Genetic Engineering, the Farm Crisis, and World Hunger

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The US farm belt has been mired in recession. Between 1960 and 2000, the food price index for major commodities dropped almost in half, and as a result, farm income has declined (Halweil 2002). Overall conditions in the farm economy in early 2000 were largely a replay of the previous year. Markets for major commodities, particularly field crops, were very weak as supplies remained large (ERS 2000). Crop prices projected for the 2001–2005 period are at, or near, lows experienced over the previous 20 years (Womack et al. 2001). The cause is overproduction (Halweil 2002).

Supply and demand

Farmers are in a no-win situation. The only way farmers can increase their income is to increase production. But increased production results in an even greater supply, which drives prices down even further, which leads to even greater financial losses. This situation is not new. For decades the government has implemented price supports and restrictions on the acreage of some crops to help maintain farm income.

Why has the government shielded farmers from the law of supply and demand? One of the reasons is cultural. Many people believe that farming is a way of life that epitomizes American values and therefore should be subsidized. But when the "freedom to farm" act (the Federal Agriculture Improvement and Reform Act of 1996) was passed in 1996, many of the subsidies and restrictions were reduced or eliminated. Although farmers thought that this bill would give them the freedom to produce more and thus profit more, in reality it has given them the freedom to produce more and profit less (Knutson et al. 2002).

Genetic engineering as the solution

Since 18 May 1994, when the US Food and Drug Administration approved the first genetically modified organism for commercial sale, genetic engineering has been hailed as a solution to many of the problems of agriculture (Thomashow and Mooney 1994). It is claimed that the increases in crop productivity brought about by genetic engineering can help relieve problems faced by farmers by decreasing the losses caused by pests, disease, weeds, and other stressors (Guerinot 2000).

From the point of view of an individual farmer, genetically engineered crops might seem to be very desirable. During the Ceres Forum on Environmental Benefits and Sustainable Agriculture through Biotechnology at Georgetown University (Doyle 1999), several farmers testified that planting genetically modified plants increased their income because of increased production and fewer losses to pests and disease. The fallacy is, of course, that if all farmers adopt genetically altered crops, there will be an even greater oversupply, resulting in a further decrease of prices. It is an interesting variation on the tragedy of the commons. If one farmer exploits the commons (the commons being a restricted market) by producing more than his or her fair share (a fair share being that amount that could be produced without genetically altered crops), then that farmer will achieve an "unfair" advantage. This farmer will profit at the expense of all other farmers. Of course, if *all* farmers planted genetically modified crops, then all would have an equal advantage, and everyone would again receive a fair share. But the result of this would be an even greater oversupply and consequent further decline in prices.

Besides increased production, another reason given for using genetically engineered crops is that such crops benefit the environment by reducing the need for pesticides (Hardy 1994). To protect a crop species from insect herbivores, transgenic varieties can be created that contain insecticidal proteins of the bacterium *Bacillus thuringiensis* (Bt), which are effective for controlling many insect pest species but do not harm

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predatory insects or mammals (Oppert et al. 1997). A problem, however, is that evolution in insect pests of resistance to the insecticide is virtually inevitable where large areas are planted to transgenic crops. If this occurs, farmers would have to return to synthetic pesticides. Further, since Bt is a natural product often used by organic farmers, evolution of resistance would harm the organic growers as well.

To slow down the rate of resistance evolution, "refuges" have been proposed, in which farmers are supposed to plant nontransgenic plants (McGaughey and Whalon 1992). The idea is that if part of a field contains nontransgenic plants, the trait for nonresistance will be maintained in the target population of insects. However, the refuge idea depends upon the resistance gene being recessive and mating being random, but these hypotheses may not hold true (Huang et al. 1999). It also depends upon the assumption that farmers will not cheat, which is not always a safe assumption. Another suggested danger is that pollen from transgenic Bt corn can harm the larvae of monarch butterflies when the pollen lands upon a food source such as milkweed (Losey et al. 1999), but comprehensive new studies have shown that Bt corn pollen poses little risk to monarchs on a national scale (Hellmich et al. 2001).

