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Agricultural Biotechnology and the Environment

R.T. Bessin, Department of Entomology, and D.F. Hildebrand, Department of Agronomy

This publication is part of a series that seeks to provide science-based information about discoveries in agricultural biotechnology. The information in these publications comes from the Biotechnology Research and Education Initiative (BREI) committee, which is comprised of a multi-disciplinary team of research, extension, and teaching professionals from the College of Agriculture. The series is designed to help Kentuckians understand and assess the risks and benefits of agricultural biotechnology.

Some people and organizations in the United States and Europe oppose the use of genetically modified (GM) crops because they believe that these crops pose an unacceptable risk to the environment. However, many of the people who have helped develop GM crops believe these crops and the technology they represent may be the solution to some important environmental problems. The environmental issues associated with GM crops are perhaps the most controversial and ironically the most promising. This publication summarizes some of the environmental issues that have been debated, along with the perceived benefits of agricultural biotechnology.

Environmental Issues Associated with GM Crops

ISSUE: Herbicide-Resistant Crops Possibly Becoming Weeds in Following Years

One environmental and agronomic issue associated with GM crops is their resistance to broad-spectrum herbicides. A broad-spectrum herbicide is one that kills a large number of weed species. Roundup™ is an example of a broad-spectrum herbicide. The concern is that the seeds left behind after the harvest of these crops may sprout and become weeds the following year. Some are concerned, for example, that if a farmer uses Roundup Ready™ corn one year and then Roundup Ready soybeans the next year, the Roundup herbicide will not control residual corn that is Roundup Ready. As more crops are developed that are resistant to the same herbicides, this will become more problematic.

Although volunteer plants sprouting from grain dropped from previous crops could become weeds if fields are rotated among crops with the same type of herbicide resistance, relying solely on a single type of herbicide year after year generally is not a good idea. Whether or not multiple crops are tolerant of the same herbicide, relying exclusively on the same herbicide for a long period of time will favor weeds, as well as volunteers, that tolerate the herbicide. With the example of Roundup Ready corn one year and then Roundup Ready soybeans the next year, there are many available herbicides that can control Roundup Ready corn in Roundup Ready soybeans and vice versa. Also, few crop plants can become difficult-to-control weeds because they lack "weedy" characteristics.

ISSUE: Potential Gene Escape and Development of "Superweeds"

One concern with the development of herbicide-tolerant, viral-resistant, or insect-resistant GM plants is that they will breed with wild relatives, resulting in superweeds that are more competitive. More competitive weeds are more difficult to control and may make weed management more complicated, expensive, and perhaps chemically intensive. Weeds that have a competitive advantage will produce more seeds and be an even more serious problem in following years.

It is possible for a crop to cross breed with weeds when the crop is grown in areas with weedy relatives that interbreed. In the U.S., for example, we do not have weeds that interbreed with corn, soybeans, or potatoes, so genes inserted into these plants have a negligible chance of "escaping" when GM plants breed with weedy relatives. However, GM squash and canola varieties can interbreed with wild relatives in the U.S., so the potential for crossing with wild relatives and the effect that it may have on weed populations needs to studied and considered before GM crops receive government approval for commercial production. This is an area of concern that is being addressed by scientists and government regulators.

ISSUE: Impact on Nontarget Organisms

The media have given much attention to the potential impact of GM crops on nontarget organisms, which include all organisms except for the pest that is being controlled. These include mammals, fish, birds, reptiles, and other insects. An ideal pest-control tactic would control the targeted pest but protect other organisms from any harm. An example of a highly specific pesticide is Spod-X™, a beet armyworm virus. This insecticide controls only this single species and is nontoxic even to its close relatives. Examples of nontarget insects to be protected include lady beetles, lacewings, and other insect predators; honeybees and other insect pollinators; and butterflies and other aesthetically pleasing insects.

