UNDERSTANDING GENETICALLY ENGINEERED ORGANISMS IN AGRICULTURE

A SERIES OF WHITE PAPERS

OSU-CAS Committee
September 30, 2014

INTRODUCTION TO THE SERIES

In spring of 2014 the Dean of OSU's College of Agricultural Sciences charged a faculty committee to review and summarize key considerations related to genetically engineered (GE) organisms. The committee chose five topics that engaged faculty expertise and that reflected public interest regarding GE organisms in agriculture.

The five topic areas are:
- Defining GE organisms in agriculture
- How human values affect views on GE crops
- Food safety and regulations for GE organisms in agriculture
- Assessing the net social benefit of GE organisms in agriculture
- Implications of gene flow and natural selection for GE crops

Committee members drafted these white papers as a service to the public for the purpose of providing information from several scientific perspectives. These papers have been reviewed by all committee members and are intended to help inform public conversations about genetically engineered organisms in agriculture.

We hope you find these papers useful in understanding various facets of genetically engineered organisms in agriculture.

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DEFINING GENETICALLY ENGINEERED ORGANISMS IN AGRICULTURE

OSU-CAS Committee
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September 30, 2014

INTRODUCTION

GMO stands for 'Genetically Modified Organism.' However, this is a somewhat flawed designation, since virtually all farmed and domesticated organisms (plants, animals and our pets) have been genetically modified for thousands of years. In our current usage, genetically engineered (GE) refers more precisely to an organism whose genetic material has been altered by means of genetic engineering.

Therefore, a GE organism is defined based on the way in which it was originally produced (genetic engineering), and not on the characteristics (or 'traits') it shows. The traits of a genetically engineered organism can vary dramatically – from herbicide tolerance to vitamin fortification – much as genetic material can vary dramatically among different organisms.

WHAT IS GENETIC MATERIAL?

All organisms harbor genetic material within their genome. A genome is composed of extraordinarily long molecules of DNA, which are organized into series of building blocks of four different chemical types (often designated A, C, G or T). The *sequence* of these chemical types provides the information that allows an organism to grow and reproduce – just as the sequence of letters in this paragraph conveys information to the reader. DNA sequence can also strongly influence an organism's traits, such as eye color, height, seed size, or ability to resist disease.

Advances in biology have allowed scientists to link some traits to distinct stretches of DNA sequence called genes. This knowledge helps predict the biological function of many genes, enabling, for example, genetic testing for inherited disorders in humans, or genetic engineering to produce genes that alter a particular trait in a crop plant.

WHAT IS GENETIC ENGINEERING?

In *civil engineering,* scientific knowledge is used to design and construct bridges or buildings. By analogy, *genetic engineering* uses knowledge of genetics and biology to design and construct DNA sequences, in order to generate particular traits in an organism. Inside an organism, DNA is synthesized biochemically by its cells. However, because it is a chemical, DNA can also be synthesized and/or manipulated outside an organism, in a test tube. Typically, genetic engineering involves assembling distinct stretches of DNA, sometimes derived from different organisms (bacteria, plants, animals), to create a new gene in a test tube. Such a gene is designed with particular characteristics in mind.

The newly assembled gene is introduced back into an organism, where it becomes part of that organism's genetic material. Thereafter, it is copied and passed on to offspring (now categorized as 'genetically engineered') through the regular biological processes of growth and reproduction. Because the new gene is present in these GE offspring, they show the trait associated with that gene. In crop plants, genetic engineering is usually followed by use of more traditional breeding techniques, which help bring the GE trait into conventional plant varieties.

HOW HAVE GENETICALLY ENGINEERED ORGANISMS BEEN USED COMMERCIALLY?

In use since the 1980s, genetic engineering is now widespread in many biologically based commercial applications, due to its ability to generate organisms with desirable traits. In many cases, these traits are unlikely to be found in existing populations. For example, current treatment of diabetes generally uses human insulin – but this insulin has been produced by GE bacteria that have been genetically engineered to produce it, rather than being extracted from human or animal cells. Another example involves cheese: up to 80% of cheese is made with extracts ('FPC rennet') from a GE microbe that produces an enzyme originally from calf stomachs. Using FPC rennet is less expensive than rennet from calf stomach, and reduces the need to slaughter calves (Johnson and Lucey 2006).

