Environmental Effects of Cultivating Genetically Modified Crops: Regulations and Scientific Findings

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Question: What regulatory agencies are responsible for ensuring the environmental safety of genetically modified crops?

Answer: In the United States, risk assessment and subsequent regulation of genetically modified (GM) crops is shared among three agencies: the U.S. Department of Agriculture Animal and Plant Health Inspection Service (APHIS), the U.S. Food and Drug Administration (FDA), which is part of the Department of Human and Health Services, and the U.S. Environmental Protection Agency (EPA), which is an independent agency in the Executive Branch. Assessment of environmental hazards and risks is primarily the responsibility of APHIS and the EPA.

The nature of specific regulations and the agency that assumes prime responsibility for enforcement of regulations after commercial development of a genetically modified crop depends on the particular characteristics of the GM crop. Although many types of GM crops are in development, presently two types are planted commercially in the U.S. The most widespread commercial GM plantings are soybean, cotton, corn, and canola that have been bred to tolerate spraying of an herbicide such as glyphosate, which is typically formulated as Roundup. These herbicide-tolerant (HT) crops have been genetically engineered to be insensitive to the herbicide.

The second most widespread GM plantings include corn and cotton that incorporate a naturally occurring protein that is selectively toxic only to specific moth or beetle pests. The protein toxin is biochemically synthesized under the direction of a gene that originates from the naturally occurring insect pathogen called *Bacillus thuringiensis* (Bt). Thus, these so-called Bt crops are able to resist pest damage much more effectively than the long-time organic agricultural practice of spraying a formulation of Bt microbial insecticide directly on plants.

Bt crops are called PIPs (plant incorporated protectants) and are regulated as a type of pesticide. Many Bt crops have been developed using different genes encoding variations of the same type of insecticidal protein. Thus, EPA actually considers the specific gene sequence and the plant containing it as a single pesticide.

Some crops have been genetically modified for the potential to tolerate an herbicide simultaneously with resistance to insects. Regardless of the specific genetic traits, any modification of one species of plant using genes from a different species is regulated by all three agencies to ensure protection of human health and the environment.

Each agency requires that crop developers supply certain information prior to commercial planting so that environmental risks can be conservatively characterized and protective regulations applied appropriately.

Question: What laws do the regulatory agencies use to make environmental regulations concerning genetically modified crops and to enforce them?

Answer: In contrast to the diverse countries and regulations of the European Union, APHIS, EPA, and the FDA have been regulating GM crops under laws existing prior to the first commercial releases of HT and Bt crops in the mid-1990s. For example, APHIS derived its authority to develop specific regulations for biotechnology-derived crops under the Plant Protection Act (PPA) of 2000, a Congressional mandate that combined the longstanding laws known as the Federal Plant Pest Act, the Plant Quarantine Act, and the Noxious Weed Act.

APHIS has a program called Biotechnology Regulatory Services that develops appropriate regulations under the Plant Protection Act. APHIS regulations are dynamic and change as new rules are needed. APHIS, as well as all regulatory agencies, publishes proposed draft rules in the Federal Register and allows a public comment period of several months before incorporating practical changes into the draft regulations.

By considering PIPs as pesticides, EPA has used the longstanding regulatory authority of the Federal Insecticide Fungicide Rodenticide Act (FIFRA; amended many times since 1947) to set regulatory requirements for conducting hazard and safety tests and submitting data for risk characterization by the agency.

A parallel law used by EPA to aid oversight and ensure safety is the Federal Food, Drug, and Cosmetic Act (FFDCA; passed in 1938, with subsequent amendments). FIFRA requires registration and labeling of all pesticide products (including PIPs), whereas under the authority of the FFDCA, the agency sets the maximum legal residue levels (i.e., tolerance) ensured to pose a reasonable certainty of no harm.

PIPs thus far have obtained exemptions from the requirements for a tolerance. However, decisions under FIFRA and FFDCA are made only after receiving raw hazard and exposure data from manufacturers tendering petitions for registration and conducting an independent risk characterization.

The Food and Drug Administration obtains its authority under the Federal Food, Drug, and Cosmetic Act and is guided by the provision that food shall be considered adulterated if it contains any substance that may render it injurious to health, or if a valuable constituent (e.g., a nutrient) has been omitted or altered. Furthermore, FDA in 1992 issued a specific policy for food derived from new plant varieties that clarified its interpretation of its authority under the FFDCA. The objective of the agency’s policy was to ensure that relevant scientific, safety, and regulatory issues are resolved prior to commercial release of a new plant variety.

