The Myth of Coexistence: Why Transgenic Crops Are Not Compatible With Agroecologically Based Systems of Production

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The coexistence of genetically modified (GM) crops and non-GM crops is a myth because the movement of transgenes beyond their intended destinations is a certainty, and this leads to genetic contamination of organic farms and other systems. It is unlikely that transgenes can be retracted once they have escaped, thus the damage to the purity of non-GM seeds is permanent. The dominant GM crops have the potential to reduce biodiversity further by increasing agricultural intensification. There are also potential risks to biodiversity arising from gene flow and toxicity to nontarget organisms from herbicide-resistant (HT) and insect-resistant (Bt) crops. Unless whole regions are declared GM agriculture free, the development of distinct systems of agriculture (GM and non-GM) will be impossible as GM agriculture emerges at the expense of all other forms of production.

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Coexistence in agriculture refers to a state where different primary production systems such as organic production, conventional agriculture, and genetically modified (GM) systems occur simultaneously or adjacent to one another, while each contributing in their own way to the overall benefit of a region or country, ensuring that their operations are managed so that they affect each other as little as possible. Many argue that this concept is not new as in many countries the organic production sector that usually comprises a relatively small group of farmers has for years been able to produce alongside conventional farmers who use products and methods forbidden in organic production (Byrne & Fromherz, 2003). This is of course not the case when one considers spray drift or pesticide residues originating in conventional systems and that adversely affect neighboring organic systems. Drift occurs unavoidably with all ground and aerial methods of pesticide application. In fact, 10% to 35% of the pesticide applied with ground application equipment misses the target area; with aircraft, 50% to 75% of the pesticide applied misses the target area. Clearly drift damage, human exposure, and widespread contamination are inherent in the process of pesticide application and expose the fact that conventional agriculture is not compatible with organic farming. Data on crop losses and environmental costs due to chemical drift are difficult to obtain, however Pimentel and Lehman (1993) estimated U.S. crop losses due to the use of pesticides to reach about $950 million. These costs do not include those derived from outbreaks of several pests triggered in whole regions due to development of pesticide resistance by pests and destruction of populations of natural enemies.

A similar case occurred with the Green Revolution in the developing world. The imposition of a Western model of agricultural development did not coexist with the indigenous systems of production because it assumed that progress and achieving development in traditional agriculture inevitably required the replacement of local crop varieties for improved ones and that the economic and technological integration of traditional farming systems into the global system was a positive step that enabled increased production, income, and common well-being (Tripp, 1996). But as evinced by the Green Revolution, the introduction of modern varieties and economic integration brought several negative impacts (Lappe, Collins, & Rosset, 1998; Shiva, 1991), including the following:

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- 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 also improved varieties did not perform well in marginal environments where the poor live.
- The spread of MVs was accompanied by a simplification of traditional agroecosystems and a trend toward monoculture that affected dietary diversity, thus raising considerable nutritional concerns.
- The replacement of folk varieties also represented a loss of cultural diversity as many varieties are integral to religious or community ceremonies.

Ecological theory predicts that the introduction of transgenic crops will probably 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 rural communities (Altieri, 2000).

Despite these warnings, proponents of biotechnology argue that transgenic crops are a strategy to improving conventional farming methods by reducing the use of synthetic chemical pesticides and that therefore comprises a production system that is compatible with more environmentally benign forms of agriculture. Globally, the cropland area planted to GM crops grew from 67.7 million hectares in 2003 to 81.0 million hectares in 2004, exhibiting a growth rate of 20%. The bulk of the production of the dominant crops (soybean, maize, canola, and cotton) is still concentrated in the United States, Argentina, and Canada, although significant adoption is occurring in Brazil, China, Paraguay, India, and South Africa. Herbicide-resistant (HT) soybean occupies 60% of the global biotech area (48 million hectares), followed by insect-resistant (Bt) maize, which occupies 23% of the biotech area (James, 2004).

