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Genetically Engineered Crops: Separating the Myths From the Reality

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Until about four decades ago, crop yields in U.S. agricultural systems depended on internal resources, recycling of organic matter, built-in biological control mechanisms, and rainfall patterns. Agricultural yields were modest but stable. Production was safeguarded by growing more than one crop or variety in space and time in a field as insurance against pest outbreaks or severe weather. Inputs of nitrogen were gained by rotating major field crops with legumes. In turn, rotations suppressed insects, weeds, and diseases by effectively breaking the life cycles of these pests. A typical corn belt farmer grew corn rotated with several crops, including soybeans, and small grain production was intrinsic to maintain livestock. Most of the labor was done by the family with occasional hired help, and no specialized equipment or services were purchased from off-farm sources (Altieri, 1996; Audirac, 1997). In the developing world, small farmers developed even more complex and biodiverse farming systems guided by indigenous knowledge that has stood the test of time (Thrupp, 1998). In these types of farming systems, the link between agriculture and ecology was quite strong, and signs of environmental degradation were seldom evident.

But as agricultural modernization progressed, the ecology-farming linkage was often broken as ecological principles were ignored and/or overridden. As profit rather than people's needs or environmental concerns shaped the modes of agricultural production, agribusiness interests and prevailing policies favored large farm size, specialized production, crop monocultures, and mechanization.

Today, monocultures have increased dramatically worldwide, mainly through the geographical expansion of land yearly devoted to single crops. Thus, monoculture has implied the simplification of biodiversity, the end result being an artificial ecosystem requiring constant human intervention in the form of agrochemical inputs that in addition to temporarily boosting yields result in a number of undesirable environmental and social costs. Aware of such effects, several agricultural scientists have arrived at a general consensus that modern agriculture confronts an ecological crisis (Conway & Pretty, 1991).

The yearly loss of yields due to pests in many crops (reaching about 30% 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 effect of outbreaking pest populations (Altieri, 1994).

When these agricultural models were exported to Third World countries through the so-called Green Revolution, environmental and social problems were exacerbated. On one hand, most resource-poor farmers of Latin America, Asia, and Africa gained very little from the processes of development and technology transfer of the Green Revolution as proposed technologies were not scale neutral. The farmers with the larger and better endowed lands gained the most, whereas farmers with fewer resources and located in marginal environments often lost, and income disparities were often accentuated (Conway, 1997).

Technological change has mainly favored the production of export and/or commercial crops produced primarily in the large farm sector, marginally affecting productivity of crops for food security, which are largely grown by the peasant sector (Pretty, 1995). In areas where conversion from a subsistence to a cash

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agricultural economy progressively occurred, a number of ecological and social problems became evident, including loss of food self-sufficiency, genetic erosion, loss of biodiversity and traditional farming knowledge, permanence of rural poverty, and so on (Conroy, Murray, & Rosset, 1996).

To sustain such agroexport systems, many developing countries have become net importers of chemical inputs and agricultural machinery, increasing government expenditures and exacerbating technological dependence. For example, between 1980 and 1984, Latin America imported about $430 million worth of pesticides and used about 6.5 million tons of fertilizers (Nicholls & Altieri, 1997). Such massive use of agrochemicals led to a major environmental crisis of yet unmeasured social and economic proportions.

What is ironic is the fact that the same economic interests that promoted the first wave of agrochemically based agriculture are the ones now celebrating and promoting 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 farmers and healthy and nutritious to consumers (Hobbelink, 1991).

The global fight for market share is leading major corporations to massively deploy genetically engineered plants (transgenic crops) around the world (more than 40 million hectares in 1999) without proper advance testing of short- or long-term effects on human health and ecosystems. This expansion has been helped along by marketing and distribution agreements entered into by corporations and marketers (e.g., Ciba Seeds with Growmark and Mycogen Plant Sciences with Cargill) and in the absence of regulations in many developing countries. In the United States, where the Food and Drug Administration (FDA) and Environmental Protection Agency (EPA), policies that consider genetically modified crops to be "substantially equivalent" to conventional crops, policies have been developed in the context of a regulatory framework that is inadequate, nontransparent, and in some cases, completely absent.

Agrochemical corporations, which increasingly control the direction and goals of agricultural innovation, claim that genetic engineering will enhance the sustainability of agriculture by solving the very problems affecting conventional farming and will spare the Third World from low productivity, poverty, and hunger.

By matching myth with reality, the objective of this article is to challenge the false promises made by the genetic engineering industry that it will move agriculture away from a dependence on chemical inputs that will increase productivity, decrease input costs, and help reduce environmental problems (Office of Technology Assessment, 1992). By challenging the myths of biotechnology, one can expose genetic engineering for what it really is—another "technological fix" or magic bullet aimed at circumventing the environmental problems of agriculture (which themselves are the outcome of an earlier round of technological fixes) without questioning the flawed assumptions that gave rise to the problems in the first place (Hindmarsh, 1991). Biotechnology develops single-gene solutions for problems that derive from ecologically unstable monoculture systems designed on industrial models of efficiency. Such a unilateral and reductionist approach was already proven ecologically unsound in the case of pesticides that also espoused a reductionist approach, using one chemical/one pest as opposed to the one gene/one pest approach now promoted by biotechnology (Pimentel & Lehman, 1993).

Modern industrial agriculture, today epitomized by biotechnology, is founded on philosophical premises that are fundamentally flawed, and precisely these premises are the ones that need to be exposed and criticized to advance toward a truly sustainable agriculture. This is particularly relevant in the case of biotechnology, where the alliance of reductionist science and multinational monopolistic industry will take agriculture further down a misguided route, jointly perceiving agricultural problems as genetic deficiencies of organisms and treating nature as a commodity while in the process making farmers more dependent on an agribusiness sector that increasingly concentrates power over the food system.

Biotechnology, World Hunger, and the Welfare of Farmers

Hungry People in the Midst of Plenty

Biotechnology companies often claim that genetically modified organisms (GMOs)—specifically, genetically altered seeds—are essential scientific breakthroughs needed to feed the world and reduce poverty in developing countries. Most international organizations around the world charged with policies and research to enhance food security in the developing world echo this view, which rests on two critical assumptions. The first is that hunger is due to a gap between food production and human population density or growth rate. The second is that genetic engineering is the only or best way to increase agricultural production and thus meet future food needs. A starting point to clarify these misconceptions is to understand that there is no relationship between the prevalence of hunger in a given country and its population. For every densely populated and hungry nation such as Bangladesh or Haiti, there is a sparsely populated and hungry nation such as Brazil and Indonesia. The world today produces more food per inhabitant than ever before. Enough food is available to provide 4.3 pounds for every person every day: 2.5 pounds of grain, beans, and nuts; about a pound of meat, milk, and eggs; and another of fruits and vegetables (F. M. Lappe, Collins, Rosset, & Esparza, 1998).