Media attention has focused on Bt corn and the impact that it may have on monarch butterflies. At one time, some believed that Bt plants would be the ideal control for some crop pests because only the pests that fed on the plant would ingest the toxin, which affects only some plant-feeding insects and no other organisms in the environment. However, some Bt corn plants have relatively high levels of the Bt protein in their pollen, and pollen released from these plants may fall on other plants and be eaten by insects that are not pests. In the case of monarch butterflies, pollen from the Bt corn drifts onto milkweed plants which are common in and near corn fields. As the monarch caterpillar feeds on the milkweed leaves, it ingests the Bt pollen, and some are killed. However, recent research has shown that the pollen from corn travels only a short distance (i.e., several feet) in concentrations sufficient to hurt monarch larvae. Within corn fields during pollen shed, pollen levels on milkweed plants may reduce monarch survival to a limited degree. It should be noted that Bt corn is used in place of insecticide sprays that are more toxic to monarch larvae and adults.

The effect on nontarget organisms is and will continue to be an important issue. New GM crops will need to be evaluated for their potential effects on nontargets. Companies developing these technologies, university scientists, and government regulators will continue to evaluate GM crops for their effects on nontarget organisms. However, a double standard has arisen for regulating nontarget effects—one for insecticides and the other for GM crops. Many of the insecticides used today are considered broad spectrum; that is, they kill a wide range of insects, including beneficials. Many are classified as Restricted Use Pesticides due to their toxicity to fish, birds, or other wildlife. Compared to most insecticides on the market, Bt crops are more selective and potentially less damaging to nontarget organisms.

ISSUE: Development of Pest Resistance

Widespread and intensive use of GM crops that are resistant to pests has the potential of favoring pests that are resistant to the GM crops. Pest populations have demonstrated the ability to adapt to the management tactics that are used to control them. Pests have a long history of developing resistance to any pest management tactic that is used for a long period of time over a wide area, and the possibility of pests developing resistance to GM crops like Bt corn is real. The examples of pests being able to overcome pest management strategies are too numerous to list.

Consider the western corn rootworm beetle in Illinois and Indiana. For more than 20 years, it was effectively controlled through the use of a corn-soybean rotation. The eggs that were laid one summer in a corn field would hatch the following year in what would become a soybean field. This pest had been a problem only with continuous corn. But the beetle adapted. Now a portion of the female beetles lay their eggs in soybean fields, and rootworms are now a serious problem in first-year corn in this area. We should not underestimate the ability of insect pests to adapt.

To counter the ability of pests to develop resistance, farmers using GM crops that produce their own plant pesticides are required by the U.S. Environmental Protection Agency to use resistance-management strategies. For example, with Bt corn, the required resistance-management plan is to plant some acreage with non-Bt hybrids. This is called the "refuge strategy." With the refuge strategy, non-Bt acreage on each farm serves as a refuge, allowing some Bt-susceptible corn borers to survive. University simulation studies have shown that use of required resistance-management strategies will delay or prevent the development of pest resistance.

ISSUE: Antibiotic-Resistant Marker Genes

Another concern is that the use of antibiotic-resistant marker genes in some GM crops may allow harmful microbes to develop resistance to antibiotics. Antibiotic resistance remains a serious issue confronting clinical medicine. The concern is that if microbes become resistant to antibiotics, we might not have drugs necessary to fight disease outbreaks.

Antibiotic-resistant marker genes are included with other genes that are used to modify the GM plants so plant breeders can quickly determine which plants have the GM traits. There is a possibility that harmful microbes could capture antibiotic-resistant genes either in the field from transgenic crops (i.e., crops that have been genetically modified), in their decaying crop residues, or when the transgenic grains are feed to livestock or other animals.

However, others argue that the type of antibiotic-resistant markers used today are not harmful because they are common in nature, and they do not provide resistance to most of the antibiotics used in clinical medicine. Nevertheless, it would be better when at all possible that the biotech-derived crops not contain antibiotic-resistant genes. In fact, this has been an active area of research, and scientists have responded to this concern by developing alternative types of markers for use in the future and phasing out the use of antibiotic markers.

ISSUE: Biodiversity

A trend throughout most agricultural history is the ever-increasing production of fewer crop species in what is called monoculture. Monoculture is the practice of planting large acreages with a single type of crop. Limiting production to just one or a few crops has the effect of reducing the crop diversity of our farmland. This trend has been due to demands of the marketplace and the specialization of farming production systems. A factor that has prevented some farmers from continuous monoculture production of certain crop plants such as corn has been the need for crop rotation for insect and/or disease control. More effective insect or disease control through biotechnology can make it easier and more economical for farmers to grow the same crop year after year.

On the other hand, biotechnology can significantly facilitate efforts to increase biodiversity (see below).