On the other hand, organic agriculture is practiced in almost all countries of the world, and its share of agricultural land and farms is growing. According to a report by Food and Agriculture Organization of the United Nations (FAO; 2002), the total organically managed area is more than 24 million hectares worldwide. Australia/Oceania holds 42% of the world's organic land, followed by Latin America (24.2%) and Europe (23%). 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 8,000 organic farms occupying about 2% of the total arable land, and in Austria about 20,000 organic farms account for 10% of total agricultural output. In the United Kingdom, the organic market is displaying growth rates of 30% to 50% per annum. Although in the United States organic farms occupy 0.25% 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% to 25% per year for the past 6 years. Cuba is the only country undergoing a massive conversion to organic farming, promoted by the drop of fertilizer, pesticide, and petroleum imports after the collapse of trade relations with the Soviet bloc in 1990. By massively promoting agroecological techniques in both urban and rural areas, productivity levels in the island have recovered substantially.

Major Differences Between Organic and Transgenic Agriculture

Organic farming is a production system that sustains agricultural productivity by avoiding or largely excluding synthetic fertilizers and pesticides (Lampkin, 1990). External resources, such as commercially purchased chemicals and fuels, are replaced by resources found on or near the farm. These internal resources include solar or wind energy, biological pest controls, and biologically fixed nitrogen and other nutrients released from organic matter or soil reserves.

Thus, organic farmers rely heavily on the use of crop rotations, crop residues, animal manures, legumes, green manures, off-farm organic wastes, mechanical cultivation, mineral-bearing rocks, and aspects of biological pest control to maintain soil productivity and tilth, to supply plant nutrients, and to control insect pests, weeds, and diseases. Most small and medium size organic farmers feature legume-based rotations, use of compost, and a series of diversified cropping systems such as cover crops or strip cropping, including crop-livestock mixtures. Research shows that these systems exhibit acceptable yields, conserve energy, and protect the soil while inducing minimal environmental impact.

In contrast, GM cropping systems are characterized by monoculture systems that may reduce the use either of herbicides or a particular insecticide but that are still heavily dependent on the use of synthetic fertilizers and other pesticides to suppress insects or weeds that the GM crop does not control. Although such systems may prove to be productive and in some cases economically profitable, several scientists argue that herbicide-resistant crops (HRCs) and Bt crops have been a poor choice of traits to feature given predicted environmental problems and the issue of resistance evolution. In fact, there is enough evidence to suggest that both these types of crops are not really needed to address the problems they were designed to solve. On the contrary, they tend to reduce the pest management options available to farmers. To the extent that transgenic crops further entrench the current monocultural system, they impede farmers from using a plethora of alternative methods (Krimsky & Wrubel, 1996).

GM crops further lead to agricultural intensification, and ecological theory predicts that as long as transgenic crops follow closely the pesticide paradigm, such biotechnological products will do nothing but reinforce the pesticide treadmill in agroecosystems, thus legitimizing the concerns that many environmentalists and some scientists have expressed regarding the possible environmental risks of genetically engineered organisms. The most important difference between organic farming and biotech agriculture is that organic farmers rely on the ecological services of agrobiodiversity and thus avoid the use of chemical fertilizers and pesticides in their farming operations. Conversely, GM crop farmers promote genetic uniformity and monocultures and do not restrict the use of chemical pesticides and fertilizers. Clearly there are sharp contrasts between organic and biotech agriculture (Table 1).

Most studies assessing the environmental impacts of transgenic crops have concentrated in comparing conventional and transgenic crops, and resulting reports about population decreases of a particular species are usually an underestimate as comparisons usually did not include organic systems. Such reductionist studies were not able to capture the full spectrum of impacts GM crops on biodiversity, and neither did they address the effects of biodiversity reductions on agroecosystem processes such as nutrient cycling or pest regulation. Merely examining the effects of GM crops on the abundance of a few target species does not provide ecological information of mush use, especially if those studies exclude agroecosystems that express high levels of biodiversity.

The rationale behind each system is substantially different: Organic farms are based on the assumption that biodiversity is an integral part of agroecosystem design and that at any given time some of the acreage is planted with legume green manures that will be plowed under or be grazed by cattle, whose manure will be returned to the soil. The transgenic farms are based on a profoundly different assumption: Their survival depends on the access to genetic resources that will provide key traits to engineered plants and to an agrochemical factory somewhere that is consuming vast amounts of fossil fuels and emitting greenhouse gases.