In 1999, enough grain was produced globally to feed a population of 8 billion people (6 billion inhabit the planet in 2000) had it been evenly distributed or not fed to animals. Seven out of 10 pounds of grain are fed to animals in the United States. Countries such as Brazil, Paraguay, Thailand, and Indonesia devote thousands of acres of agricultural land to produce soybeans and manioc for export to feed cattle in Europe. By channeling one third of the grain produced worldwide to needy people, hunger could be eradicated instantly (F. M. Lappe et al., 1998). Hunger is also compounded by globalization, especially when developing countries embrace free trade policies (lowering tariffs and allowing goods from industrialized countries to flow in) advocated by international lending agencies. The experience of Haiti, one of the world's poorest countries, is illuminating. In 1986, Haiti imported just 7,000 tons of rice; the majority was grown on the island. After opening its economy to the world, cheaper rice immediately flooded in from the United States where the rice industry is subsidized. By 1996, Haiti imported 196,000 tons of foreign rice at the cost of $100 million (US) a year. Haitian rice production became negligible once the dependence on foreign rice was complete, and the cost of rice rose, leaving large numbers of poor people at the whim of rising world grain prices. Hunger increased dramatically (Aristide, 2000).

The real causes of hunger are poverty, inequality, and lack of access to food and land. Too many people are too poor (about 2 billion survive on less than $1/day) to buy the food that is available (but often poorly distributed) or lack the land and resources to grow it themselves (F. M. Lappe et al., 1998). Because the true root cause of hunger is inequality, any method of boosting food production that deepens inequality is not only bound to fail to reduce hunger but exacerbate it. Conversely, only technologies that have positive effects on the distribution of wealth, income, and assets, that are pro-poor, can truly reduce hunger. Fortunately, such technologies do exist and can be loosely grouped together under the discipline of agroecology, the potential of which has been amply demonstrated and later in this article analyzed more fully (Altieri, Rosset, & Thrupp, 1998; Uphoff & Altieri, 1999).

Furthermore, attacking inequality head-on via true land reform holds the promise of productivity gains far outweighing the potential of agricultural biotechnology. Whereas industry proponents will often hold out the promise of 15%, 20%, or even 30% yield gains from biotechnology, smaller farms today produce from 200% to 1,000% more per unit area than larger farms worldwide (Rosset, 1999). Land reforms that bring average land holdings down to their optimum (small) size from the inefficient, unproductive, overly large units that characterize much of world agriculture today could provide the basis for production increases beside which the much ballyhooed promise of biotechnology would pale in comparison.

It is critical to understand that most innovations in agricultural biotechnology have been profit driven rather than need driven. The real thrust of the genetic engineering industry is not to make agriculture more productive but rather to generate profits (Busch, Lacy, Burkhardt, & Lacy, 1990). This is illustrated by reviewing the following principle technologies on the market today: (a) herbicide resistant crops, such as Monsanto's "Roundup Ready" soybeans, seeds that are tolerant to Monsanto's herbicide Roundup; and (b) *Bacillus thuringiensis* (*Bt*) crops that are engineered to produce their own insecticide. In the first instance, the goal is to win greater herbicide market share for a proprietary product and in the second to boost seed sales at the cost of damaging the usefulness of a key pest management product (the *Bt*-based microbial insecticide) relied on by many farmers, including most organic farmers, as a powerful alternative to insecticides. These technologies respond to the need of biotechnology companies to intensify farmers' dependence on seeds protected by so-called intellectual property rights that conflict directly with the age-old rights of farmers to reproduce, share, or store seeds (Fowler & Mooney, 1990). Whenever possible, corporations will require farmers to buy a company's brand of inputs and will forbid farmers from keeping or selling seed. In the United States, farmers adopting transgenic soybeans must sign an agreement with Monsanto. If they sow transgenic soybeans the next year, the penalty is about $3,000/acre and depending on the acreage, could cost farmers their farms and thus their livelihood. By controlling germplasm from seed to sale and by forcing farmers to pay inflated prices for seed-chemical packages, companies are determined to extract the most profit from their investment (Krimsky & Wrubel, 1996).

What About Golden Rice?

Scientists who support biotechnology and disagree with the assertion that most biotechnology research is profit rather than need driven use the newly developed but not yet commercialized golden rice to hide behind a rhetoric of humanitarianism. This experimental rice is rich in beta carotene, or vitamin A precursor, which is an important nutrient to millions of children, especially in Asia, who suffer from vitamin A deficiency, which can lead to blindness.

Developers of the golden rice say that this new crop was developed with public funds and that once the rice proves viable in field plantings, it will be freely distributed to the poor. The suggestion that genetically altered rice is the proper way to address the condition of 2 million children at risk of vitamin-A-deficiency-induced blindness reveals a tremendous naiveté about the reality and causes of vitamin and micronutrient malnutrition. If one reflects on the patterns of human development and nutrition, one must quickly realize that vitamin A deficiency is not best characterized as a problem but, rather, as a symptom, a warning sign if you will. It warns us of broader inadequacies associated with both poverty and with agricultural change from diverse cropping systems toward rice monoculture promoted by the Green Revolution. People do not exhibit vitamin A deficiency because rice contains too little vitamin A or beta carotene but, rather, because their diet has been reduced to rice and almost nothing else and they suffer from many other dietary illnesses that cannot be addressed by beta carotene but that could be addressed, together with vitamin A deficiency, by a more varied diet. Golden rice must be seen as a one-dimensional attempt to fix a problem created by the Green Revolution: the problem of diminished crop and dietary diversity. A magic-bullet solution, which places beta carotene into rice—with potential health and ecological hazards—while leaving poverty, poor diets, and extensive monoculture intact is unlikely to make any durable contribution to well- being. To use the words of Vandana Shiva, “such an approach reveals blindness to readily available solutions to Vitamin A deficiency-induced blindness, including many ubiquitous leafy plants which when introduced (or reintroduced) into the diet provide both needed beta-carotene and other missing vitamins and micro-nutrients.” Although wild green vegetables have been regarded as peripheral to the peasant household, gathering, as currently practiced in many rural farming communities, affords a meaningful addition to the peasant family nutrition and subsistence. Within and in the periphery of paddy rice fields, there is an abundance of wild and cultivated green leafy vegetables rich in vitamins and nutrients, most of which are eliminated when farmers adopt monocultures and associated herbicides (Greenland, 1997).

Rice biotechnologists have no understanding of the deeply rooted cultural traditions that determine food preferences among Asian people, especially the social and even religious significance of white rice. It is highly unlikely that the golden rice will replace white rice, which for millennia has played a variety of nutritional, culinary, and ceremonial roles. No doubt that golden rice will bump into the traditions associated with white rice as green or blue French fries would bump into Western food preferences in the United States.

But even if golden rice made it into the bowls of poor Asians, there is no guarantee that it would benefit poor people that do not eat fat-rich or oil-rich foods. Beta carotene is fat soluble, and its uptake by the intestine depends on fat or oil in the diet. Moreover, people suffering protein-related malnutrition and lacking dietary fats and oils cannot store vitamin A well in the liver or transport it to the different body tissues where the vitamin is needed. Moreover, given the low concentration of beta carotene in the miracle rice, people would have to eat more then 1 kg of rice per day to obtain a recommended daily allowance dose of vitamin A.

Does Biotechnology Increase Yields?

A major argument advanced by biotechnology proponents is that one of the main features of transgenic crops is that they will significantly boost crop yields. These expectations have been dealt a blow by a U.S. Department of Agriculture (USDA) (1999) Economic Research Service (ERS) report that analyzed data collected in 1997 and 1998 for 12 and 18 U.S. region/crop combinations, respectively. The crops surveyed were *Bt* corn and cotton and herbicide-tolerant (HT) corn, cotton, and soybeans and their nonengineered counterparts.