Genetically altered plants also are praised for reducing the need for herbicides. Before the advent of herbicides, weeds were controlled by plowing, disking, and harrowing, activities that break down soil structure and cause erosion. Transgenic crop plants with genes for herbicide resistance can obviate the need for mechanical weed control. Seeds are planted into untilled soil with a "no-till" planter, a machine that cuts a thin slice into the soil, injects a seed into the groove, and smooths over the cut. As crops and weeds emerge, herbicides are sprayed, but only the weeds are killed.

However, as with evolution of resistance to Bt crops by insect pests, there also can occur evolution in weeds of resistance to herbicides (Powles et al. 1997). There can be transgene escape into weedy relatives, even in a species considered to be almost completely selfing (Bergelson et al. 1998). Mikkelsen and colleagues (1996) have shown that herbicide-tolerant weeds can develop in one to two generations from transgenic oilseed rape *(Brassica napus)*. Once weedy species become herbicide tolerant, herbicides will become useless. This can be delayed somewhat by alternating different types of herbicides (Powles et al. 1997). If herbicide resistance occurs, the need for more and other types of herbicides will increase (Rissler and Mellon 1996), and costs of production will increase (Paoletti and Pimentel 1996).

Thermodynamic considerations

Greenstone (2001) has criticized those who oppose genetically altered crops by saying, "They want the free lunch, to have a Green World where humankind lives lightly off the bounty of a benign and unmanipulated nature." He has a point, but proponents of genetically engineered crops also claim a free lunch. They claim that it is possible to get increased yield but, at the same time, get plants that are insect protected, stress tolerant, herbicide resistant, and perennial (Horsch 2001). This claim raises the question of energy tradeoffs in transgenic plants: Can genetically engineered plants actually increase food production and, at the same time, repel pests, resist herbicides, and compete with weeds for water and nutrients? Thermodynamic considerations suggest that they cannot.

There is only so much solar energy that reaches an acre of field every year. Some of that energy is captured through photosynthesis and converted to carbohydrates, which are then transformed and used for growth and metabolic processes of the plant. The ability of plants to capture and fix that energy is inherently limited by the physics of intercepting photons and capturing carbon dioxide, the biochemistry of photosynthesis and the physiology of nutrient uptake and utilization (Federoff and Cohen 1999). What plant breeding does is change how the captured energy is used. When crop plants were domesticated, certain traits, such as ability to compete for nutrients and ability to resist pests, were traded for other qualities, such as high production, especially production of grain. The farmer took over the functions of plant nutrition and pest control using machinery and agrochemicals. What plant breeding does not do is increase the amount of energy captured through photosynthesis. In certain cases, breeding changed the structure or architecture of species such as rice plants so that plants could take better advantage of environmental conditions in the farmer's field or paddy. By decreasing stem length, rice could be made more productive under certain management regimes (Conway 1997). However, such changes do not mean that scientists have overcome the first law of thermodynamics: Matter and energy cannot be created, only transformed.

There is now evidence that traits such as herbicide resistance and pest resistance, which are achieved through genetic engineering, have a thermodynamic cost. Purrington and Bergelson (1999) found that seed production in herbicide-resistant *Arabidopsis thaliana* was lower than in nonresistant varieties. Fineblum and Rausher (1995) showed that there was a tradeoff between resistance and tolerance to herbivore damage in a morning glory. As crop plants are modified to be more weed and pest resistant, they become more and more like their wild ancestors. Conway and Sechler (2000) pointed out that the technology of the first Green Revolution allowed plants to channel more photosynthate into grain production, dramatically increasing yields, but diminished other useful traits such as vigorous deep roots, sturdy stems, and ability to compete with weeds. Unless the first law of thermodynamics can be repealed, the second Green Revolution (breeding genetically modified crops that have deep roots, sturdy stems, and high competitive ability) will merely reverse the changes of the first revolution.

Genetically altered crops may also result in energy losses at the farm level. The refuges that farmers must plant to sustain populations of nonresistant pests may represent a net loss of energy. Yield losses can be exceptionally high in these refuges, because of the swarms of pests that have fled from genetically protected fields (Alstad and Andow 1995).