Environmental Benefits Associated with GM Crops

ISSUE: Reduced Pesticide Usage

Reduced pesticide usage is one of the benefits of GM crops that are pest resistant. Currently, GM pest-resistant crops include Bt cotton, Bt corn, Bt sweet corn, Bt potatoes, and virus-resistant squash. These crops are able to resist certain pests and need fewer pesticide sprays. In the past, pesticide usage on cotton, sweet corn, and potatoes has been very high, with some of these crops requiring more than a dozen insecticide sprays per season. However, Bt sweet corn needs less than 15 percent of the insecticide sprays that traditional varieties require.

But Bt crops still need some insecticide sprays. Bt is very selective and protects only against some pests. So, while Bt crops are protected from the primary pests, control of secondary pests may sometimes require the use of insecticide sprays.

ISSUE: Plant Pesticides Impact Less on Nontarget Organisms

GM plants that produce their own plant pesticides include Bt cotton, Bt corn, Bt sweet corn, and Bt potatoes. Rather than needing to be sprayed with an insecticide, these crops produce their own natural insecticide to control some key pests. These plant pesticides are very selective; for example, the type of Bt in Bt corn controls only the caterpillars of some moths and butterflies. The type of Bt in Bt potatoes controls Colorado potato beetles. In addition, the Bt is inside the plant, so only insects that feed on the plant or plant parts are exposed to the pesticide. An exception to this is wind-blown pollen from Bt corn. The Bt corn pollen also contains the Bt toxin. It has been shown in the laboratory to reduce the survival of monarch caterpillars that feed on milkweed dusted with this pollen.

It is important to keep in mind that these GM crops that produce their own plant pesticides require fewer pesticide sprays. Most of the commonly used insecticides that have been sprayed on these crops in the past are referred to as broad-spectrum insecticides. They are generally as toxic to nontarget organisms as they are to the target pest. Plants that produce their own plant pesticides are more selective because they control pests without damaging nontarget organisms. The impact on nontarget organisms is further reduced because fewer broad-spectrum pesticide sprays are required.

ISSUE: GM Crops Complement Biological Control

One group of nontarget organisms that needs to be encouraged is the natural enemies of our crop pests. Natural enemies are composed of a wide array of parasitic and predatory insects and other arthropods. Natural enemies include lady beetles and green lacewings. Control of crop pests by natural enemies is referred to as biological control. Universities, as well as federal and state agencies, have been working for many years to increase the effectiveness of and reliance on biological control.

Unfortunately, biological control cannot prevent crop damage in all circumstances, and farmers often need to apply pesticide sprays. When these sprays include nonselective insecticides, the natural enemy populations are often hurt more than the pest that needed controlling. The pesticide may kill both the pest and its natural enemies, and by killing the pest, it has also eliminated the food source that the natural enemy populations will need to recover. Because of the reduction to its own population and that of its prey, it often takes much longer for populations of the natural enemy to recover than the pest population itself. In the absence of natural enemies, pest populations are able to increase much more rapidly. This increase can result in greater reliance on pesticide sprays after the natural enemies are eliminated.

GM crops that produce their own plant pesticides are more compatible with biological control. Their "built-in" plant pesticides are more selective than most insecticide sprays. In addition, because fewer pesticide applications are needed, they preserve populations of natural enemies, making them still more compatible with biological control.

ISSUE: Increased Yields, Reducing the Need to Expand Agricultural Acreage

GM crops on the market today do not increase yields per se. For example, the GM crops that produce their own plant pesticides do not yield more than traditional varieties; these plant pesticides just protect the plants from yield loss. Differences in yield do not represent the ability of the plant to produce more. Rather, the differences are due to yield losses that traditional varieties suffer from pests. In fact, in the absence of pests, GM hybrids and cultivars should have yields equal to traditional hybrids.

However, GM crops that increase yields are under development, and the future looks very promising. Unless yield increases are able to keep pace with population growth, more land will need to be devoted to commercial agriculture. Current trends show that the amount of prime agricultural land available is decreasing and being converted to nonagricultural uses. Crop yields may need to increase by 20 to 40 percent in the next 20 years in order to feed an expanding population. Using biotechnology to transfer three maize genes into rice, researchers have developed new rice varieties with elevated photosynthesis levels. These new rice varieties can outyield traditional hybrids by as much as 35 percent. Biotechnology provides some of the tools needed to continue to increase the yields of the world's important staple crops.