The Agroecological Basis of Incompatibility Between GM and Organic Forms of Agriculture

For promoters of biotechnology, chemical drift and potential gene flow problems do not mean that the concept of coexistence between different production systems is unworkable but rather involves managing conflicting values and also requires certain technical issues to be resolved such as preventing chemical drift or minimizing the physical transfer of material between GM and non-GM systems (e.g., pollen from a GM plant fertilizing a neighbor's non-GM crop or the presence of GM pollen in honey, etc). But the problems are much deeper than that because the differences between biotechnology-based and organic agriculture are so fundamental that both systems are based on totally different ecological rationales. In fact, as currently implemented, the two forms of agriculture are in conflict because international organic standards prohibit the use of genetically engineered inputs and do

Table 1. Characteristics of Organic Farming and Genetically Modified Based Agriculture

Characteristics	Biotech	Organic
Petroleum dependency	High	Medium
Labor requirements	Low, hired	Medium, family or hired
Management intensity	High	Low-medium
Intensity of tillage	High, except in no-till systems	Low (no till without herbicides) to medium
Plant diversity	Low	Medium to high
Crop varieties	Genetically modified, genetically homogenous, one variety over large areas	Hybrid or open pollinated, variety mixtures
Source of seeds	Multinational corporations, all purchased, patented	Purchased from small seed companies, some saved
Integration of crops and livestock	None	Little (use of manure) to crop-livestock mixtures
Insect pests	Very unpredictable	Unpredictable
Insect management	Insect-resistant crops	Integrated pest management, biopesticides, biocontrol, habitat management
Weed management	Herbicide-resistant crops, chemical, tillage	Cultural control, rotations
Disease management	Chemical, vertical resistance	Antagonists, horizontal resistance, multiline cultivars
Plant nutrition	Chemical, fertilizers applied in pulses, open systems	Microbial biofertilizers, organic fertilizers, semi-open systems
Water management	Large-scale irrigation	Sprinkler and drip irrigation, water-saving systems

not tolerate GM crop pollen drift that may reduce the marketability of organic crops.

The biodiversity associated with agricultural systems is already being affected significantly by conventional agricultural intensification, with many species of farmland birds, butterflies, and plants having declined substantially during the past 50 years in agricultural landscapes worldwide. Using certain types of GM crops has the potential to reduce biodiversity further by increasing such intensification. There are also potential risks to biodiversity arising from gene flow and toxicity to nontarget organisms from some GM crops. In fact, there are several widely accepted environmental drawbacks associated with the rapid deployment and widespread commercialization of such crops in large monocultures, including the following (Kendall et al., 1997; Rissler & Mellon, 1996; Snow & Moran, 1997):

a. the spread of transgenes to related weeds or conspecifics via crop-weed hybridization;
b. reduction of the fitness of nontarget organisms (especially weeds or local varieties) through the acquisition of transgenic traits via hybridization;
c. the rapid evolution of resistance of insect pests such as Lepidoptera to Bt;
d. accumulation of the insecticidal Bt toxin, which remains active in the soil after the crop is plowed under and binds tightly to clays and humic acids;
e. disruption of natural control of insect pests through intertrophic-level effects of the Bt toxin on natural enemies;
f. unanticipated effects on nontarget herbivorous insects (i.e., monarch butterflies) through deposition of transgenic pollen on foliage of surrounding wild vegetation (Losey, Rayor, & Cater, 1999); and
g. vector-mediated horizontal gene transfer and recombination to create new pathogenic organisms.

By further examining the fundamental premises on which organic farming operates, it is clear that GM crops are totally incompatible with agroecologically based approaches. By describing the main features of organic farming, it is possible to visualize why GM agriculture is a model of farming that is incompatible with the tenets of a sustainable agriculture as it expands at the expense of other production forms.

Organic agriculture relies on diversification strategies such as polycultures, rotations, cover crops, and animal integration to optimize productivity and achieve agroecosystem health. Transgenic crops (especially HRCs) condemn farmers to monocultures as herbicides such as Roundup are broad spectrum, eliminating all vegetation except the engineered crop. Under such scheme, it is impossible to promote designs that involve intercropping and rotational systems when associated crops are susceptible to the herbicide or its residues. Perhaps the greatest problem of using HRCs to solve weed problems is that they steer efforts away from alternatives such as crop rotation or cover crops, encouraging maintenance of simplified cropping systems dominated by one or two annual species (Paoletti & Pimentel, 1996). Crop rotation not only reduces the need for herbicides but also improves soil and water quality, minimizes requirements for synthetic nitrogen fertilizer, regulates insect pest and pathogen populations, increases crop yields, and reduces yield variance (Altieri, 1995). Thus, to the extent that transgenic HRCs inhibit the adoption of rotational crops and cover crops they hinder the development of sustainable agricultural systems.