Many foods categorized as 'GMO' are produced by plants that have been genetically engineered to express agriculturally beneficial traits. In plants, the most widespread GE traits are currently herbicide tolerance and insect resistance (EFSA 2008). These traits are dependent on the production, in the engineered plants, of proteins originally found in bacteria. However, other GE traits are present in agricultural production on a smaller scale, or are currently in development. For example, a current GE papaya variety is resistant to a viral disease because it is 'immunized' by producing a viral protein itself (Fermin et al 2011). The Golden Rice project has engineered two genes for production of beta-carotene (a precursor for Vitamin A), generating GE rice plants that produce an enriched yellow grain. This enhances the nutritional quality of the engineered rice (Tang et al 2009), and is targeted towards malnourished people in developing countries.

A key point: due to the variety of engineered traits and genes in genetic engineering, it is challenging to develop broadly applicable principles for predicting how a particular genetically engineered organism will affect the environment or the food supply. This is an underlying reason for testing each GE organism separately prior to commercial release, based on the specific concerns associated with each engineered gene and trait (see accompanying paper, "Food Safety Issues with Genetically Modified Foods").

IS GENETIC MODIFICATION ASSOCIATED WITH NON-GENETICALLY ENGINEERED PLANT VARIETIES?

Genetic modification, or alteration of DNA sequences, happens continuously and throughout nature, in many different ways. The genetic modification that occurs in wild and cultivated plants was used by ancient cultures to generate the progenitors of modern crops. For example, bread wheat evolved from the crossbreeding of a primitive wheat with a wild goatgrass species (Shewry 2009). Maize (corn) differs dramatically from its wild, weedy ancestor (teosinte) due to ancient mutations that alter many of its growth traits (Carroll 2010; Doebley 2004). The advent of modern plant breeding in the last century accelerated the use of genetic modification to generate useful traits, and to incorporate them into commercial plant varieties. Plant breeding methods that cause genetic modification include not only crossbreeding (hybridization) between different varieties within a crop species, but also 'wide crossing' with more distantly related and wild plant species; and stimulating mutation with chemicals or radiation (mutagenesis). One common food developed using mutations and plant breeding is sweet corn, in which the sugar content in the seed has been increased (Grubinger 2004).

Some of these traditional approaches introduce more genetic modification than does genetic engineering, and with less predictable results. However, none of these methods generates plant varieties that are categorized as GMOs, even though some traits associated with such breeding techniques are similar to those in genetic engineering. For example, herbicide tolerance is present naturally in certain plant species, or has been generated via mutational approaches (Darmency 2013; Jones et al 2014); insect and disease resistance and nutritional fortification are also traits of commercial interest that have been developed in non-genetically engineered plant varieties.

WHAT DISTINGUISHES GENETIC MODIFICATION IN TRADITIONAL BREEDING FROM GENETIC ENGINEERING?

There are two major distinctions between the genetic modification associated with traditional plant breeding and genetic engineering. First, in genetic engineering, genes are designed and constructed to generate or improve particular traits, using information regarding DNA sequences and their function. Such constructed genes can be designed to incorporate unique combinations of DNA that lead to specific and novel functions. In traditional breeding, choice of genes and traits is limited to those that are present, or have been generated randomly (through mutagenesis), in species that can be crossbred with crop species. Increasingly, traditional breeding is being guided by knowledge of plant genomes and of the DNA sequences associated with useful genes and traits. Traditional breeding can be used to combine traits (initially derived from genetic engineering, mutagenesis, or breeding populations) in the seed stocks that are ultimately released as commercial varieties.

Second, because genetic engineering assembles a gene in a test tube, and then introduces the gene back into an organism, the DNA sequences that are used to build that gene could (theoretically) be derived from any species, including bacteria, animals, or plants. Thus, traits of agricultural value that have been found, for example, in bacteria – such as herbicide tolerance, insect resistance, production of nutrients – can be moved into plant species via genetic engineering. Traditional breeding is limited to working with genes and traits that are present, or have been generated, in species that can be crossbred with crop species. However, it should be noted that genetic engineering does not necessarily involve DNA sequences from widely different species. So-called 'cisgenic' plant varieties are under development that use genetic material that is moved within a species via genetic engineering techniques (e.g., a disease resistance gene from a wild potato to a cultivated potato; Jones et al 2014).