In 1997, yields were not significantly different in engineered versus nonengineered crops in 7 of 12 crop/region combinations. Four of 12 regions showed significant increases (13% to 21%) in yield of engineered versus nonengineered crops (HT soybeans in 3 regions and *Bt* cotton in 1 region). Herbicide- tolerant cotton in 1 region showed a significant reduction in yield (12%) compared with its nonengineered counterparts.

In 1998, yields were not significantly different in engineered versus nonengineered crops in 12 of 18 crop/region combinations. Six crop/region combinations (*Bt* corn in 3 regions, HT corn in 1 region, *Bt* cotton in 2 regions) showed significant increases in yield (5% to 30%) of engineered over nonengineered crops but only under high European corn borer pressure, which is sporadic. Herbicide-tolerant cotton (glyphosate-tolerant) was the only engineered crop that showed no significant increase in yield in either region where it was surveyed. In 1999, researchers at the University of Nebraska's Institute of Agriculture and Natural Resources grew five different Monsanto soybean varieties together with their closest conventional relatives and the highest yielding traditional varieties in four locations around the state using both dry lands and irrigated fields. Researchers found, on average, the genetically engineered varieties— although more expensive—produced 6% less than their non-genetically engineered near relatives and 11% less than the highest yielding conventional crops. Reports from Argentina show the same non-yield-enhancing results with HT soybeans, which universally seems to exhibit yield drag.

Yield losses are amplified in crops, such at *Bt* corn, where it is mandatory for farmers to leave 20% of their land as refuges made up of nontransgenic corn. It is expected that patchworks of transgenic and nontransgenic crops can delay the evolution of resistance by providing susceptible insects harbored in the refuges for mating with resistant insects. The crops in the refuge are likely to sustain heavy damage, and thus, farmers will incur yield losses. A refuge kept completely free of pesticides must be 20% to 30% the size of the engineered plot, but the refuge should be about 40% the size of the biotechnology plot if pesticides are to be used because insecticide spraying can increase the odds of *Bt* resistance developing (Mellon & Rissler, 1999).

If, instead, 30% of arable land were devoted to growing soybeans in a strip-cropping design (as many alternative farmers do in the Midwest), yield up to 10% over comparable monocultures of corn and soybeans would be achieved as well as introducing potential for internal rotation in the field and contour arrangements of strips to minimize erosion on hillsides (Ghaffarzadeh, Prechac, & Cruse, 1999). Moreover, European corn borer would be minimized as pest populations tend to be lower in mixed and rotational cropping systems (Andow, 1991).

In the case of cotton, there is no demonstrated need to introduce *Bt* toxin in the crop at all as most Lepidopteran pests of this crop are pesticide-induced secondary pests. Therefore, the best way to deal with them is not to spray insecticides but instead use biological control or cultural techniques such as rotation or strip cropping with alfalfa. In the Southwest, the key pest is the boll weevil, a beetle immune to the *Bt* toxin.

What Are the Costs to U.S. Farmers?

To assess farm economics and the effects of transgenic crops on U.S. farms, it is useful to examine the realities faced by Iowa farmers who live in the heartland of transgenic corn and soy. Although weeds are an annoyance, the real problem they face is falling farm prices, driven down by long-term overproduction. From 1990 to 1998, the average price of a metric ton of soybeans decreased 62%, and returns over nonland costs declined from $530 to $182 per hectare, a 66% drop. Faced with falling returns per hectare, farmers have no choice but to get big or get out. Only by increasing acreage to compensate for falling per acre profits can farmers stay in business. Any technology that facilitates getting big will be seized on, even if short-term gains are wiped out by prices that fall still further as the industrial agricultural model expands.

For these Iowa farmers, reductions in returns per unit of cropland have reinforced the importance of herbicides within the production process as they reduce time devoted to mechanical cultivation and thus allow a given farmer to farm more acres. A survey of Iowa farmers conducted in 1998 indicated that the use of glyphosate with glyphosate-resistant soybean varieties reduced weed control costs by nearly 30% compared with conventional weed management for nontransgenic varieties. Yields for the glyphosate-resistant soybeans were about 4% lower, however. Yet, net returns per unit land area from glyphosate-resistant and conventional soybeans were nearly identical (Duffy, 1999).

From the standpoint of convenience and cost reduction, the use of broad-spectrum herbicides in combination with herbicide-resistant varieties appeals to farmers. Such systems fit well with large-scale operations, no-tillage production, and subcontracted chemical applications. However, from the standpoint of price, any penalty for transgenic varieties in the marketplace will make the effect of existing low prices even worse. Taking into account that American exports of soybeans to the European Union plummeted from 11 million tons to 6 million in 1999 due to rejection of GMOs by European consumers, it is easy to predict disaster for transgenic-crop-dependent farmers. Durable solutions to the dilemmas facing Iowa farmers will not come from herbicide-tolerant crops but from a fundamental restructuring of Midwestern agriculture (Brummer, 1998).

The integration of the seed and chemical industries appears to accelerate increases in per acre expenditures for seeds plus chemicals, delivering significantly lower returns to growers. Companies developing herbicide-tolerant crops are trying to shift as much per acre cost as possible from the herbicide onto the seed via seed costs and technology charges. Increasingly, price reductions for herbicides will be limited to growers purchasing technology packages. In Illinois, the adoption of herbicide-resistant crops makes for the most expensive soybean seed-plus-weed management system in modern history—between $40 and $60 per acre depending on fee rates, weed pressure, and so on. Three years ago, the average seed-plus-weed control costs on Illinois farms was $26 per acre and represented 23% of variable costs; today, they represent 35% to 40% (Carpenter & Gianessi, 1999). Many farmers are willing to pay for the simplicity and robustness of the new weed management system, but such advantages may be short-lived as ecological problems arise.

But as emphasized before, the ultimate cost that farmers pay is their increased dependence on biotechnological inputs protected by a ruthless system of intellectual property rights that legally inhibits the right of farmers to reproduce, share, and store seed (Busch et al., 1990). Farmers who exert this right by breaking the signed contract with a corporation stand to lose their farms.

Will Biotechnology Benefit Poor Farmers?

Most biotechnological innovations available today bypass poor farmers as these farmers are not able to afford the seeds, which are protected by patents owned by biotech corporations. Moreover, extending modern technology to resource-poor farmers has been historically constrained by considerable environmental obstacles. An estimated 850 million people live on land threatened by desertification. Another 500 million reside on terrain that is too steep to cultivate. Because of those and other limitations, about 2 million people have been untouched by modern agricultural science. Moreover, most of the rural poor live in the latitudinal band between the Tropic of Cancer and the Tropic of Capricorn, a region that will be most vulnerable to the effects of global warming. In such environments, a plethora of cheap and locally accessible technologies must be made available to enhance rather than limit farmers' options, a trend that corporate-controlled biotechnology inhibits.

