C.A. (1986), *Multiple Cropping Systems*, New York: MacMillan.
- Gliessman, S.R. (1998), *Agroecology: Ecological Process in Sustainable Agriculture*, Michigan: Ann Arbor Press.

- Hilbeck, A., M. Baumgartner, P.M. Fried and F. Bigler (1998), 'Effects of transgenic *Bacillus thuringiensis* corn fed prey on mortality and development time of immature *Chrysoperla carnea* (Neuroptera: Chrysopidae)', *Environmental Entomology*, **27**, 460–87.
- Holt-Gimenez, E. (2001), 'Measuring farms' agroecological resistance to Hurricane Mitch', *LEISA*, **17**, 18–20.
- Jackson, D. and L. Jackson (2002), *The Farm as Natural Habitat: Reconnecting Food Systems and Ecosystems*, Washington, DC: Island Press.
- James, C. (2004), *Global Review of Commercialized Transgenic Crops: 2004*, International Service for the Acquisition of Agri-Biotech Application Briefs No 23-2002, Ithaca, New York.
- Jennings, B.H. (1988), *Foundations of International Agricultural Research*, Boulder: Westview Press.
- Jordan, C.F. (2001), 'Genetic engineering, the farm crisis and world hunger', *BioScience*, **52**, 523–9.
- Lappe, F.M., J. Collins and P. Rosset (1998), *World Hunger: Twelve Myths*, New York: Grove Press.
- Lipton, M. and R. Longhurst (1989), *New Seeds and Poor People*, Baltimore: Johns Hopkins University Press.
- Obrycki, J.J., J.E. Losey, O.R. Taylor and L.C.H. Jessie (2001), 'Transgenic insecticidal maize: beyond insecticidal toxicity to ecological complexity', *BioScience*, **51**, 353–61.
- Mader, P. et al. (2002), 'Soil fertility and biodiversity in organic farming', *Science*, **296**, 1694–7.
- Marvier, M. (2001), 'Ecology of transgenic crops', *American Scientist*, **89**, 160–67.
- McNeely, J.A. and S.J. Scherr (2003), *Ecoagriculture: Strategies to Feed the World and Save Wild Biodiversity*, Washington: Island Press.
- National Academy of Sciences (1972), *Genetic Vulnerability of Major Crops*, Washington, DC: NAS.
- National Research Council (NRC) (1984), *Alternative Agriculture*, Washington, DC: National Academy Press.
- Netting, R. McC. (1993), *Smallholders, Householders*, Stanford, CA: Stanford University Press.
- Pengue, W. (2005), 'Transgenic crops in Argentina: the ecological and social debt', *Bulletin of Science, Technology and Society*, **25**, 314–22.
- Pimentel, D. and H. Lehman (1993), *The Pesticide Question*, New York: Chapman and Hall.
- Pimentel, D., P. Hepperly, J. Hunson, D. Douds and R. Seidel (2005), 'Environmental, energetic and economic comparisons of organic and conventional farming systems', *Bioscience*, **56**, 573–82.
- Pimentel, D., D. Andow, R. Dyson-Hudson, D. Gallahan, S. Jacobson, M. Irish and M. Shepard (1980), 'Environmental and social costs of pesticides: a preliminary assessment', *Oikos*, **34**, 126–40.
- Pingali, P.L., M. Hossain and R.V. Gerpacio (1997), *Asian Rice Bowls: the Returning Crisis*, Wallingford, UK: CAB International.
- Pinstrup-Andersen, P. and M.J. Cohen (2000), 'The present situation and coming trends in world food production and consumption', in: T.T. Chang (ed.), *Food Needs of the Developing World in the early 21st Century*, pp. 27–56, Proc. Study-week of the Pontifical Academy of Science, Vatican City.

- Pretty, J. (1995), *Regenerating Agriculture: Policies and Practices for Sustainability and Self-reliance*, Washington, DC: World Resources Institute.
- Pretty, J. (2005), *The Pesticide Detox: Towards a More Sustainable Agriculture*, London: Earthscan.
- Pretty, J. and R. Hine (2000), 'Feeding the world with sustainable agriculture: a summary of new evidence', final report from 'SAFE-World' Research Project, University of Essex, Colchester, England.
- Quist, D. and I.H. Chapela (2001), 'Transgenic DNA introgressed into traditional maize landraces in Oaxaca, Mexico', *Nature*, **414**, 541–3.
- Reganold, J.P., J.D. Glover, P.K. Andrews and H.R. Hinman (2001), 'Sustainability of three apple production systems', *Nature*, **410**, 926–30.
- Reinjes, C., B. Haverkort and Ann Waters-Bayer (1992), *Farming for the Future*, London: MacMillan.
- Rissler, J. and M. Mellon (1996), *The Ecological Risks of Engineered Crops*, Cambridge: MIT Press.
- Shiva, V. (1991), *The Violence of the Green Revolution: Third World Agriculture, Ecology and Politics*, Pengany, Malaysia: Third World Network.
- Stabinski, D. and N. Sarno (2001), 'Mexico, centre of diversity for maize, has been contaminated', *LEISA magazine*, **17**, 25–6.
- Stanhill, G. (1990), 'The comparative productivity of organic agriculture', *Agriculture, Ecosystems and Environment*, **30**, 1–26.
- Thrupp, L.A. (1996), *New Partnerships for Sustainable Agriculture*, Washington, DC: World Resources Institute.
- Thrupp, L.A. (1998), *Cultivating Diversity: Agrobiodiversity and Food Security*, Washington, DC: World Resources Institute.
- Tripp, R. (1996), 'Biodiversity and modern crop varieties: sharpening the debate', *Agriculture and Human Values*, **13**, 48–62.
- Uphoff, N. and M.A. Altieri (1999), *Alternatives to Conventional Modern Agriculture for Meeting World Food Needs in the Next Century*, Ithaca, NY: Cornell International Institute for Food, Agriculture and Development.
- Wilkes, H.G. and K.K. Wilkes (1972), 'The green revolution', *Environment*, **14**, 32–9.