DO ‘GENETIC ENGINEERING’ TYPES OF GENETIC MODIFICATION OCCUR WITHOUT HUMAN INTERVENTION?

Recent advances in DNA sequencing technologies have given biologists an unprecedented view into the processes that have altered genomes over the course of evolution. These data support the idea that genetic changes similar to those present in genetically engineered organisms (i.e., new combinations of DNA sequences resulting in appearance of novel genes and traits) do appear in natural populations on occasion. There are numerous examples in bacteria, plants, and animals of the formation of a new gene (called a ‘chimera’) in a genome by joining two distinct, and formerly separate, stretches of DNA. The movement of DNA from one species to another distantly related species is very rare, but has also been observed (e.g., from bacteria to arthropods; Wybouw et al 2014). One of the most notable movements of DNA sequences across species occurred between bacteria and the ancestors of animals and plants, forming mitochondria (the ‘powerhouses’ of the cell) that allow efficient use of oxygen for biological energy generation. Due to this event, the human genome includes an estimated several hundred mitochondrial genes that originated in bacteria (Timmis et al 2004).

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HOW HUMAN VALUES AFFECT VIEWS ON GENETICALLY ENGINEERED CROPS

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September 30, 2014

INTRODUCTION

Why haven't assurances by the U.S. Food and Drug Administration, the U.S. Department of Agriculture, and scientific organizations convinced everyone to accept genetically engineered crops in agriculture and food?

How do people see the same situation in different ways?

The answer is: people are judging the creation and use of genetically engineered crops based on their *values*.

WHAT ARE VALUES AND HOW DO THEY AFFECT US?

Values affect how we see things. Our values provide a vision of how things work, how things should be, and what the future should look like. Values indicate what is important to us in life and guide our judgment of actions, policies, people, and events (Schwartz 2012). Values act as a lens through which we define what is real (Smith and Gilden 2000).

Our values assess things as good or bad, pleasant or unpleasant, true or false, virtues or vices (Williams 2008), justified or illegitimate, worth doing or avoiding (Schwartz 2012), desirable or undesirable, right or wrong, appropriate or inappropriate (Smith and Gilden 2000). Everyone holds numerous values. A specific value may be important to one person but not important to another. Sometimes differences in values are hotly debated. Agriculture is not free from this and disputes about policies and practices in agricultural research are often about values (Hollander, 1986).

Values serve as standards for how people will act in most circumstances (Williams 2008). "People's actions—what they say, what they write, what they purchase, where they live, how they vote, and how they interact with others reflects their values." (Smith and Gilden 2000: 7)

Cultures, individuals, and groups all have values. Cultures differ in their values and because of that, values vary tremendously throughout the world. Individuals have values that are derived from their culture and personal experience. Everyone has a system of value priorities that characterizes them as individuals (Schwartz 2012). Groups of individuals form “communities of interest” such as religious groups, clubs, civic organizations, and professional societies. These communities of interest, also called “interest groups,” have specific reasons for being and share common interests and values (Smith and Gilden 2000). We join these groups based on their alignment with our values.

For a given issue, there is a continuum of values. Value positions form along the continuum and distinguish the contrasting values people hold (Smith and Gilden 2000). A values continuum for genetically engineered crops might consider technological versus traditional approaches to plant breeding and food production. The values of individuals, non-governmental organizations, scientific societies, corporations, and other interest groups fall along this continuum. For any issue—especially one as controversial as genetic engineering—positions are divergent and can be antagonistic.

HOW DO OUR VALUES AFFECT OUR PERCEPTION OF GENETICALLY ENGINEERED CROPS?

Values affect how people act, but their effect is rarely conscious. Values enter our awareness when one is confronted with something that has implications for the values one embraces (Schwartz 2012).

The issue of genetically engineered crops has become more than a debate over contrasting positions. The issue is political, and positions are often polarized. We have experienced similar polarization in environmental conflicts over salmon and old growth timber and in social conflicts over abortion rights and gay marriage. As Stone (2010: 386) notes, “Conflicts over GM [genetically modified] crops have been fierce because there is so much at stake: ecologically, economically, and politically.” Whether one views genetically engineered crops as representing, at one extreme, a bright future, or at the other, the avarice of corporations, is based on the values of the individuals and groups involved in the issue. As long as there are those who feel that only their values have merit, the conflict will continue (Smith and Gilden 2000).