While there is no free lunch at the population level over a long period of time, there may be a short-term energy benefit for a genetically altered individual plant. For example, the energy benefit-cost ratio may be positive for an individual plant genetically engineered to express a Bt protein, because the energy cost for such expression may be less than the energy loss that would occur through herbivory were that protein not present. Such a benefit would be possible only as long as herbivores do not evolve resistance to Bt proteins.

Alternative solutions

Jordan (1998) has summarized the extensive literature on alternative solutions to the problem of insect pests, diseases, and weeds. The approaches are based upon the idea that it is more economical and environmentally desirable to use natural means of control and live with low populations of pests than it is to attempt to eliminate all the pests. One example of such ecological control is the use of soldier bugs to control populations of the Mexican bean beetle, whose larvae are a pest to soybeans (NRC 1989). As long as the farmer allows a few beetles to remain in the field, the probability is high that there will also be soldier bugs to prevent an outbreak.

Organic agriculture. There is a variety of terms for the concept of an agriculture that employs the services of nature, among them being ecologically sustainable agriculture, alternative agriculture, permaculture, agroforestry, low-input agriculture, holistic management, and organic agriculture. Organic agriculture is often dismissed by mainstream agronomists as being impractical for two reasons: Productivity of organic agriculture supposedly is low—it would be impossible to feed the United States, let alone the world, with organic agriculture; organic agriculture is necessarily labor intensive and thus is expensive where labor is scarce (Lampkin 1994).

Low productivity of organic agriculture. Productivity of organic agriculture can indeed be low, when a farmer begins a transition from conventional cultivation. Many factors influence the length of the transition period, which can last up to five years. These factors include development of a community of natural enemies to control insect pests, development of soil fertility through the use of legumes, and development of a farmer's skills (NRC 1989). Once an organic system has matured, however, production can be as high as or higher than conventionally cultivated farms, and net profit can be higher, when premium prices for organic produce are considered (Lampkin 1994).

High cost of organic agriculture. Conventional farms are generally simple monocultures, to allow for more convenient machine planting, cultivating, and harvesting. In contrast, organic farms are complex, and consequently, few organic farms are highly mechanized. Thus many organic farms are small-scale operations in which the farmer cultivates and harvests by hand or with a garden tractor. This often limits the amount of economic income on organic farms (Lampkin 1994).

Overcoming limitations of organic agriculture. There may be various ways to overcome the problems of organic farms. We have been working on one approach in the Georgia Piedmont, where more than a century of intense cropping has reduced the soil over most of the region to a heavy clay B horizon, almost completely devoid of soil organic matter (Trimble 1974). We are looking for economical ways to restore a healthy topsoil that supports a complex community of soil organisms. Such a community will improve the efficiency of nutrient cycling, as well as help protect the crop against insect pests and diseases.

The key to restoring healthy soil is the elimination of plowing and tilling, processes that destroy soil organic matter, the very resource essential to organic farming. The purpose of plowing and tilling is to control weeds and to develop a bed where seeds or transplants can obtain adequate moisture. How can these ends be met, if plowing or rototilling are eliminated?

Weeds can be controlled by cover crops, species that are alternated with economic crops in a farmer's field. As cover crops such as rye or clover reach maturity, they are knocked over or cut to form a layer of mulch that inhibits germination and growth of weed species. Then row crops or vegetable transplants are planted through the mulch with the use of a no-till planter that utilizes a sharp disk (coulter wheel) to cut through the mulch, followed by a conventional seed planter that drops a seed or seedling into a groove directly aligned with the coulter wheel cut.

Because the management of cover crops and the planting of no-till row crops or vegetables can be mechanized, the disadvantage of high labor costs inherent in traditional organic gardens can be overcome. The long transition time to achieving high-yield organic farming also can be solved through the application of manure to the field. This, of course, involves an expense, but any type of transition involves expense and temporary decrease of income.