Biotech researchers pledge to counter problems associated with food production in such marginal areas by developing genetically managed (GM) crops with traits considered desirable for small farmers, such as enhanced competitiveness against weeds and drought tolerance. These new attributes, however, would not necessarily be a panacea. Traits such as drought tolerance are polygenic, which means they are determined by the interaction of multiple genes. Consequently, the development of crops with such traits is a complex process that could take at least 10 years. And under these circumstances, genetic engineering does not give you something for nothing. When you tinker with multiple genes to create a desired trait, you inevitably end up sacrificing other traits, such as productivity. As a result, use of a drought-tolerant plant would boost crop yields by only 30% to 40%. Any additional yield increases would have to come from improved environmental practices (i.e., water harvesting or enhancing soil organic matter for improved moisture retention) rather than from the genetic manipulation of specific characteristics (Persley & Lantin, 2000).

Even if biotechnology contributes to increased crop harvests, poverty will not necessarily decline. Many poor farmers in developing countries do not have access to cash, credit, technical assistance, or markets. The so-called Green Revolution of the 1950s and 1960s bypassed such farmers because planting the new high-yield crops and maintaining them through the use of pesticides and fertilizers was too costly for impoverished landowners. Data show that in both Asia and Latin America, wealthy farmers with larger and better endowed lands gained the most from the Green Revolution, whereas farmers with fewer resources often gained little (F. M. Lappe et al., 1998). The

"Gene Revolution" might only end up repeating the mistakes of its predecessor. Genetically modified seeds are under corporate control and patent protection; consequently, they are very expensive. Because many developing countries still lack the institutional infrastructure and low-interest credit necessary to deliver these new seeds to poor farmers, biotechnology will only exacerbate marginalization.

Moreover, poor farmers do not fit into the marketing niche of private corporations, which focus on biotechnological innovations for the commercial-agricultural sectors of industrial and developing nations, where these corporation expect a huge return on their research investment. The private sector often ignores important crops such as cassava, which is a staple for 500 million people worldwide. The few impoverished landowners who will have access to biotechnology will become dangerously dependent on the annual purchase of genetically modified seeds. These farmers will have to abide by onerous intellectual property agreements not to plant seeds yielded from a harvest of bioengineered plants. Such stipulations are an affront to traditional farmers who for centuries have saved and shared seeds as part of their cultural legacy (Kloppenburg, 1998).

Some scientists and policy makers suggest that large investments through public-private partnerships can help developing countries acquire the indigenous scientific and institutional capacity to shape biotechnology to suit the needs and circumstances of small farmers. But once again, corporate intellectual property rights to genes and gene-cloning technology hinder this initiative. For instance, Brazil's national research institute (EMBRAPA) must negotiate license agreements with nine different companies before a virus-resistant papaya developed with researchers at Cornell University can be released to poor farmers (Persley & Lantin, 2000).

Genetically Modified Crops and Human Health

Are Transgenic Crops Similar to Environmentally Bred Crops?

Government regulatory agencies consider that crops bred through biotechnology or conventional plant breading are substantially equivalent. Such presumption is profoundly flawed and scientifically unsupported. Most evidence shows that it is clear that gene transfer using rDNAtechniques is substantially different from the processes that govern gene transfer in traditional breeding. In such endeavors, plant breeders develop new varieties through the process of selection and seek to achieve expression of genetic material that is already present within a species. Conventional crossing involves the movement of clusters of functionally linked genes, primarily between homologous chromosomes, including the relevant promoters, regulatory sequences, and associated genes involved in coordinated expression of the character of interest in the plant.

Genetic engineering works primarily through insertion of genetic material, usually from unprecedented sources, that is, genetic material from species, families, and even kingdoms that could not previously be sources of genetic material for a particular species. The process involves a "gene gun," a "promoter" gene from a virus, and a marker as a part of the package or construct inserted into the host plant cell. Current rDNA technologies involve the random insertion of genes in the absence of normal promoter sequences and associated regulatory genes. As there are very few examples of plant traits in which we have identified the associated regulatory genes, the introduction of a fully functional gene using rDNA techniques is currently not possible. These rDNA techniques also involve the simultaneous insertion of viral promoters and selectable markers and facilitate the introduction of genes from incompatible species. These genetic transformations cannot occur using traditional approaches—which further illustrates the profound manner in which these two processes differ (Hansen, 1999).

In summary, genetic engineering clearly differs from conventional breeding as this method relies primarily on selection, using natural process of sexual and/or asexual reproduction between a species or within closely related genera. Genetic engineering uses a process of insertion of genetic material via a gene gun or a special bacterial truck that does not occur in nature. Biotechnologists can insert genetic material from any life form into any other, thus creating novel organisms of which there is no evolutionary experience.

Are Transgenic Crop Safe to Eat?

The premature commercial release of transgenic crops due to commercial pressures and lax Food and Drug Administration and Environmental Protection Agency policies that consider genetically modified crops to be substantially equivalent to conventional crops has occurred in the context of a regulatory framework that seems inadequate, nontransparent, and in some cases, completely absent. In fact, approval for commercial release of transgenic crops is based on scientific information provided voluntarily by companies producing biotech crops.

It is estimated that about 50% of the corn- and soybean-based food in the United States comes from genetically modified corn and soybeans. Most consumers are not aware of this and have no possibility of discerning it, as trangenic food is not labeled as such. Given the fact that no scientist can ascertain that such foods are completely risk free, it could be considered that the majority of the population in the United States is being subjected to a large-scale feeding experiment. Consumers in Europe have rejected such GMO foods (F. M. Lappe & Bailey, 1998).

Because of the unusual methods used to breed GM crops, some fear that the genetic variants produced could introduce foreign substances into the food supply with unanticipated negative effects on human health. A major concern is that a protein encoded by an introduced gene may be allergenic and cause allergic reactions in exposed populations (Burks & Fuchs, 1995). Biotechnology is used to introduce genes into various plants that are sources of foods and food components. Introduced traits include insect and virus resistance, herbicide tolerance, and changes in composition or nutritional content. Given such a diversity of traits, at issue here is the allergenic potential for proteins introduced into foods from sources with no history of allergenicity or that have amino acid sequence similarities to known food allergens. There is a small but real chance that genetic engineering may transfer new and unidentified proteins into food, triggering allergic reactions in millions of consumers who are sensitive to allergens but have no way of identifying or protecting themselves from offending foods.

Another concern is associated with the fact that antibiotic resistance genes are incorporated into nearly every genetically modified crop plant as markers to indicate that a plant has been successfully engineered. It is expected that these genes and their enzyme products, which inactivate antibiotics, will be present in engineered foods, raising important questions about the implications of such an event on human health, particularly if it compromises human immunity (Ticciati & Ticciati, 1998).

Genetic engineering may also remove or inactivate a valuable nutritional substance in a food. Recent research shows that genetically engineered (GE) herbicide-resistant soybeans have lower levels (12% to 14%) of isoflavones, key naturally occurring phytoestrogens (mostly genistin) in soybeans that may protect women from several forms of cancer (F. M. Lappe et al., 1999).

There is no scientist that can negate the possibility that changing the fundamental genetic make-up of a food could cause new diseases or health problems. There are no long-term studies to prove the safety of genetically modified crops. These products are not being thoroughly tested before they arrive on the grocery shelves. Rather, they are being tested on consumers.