Often, people want to change the values of those who oppose them, and one of the most common ways to change values is through education. “We assume if people have the right facts, then they will support what we believe the facts show. However, education will not work unless it addresses the underlying value concerns that people have” (Smith and Gilden 2000: 37). For instance, a common view based on the values of supporters of genetically engineered crops in industry and academia is that 1) they are safe and 2) the growing need for food requires continuous improvement of plants and animals (Stone 2010). However, others have value concerns that are not addressed by that view, such as:

- Corporate control over agriculture (Lewontin 2000)
- Patenting genes and restricting access to the genome (Stone 2010)
- Advance of the consolidation of wealth and power (Stone 2010)
- The biodiversity available to farmers controlled by seed companies (Marsden 2006)
- Desire for a natural agricultural future (Marsden 2006)
- The religious morality of creating or patenting new life forms (Warner 2000 and 2001)
- The threat to the virtue and values of agricultural communities (Berry 1977 in Burkhardt 2001a)

Indeed, examining genetically engineered crops through a human values lens reveals the debate is not strictly scientific. The focus for some people has been on consequences—weighing benefits versus risks; the focus for others has been questions of intrinsic right and wrong (Scoville 2001). And, there are other ethical perspectives, including self-determination, transparency, morality, and nature (Burkhardt 2001a).

The issue of genetically engineered crops is really four separate issues that are generally closely linked:

- The ethics of genetic engineering (whether it is right or wrong, good or bad)
- The products commercialized using the technology and associated risks and unintended consequences (whether or not these crops are effective in meeting their goals or will or will not cause environmental, health, or other problems)
- Labeling food products with genetically engineered ingredients (whether consumers will choose to purchase or reject food from genetically engineered crops, based on the consumer's right-to-know versus confusion regarding genetically engineered ingredients).
- The control by corporations of seed property rights through patents and licenses (what type of seed, the cost, and even whether some seed is available).

When examined as four separate issues, the values of individuals may or may not align perfectly with what we think of as "pro" or "anti" camps; or they may tightly align themselves with one camp based on how strong an individual's values are about one of the issues.

The tone of the debate surrounding genetically engineered crops has been fierce, reflecting what Rollin (1995) refers to as "Moral Sumo" and "Moral Judo." Moral Sumo is a combative style of argument prevalent nowadays. Its strategy is to overwhelm one's opponent with an arsenal of facts and logic and prove the opponent to be wrong. Moral Sumo may win some academic arguments but may not affect any real change. Moral Judo, on the other hand, is an exercise in finesse. Its goal is not to prove the opponent wrong but instead to lead him/her to where there can be agreement. This is more likely to result in discourse that leads somewhere (Burkhardt, 2001b). Understanding that everyone—consumers, scientists, advocates of all positions—has values that affect how he or she view genetically engineered crops is a step toward a more sensible discussion.

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FOOD SAFETY ASSESSMENT AND REGULATIONS FOR GENETICALLY ENGINEERED ORGANISMS IN AGRICULTURE

OSU-CAS Committee
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September 30, 2014

INTRODUCTION

The safety of our food supply is an important public concern, whether the food is derived from conventional methods, organic production, or biotechnology. The assessment of the safety of genetically engineered (GE) organisms, in particular, in our food supply is critical. The available scientific evidence suggests that the biotechnology currently used in genetically engineered organisms does not present food safety issues that differ from traditional agricultural or breeding practices. Furthermore, there is no verifiable scientific evidence that consumption of a GE organism has resulted in adverse health effects. This paper explores questions related to food safety and regulations for GE organism s in agriculture.

WHAT ARE FOOD SAFETY CONCERNS WITH GENETICALLY ENGINEERED ORGANISMS ?