The rapid spread of transgenic crops further threatens crop diversity by promoting large monocultures in a rapid scale, leading to further environmental simplification and genetic uniformity. History has repeatedly shown that uniformity characterizing agricultural areas sown to a smaller number of varieties, as in the case of GM crops, is a source of increased risk for farmers as the genetically homogeneous fields tend to be more vulnerable to disease and pest attack (Robinson, 1996). Examples of disease epidemics associated with homogeneous crops abound in the literature, including the $1 billion loss of maize in the United States in 1970 and the 18 million citrus trees destroyed by pathogens in Florida in 1984 (Thrupp, 1998).

Organic agriculture privileges the use of local varieties adapted to specific conditions and to low input management. Clearly, the use of genetic diversity by organic farmers has special significance for the maintenance and enhancement of productivity of farming systems as diversity provides security to farmers against diseases, pests, droughts, and other stresses and also allows farmers to exploit the full range of agroecosystems existing in each region. Gene exchanges pose major threats to centers of diversity; in biodiverse farming systems, the probability for transgenic crops of finding sexually compatible wild relatives is very high. Unwanted gene flow from GM crops may compromise native crop biodiversity (and therefore the associated systems of agricultural knowledge and practice along with the ecological and evolutionary processes involved) and may pose a threat worse than cross-pollination from conventional (non-GM) seed. In fact, some researchers believe that DNA from engineered crops is likely to confer an evolutionary advantage, and if transgenes do persist, they may actually prove disadvantageous to farmers and crop diversity (Stabinski & Sarno, 2001). Can genetically engineered plants actually increase crop production and at the same time repel pest, resist herbicides, and confer adaptation to stressful factors commonly faced by small farmers? At issue is the possibility that traits important to indigenous farmers (resistance to drought, competitive ability, performance on intercrops, storage quality, etc) could be traded for transgenic qualities that may not be important to farmers (Jordan, 2001). Under this scenario, risk could increase and farmers would lose their ability to adapt to changing biophysical environments and produce relatively stable yields with a minimum of external inputs while supporting their communities' food security.

A major ecological risk is that large-scale releases of HT transgenic crops may promote transfer of transgenes from crops to other plants, which then could become weeds (Snow & Moran, 1997). Transgenes that confer significant biological advantage may transform wild/weedy plants into new or more invasive weeds (Rissler & Mellon, 1996). The biological process of concern here is introgression—hybridization among distinct plant species. This is worrisome given that a number of 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). Bt crops can also contribute to the creation of super weeds. Snow et al. (2003) showed that when a transgene coding for an insecticidal compound moved from commercial transgenic sunflower into weedy sunflowers, the weeds experienced reduced herbivory and produced more seeds, thus transgene escape is making a weed problem worse.

The transfer of genes from transgenic crops to organically grown crops poses a specific problem to organic farmers. 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. There are no regulations that enforce minimum isolating distances between transgenic and organic fields (Royal Society, 1998).

Organic farms depend on the presence of functional biodiversity in their farms as it provides ecological services such as pest regulation, pollination, nutrient cycling, and so on. During the past half-century, crop diversity has declined precipitously in conventional high-input farming systems in the United States and other industrialized countries as well as in the agroexport regions of the developing world. Such reduction in crop diversity has resulted in the simplification of the landscape. The expansion of monocultures has decreased abundance and activity of natural enemies due to the removal of critical food resources and overwintering sites (Altieri & Nicholls, 2004). Many scientists are concerned that with accelerating rates of habitat removal, the contribution to pest suppression by biocontrol agents using these habitats is declining and consequently agroecosystems are becoming increasingly vulnerable to pest invasion and outbreaks. In general, monocultures do not constitute good environments for natural enemies. Such simple crop systems lack many of the resources, such as refuge sites, pollen, nectar, and alternative prey and hosts, that natural enemies need to feed and reproduce; therefore, insect pests usually drive and reach pest outbreak proportions.