Biotechnology, Agriculture, and the Environment

Biotechnology is being pursued to patch up the problems (e.g., pesticide resistance, pollution, soil degradation, etc.) caused by previous agrochemical technologies promoted by the same companies now leading the biorevolution. Transgenic crops developed for pest control closely follow the paradigm of using a single-control mechanism (a pesticide) that has proven to fail over and over again with insects, pathogens, and weeds (National Research Council, 1996). The touted one gene-one pest approach will also be easily overcome by pests that are continuously adapting to new situations and evolving detoxification mechanisms (Robinson, 1996).

The agricultural systems developed with transgenic crops will favor monocultures characterized by dangerously high levels of genetic homogeneity, leading to higher vulnerability of agricultural systems to biotic and abiotic stresses (Robinson, 1996). By promoting monocultures, it will also undermine ecological methods of farming, such as rotation and polycultures, thus exacerbating the problems of conventional agriculture (Altieri, 2000b).

As the new bioengineered seeds replace the old traditional varieties and their wild relatives, genetic erosion will accelerate in the Third World (Fowler & Mooney, 1990). Thus, the push for uniformity will not only destroy the diversity of genetic resources but will also disrupt the biological complexity that underlies the sustainability of indigenous farming systems (Altieri, 1996).

There are many unanswered ecological questions regarding the effect of the release of transgenic plants and microorganisms into the environment, but the available evidence supports the hypothesis that effects could be substantial (Steinbrecher, 1996). Among the major environmental risks associated with genetically engineered plants are the unintended transfer to plant relatives of the transgenes and the unpredictable ecological effects (Rissler & Mellon, 1996).

Herbicide resistance

It is clear that by creating crops resistant to its herbicides, a company can expand markets for its patented chemicals. (In 1997, 50,000 farmers grew 3.6 million hectares of HT soybeans, equivalent to 13% of the 71 million national soybean acreage in the United States [Duke, 1996].). Observers gave a value of $75 million for HT crops in 1995, the first year they were marketed, indicating that by the year 2000, the market will be approximately $805 million, representing a 61% growth (Carpenter & Gianessi, 1999).

The continuous use of herbicides such as bromoxynil and glyphosate (also known as Roundup), which herbicide-resistant crops tolerate, can lead to problems (Goldberg, 1992). It is well documented that when a single herbicide is used repeatedly on a crop, the chances of herbicide resistance developing in weed populations greatly increases (Holt, Powles, & Holtum, 1993). About 216 cases of pesticide resistance have now been reported in one or more herbicide chemical families (Holt & Le Baron, 1990). Triazine herbicides have the most resistant weed species (about 60).

The problem is that given industry pressures to increase herbicide sales, acreage treated with these broad-spectrum herbicides will expand, exacerbating the resistance problem. For example, it has been projected that the acreage treated with glyphosate will increase to nearly 150 million acres. Although glyphosate is considered less prone to weed resistance, the increased use of the herbicide will result in weed resistance, even if more slowly, as it has already been documented with Australian populations of annual ryegrass, quackgrass, birdsfoot trefoil, *Cirsium arvense*, and *Eleusine indica* (Gill, 1995).

Herbicides Kill More Than Weeds

Companies affirm that bromoxynil and glyphosate when properly applied degrade rapidly in the soil, do not accumulate in groundwater, have no effects on nontarget organisms, and leave no residue in foods. There is, however, evidence that bromoxynil causes birth defects in laboratory animals, is toxic to fish, and may cause cancer in humans (Goldberg, 1992). Because bromoxynil is absorbed dermally and because it causes birth defects in rodents, it is likely to pose hazards to farmers and farm workers. Similarly, glyphosate has been reported to be toxic to some nontarget species in the soil—both to beneficial predators such as spiders, mites, carabid, and coccinellid beetles and to detritivores such as earthworms as well as to aquatic organisms, including fish (Paoletti & Pimentel, 1996). As this herbicide is known to accumulate in fruits and tubers as it suffers little metabolic degradation in plants, questions about food safety also arise, especially now that more than 37 million pounds of this herbicide are used annually in the United States alone. Moreover, research documents that glyphosate seems to act in a similar fashion to antibiotics by altering soil biology in a yet unknown way and thus exerting effects such as reducing the ability of soybeans and clover to fix nitrogen, rendering bean plants more vulnerable to disease, and reducing growth of beneficial soil-dwelling mycorrhizal fungi that are key for helping plants to extract phosphorous from the soil.

Creation of Superweeds

Although there is some concern that transgenic crops themselves might become weeds, a major ecological risk is that large-scale releases of transgenic crops may promote transfer of transgenes from crops to other plants, which then could become weeds (Darmency, 1994). Transgene that confer significant biological advantage may transform wild or weedy plants into new or worse weeds (Rissler & Mellon, 1996). The biological process of concern here is introgression, that is, hybridization among distinct plant species. Evidence indicates that such genetic exchanges among wild, weed, and crop plants already occur. The incidence of shattercane (*Sorghum bicolor*), a weedy relative of sorghum, and the geneflows between maize and teosinte demonstrate the potential for crop relatives to become serious weeds. This is worrisome given that a number of U.S. crops are grown in close proximity to sexually compatible wild relatives (Lutman, 1999). Extreme care should be taken in plant systems exhibiting easy cross-pollination such as oats, barley, sunflowers, and wild relatives and between rapeseed and related crucifers (Snow & Moran, 1997). In Europe, there is a major concern about the possibility of pollen transfer of herbicide tolerant genes from *Brassica* oilseeds to *Brassica nigra* and *Sinapis arvensis* (Casper & Landsmann, 1992).

There are also crops that are grown near wild weedy plants that are not close relatives but may have some degree of cross-compatibility such as the crosses of *Raphanus raphanistrum* by *R. Sativus* (radish) and Johnson grass by sorghum corn (Radosevich, Holt, & Ghersa, 1996). Cascading repercussions of these transfers may ultimately mean changes in the make-up of plant communities. Gene exchanges pose major threats to centers of diversity, where in biodiverse farming systems, the probability for transgenic crops of finding sexually compatible wild relatives is very high.

Transfer of genes from transgenic crops to organically grown crops poses a specific problem to organic farmers as organic certification depends on the growers being able to guarantee that their crops have no inserted genes. Crops able to outbreed, such as maize or oilseed rape, will be affected to the greatest extent, but all organic farmers are at risk of genetic contamination as there are no regulations that enforce minimum isolating distances between transgenic and organic fields (Royal Society, 1998).

In conclusion, the fact that interspecific hybridization and introgression are common to species such as sunflower, maize, sorghum, oilseed rape, rice, wheat, and potatoes provides a basis to expect gene flow between transgenic crops and wild relatives to create new herbicide-resistant weeds (Lutman, 1999). There is consensus among scientists that transgenic crops will eventually allow transgenes to escape into free-living populations of wild relatives. The disagreements lie in how serious are the effects of such transfers (Snow & Moran, 1997).

Environmental Risks of Insect-Resistant Crops (*Bt* Crops)

Resistance

According to the biotech industry, the promise of transgenic crops inserted with *Bt* genes is the replacement of synthetic insecticides now used to control insect pests. But this is not so clear because most crops have a diversity of insect pests, and therefore insecticides will still have to be applied to control non-Lepidoptera pests, which are not susceptible to the *Bt* toxin expressed by the crop (Gould, 1994). In fact, in a recent report (USDA, 1999), an analysis of pesticide use in the 1997 U.S. growing season in 12 region/crop combinations showed in 7 sites no statistically significant difference in pesticide use on *Bt* crops versus non-*Bt* crops. In the Mississippi Delta, significantly more pesticides were used on *Bt* versus non-*Bt* cotton.