When assessing food safety, many regulatory agencies test the final product and not the process of developing the food. If the new food produced through biotechnology is essentially the same as its existing counterpart, regulatory agencies generally conclude the new food to be equally safe. This concept is known as *substantial equivalence* and serves as the basis for evaluating the safety of GE organism s in the U.S. and many countries. If the food and/or its new ingredients are *substantially equivalent* to existing foods or ingredients, it is treated like conventional foods with respect to certain aspects of its safety. Food or food ingredients that have been used safely over long periods of time, or foods that are *substantially equivalent* in nutritional characteristics, do not require additional extensive safety testing.

However, GE-associated traits or substances that raise scientifically-based safety issues require additional testing in the laboratory or in animal models. In this assessment, we do consider differences in nutritional content between conventional and biotechnology-derived foods, as well as the potential for production of allergens and novel toxins.

WHAT REGULATIONS EXIST TO TEST GENETICALLY ENGINEERED FOODS?

GE food commodities and products made from them are under the regulatory control of three U.S. federal agencies:

The Food & Drug Administration

The Food & Drug Administration (FDA) is responsible for the safety and labeling of foods and animal feeds from all crops, including those that are genetically engineered. The FDA requires full evaluation of GE foods by chemical, biochemical, and nutritional analyses to assess: uncharacterized DNA sequences; significantly altered nutrient levels, or anti-nutrients; different composition relative to existing foods; potentially allergenic or toxic proteins; and/or new selection marker genes (EPA 2012). Specific testing includes: total food and feed analysis by composition data and proximate analyses of fats/oils, carbohydrates, proteins, minerals, water content; amino acid homology; potential allergen assessment; digestibility; acute oral toxicity; animal performance; and identities and levels of toxicants.

The FDA's labeling policy for GE foods is the same as for conventional foods, and it assures that consumers are given information about changes in nutrition, health safety, or food quality in the end product. FDA-mandated labels are not used to provide information about the process by which the food is grown or produced. However, if a GE food is significantly different from its conventional counterpart, the food must be labeled to indicate the difference. For example, changes in the nutritional profile are declared if the GE food is created using genetic information from a previously recognized allergenic source (such as peanut, soy, or wheat) or if the new protein has characteristics of known allergens.

U.S. Department of Agriculture

The U.S. Department of Agriculture – Animal and Plant Health Inspection Service (USDA-APHIS) regulates and oversees the environmental consequences, safety, and field-testing of biotechnology-enhanced plants. The agency's role is to ensure that field tests of GE crops are conducted under controlled conditions and that any unusual occurrences are reported. APHIS approval must be obtained prior to field-testing or marketing a biotechnology-derived plant. A bio-safety peer-review committee of scientific experts provides oversight. Factors considered before approval is granted for release of a new GE plant variety are:

- the genetic material is stably integrated;
- plant modification does not contain genetic material derived from an animal or human pathogen;
- the function of the genetic material is known, and its expression does not result in plant disease;
- introduced genetic material does not produce an infectious entity, or encode substances likely to be toxic to non-target organisms likely to feed on the plant; and,
- new GE sequences do not pose significant risk for creating a new plant virus.

Once the appropriate and sufficient data have been collected and submitted to the agency regarding the environmental impact of a biotech-derived plant, the developers of the plant can petition APHIS for "nonregulated status." This status means that the plant no longer needs to be regulated as a potential risk or pest.

U.S. Environmental Protection Agency

The U.S. Environmental Protection Agency (EPA) evaluates food safety and environmental issues associated with plants and microbiological organisms that produce new pesticides and pesticide products (insecticides, herbicides). Bt (*Bacillus thuringiensis*) corn and the pesticide Bt product it contains fall under EPA's jurisdiction, for example. The agency reviews effects of the plants on the environment (toxicity) and fate in soils (residuals); sets tolerance levels for pesticide residues; determines acute oral toxicity, typically in animals; evaluates human health and safety data; reviews an insect resistance management plan; approves experimental use permits; and authorizes product registration for new pesticides.

WHAT TOXICOLOGICAL STUDIES ARE CONDUCTED TO DETERMINE POSSIBLE RISKS FROM CONSUMPTION OF A GENETICALLY ENGINEERED ORGANISM?

Since the composition of genetically engineered foods differs little from their conventional counterparts, the potential for adverse health effects should not differ substantially. However, given the importance of food safety issues, several types of toxicological testing have been developed to assess GE foods. Most of these are based on single chemical assays, such as structural analysis or allergen testing (SOT 2002).