The world hunger crisis

There has always been hunger somewhere in the world, but the belief that it is a problem that developed countries should solve is relatively recent. Only after World War II, when pesticides, herbicides, and inorganic fertilizers became readily available, was it even possible to think that world hunger could be alleviated. To do the job, however, it was necessary to breed crops that could take advantage of these new chemicals. The term *Green Revolution* has been used to signify the introduction of these crops, along with the necessary infrastructure (tractors, cultivation equipment, irrigation systems) in underdeveloped countries.

There are claims of impressive gains in food production as a result of the Green Revolution, especially in Southeast Asia. During two decades of Green Revolution advances (1970–1990), figures from the United Nations show that the total food available per person in the world rose by 11 percent, while the estimated number of hungry people fell from 942 million to 786 million, a 16 percent drop (Rosset and Mittal 2001). This was apparent progress, for which those behind the Green Revolution took credit. But if China (where Green Revolution techniques were not emphasized and employed) is eliminated from the analysis, the number of hungry people in the rest of the world actually increased by more than 11 percent, from 536 million to 597 million. In South America, for example, while per capita food supplies rose almost 8 percent, the number of hungry people also went up by 19 percent (Rosset and Mittal 2001).

World population continues to grow, while food production resulting from the first Green Revolution is tapering off and may have reached its ceiling (Conway 1997). As a result, there has been a call for a second Green Revolution (Conway and Toenniessen 1999). Genetically altered plants have been proclaimed to be the key to this revolution that will stave off future world shortages of food. In an article in *Science,* Ismail Serageldin, vice president for special programs at the World Bank, made a strong pitch for further development of genetically modified crops. He quoted figures that showed average grain yields throughout the world must increase by 80 percent over the 1990 average to meet projected food demands by 2025 (Serageldin 1999). An important strategy, he says, is harnessing the genetic revolution, with cutting-edge work associated with gene mapping, molecular markers, and biotechnology.

World Health Organization data show that even now, one third of the world's children suffer from malnutrition (De Onis et al. 2001). Hoisington and colleagues (1999) cited the need for genetic engineering "to feed a world population growing by up to 160 people per minute, with more than 90 percent of them in developing countries." Mann (1997) predicts that through the work of plant breeders, crop physiologists, and botanical geneticists, humankind ultimately will be able to feed itself, but only if the world engages in a gigantic, multiyear, multibillion-dollar scientific effort that emphasizes genetic engineering.

Goklany (1998) claims that biotechnology not only has the potential to feed the world's billions, it also carries the promise of conserving biodiversity, by reducing the amount of new land brought under cultivation. McGloughlin (1999) feels the same way. She has stated, "In the absence of significant productivity gains, or expansion of agriculture into marginal lands (e.g., forests), there will not be sufficient food quantities to feed the projected levels of population. So in the absence of a good alternative—and in the face of a proven slowdown in the productivity gains from the Green Revolution—biotechnology is by default our best and, maybe, only way to increase production to meet future food needs."

The real problems

The problem of hunger in developing countries is not caused by lack of genetic engineering to produce more food. In most countries where hunger is prevalent, there is an excess of staples—"the world already produces sufficient food" (Alexandratos 1999). Today, there is enough grain produced to provide every human being on the planet with thirty-five hundred calories a day (Lappé et al. 1998). This estimate does not even count many other commonly eaten foods such as vegetables, beans, nuts, root crops, fruits, meat from grass-fed animals, and fish.

"The undernourished and the food-insecure persons are in these conditions because they are poor in terms of income to purchase food, or in terms of access to agricultural resources, education, technology, infrastructure, and credit to produce their own food" (Alexandratos 1999). Even in rich countries there are urban and rural ghettos where poverty, not lack of food, is the problem.

Political problems. During the last two decades on through the beginning of the 21st century, there have been many countries whose people have suffered deprivation and starvation caused by political upheavals. Sudan is an example. According to the *New York Times,* an estimated two million Sudanese have died during 17 years of famine, caused by a war between the Arabs in the north and the people in the south of the country over the southern oil deposits (Anonymous 2001). In the 1990s, tens of thousands of hungry Afghans moved to Herat, near the border of Iran, driven by civil war, bad government, and drought. In 2001, they fled to Pakistan. In the Congo, people are fleeing into Zambia, where Angolans also seek shelter. The small nation of Guinea is being overwhelmed by hundreds of thousands of people fleeing a cruel government in Liberia and a civil war in Sierra Leone (Crosette 2000).