On the other hand, several Lepidoptera species have been reported to develop resistance to *Bt* toxin in both field and laboratory tests, suggesting that major resistance problems are likely to develop in *Bt* crops that through the continuous expression of the toxin create a strong selection pressure (Tabashnik, 1994a). No serious entomologist questions whether resistance will develop or not. The question is how fast. In fact, scientists have already detected development of “behavioral resistance” by some insects that take advantage of the fact that expression of toxin potency is uneven within crop foliage, thus attacking tissue patches with low toxin concentrations. Moreover, as genetically inserted toxins often decrease in leaf and stem titer as crops reach maturation, the low dose can only kill or debilitate completely susceptible larvae (homozygotes), and consequently, adaptation to the *Bt* toxin can occur much faster if the concentration always remains high. Observation of transgenic corn plants in late October indicated that most European corn borers that survived had entered diapause in preparation for emergence in the following spring as adults (Onstad & Gould, 1998).

To delay the inevitable development of resistance by insects to *Bt* crops, bioengineers are preparing resistance management plans that, as explained before, consist of patchworks of transgenic and nontransgenic crops (called *refuges*) to delay the evolution of resistance by providing susceptible insects for mating with resistant insects. Although refuges should be at least 30% of the crop area in size according to members of the Campaign for Food Safety, Monsanto’s new plan calls for only 20% refuges even when insecticides are to be used. Moreover, the plan offers no details about whether the refuges must be planted alongside the transgenic crops or at some distance away, where studies suggest they would be less effective (Mallet & Porter, 1992). In addition to refuges requiring regional coordination between farmers (a difficult goal), it is unrealistic to expect most small- and medium-sized farmers to devote up to 30% to 40% of their crop area to refuges, especially if crops in these areas are to sustain heavy pest damage.

The farmers who face the greatest risk from the development of insect resistance to *Bt* are neighboring organic farmers who grow corn and soybeans without agrochemicals. Once resistance appears in insect populations, organic farmers will not be able to use *Bt* in its microbial insecticide form to control Lepidoptera pests that move in from adjacent neighboring transgenic fields. In addition, genetic pollution of organic crops, resulting from gene flow (pollen) from transgenic crops, can jeopardize the certification of organic crops, and thus, farmers may lose premium markets. Who will compensate organic farmers for such losses?

We know from the history of agriculture that plant diseases, insect pests, and weeds become more severe with the development of monocultures and that intensively managed and genetically manipulated crops soon lose genetic diversity (Altieri, 1994; Robinson, 1996). Given these facts, there is no reason to believe that resistance to transgenic crops will not evolve among insects, weeds, and pathogens as has happened with pesticides. No matter what resistance management strategies will be used, pests will adapt and overcome the agronomic constraints (Green, LeBaron, & Moberg, 1990). Studies of pesticide resistance demonstrate that unintended selection can result in pest problems that are greater than those that existed before deployment of novel insecticides. Diseases and pests have always been amplified by changes toward genetically homogenous agriculture, precisely the type of farming that biotechnology promotes (Robinson, 1996).

Effects on Nontarget Species

By keeping pest populations at extremely low levels, *Bt* crops could potentially starve natural enemies as predators and parasitic wasps that feed on pests need a small amount of prey to survive in the agroecosystem. Among the natural enemies that live exclusively on insects that the transgenic crops are designed to kill (Lepidoptera), egg and larval parasitoids would be most affected because they are totally dependent on live hosts for development and survival, whereas some predators could theoretically thrive on dead or dying prey (Schuler, Potting, Dunhom, & Poppy, 1999).

Natural enemies could also be affected directly through intertrophic-level effects of the toxin. The potential of *Bt* toxins moving through arthropod food chains poses 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 (Hilbeck, Baumgartnet, Fried, & Bigler, 1998). Studies in Switzerland show that mean total mortality of predaceous lacewing larvae (Chrysopidae) raised on *Bt*-fed prey was 62% compared to 37% 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). Intertrophic level effects of the *Bt* toxin raise serious concerns about the potential of the disruption of natural pest control. Polyphagous predators that move within and between mixed crops cultivars will encounter *Bt*-containing nontarget prey throughout the crop season (Hilbeck, Moar, Putzai-Carey, Filippini, & Bigler, 1999). Disrupted biocontrol mechanisms may result in increased crop losses due to pests or to the increased use of pesticide by farmers, with consequent health and environmental hazards.

It is also now known that windblown pollen from *Bt* crops found on natural vegetation surrounding transgenic fields can kill nontarget insects. A Cornell study (Losey, Rayor, & Carter, 1999) showed that corn pollen containing *Bt* toxin can drift several meters downwind and deposit itself on milkweed foliage with potentially deleterious effects on monarch butterfly populations. These findings open a whole new dimension on the unexpected effect of transgenic crops on nontarget organisms that play key and many times unknown roles in the ecosystem.

But environmental effects are not limited to the interface of crops and insects. *Bt* toxins can be incorporated into the soil through leaf materials when farmers incorporate transgenic crops' residues after harvest (Donnegan et al., 1995). Toxins may persist for 2 to 3 months, resisting degradation by binding to clay and humic acid soil particles while maintaining toxin activity (Palm, Schaller, Donegan, & Seidler, 1996). Such active *Bt* toxins that end up and accumulate in the soil and water from transgenic leaf litter may have negative effects on soil and aquatic invertebrates and nutrient cycling processes (Donnegan & Seidler, 1999).

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 instead rely 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 (Saxena, Flores, & Stotzky, 1999).

A Precautionary Tale

The ecological effects of engineered crops are not limited to pest resistance and creation of new weeds or virus strains (Kendall et al., 1997). As argued herein, transgenic crops can produce environmental toxins that move through the food chain and also may end up in the soil and water, affecting invertebrates and probably ecological processes such as nutrient cycling. Moreover, the largescale landscape homogenization with transgenic crops will exacerbate the ecological vulnerability already associated with monoculture agriculture (Altieri, 2000b). Unquestioned expansion of this technology into developing countries is not desirable. There is strength in the agricultural diversity of many of these countries, and it should not be inhibited or reduced by extensive monoculture, especially when the consequences of doing so results in serious social and environmental problems (Thrupp, 1998).

Despite these concerns, transgenic crops have been rushed into international markets and massively deployed in the agricultural landscapes of the United States, Canada, Argentina, China, and other countries. It is unfortunate that only now, after 4 years of massive commercial use of transgenic crops, U.S. Secretary of Agriculture Dan Glickman has called for studies assessing the long-term ecological and health effects of these crops. A bit late, given that the ecological release of genes is nonretrievable and their effects are irreversible. The rapid release of transgenic crops and the ensuing financial disarray (share prices for biotechnology companies are sinking toward all-time lows) are disturbingly reminiscent of the earlier uncritical bandwagons for nuclear energy and chlorinated pesticides such as DDT. A combination of public opposition and financial liability eventually forced retrenchment of these earlier technologies after their effects on the environment and human health proved to be far more complex, diffuse, and lingering than the promises that accompanied their rapid commercialization.