Food allergies restrict millions of people in the U.S. from eating natural and conventionally produced food. While new or higher levels of allergens would not be expected in genetically engineered foods compared with their conventional counterparts, scientists have a variety of approaches to assess this risk. The first is to determine if there is structural similarity with proteins of interest and known allergens. Another approach is to determine if new proteins react with specific antibodies, known as IgE antibodies. A separate technique determines the digestibility of the protein of interest in simulated gastric fluid. A good correlation exists between resistance to digestion and potential for allergenic properties. These approaches, while robust, cannot completely characterize all possibilities for all allergenic individuals.

Before making a regulatory decision about genetically engineered pesticides used on plants, EPA requires several types of toxicological data (EPA 2012). These data include identification of any new proteins or genetic material; mammalian toxicity tests of the new proteins; comparison of the new proteins with known allergens; several ecological toxicity tests; and the amount of time it takes for the new protein to degrade. EPA conducts these tests on a range of doses, including doses that are 100 times higher than those expected in normal conditions.

WHAT DOES THE SCIENTIFIC COMMUNITY SAY ABOUT THE SAFETY OF GENETICALLY ENGINEERED ORGANISMS IN FOOD?

Extensive food safety testing is conducted on genetically engineered foods prior to their release. Therefore GE foods have undergone considerably more scrutiny than conventional foods, which have been bred using classical breeding and mutation methods. Does this mean that GE foods are 100% safe? A statement that claims 100% safety cannot be made about *any* food – be it conventional, genetically engineered, or organic. For example, a peanut, whether grown conventionally, organically, or genetically engineered, can cause severe allergies in sensitive individuals.

Based on the perspective of government regulators and independent scientists who have studied the safety and applications of modern biotechnology, the overwhelming consensus is that genetic engineering technology is safe in foods. GE technology has been endorsed by the Institute of Food Technologists, the U.S. National Academy of Sciences, American Association for the Advancement of

Science, National Research Council, American Dietetic Association, American Medical Association, Center for Science in the Public Interest, and the World Health Organization, among others.

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ECONOMICS OF GENETICALLY ENGINEERED CROPS IN AGRICULTURE: ISSUES FOR CONSIDERATION

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September 30, 2014

INTRODUCTION

The adoption of genetically engineered (GE) crops (also known as GMOs) in the U.S. began in 1996. It has been limited to a small number of crops, but now accounts for about half of U.S. cropland. By 2013, at least 90 percent of corn, cotton and soybeans planted in the U.S. were genetically engineered (Ervin 2014). Other GE crops include sugar beets and papaya. Internationally, GE crops have grown in economic importance, including soybeans in Argentina and Brazil, canola and corn in Canada, and cotton in China, India, Mexico, and Australia.

The information presented in this paper addresses questions about the economic and market effects of genetically engineered crops. Unless indicated otherwise the information is based primarily on the U.S. experience with soybeans, corn and cotton during the last 15 to18 years since these crops have been introduced and expanded. Given this relatively short period of time, some aspects of the long-term economic effects of these crops cannot be assessed based on available evidence. This caveat is relevant in particular to the effects of herbicide resistant weeds on farm-level costs and net benefits.

HOW HAS THE INTRODUCTION OF GENETICALLY ENGINEERED CROPS AFFECTED FOOD PRODUCTION AND FOOD PRICES?

Following the adoption and expansion of GE crops, many farmers have experienced lower costs of production. Many have obtained higher yields, mainly because of reduced pest damage by using GE insect-resistant crops.By contrast, yield increases for GE herbicide-tolerant crops have not been definitively documented. Many farmers have benefited economically from the adoption of genetically engineered Bt (*Bacillus thuringiensis*) crops by using lower amounts of or less expensive insecticide applications, particularly where insect pest populations were high and difficult to treat before the advent of Bt crops (Ervin et al. 2010).

Although it is difficult to isolate the yield changes due directly to the introduction of GE crops, studies have found U.S. yield gains to be only about 10 percent for cotton and 5 percent for Bt corn. These estimates are for the "gene effects" only, as distinct from the effects of also using other inputs (fertilizer, labor) to boost yield.