Total weed removal associated with herbicide-resistant crops will surely aggravate pest problems associated with vegetation-free monocultures. The massive use of Roundup and other broad-spectrum herbicides eliminates many weed species that offer many important requisites for natural enemies such as alternative prey/hosts, pollen, or nectar as well as microhabitats that are not available in weed-free monocultures (Altieri & Nicholls, 2004). In the past 20 years, research has shown that outbreaks of certain types of crop pests are less likely to occur in weed-diversified crop systems than in weed-free fields, mainly due to increased mortality imposed by natural enemies. Crop fields with a dense weed cover and high diversity usually have more predaceous arthropods than do weed-free fields. The successful establishment of several parasitoids usually depends on the presence of weeds that provide nectar for the adult female wasps. Relevant examples of cropping systems in which the presence of specific weeds has enhanced the biological control of particular pests were reviewed by Altieri and Nicholls (2004). A literature survey by Baliddawa (1985) showed that population densities of 27 insect pest species increased in weed-free crops compared to weedy crops. Obviously, total elimination of weeds, as it is common practice under HRC crops, can have major ecological implications for insect pest management.

Organic agriculture promotes small to medium farms that promote local and economically viable family farming. During the postwar period, numbers of farms in the United States experienced a sharp decline. More than 4 million farmers have gone out of business in the past 50 years, an average of 219 farms lost per day. The reality is that U.S. farmers have increasingly been caught in a cost-price squeeze whereby the ballooning costs of modern farm technology have consistently swallowed any increases in farm income. While food prices have long been stagnant due to overproduction, costs of manufactured inputs have soared. Farmers have been driven into debt to cover the costs of $40,000 tractors and $100,000 harvesters, and by and large their slim profit margins have not been enough to cover debt service, thus leading to waves of bankruptcies and foreclosures. It is important to note that both overproduction and high production costs are results of the same productionist technology, which is thus responsible for both the cost and the price side of the economic squeeze affecting farmers (Rosset, 2002).

Biotechnological innovations are a prime example of a technology that promotes economies of scale and concentration of land in larger holdings throughout the world, both in the North and the South. In this regard, it is useful to examine the realities faced by Iowa farmers who live in the heartland of U.S. transgenic corn and soy. Although weeds are an annoyance, the real problem the farmers 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 had 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 continue to fall as the industrial agricultural model expands. For these Iowa farmers, reductions in return per unit of cropland have reinforced the importance of herbicides within the production process as they reduce time devoted to mechanical cultivation, allowing 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. However, yields for the glyphosate-resistant soybeans were about 4% lower, and net returns per unit land area from glyphosate resistant and conventional soybeans were nearly identical (Altieri, 2004).

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 impact of existing low prices even worse. Taking into account that American exports of soybeans to the European Union plummeted from 11 million to 6 million tons in 1999 due to rejection of genetically modified organisms (GMOs) by European consumers, it is easy to predict disaster for farmers dependent on transgenic crops (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-by-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. Just 3 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). Farmers may experience significant savings in herbicide costs (up to 30%), but the difference is in seed cost. In 1998, Iowa farmers spent $26.42 per acre on genetically engineered seeds while the cost of conventional seed was only $18.89 per acre. 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.

In Argentina, virtually all of its 15 million hectares of soybean has been planted with herbicide-tolerant soybean. Although the transgenic area increased, so did the use of glyphosate, big tractors (combines), and acreage under no-till farming. This agricultural transformation has occurred in a context of profit margins falling down by 50% between 1992 and 1999, which drove many farmers out of business. Farmers are indebted with bank loans linked to high interest rates to pay back for investments in machinery, chemical inputs, and seeds. This situation has favored the establishment of large holdings and the disappearance of smaller farmers. Just in 7 years, the number of farms in La Pampa declined from 170,000 to 116,000, while the average size of farms increased from 243 to 538 hectare in 2003. The 126% increase of soybean acreage in the past decade also occurred at the expense of significant areas previously devoted to fruits, dairy, cattle, maize, wheat, sunflower, cotton, sugarcane, and others. When the economic crisis hit the country, there was not much food to offer the growing hungry population other than soybean, a food that Argentineans have never been accustomed to consuming (Pengue, 2000).

In Europe, a recent study by the Institute for Prospective Technological Studies of the EU Joint Research Centre (Bock et al., 2002) stated that all farmers would face high additional, in some cases unsustainable costs of production if GM crops were commercially grown in a large scale. The study predicted that commercialization of GM oilseed rape and maize and to a lesser extent potatoes will increase costs of farming for conventional and organic farmers at a range between 10% and 41% of farm prices for oilseed rape and between 1% and 9% for maize and potatoes. Under such a scenario, coexistence would be very difficult as seed and crop purity from GM crops at a detection level of 0.1% would be virtually impossible in most cases, namely, all products and seeds of oilseed rape and maize would be contaminated with GM to a certain extent. Unfortunately, this seems to be the case in the United States, where recent tests on local varieties of corn, soybeans, and canola have found pervasive transgenic contamination (Mellon & Rissler, 2004).