When the issue is environmental protection, APHIS and EPA clearly have the main authority for ensuring that hazards are fully assessed and risk minimized to achieve a reasonable certainty of no harm. FDA is tangentially involved as it determines whether a new food is substantially equivalent to an already commercialized cultivar. Such determinations would help, for example, to inform other agencies for extrapolation of the information to potential effects on wildlife that may browse on crops in the field.

Question: How do federal agencies implement the environmental regulation of genetically modified crops and oversee commercial-scale plantings?

Answer: Before GM crops are released for planting, developers of the cultivar must obtain a permit from APHIS when the crop expresses a new trait. Developers of crops with familiar or well-known traits similar to those already planted must at least notify APHIS of intended releases. Permits are granted after the agency has reviewed all pertinent information that informs whether the genetically modified crop can harm agriculture directly or indirectly through adverse effects on the environment. These regulations apply to both herbicide-tolerant and Bt crops.

Because Bt crops are also regulated as pesticides, they must first be approved and registered by the EPA before they can be released. Thus, APHIS and EPA work cooperatively in ensuring environmental protection. Although EPA does not regulate HT crops as pesticides and thus does not register them, any change in herbicide use on those crops is regulated. In effect, EPA indirectly regulates HT crops when a change in herbicide use can potentially create new environmental or human health hazards.

APHIS and EPA exert regulatory control both during development and after commercialization of genetically modified crops. Regulatory control during development occurs through demands for specific types of information on GM crop hazards and requires that testing protocols follow written guidelines. The information is subject to quality assurance procedures that ensure its validity, and all data must be submitted to the agencies for review. The regulatory agencies, not the crop developers, directly characterize the risk to the environment. Based on the agency’s risk characterization, appropriate commercialization regulations may be applied.

After years of testing of experimental plantings, APHIS can issue an exemption to permitting and place a genetically modified crop into non-regulated status. This regulatory designation allows a GM crop to be grown commercially year after year. However, APHIS can revoke non-regulated status if new evidence reveals that a GM crop shows an unacceptably high potential for environmental harm.

APHIS’s decisions regarding non-regulated status for any GM cultivar (= crop variety) can also be challenged in court through the tort process. Such challenges are typically made when the plaintiff considers APHIS (or any other regulatory agency) to have not followed applicable laws. For example, APHIS was alleged in a lawsuit to not have conducted a proper environmental impact assessment (EIA) under the federal National Environmental Policy Act (NEPA). The case specifically addressed APHIS’s decision to grant non-regulated status to alfalfa and sugar beet bred for resistance to glyphosate herbicide. The federal judge ruled that APHIS had to revoke non-regulated status until a proper EIA was conducted. Pertinently, the court ruling was not concerned about proper review of environmental safety but rather a need to address perceived economic damage to organic crops should cross pollination occur.

EPA will likely continue to regulate Bt crops (as well as other PIPs) as pesticides, and thus the agency maintains active regulatory control throughout the commercial use of the plant. Acceptable practices of production can be altered or limited if the agency finds new adverse effects on human health or the environment. For example, EPA can initiate revocation of the registration of a specific type of Bt crop.

EPA also grants registrant requests for revocation, such as occurred with the Bt corn cultivar StarLink that was bred with a gene for synthesizing the insecticidal toxin called Cry 9C. StarLink corn had only been approved for use in livestock feed but became mixed with stocks designated for human consumption.

Question: Are regulations sufficient to test for potential ecological hazards of genetically modified crops prior to commercial release?

Answer: Testing for ecological hazards is carried out as a research activity by industry, academia, government, and consultants. Research should be considered in light of its objectives. Two perspectives on research can help answer questions about adequacy of testing guidelines used to generate data for informing decisions about the safety of commercial GM crops. Is research formulated to testing basic theory about a system? Is research formulated to help regulators make a decision while minimizing uncertainty? The first question belongs to the realm of basic research, but the second one is part of risk assessment.

Present testing regulations are not designed to generate basic mechanistic information about “how the world works,” although occasionally such information may serendipitously arise. For example, a basic question might be “how does a particular Bt toxin affect non-target insects?” The biochemical means of toxicity is an interesting question and may lead to generalizations about toxicity of microbial proteins in general.