The effects of GE crops on total production (yields and acres) are more difficult to assess. Careful estimates have found that the overall effect on supply (due to both yield and acreage changes) varies from a low range of 2 to14 percent to a high range of 9 to19 percent of total corn supply (Qaim 2009; Barrows, et al., 2013; Sexton, and Zilberman 2013). The smallest estimates are for the U.S., Spain and South Africa.

It is difficult to evaluate how these production increases have affected market prices. One study has calculated that the adoption of genetically engineered corn lowered prices by 13 percent, and for cotton by 18 percent. For GE soybeans, the estimated price reduction ranged from 2 to 65 percent (Barrows et al. 2013). In general, however, the effect GE crops have had on prices received by farmers in not well understood (Ervin et al. 2010).

HOW LARGE HAVE THE ECONOMIC BENEFITS BEEN FROM GENETICALLY ENGINEERED CROPS, AND HOW HAVE THEY BEEN DISTRIBUTED AMONG PRODUCERS, CONSUMERS, AND SEED DEVELOPERS?

Increased production will generally lead to lower prices, which will benefit consumers but comes at the expense of farmers. A small number of studies estimate the share of the benefits accruing to farmers. One study concluded that the share of gains accruing to farmers was between 5 to 40 percent; seed developers were estimated to have captured 10 to 70 percent of the benefits; and the share going to U.S. consumers was estimated to be between 6 and 60 percent. Consumers in the rest of the world capture between 6 to 30 percent of the total benefits in other countries.

Some studies have found mixed evidence on the net return from adoption of GE crops. For example, a survey of evidence for net returns from adoption of GE herbicide-tolerant soybeans found that the evidence is inconclusive since some studies found no significant difference between net returns of adopters and nonadopters (Fernandez-Cornejo et al., 2014).

The global net benefit to producers from 1996 to 2009 has been estimated to be $65 billion, of which $30 billion accrued to U.S. producers (Brooks and Barfoot, 2012). Estimating the overall benefits of GE crops and the distribution of those benefits is an ongoing area of research.

The gains or losses to specific consumer and producer groups (e.g., GE crop producers versus non-GE crop producers) are difficult to predict. Some market analysis has concluded that all farmers who adopt GE crops do not necessarily gain from their introduction to the market; all consumers who object to GE crops do not necessarily lose from their introduction to the market; all farmers who refuse to grow GE crops do not necessarily lose because of their introduction; and all consumers who accept GE crops do not necessarily gain from their introduction (Desquilbet and Bullock 2009).

Another category of potential beneficiaries are farm workers. The data suggests that adopters of GE crops experience increased worker safety and greater simplicity and flexibility in farm management, benefitting farmers even though the cost of GE seed is higher than non-GE seed. Newer varieties of GE crops with multiple GE traits appear to reduce production risk for adopters (Ervin 2010).

HOW COSTLY WOULD IT BE TO LABEL GENETICALLY ENGINEERED COMMODITIES?

In order to label non-GE crops, they would have to undergo segregation and identity preservation which would involve additional costs for seed producers, farmers, and grain handlers in the U.S. Farmers would have to clean planting and harvesting equipment; product handlers would have to dedicate equipment and handling channels, one for GE crops and one for non-GE crops). For corn, an additional significant cost comes from preventing pollination of non-GE varieties by GE pollen at the seed and farm production stages. Tolerance levels are a key element of the costs of segregation (Bullock and Desquilbet 2002).

Very few studies have estimated the costs of segregation and identity preservation for crops like corn and soybean. Bullock and Desquilbet (2002) estimated the costs of on-farm segregation and identity preservation to be small ($0.07/ton). They estimated the costs of testing from farm to destination to be $0.87/ton for soybeans and $3.31/ton for corn.

In current segregated markets, such as exports to Japan, there is a premium price for non-GE products in the marketplace, but this cannot be interpreted as the additional costs of segregation and identity preservation alone because these premiums would also reflect the higher costs of production on-farm (due to lower yields, for example), and the demand-side willingness to pay a premium for non-GE products by some consumers.