Small organic farms are more productive and environmentally sound than large-scale conventional and transgenic farms. This GM agriculture–induced trend toward land consolidation into large farms not only displaces farmers but also attempts against the diversity of production of a country and consequently its food security. Designed to maximize the productivity of a single resource that is scarce in the First World—labor—this technology has proven to be wasteful of land and capital. When exported to countries with chronic unemployment and little capital, it rapidly leads to enormous rural-urban migration, social problems, and the penetration of agriculture by foreign capital (Rosset, 1999). The monoculture/large farm trap is also an underlying cause of low productivity in most countries as large farms almost always display much lower productivity per unit area than smaller farms.

Large farmers tend to plant monocultures because they are the simplest to manage with heavy machinery. Small farmers on the other hand, especially in the Third World, are much more likely to plant crop mixtures—intercropping—where the empty niche space that would otherwise produce weeds instead is occupied by other crops. They also tend to combine or rotate crops and livestock, with manure serving to replenish soil fertility. Such integrated farming systems produce far more per unit area than do monocultures. Although the yield per unit area of one crop—corn, for example—may be lower on a small farm than on a large monoculture, the total output per unit area, often composed of more than a dozen crops and various animal products, can be much higher. Therefore, total output rather than yield is a better parameter to compare yields of large and small farms. Total output is the sum of everything a small farmer produces: various grains, fruits, vegetables, fodder, animal products, and so on. Whereas yield almost always biases the results toward larger farms, total output allows us to see the true productivity advantage of small farms (Rosset, 1999).

Data show that small farms almost always produce far more agricultural output per unit area than larger farms both in industrial and developing countries. This is now widely recognized by agricultural economists across the political spectrum as the "inverse relationship between farm size and output." In the United States, the smallest farms, those of 27 acres or less, have more than 10 times greater dollar output per acre than larger farms. Although this is in large part due to the fact that smaller farms tend to specialize in high-value crops such as vegetables and flowers, it also reflects relatively higher labor and input efficiency and the yield-enhancing effects of more diverse farming systems (Rosset, 1999).

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 1989, the National Research Council 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—once again showing they could be sustained year after year without costly synthetic inputs (National Research Council, 1994).

Recent long-term studies such as the one conducted at the Farming Systems Trial at the Rodale Institute, a nonprofit research facility near Kutztown, Pennsylvania, tested three kinds of experimental plots 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%. 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. During the record drought of 1999, 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 (FAO, 2002).

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. FIBL (Research Institute of Organic Agriculture) 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% lower in the organic systems, although input of fertilizer and energy was reduced by 31% to 53% and pesticide input by 97%. They concluded that enhanced soil fertility and higher biodiversity found in organic plots rendered these systems less dependent on external inputs (Mader et al., 2002).

In terms of environmental benefits, the evidence shows that organic farming conserves natural resources and protects the environment more than conventional farming. Soil erosion rates are lower in organic farms, and levels of biodiversity are higher in organic farming systems than in conventional ones. Most practitioners of organic agriculture believe that organic farms have positive impacts on biodiversity and that farmland under organic agriculture does not exhibit the dramatic declines of many animal species as observed in areas dominated by conventional agriculture. In a recent survey of the literature, Hole et al. (2005) reviewed 76 published studies and found that species abundance and/or richness across a wide range of taxa was higher on organic farms than on locally representative conventional farms. Of particular importance from a conservation perspective is that many of these differences apply to species known to have experienced declines in range and/or abundance as a consequence of past agricultural intensification, a significant number of which are now the subject of direct conservation legislation (e.g., skylark, lapwing, greater and lesser horseshoe bat, corn buttercup *Ranunculus arvensis*, and red hem-nettle are all U.K. government Biodiversity Action Plan species). These biodiversity benefits are likely to derive from the specific environmental features and management practices employed within organic systems, which are either absent or only rarely used in the majority of conventional systems.