ISSUE: Biodiversity

The main negative consequence of agriculture (and most other human activity) on the environment is habitat loss. This is especially a problem in developing countries. For example, in Brazil, native habitat, including tropical rain forests, is being plowed under or burned for agricultural production for export markets. With higher yields per unit of land, there will be less need or incentive to destroy native habitat, including rain forests, to grow crops.

A little-known fact is that modern agricultural technology greatly reduces the need to convert natural habitat to agricultural production. Farmers have been able to increase the yield per acre rather than the number of acres farmed to meet the demands of a growing population. Application of modern biotechnology can further minimize habitat loss needed to feed an expanding world population, and it can actually help restore natural habitats for watersheds and wildlife. Natural habitat is nearly always more diverse biologically than farming situations, but farming the most diverse number of crop species is ecologically desirable.

Although GM crops can facilitate the trend toward monoculture, they can also facilitate the introduction of new crop species into commercial agricultural production, thereby increasing the biological diversity of cropped plants. One way this can happen is to allow the use of an already developed and used herbicide on the new crop species. A major dilemma facing the commercial production of new crops is that their production is often not economically feasible without an effective and available herbicide for weed control. But herbicide developers usually will not invest in the development of a herbicide for a crop until it is widely grown. Using biotechnology to transfer a Liberty™, Roundup, or another herbicide-resistant gene into the new crop greatly facilitates its commercial production.

Many environmentalists, including farmers themselves, are very concerned about the loss of biodiversity. Although the increased adoption of conventionally bred crops has raised similar concerns, as a society we want to make sure that we maintain the pool of genetic diversity needed for the future. Scientists continue to work actively to preserve plant species through the preservation of genetic material (DNA). The science of biotechnology has dramatically increased our knowledge of how genes express themselves and has highlighted the importance of preserving genetic material. Biotechnology helps preserve DNA and may even help bring species back from the verge of extinction.

Another concern relates to the narrow range of crops that farmers currently grow. There are only about 35 crops with significant world production. For example, if all farmers grew the same variety of corn, one unstoppable corn blight could easily destroy a huge amount of worldwide corn production. This has been a concern with conventionally bred crop varieties as well. Biotechnology can help in two ways. First, "disaster-resistant" crop varieties can be developed much more quickly through biotechnology than through conventional breeding. Second, biotechnology has the increased capability of developing multiple sub-species of the same crop, tailored to specific agronomic conditions and consumer needs, thereby reducing the chance of an entire corn crop being wiped out.

In addition, because some biotech crops produce their own plant pesticides and allow for reduced pesticide sprays, the potential effects of these pesticides on nontarget organisms are reduced. A concern with traditional pesticide applications has been the movement of pesticides out of the field into soil and water. GM crops can lessen this concern.

ISSUE: Reduced Soil Erosion

A major negative side effect of much crop production is that the need to plow or till the land increases soil erosion. The *no-till* or *reduced-tillage* agriculture practices that resulted from modern agricultural research begun at the University of Kentucky allow farmers to produce crops such as corn, wheat, and soybeans without plowing the land. This kind of agriculture not only reduces the use of fossil fuels and the associated air pollution but also greatly reduces soil erosion while it greatly increases the cleanliness and safety of our drinking water. No-till agriculture can also reduce the need for fertilizer and irrigation water for food production.

New herbicide-resistant crops may help reduce soil erosion. We need to prevent soil erosion in order to maintain farm sustainability and to reduce pollution of streams, rivers, and wetlands. These crops are tolerant of certain nonselective herbicides such as Roundup or Liberty. This allows the producer greater flexibility in terms of when to control weeds. Rather than using preemergence herbicides that may need to be incorporated into the soil, these are applied over the crop and the weeds as they are actively growing. GM herbicide-resistant crops are compatible with and encourage no-till agriculture.

Conclusion

Some genuine concerns have been raised about the possible environmental impact of GM crops, and agricultural scientists need to proceed with caution. On the other hand, GM crops have the promise of combining environmentally compatible methods of food production with reduced chemical usage and increased nutrition. One of the greatest benefits of biotechnology will be to help stem the loss of natural habitat and ecosystems, especially in the tropics.