However, knowing a Bt toxin has the potential to affect insect biochemistry does not help a regulator make a specific decision as to the likelihood that such toxin would harm a non-target insect in the field. One reason is that the hypothesis can only be feasibly tested if the toxin is presented to a non-target insect in sufficiently high doses that cause a measurable reaction. Such an experimental design does not provide answers to regulators’ questions about risk, namely what toxin exposure would occur in the field. To help answer such questions, a regulatory agency typically requires specific tests to generate information most useful to decision making.

Genetically modified crops that are bred to resist pests are most likely going to be regulated as PIPs under FIFRA, and therefore the information required for answering regulatory questions are quite similar to those long used for chemical pesticides. The guidelines describe a myriad of tests that answer questions about acute and chronic toxicity.

Acute toxicity testing involves short-term, high-level exposure to a toxin, typically resulting in death or obvious physical trauma. Chronic toxicity testing involves longer-term exposure to answer questions on more subtle effects that can lead to problems with development and reproduction. For ecological considerations, the latter concerns are perhaps most important to predicting the effects of exposure to new plant varieties on population ecology.

The guidelines include mandates for tests in the lab and in the field. However, the guidelines also presume that lack of effects under high-testing doses in the lab is unlikely to have effects on organisms exposed to much lower doses in the field. Such an assumption is reasonable given that the mechanism of toxic action of GM traits, if any, are well characterized by the time ecological testing begins.

In addition to answering questions about specific hazards and how those hazards vary with exposure levels, ecological testing guidelines focus on a diversity of aquatic and terrestrial species. Several representative aquatic invertebrate, fish, and bird species are exposed to a PIP trait, either as the purified protein, an extract from the crop, or as the crop itself. Rodent and livestock feeding studies suffice to inform regulators about hazards to small wild mammals. Non-target insect predators (lady beetles) and parasitoids (parasitic wasps) and beneficial insects (e.g., honey bees, butterflies) are also included in current testing guidelines.

Soil fertility is indirectly addressed by requiring tests on earthworms and prominent soil microorganisms. By focusing on a diversity of species grouped by habitat and major taxa, different trophic levels are automatically included so that predictions about community ecology are feasible.

Testing for ecological harm prior to commercial release cannot possibly include every species under every field scenario. Such an investment in time would be impractical. However, once products are commercially released, the regulations require continual monitoring of effects in the field and submittal of information to the Environmental Protection Agency.

EPA reviews new information to determine whether regulations need to be enhanced, or in some cases whether regulatory approval of a novel PIP trait should be withdrawn. Thus, the regulatory scheme for testing ecological effects is dynamic. As more field data are collected over time, new types of tests may be required if concerns about harm change.

Question: Do GM crops have traits that can adversely affect non-target organisms or their food webs?

Answer: When one considers the wider ecological effects of planting genetically modified crops, only two basic traits need be considered along with their mechanism of action. By virtue of acreage, the vast majority of GM crops are those resistant to herbicides (HT crops), especially herbicides with the active ingredient glyphosate. The greatest proportion of acreage is planted to glyphosate-resistant crops, also known commercially as Roundup Ready.

Soybeans represent the greatest proportion of HT crops, followed by corn, cotton, and canola. Glyphosate resistance is bred into these crops using a gene from a soil bacterium. The specific gene codes for an enzyme called EPSPS in the metabolic pathway that eventually synthesizes aromatic amino acids in all plants and many bacteria. This pathway is absent from animals.

The specific gene encoding the enzyme binds glyphosate very poorly so it is not inhibited by the herbicide. Thus plants with a copy of the resistant EPSPS gene in addition to their native gene can still produce enough aromatic amino acids to survive glyphosate exposure. This specific mechanism of action allows a prediction of the improbability of ecological effects; i.e., aquatic and terrestrial animals are not going to be affected by the genetically engineered version of the enzyme because the protein is very similar to the structure of the native protein that animals have always been exposed to. This assessment is supported by the myriad of laboratory tests wherein no toxicity has been noted following high levels of exposure to the native or bacterially derived EPSPS protein.

The second major trait encompassing widespread plantings is a toxic protein derived from a gene in various isolates of *Bacillus thuringiensis* (Bt). Of course, the gene for this protein is not normally present in plants. Furthermore, several forms of the gene encode proteins with different spectra of toxicity. Each of these proteins is designated with the acronym “Cry” (from “crystalline protein”) and a number/letter designation (e.g., Cry1Ab or Cry3B in corn).