Reganold, Glover, Andrews, and Hinman (2001) assessed the sustainability of organic, conventional, and integrated apple production systems in Washington State from 1994 to 1999. All three systems gave similar apple yields, although organic systems performed better in dry years. The organic and integrated systems had higher soil quality and potentially lower negative environmental impact than the conventional system. The results from this study show that organic and integrated apple production systems in Washington State are not only better for soil and the environment than their conventional counterpart but have comparable yields and for the organic system, higher profits and greater energy efficiency. Although crop yield and quality are important products of a farming system, the benefits of better soil and environmental quality provided by the organic and integrated production systems are equally valuable and often overlooked.

Conclusions and Recommendations

The available, independently generated scientific information suggests that because the massive use of transgenic crops poses substantial potential ecological risks, GM crops are not compatible with organic farming or other alternative forms of production. GM agriculture undermines coexistence mechanisms as it prejudices the ability of farmers to manage their land for the benefit of biodiversity or natural resources, for example by requiring increased use of herbicides to control volunteers or by reducing farmers' choice of rotations or other diversification management practices.

The first important argument against the concept of coexistence is that the movement of transgenes beyond their intended destinations and hybridization with weedy relatives and contamination of other non-GM crops is a virtual certainty (Marvier, 2001). Removing or recalling genes once they have escaped into natural gene pools is impossible. There are no adequate safeguards against gene flow between the GMO and native organisms where transgenes are likely to affect fitness, decrease genetic diversity, or increase toxicity (Steinbrecher, 1996). Although the preferred method should be to avoid releasing transgenic organisms in areas with sexually compatible wild relatives, there is no guarantee that this will happen due to corporate pressures, lack of biosafety regulations, human error, or corruption.

The environmental effects are not limited to pest resistance and creation of new weeds or virus strains via gene flow (Kendall et al., 1997). Direct risks from GMOs may include toxicity of transgenic organisms to wildlife, competitive displacement of native species by transgenic organisms or hybrids with wild species, and effects on soil and aquatic ecosystems. Indirect risks include changes in land and water use and management that are detrimental to the wildlife that use farmland, woodland, freshwater, or the seas. It is known that transgenic crops can produce environmental toxins that move through the food chain and also end up in the soil where they bind to colloids and retain their toxicity, affecting invertebrates and possibly nutrient cycling (Altieri, 2000). No one can really predict the long-term impacts on agrobiodiversity and the processes they mediate from the massive deployment of such crops, an unfortunate trend as most scientists feel that such knowledge was crucial to have before biotechnological innovations were upscaled to actual levels.

Although there is a clear need to further assess the severity, magnitude, and scope of risks associated with the massive field release of transgenic crops, transgene movement via pollen and seed is already so pervasive that the only possible safe route to secure an agriculture free of GM contamination is to create GMO-free isolated geographical areas and to maintain some non-GM seed lineages for cases where people desire cropping systems that are free of GM traits. Moreover, the repeated use of transgenic crops in an area may result in cumulative effects such as those resulting from the buildup of toxins in soils, which will make those soils unsuitable for other forms of agriculture for an unknown number of years. Decreases in pesticide use are not acceptable as proxies for environmental benefits as this does not mean that the GM crop do not exudate, toxins, or associated herbicides do not exert multitrophic effects and impacts on agroecosystem function.

There is no doubt that the large-scale landscape homogenization with transgenic crops will exacerbate the ecological problems already associated with monoculture agriculture (Altieri, 2000). Unquestioned expansion of this technology into developing countries may not be wise or 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 consequences of doing so results in serious social and environmental problems (Altieri, 2003). Under conditions of poverty, marginalized rural populations have no option but to maintain low-risk agroecosystems that are primarily structured to ensure local food security. Farmers in the margins have a need to continue producing food for their local communities in the absence of modern inputs, and this can be reached by preserving in situ ecologically intact, locally adapted agrobiodiversity. For this, it may be necessary to maintain geographically isolated areas of traditional agroecosystems and pools of genetic diverse material as these islands of traditional agriculture can act as extant safeguards against the potential ecological failure derived from an inappropriate agricultural modernization led by GM crops. It is precisely the ability to generate and maintain diverse crop genetic resources that offer "unique" niche possibilities to marginal farmers that cannot be replicated by other farmers with uniform cultivars in the more favorable lands. This "difference" inherent to traditional systems can be strategically used by exploiting unlimited opportunities that exist for linking traditional agrobiodiversity with local/national/international markets as long as these activities are carefully planned and remain under grass-roots control.

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