In the context of negotiations within the Convention on Biological Diversity (CBD), last year 130 countries that signed a global treaty that will govern the trade of genetically modified organisms were wise in adopting the *precautionary principle*. The precautionary principle holds that when a new technology may cause suspected harm, scientific uncertainty as to the scope and severity of the harm should not prevent precautionary action. Instead of requiring critics to prove that the technology poses potential damages, the producers of the technology shoulder the burden of presenting evidence that the technology is safe. There is a clear need today for independent testing and monitoring to make sure that self-generated data presented to government regulatory agencies is not biased or twisted to accommodate industry interests. Moreover, a worldwide moratorium should be enforced until the questions raised, both by credible scientists who are seriously investigating the ecological and health effects of transgenic crops and by the public at large, can be cleared up by independent bodies of scientists.

Many environmental and consumer groups advocating for a more sustainable agriculture demand continued support for ecologically based agricultural research as all the biological problems that biotechnology aims at can be solved using agrochemical approaches. The problem is that research at public institutions increasingly reflects the interests of private founders at the expense of public good research such as biological control, organic production systems, and general agroecological techniques (Busch, Lacy, Burkhardt, & Lacy, 1990). Civil society must request more research on alternatives to biotechnology by universities and other public organizations. There is also an urgent need to challenge the patent system and intellectual property rights intrinsic to the World Trade Organization (WTO) that not only provide multinational corporations with the right to seize and patent genetic resources but that will also accentuate the rate at which market forces already encourage monoculture cropping with genetically uniform transgenic varieties.

More Sustainable Alternatives to Biotechnology Do Exist

What Is Agroecology?

Proponents of a second Green Revolution argue that developing countries should opt for an agroindustrial model that relies on standardized technologies and ever-increasing fertilizer and pesticide use to provide additional food supplies for growing populations and economies. In contrast, a growing number of farmers, nongovernmental organizations (NGOs), and sustainable agriculture advocates propose that instead of this capital- and input-intensive approach, developing countries should favor an agroecological model that emphasizes biodiversity; recycling of nutrients; synergy among crops, animal, soils, and other biological components; as well as regeneration and conservation of resources (Altieri, 1996).

A sustainable agricultural development strategy that is environmentally enhancing must be based on agroecological principles and on a more participatory approach for technology development and dissemination. Agroecology is the science that provides ecological principles for the design and management of sustainable and resource-conserving agricultural systems—offering several advantages for the development of farmer-friendly technologies. Agroecology relies on indigenous farming knowledge and selected low-input modern technologies to diversify production. The approach incorporates biological principles and local resources into the management of farming systems, thus providing for an environmentally sound and affordable way for smallholders to intensify production in marginal areas (Altieri et al., 1998).

It is estimated that about 1.9 to 2.2 billion people remain directly or indirectly untouched by modern agricultural technology. In Latin America, the rural population is projected to remain stable at 125 million until the year 2000, but more than 61% of this population is poor and is expected to increase. The projections for Africa are even more dramatic. The majority of the rural poor (about 370 million of the poorest) lives in areas that are resource poor, highly heterogeneous, and risk prone. Their agricultural systems are small scale, complex, and diverse. The worst poverty is often located in arid or semiarid zones and in mountains and hillsides that are ecologically vulnerable. Such farms and their complex farming systems pose tough challenges to researchers.

To be of benefit to the rural poor, agricultural research and development should operate on the basis of a bottom-up approach, using and building on the resources already available, such as local people, their knowledge, and their autochthonous natural resources. It must also seriously take into consideration through participatory approaches the needs, aspirations, and circumstances of smallholders. This means that from the standpoint of poor farmers, innovations must be input saving and cost reducing, risk reducing, expanding toward marginal-fragile lands, congruent with peasant farming systems, and nutrition, health, and environment improving.

Precisely because of the aforementioned requirements, agroecology offers several advantages over Green Revolution and biotech approaches, as agroecological technologies tend to be based on indigenous knowledge and rationale; economically viable, accessible, and based on local resources; environmentally sound and socially and culturally sensitive; risk averse; adapted to farmer circumstances; and enhancing of total farm productivity and stability.

Thousands of examples exist of rural producers in partnerships with NGOs and other organizations promoting resource-conserving yet highly productive farming systems while meeting the aforementioned criteria. Increases in production of 50% to 100% are fairly common with most alternative production methods. In some of these systems, yields for crops that the poor rely on most—rice, beans, maize, cassava, potatoes, and barley—have been increased by several-fold by relying on labor and local know-how more than on expensive purchased inputs and capitalizing on processes of intensification and synergy. More important than just yields, it is possible to raise total production significantly through diversification of farming systems using available resources as much as possible (Uphoff & Altieri, 1999).

There are many examples of the application of agroecology throughout the developing world. It is estimated that about 1.45 million poor rural households covering about 3.25 million hectares have adopted resource-conserving technologies. Some examples include the following (Pretty, 1995):

- Brazil: 200,000 farmers using green manures/cover crops doubled maize and wheat yields.
- Guatemala-Honduras: 45,000 farmers using the legume *Mucuna* as a cover for soil conservation systems tripled maize yields in hillsides.
- Mexico: 100,000 small organic coffee producers increased production by half.
- Southeast Asia: 100,000 small rice farmers involved in IPM farmer's schools substantially increased yields while eliminating pesticides.
- Kenya: 200,000 farmers using legume-based agroforestry and organic inputs doubled maize yields.

Some Success Stories From Latin America

Stabilizing the hillsides of Central America. Perhaps the major agricultural challenge in Latin America has been to design cropping systems for hillside areas that are productive and reduce erosion. World Neighbors took on this challenge in Honduras in the mid-1980s. The program introduced soil conservation practices, such as drainage and contour ditches, grass barriers, and rock walls, and organic fertilization methods, such as the use of chicken manure and intercropping with legumes. Grain yields tripled, and in some cases quadrupled, from 400 kilograms per hectare to 1,200 to 1,600 kilograms. The yield increase has ensured that the 1,200 families participating in the program have ample grain supplies.

Several NGOs in Central America have promoted the use of legumes as green manure and an inexpensive source of organic fertilizer. Farmers in northern Honduras are using velvet beans with excellent results. Corn yields are more than double the national average, erosion and weeds are under control, and land preparation costs are lower. Taking advantage of well-established farmer-to-farmer networks in Nicaragua, more than 1,000 peasants recovered degraded land in the San Juan watershed in just 1 year after using this simple technology. These farmers have decreased use of chemical fertilizers from 1,900 to 400 kilograms per hectare while increasing yields from 700 to 2,000 kilograms per hectare. Their production costs are about 22% lower than those for farmers using chemical fertilizers and monocultures.

Moreover, hillside farmers adapting these soil conservation systems suffered significantly lower damage (mud slides and soil loss) than monoculture farms during Hurricane Mitch in 1998.