However, nearly 100 years after discovery of the first pathogenic Bt strain, proteins from this bacterium still affect only very specific groups of insects when they are deployed for field use. The most prevalent major groups affected in commercial plantings are presently the moth larvae that ingest corn foliage, stems, and seeds (e.g., European corn borer, corn earworm), the moth larvae eating cotton bolls (e.g., pink bollworm, cotton bollworm), and the beetles eating corn roots (e.g., corn rootworms).

Cry proteins are toxic to insects because of midgut (insect “intestine”) receptors that the proteins bind to, causing severe disruption of the intestinal cell membrane integrity and eventual death of the insect. The toxic potencies of Cry proteins are very specific to a handful of insect species.

Cry proteins are considered selective toxins because most insects are unaffected by them. Furthermore, the intestinal cells of non-target insects as well as all vertebrates cannot bind the Cry proteins to cause an adverse biochemical effect. Thus, based on an understanding of the mechanism of biochemical interactions of the toxin, as well as a myriad of high-dose laboratory tests to determine potency of the proteins to a wide range of animals, effects on non-target animals are unlikely to occur under field conditions where levels of potential exposure are much lower.

As new crop traits are developed using modern genetic modification techniques, they will receive the same levels of scrutiny that current generations of HT and Bt crops have been receiving. The new generation of traits will be deployed on smaller acreages than the current traits given a tendency for increased competition among seed varieties. Such additional plantings will increase the overall area planted to GM crops and may raise concern about landscape level ecological effects. However, no evidence has been generated to indicate such effects have occurred with the current generation of GM crops. Indeed, evidence suggests an absence of such effects amidst plantings consisting presently of about 300 million acres per year.

Question: If some genetically modified crops actually contain toxins, aren't the potential ecological hazards identical to those of traditional pesticides? For example, can the toxins accumulate in animal bodies and be transferred to other animals through the food web?

Answer: If one understands the basic biochemical mechanism of interaction of toxin molecules with an organism's cell receptors and enzymes, then predictions about adverse effects can be made. Such predictions are enhanced by also knowing the pharmacokinetics of the toxin, a field of study asking questions about how quickly toxin molecules are assimilated by an organism, degraded by metabolism, and whether they are stored in the tissues.

In the case of the Bt toxin in GM corn and cotton, the level of protein in the plant does not interact sufficiently with the receptors in non-target animals to cause any biochemical effects. Another way of expressing this lack of toxicity is to conclude that intestinal membrane proteins of non-target animals are insensitive to binding by Cry proteins.

In addition to the insensitivity of intestinal membrane proteins for binding with Cry toxins, when non-target animals are exposed in the field to Cry proteins, the protein is likely to be digested rapidly in the intestinal tract. Such results showing rapid degradative metabolism of Cry proteins have been observed directly with mammalian stomach and intestinal fluid preparations. Because of rapid protein digestion, therefore, the toxin is not stored in an animal's tissues.

Some research has suggested that insect pests that eat the Cry toxins can transfer them to their predators, possibly creating a hazard to these beneficial insects. First, if this hazard exists in the field it is a problem only with contemporary exposure to an insect directly feeding on the toxin. In other words, no long-term storage of the toxin is expected based on its metabolic degradation rate.

However, laboratory experiments have proven that if predators or parasites are affected, it is not from direct toxicity to the Cry protein. Rather, any noted effects are due to the poor nutritional quality of the prey because it becomes sick upon exposure to the toxin. These studies have proven the safety of the presently available Bt proteins to important beneficial predators and parasites.

Question: What is the environmental fate of toxins from genetically modified crops? Are the toxins from GM crops persistent in the soil, and do they move around in the environment? Can these toxins affect soil fertility?

Answer: The traits that are prevalent in genetically modified crops, namely herbicide resistance and insect resistance, are proteins. All kinds of proteins are released to the environment every time any type of crop, GM or traditionally selected, is planted and harvested. Indeed, soil macrofauna (e.g., typically nematodes and various kinds of insects and relatives) and soil microorganisms have all the enzyme systems necessary for breaking down proteins into constituent amino acids for absorption and utilization to build new tissues. Thus, many proteins are rapidly degraded and do not accumulate in the environment. Some proteins bind to soil constituents and their biological activity becomes inactivated.

The EPSPS protein has been occurring in the environment since bacteria (and later plants) first evolved hundreds of millions of years ago. EPSPS could therefore be considered a natural soil constituent that is easily processed by soil organisms. Such a protein should have no more effect on soil fertility than plants in any commercial agricultural system.