Economic and logistical problems. Conway (1997) has summarized other reasons that, despite the Green Revolution, hunger continues in developing countries: economic policies that discriminate against agriculture; restricted markets for farm inputs and outputs; inefficient rural financial institutions, including inadequate access by farmers to credit, inputs, and marketing services; lack of land reform or redistribution; inadequate rural infrastructure, including irrigation, transport, and marketing; lack of investment in rural education, clean water, health, nutrition programs, and family planning; lack of attention to the needs and legal rights of women and ethnic minorities; and lack of development and dissemination of appropriate agricultural technologies.

If these problems are ignored, there is no possibility that world hunger can be alleviated. If these problems were to be solved, then indeed increased production could be helpful. But it is not clear that genetically engineered crops are necessary to achieve this increase. In the report "Agriculture: Towards 2015/30, Technical Interim Report, April 2000" (FAO 2002), researchers in the Economic and Social Department at the Food and Agriculture Organization of the United Nations concluded that the world can produce enough food to meet global demands using current agricultural techniques. Their conclusion does *not* allow for any production improvements from genetically modified crops.

Development in the Sahel. What happens when technological development programs are instituted without attention to social, cultural, and economic aspects? A case study of traditional rice producers in the Sahel of Africa provides an illustration.

The climate in the Sahel region of Africa, made up in part by what is now Mali and Niger, is very dry. Average rainfall is less than 600 mm per year. As a result, the welfare of the Marka, a local ethnic group who are experts in the cultivation of rice, is highly influenced by climatic fluctuations. They have been cultivating native rice since prehistoric times, and they make complex and sophisticated decisions about when to plant and what varieties to plant (McIntosh 1993). Their decisions are influenced by environmental clues—different varieties of rice have different vegetative periods, different adaptations to various flood depths, flood timing, pH tolerance, and fish predation. Different varieties are sown at different time intervals on different soil types.

The knowledge that the Marka possess about rice and its cultivation is secret and has been developed over a long period of time. It is a means of maintaining a specific ethnic identity. Social relations with other groups have become instituted as buffering mechanisms against potential bad times, allowing trade to occur without the necessity of immediate equal compensation. This buffering is useful, for example, with the Bozo fishers, who trade labor, goods, and services with the Marka. The buffering is beneficial to both groups, because weather that favors one group may disfavor the other.

Another important aspect of the Marka system is prioritized tenure on property held in common with the entire ethnic group. A hierarchical system prioritizes access to land, and the rules regulating access to common property have been encoded into local Islamic law. Prioritized access ensures that those with the specialized knowledge are those that make decisions on varieties of rice to be planted, as well as the timing of the planting (Park 1992).

Ensuring sustainability of rice production requires a deep understanding of how various social systems work. Social systems have deep ties to the environment through culturally mediated and specialized relationships (Halstead and O'Shea 1989). To know the physical needs of a particular crop is not enough information to produce consistent quantities in a sustainable manner. Farmers make decisions based on variables that may seem "unscientific," because the farmers are considering these variables from a different temporal and spatial scale than normally understood in the developed world. One needs to understand the evolutionary nature of "secret knowledge" and intergroup relations that function together as part of a subsistence system and that buffer the system against environmental and political variability.

Regional development projects in the Sahel break down this system of rice production. The goals of regional development projects are to increase the national market economy through production of rice and to technically mediate the uncertainty of the climate so as to guarantee a more steady supply to the market (Ba and Crousse 1985). Development programs usually require a change in cultivars from indigenous rice varieties to the Asian variety of rice *Oryza sativa,* which is more marketable and has a higher yield, but requires consistent amounts of water. The knowledge about Asian rice is held by outsiders and is not secret. As a result of development, prioritized tenure on commonly held lands is eliminated, and equal access is gained by those without the "secret" environmental and social knowledge. The traditional allocation system, which is built on the recognition of natural variables, is replaced by a system organized to suit the demands of a capitalist economy.