Recreating Incan agriculture. In 1984, several NGOs and state agencies assisted local farmers in Puno, Peru, to reconstruct ancient systems (*waru-warus*) consisting of raised fields surrounded by ditches filled with water that produced bumper crops despite killing frosts common at altitudes of 4,000 meters. The combination of raised beds and canals moderates soil temperature, thereby extending the growing season and leading to higher productivity on the *waru-warus* than on chemically fertilized normal pampa soils. In the district of Huatta, the *waru-warus* have produced annual potato yields of 8 to 14 metric tons per hectare, contrasting favorably with the average regional potato yields of 1 to 4 metric tons per hectare.

Various NGOs and governmental agencies in the Colca Valley of southern Peru have sponsored terrace reconstruction by offering peasants low-interest loans or seeds and other inputs to restore abandoned terraces. First-year yields of potatoes, maize, and barley showed a 43% to 65% increase compared to yields from sloping fields. A native legume was used as a rotational or associated crop on the terraces to fix nitrogen, minimizing fertilizer needs and increasing production. Studies in Bolivia, where native legumes have been used as rotational crops, show that although yields are greater in chemically fertilized and mechanically operated potato fields, energy costs are higher and net economic benefits lower than with the agroecological system.

Integrated farms. A number of NGOs have promoted diversified farms in which each component of the farming system biologically reinforces the other components—wastes from one component, for instance, become inputs to another. Since 1980, CET (an NGO) has helped peasants in south central Chile reach year-round food self-sufficiency while rebuilding the productive capacity of the land. Small model farm systems consisting of polycultures and rotating sequences of forage and food crops, forest and fruit trees, and animals have been set up. Components are chosen according to their nutritional contributions to subsequent rotations, their adaptability to local agroclimatic conditions, the local peasant consumption patterns, and market opportunities.

Soil fertility of these farms has improved, and no serious pest or disease problems have appeared. Fruit trees and forage crops achieve higher than average yields, and milk and egg production far exceeds that of conventional high-input farms. A nutritional analysis of the system shows that for a typical family it produces 250% surplus of protein, 80% and 550% surpluses of vitamins A and C, respectively, and 330% surplus of calcium. If all of the farm output were sold at wholesale prices, the family could generate a monthly net income 1.5 times greater than the monthly legal minimum wage in Chile while dedicating only a few hours per week to the farm. The time freed up is used by farmers for other on- and off-farm income-generating activities.

Recently a Cuban NGO helped establish a number of integrated farming systems in cooperatives in the province of Havana. Several polycultures, such as cassava-beans-maize, cassava-tomato-maize, and sweet potato-maize, were tested in the cooperatives. The productivity of these polycultures was 1.45 to 2.82 times greater than the productivity of the monocultures. The use of green manure ensured a production of squash equivalent to that obtainable by applying 175 kilograms of urea per hectare. In addition, such legumes improved the physical and chemical characteristics of the soil and effectively broke the cycle of insect-pest infestations.

The aforementioned examples (also see Altieri, 2000a) are a small sample of the thousands of successful experiences of sustainable agriculture implemented at the local level. Data show 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 and enhance agrobiodiversity. More important, these experiences, which emphasize farmer-to-farmer research and grassroots extension approaches, represent countless demonstrations of talent, creativity, and scientific capability in rural communities. They point to the fact that human resource development is the cornerstone of any strategy aimed at increasing options for rural people and especially resource-poor farmers.

Organic Farming

Agroecological approaches can also benefit medium to large farmers involved in commercial agriculture both in the developing world as well as the United States and Europe (Lampkin, 1990). Much of the area under organic farming is based on agroecology, and it is widespread throughout the world, reaching about 7 million hectares of which half are in Europe and about 1.1 million in the United States. In Germany alone, there are about 8,000 organic farms occupying about 2% of the total arable land. In Italy, organic farms number around 18,000, and in Austria, about 20,000 organic farms account for 10% of total agricultural output. In 1980, the USDA estimated that there were at least 11,000 organic farms in the United States and at least 24,000 farms that use some organic techniques. In California, organic foods are one of the fastest growing segments of the agricultural economy, with retail sales growing at 20% to 25% per year. Cuba is the only country undergoing a massive conversion to organic farming, promoted by the drop of fertilizer, pesticides, and petroleum imports after the collapse of trade relations with the Soviet bloc in 1990. Promoting agroecological techniques massively in both urban and rural areas, productivity levels in the island have recovered.

Research has shown that organic farms can be as productive as conventional ones but without using agrochemicals, consuming less energy, and saving soil and water. In fact, there is a strong body of evidence that organic methods can indeed produce enough food for all—and can do it from one generation to the next without depleting natural resources or harming the environment. The National Research Council (1984) wrote up case studies of eight organic farms that ranged from a 400-acre grain/livestock farm in Ohio to 1,400 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—and once again, they could be sustained year after year without costly synthetic inputs.

Recent studies include long-term studies such as the one conducted at the Farming Systems Trial at the Rodale Institute, a nonprofit 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 has been 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%. 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. And during 1999's record drought, the chemically dependent plots yielded just 16 bushels of soybeans per acre, the legume-fed organic fields delivered 30 bushels per acre, and the manure-fed organic fields delivered 24 bushels per acre.

In what must be the longest running organic trial in the world—150 years—the Rothamsted Experimental Station (also known as the Institute of Arable Crops Research) in England reports that its organic manured plots have delivered wheat yields of 1.58 tons per acre compared with 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.

The evidence shows that in many ways, organic farming conserves natural resources and protects the environment more than conventional farming. Research also shows that soil erosion rates are lower in organic farms and that levels of biodiversity are higher in organic farming systems than in conventional ones. The rationales of both systems are significantly different. Organic systems are based on the assumption that at any given time, some of the acreage is planted with legume green manure or fodder crop that will go to feed cows, whose manure will be returned to the soil. The chemical farms are based on a profoundly different assumption—that their survival depends on a fertilizer factory somewhere that is consuming vast amounts of fossil fuels and emitting greenhouse gases.

What Is Needed?

There is no question that small farmers located in marginal environments in the developing world can produce much of the needed food. The evidence is conclusive: New approaches and technologies spearheaded by farmers, local governments, and NGOs around the world are already making a sufficient contribution to food security at the household, national, and regional levels. A variety of agroecological and participatory approaches in many countries show very positive outcomes even under adverse conditions. Potentials include raising cereal yields from 50% to 200%, increasing stability of production through diversification and soil/water management, improving diets and income with appropriate support and spread of these approaches, and contributing to national food security and to exports (Uphoff & Altieri, 1999).

Whether the potential and spread of these thousands of local agroecological innovations is realized depends on investments, policies, and attitude changes on the part of researchers and policy makers. Major changes must be made in policies, institutions, and research and development to make sure that agroecological alternatives are adopted, made equitably and broadly accessible, and multiplied so that their full benefit for sustainable food security can be realized. Existing subsidies and policy incentives for conventional chemical approaches must be dismantled. Corporate control over the food system must also be challenged. It is urgent that governments and international public organizations encourage and support effective partnerships between NGOs, local universities, and farmer organizations to assist and empower poor farmers to achieve food security, income generation, and natural resource conservation.

Equitable market opportunities must also be developed, emphasizing fair trade and other mechanisms that link farmers and consumers more directly. The ultimate challenge is to increase investment and research in agroecology and scale up projects that have already proven successful to thousands of other farmers. This will generate a meaningful effect on the income, food security, and environmental well-being of the world's population, especially of the millions of poor farmers yet untouched by modern agricultural technology.

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