Bt proteins are ubiquitous in the environment because research has found *Bacillus thuringiensis* living in just about every sample analyzed. Indeed, Bt was discovered serendipitously as a naturally occurring pathogen of insect moth larvae. Nevertheless, early research on Bt suggested that the isolated Cry proteins could persist in the soil and maintain their biological activity. However, further research showed that only one particular group of Cry proteins (Cry 1Ab) persisted if it became adsorbed to clay particles.

Adsorption of organic compounds to clay has been known for a long time to reduce microbial access to the compounds for metabolism. Studies with other Bt Cry proteins, especially field-based studies, showed lack of persistence with half-lives of a few days to a few weeks (i.e., every few days, half of the amount would disappear) and no accumulation over years of plantings.

Whether Bt Cry proteins can move in soils is dependent on soil type as well as precipitation rates. A lab study does suggest limited movement of Bt vertically in soil, but adsorption to soil constituents moderates this movement. Bt protein can move from fields into adjacent streams, but the protein is found ubiquitously at very low levels regardless of whether Bt corn is planted in a field or a spray of a commercial Bt formulation is used, as is common for cultivation of certified organic crops.

Studies have compared soil microbial bioactivity in fields with Bt crops and non-Bt versions of the same crops. Microbial activity has not differed significantly between the two systems. One issue that might affect soil ecology is whether Bt corn has a significantly different composition than non-Bt corn of the same variety. One laboratory study suggested that Bt corn with Cry 1Ab toxin may have comparatively higher levels of lignin than its non-Bt counterpart. However, a more extensive study based on monitoring corn in numerous fields and examining its constituents showed that Bt corn did not have a higher lignin content. Thus, in consideration of the general lack of effects on microbial activity of soils where Bt crops are grown and the field observation of no substantial difference in constituents among different corn cultivars, a conclusion of no effect on soil fertility is warranted.

Question: Do genetically modified crops have an effect on water quality?

Answer: Testing guidelines under FIFRA require that any GM crop regulated as a pesticide must have toxicity data submitted for the effect of the engineered trait on aquatic invertebrate and vertebrate organisms. These tests examine both the effects of acute exposure over a 48- to 96-hour period and a chronic exposure during critical points of the reproductive cycle. The acute toxicity tests examine how the amount of toxic material can change mortality response. The longer-term exposure studies focus on fecundity, fertility, and development of neonatal offspring. Based on these studies, the EPA can project what the likely risk of adverse effects on a population could be given the most likely worst-case exposure scenario. Thus far, EPA has not considered any aquatic animal’s exposure to a GM crop to be of concern, nor required the imposition of special restrictions as are often imposed on chemical insecticides.

Historically, ecotoxicologists have debated whether the current toxicity guidelines for aquatic organisms are accurately depicting possible hazards to populations and, by implication, to communities with complex food webs. A corollary question is whether the most sensitive aquatic organism is included in the testing guidelines. To start addressing such issues, scientists have been testing nontraditionally tested aquatic insects like caddisflies. Thus far, the preponderance of published studies do not support a hypothesis of direct toxic or developmental effects, nor do they show any adverse effects on caddisfly species and the abundance of other aquatic insects that is related to widespread planting of Bt corn crops. The degradation rate of Bt corn refuse in aquatic systems does not seem different than that of other corn cultivars.

Question: Are genetically modified crops that control insects linked to the widespread decline of wild and domesticated bees? Is there any link with honey bee colony collapse disorder?

Answer: Testing requirements before commercial release of genetically modified crops include toxicity tests with honey bees, similar to what is expected for chemical pesticides. One would not expect the EPSPS protein to be toxic to honey bees, but bee exposure through nectar or pollen is implausible because the enzyme is confined within the plant cell chloroplast, the organelle where photosynthesis occurs.

Very low levels of some Cry proteins have been found in pollen, so it is possible that bees may be exposed because they naturally carry pollen back to their hives. However, toxicity testing has not shown any adverse effects even at concentrations higher than what is expected in the field.