Development goals of increasing production result in ecological deterioration. For example, in Senegal, 25,000 hectares put under irrigation for rice are now degraded, as inexperienced people quickly erected poorly built irrigation structures in order to satisfy a government requirement for establishing tenure (Ba and Crousse 1985). Polders constructed to control water flow are not flexible enough in times of drought. Polders also affect fishing, as changes in the flow of the river and the displacement of water through polders affect fish breeding and feeding. The transition to a market economy ignores the nature of the Sahelian climate and soils and deprives traditional Marka groups of their ability to respond flexibly in times of environmental distress.

Introduction of transgenic crops into such regions will further accelerate the loss of indigenous knowledge and culture that make the traditional system sustainable. For example, Nigh and colleagues (2000) have pointed out that characteristics of genetically altered grain could spread to local varieties favored by small-scale farmers and dilute the natural sustainability of these races.

Alternative approaches

In developing regions of the world, owners of large farms are much more likely to adopt genetically modified crops because they are better able to afford the seeds. However, small farms are often able to be more productive per unit of land than large farms, because small farms are more likely to be managed intensively (Bray 1994, Castellanet and Jordan 2002). These authors give specific reasons why intensively managed farms may be more productive:

- Small farmers are more likely to plant various crops on the same field, plant multiple times during the year, and integrate crops, livestock, and even aquaculture, making more intensive use of space and time.
- Large farms are oriented toward large land enterprises such as cattle grazing or extensive grain monocultures, while small farmers emphasize labor and resource-intensive use of land.
- Farmers with large holdings are often more interested in land speculation.
- Small farmers are often more interested in sustainability, so that they can pass the farm on to at least some of their children.

- Small farms generally use family labor that is personally committed to the success of the farm, and large farms use relatively alienated hired labor.
- Because small farms have less land, small farmers often apply more labor per unit area.
- Small farms generally tend to use nonpurchased inputs like manure and compost, whereas large farms tend to use purchased inputs like agrochemicals.
- Small farmers may make more efficient use of irrigation.
- Large-scale farmers are less committed to management of other resources such as surrounding forest and streams, which are important for regional sustainability.

Conway (1997) argues that genetic engineering should be included in the list of factors that are important in intensification of agriculture in developing countries. However, Cleveland and colleagues (1994) suggest that incorporating folk varieties into the development of locally based agriculture may be a better approach, because farmer management of selection supports long-term yield stability that has been adapted to local conditions and cultural values. In contrast, genetically modified crops are engineered to perform well where agrochemicals are cheap and easily available, a situation that is not common in regions where hunger is a problem.

Equal time. Just because alternative agriculture cannot solve world hunger today, that does not mean that it should be ignored and that all hope be placed in biotechnology. Technologies by themselves are not enough (Conway 1997).

> "There is a limit to technical cures for social pathologies. Too often the new technologies have been injected into communities with rapidly growing populations already dominated by excessive inequalities where, in the absence of countervailing policies, the powerful and the better-off have acquired the major share of the benefits. As a consequence, a high proportion, over 20 per cent, of the developing world's population is still poor and hungry" (Michael Lipton, quoted in Conway 1997, p. 81).

It may be time to give equal resources to alternative approaches. Shouldn't we give a chance to agriculture that does not rely on genetic engineering? As Wes Jackson of the Land Institute likes to say, "Sustainable agriculture at this point in time is comparable to where flight was with the Wright Brothers in 1903."

Conclusions

The belief that genetic engineering can benefit the small farmer and relieve world hunger has made it difficult to realize that genetically modified crops have already contributed to the financial crisis of American farmers and widened the gap between rich and poor in developing countries. Reluctance to challenge such beliefs has led to massive investments in genetic engineering to the neglect of other more promising but less glamorous approaches. In the United States, such approaches could include decreasing overproduction through elimination of crop subsidies that promote overproduction and using subsidies instead to promote conversion of land to conservation uses. In developing countries, new approaches could mean encouraging rediscovery of local crop varieties that are ecologically and culturally adapted to local conditions. Finally, small farmers in food-deprived countries could be encouraged to grow food for their families and neighbors instead of commodities to be sold abroad by the national government.

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