An association between colony collapse disorder and exposure of bees to Bt toxins has not been made at this time. Indeed, exposure to Bt toxin is not even a prevalent hypothesis that is being tested. First, colony collapse disorder is not a singular unitary disease but rather a description of a condition wherein bees fail to return to their hives, eventually leading to collapse of the colony owing to lack of food resources for developing larvae. Second, the prevailing hypotheses on the syndrome range from exposure to certain pesticides to infection by either viruses or microsporidian organisms. Another hypothesis proposes a possible interaction between the diseases and the varroa mite that has long plagued bee colonies. In short, no evidence has yet to emerge suggesting that bees are affected by exposure to Bt toxin.

The plausibility of lack of effects of GM plants on bees is given weight by an observed lack of effects on bees following exposures to Bt sprays, as is common in certified organic agriculture.

Furthermore, colony collapse has been observed in areas of the world where no GM crops are grown, proving that the phenomenon is independent of crop cultivar.

Q: Can planting GM crops over large acreages create a problem with escapees that become invasive in surrounding non-crop ecosystems, similar to the problems created by weeds?

Answer: The APHIS Biotechnology Regulatory Service is assigned the specific task of reviewing all relevant data on possible environmental effects of genetically modified crops that could impinge on agriculture. Thus, the issue of whether release of GM crops themselves pose a risk of weediness has been addressed for all commercially planted GM cultivars. In addition, independent research has examined this issue. After 15 years of field experience, no released GM cultivars have established populations outside of cultivated fields nor acquired weedy traits. This is not surprising because research has shown that most crop varieties tend to be poor survivors outside of cultivated fields.

One issue that has been addressed concerns whether GM seeds from one year’s planting could become “weedy” when the field is rotated to a different crop species. These plants, which are often called “volunteers,” have been an ongoing issue requiring control measures long before the advent of GM plants. These plants have historically been removed by either mechanical roguing or spraying with herbicides. Genetically modified plants are not expected to behave any differently than conventionally bred plants when preventing seed set. A variety of herbicides is still available to adequately control the most prevalent types of HT plants.

Question: Do the crops genetically modified to tolerate herbicide toxicity cause a significant increase in herbicide use? What do we know about the herbicides used on these types of crops? Are the herbicides used for these types of crops just as hazardous as herbicides used on conventional crops?

Answer: Since synthetic herbicides became widely available in the 1960s, well over 95 percent of corn and soybean acreage has been treated annually for weed control. The main result of the widespread adoption of glyphosate-tolerant (HT) crops has been the expected significant increased use of glyphosate while usage of other herbicides has dropped significantly. Thus, herbicide use trends are one of substitution of glyphosate for other herbicides.

Reports of increased pesticide use based on raw pounds applied to a field often implicitly, if not explicitly, associate pounds of product use with hazard. However, such a correlation is based on a false premise that fails to take into account how a compound is used and, more importantly, its potency.

How simply counting pounds of product used as a measure of hazard leads to a false conclusion is aptly illustrated by considering the use of corn gluten meal to suppress weeds. Iowa State University recommends an effective application rate of 800 pounds of product per acre. Thus, in terms of pounds alone, at least 350 times more corn meal would be applied than glyphosate in a single growing season. Yet, corn meal does not have any measurable toxicity. This example argues that toxic potency of an herbicide in addition to how much is used should be the benchmark for determining whether increased hazards exist. In fact, an analysis of toxicological benchmarks used in regulating pesticides reveals that glyphosate is arguably at least ten times less potent than the herbicides it has been replacing. In other words, the overall human and ecological risks appear to have been reduced as older herbicides are replaced by glyphosate.

A final perspective on the use of herbicides in crop production, whether cultivars are considered genetically modified or conventional, should consider what benefits occur. For example, herbicides replace significant amounts of physically demanding hand labor, often allowing just one member of a family to weed hundreds of acres. Because a single judiciously timed herbicide application is sufficient to control weeds, fuel savings can be substantial compared to frequent cultivations when mechanical control is solely used. Herbicides can also facilitate adoption of no-till agronomic management, thereby promoting better soil tilth and less erosion. Finally, research supports lower emissions of greenhouse gases from increased use of no-till soil management. Thus, simply counting how much herbicide is used does not reflect contributions to longer-term sustainability of farming practices.

Question: What is the final conclusion about the environmental effects from GM crops?

Answer: After nearly 15 years of commercial GM crop plantings, no argument of environmental harm has withstood scrutiny, despite the fact that the number of papers focused on testing for environmental effects has grown exponentially. In fact, based on the reduction of insecticide use due to Bt crops and the switch to safer herbicides due to HT crops, a strong argument can be made that the present genetically modified crops have led to enhanced environmental safety in agriculture.

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