Data from these export markets can provide an indication of the upper limits on these costs, however. Relying on the assumption that producers and contractors would not be willing to take a loss on these products, Bullock and Desquilbet infer from price data in exports to Japan that farmers contracting for non-GE soybeans receive a premium of $7.50/ton, and so this can be seen as an upper limit on the costs associated with non-GE segregation and identity preservation. Similarly in the case of handlers and exporters, Bullock and Desquilbet conclude that the additional costs for segregation and identity preservation in the marketing chain must be less than $20/ton.

Segregation and labeling of genetically engineered products could affect different consumer groups. Among consumers with different attitudes toward GE crops, it is difficult to know which group will benefit by the introduction and segregation of non-GE crops. A study of this topic finds, for example, that consumers who are indifferent toward genetic engineering may stand to lose more from their introduction than do consumers who oppose genetic engineering (Desquilbet and Bullock 2009).

ARE THE BENEFITS FROM GENETICALLY ENGINEERED CROPS SUSTAINABLE?

A full assessment of the sustainability of GE crops is an ongoing task, limited currently by information gaps on certain environmental, economic and social impacts. Ervin et al. (2010) reviewed existing peer-reviewed information and, with a focus on farm sustainability, concluded that genetic-engineering technology:

> "… has produced substantial net environmental and economic benefits to U.S. farmers compared with non-GE crops in conventional agriculture. However, the benefits have not been universal; some may decline over time; and the potential benefits and risks associated with the future development of the technology are likely to become more numerous as it is applied to a greater variety of crops."

In particular, when adopting herbicide-resistant GE crops, farmers substitute the herbicide glyphosate for more toxic herbicides. However, they say "the predominant reliance on glyphosate is now reducing the effectiveness of this weed-management tool.". Ervin et al. (2010) go on to indicate that:

"weed problems in fields of herbicide resistant crops will become more common as weeds evolve resistance to glyphosate or weed communities less susceptible to glyphosate become established in areas treated exclusively with that herbicide. Though problems of evolved resistance and weed shifts are not unique to herbicide resistant crops, their occurrence, which is documented, diminishes the effectiveness of a weed-control practice that has minimal environmental impacts. Weed resistance to glyphosate may cause farmers to return to tillage as a weed-management tool and to the use of potentially more toxic herbicides."

Data reported in *Weed Science* indicate that herbicide resistance was found in an estimated 61.2 million acres nationwide in 2012, or about double the acreage found in 2010, based on a survey conducted by Stratus Agri-Marketing. Iowa State University weed specialist Mike Owen reports that the Iowa Soybean Association showed about 65 to 70 percent of Iowa soybean fields have resistant weeds to more than one herbicide (Iowa Soybean Association 2014).

Because pollen and seeds from many weed species can disperse between farms on equipment, animals, and in the air, the incentives are reduced to adopt best management practices that will maintain the effectiveness of glyphosate. This represents a "tragedy of the commons" problem when a farmer's pesticide-use decisions do not take account of the effects on nearby farmers (Fernandez-Cornejo et al., 2014). This phenomenon has contributed to overreliance on glyphosate, a reduction in the diversity of weed management practices, and the evolution of glyphosate resistance in some weed species. Without interventions to change these incentives, the further evolution of glyphosate-resistant weeds can be expected to lead to higher management costs, reduced yields and profits, and increased use of less environmentally benign herbicides (Fernandez-Cornejo et al., 2014).

Other findings from Ervin et al. (2010) include:

- Adoption of herbicide resistant crops complements conservation tillage practices, which reduce the adverse effects of tillage on soil and water quality.
- Insecticide use has decreased with the adoption of GE insect-resistant crops. The emergence of insect resistance in Bt corn has been low so far and of little economic and agronomic consequence; two pest species have evolved resistance to Bt corn in the United States.
- Gene flow to non-GE crops has been a concern for farmers whose markets depend on an absence of GE traits in their products. The potential risks presented by gene flow may increase as GE traits are introduced to more crops.
- Given that agriculture is the largest source of surface water pollution, improvements in water quality resulting from the complementary nature of herbicide-resistance technology and conservation tillage may represent the largest single environmental benefit of GE crops. However, the infrastructure to track and analyze these effects is not in place.

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In spring of 2014 the Dean of OSU's College of Agricultural Sciences charged a faculty committee to review and summarize key considerations related to genetically engineered (GE) organisms. The committee chose five topics that engaged faculty expertise and that reflected public interest regarding GE organisms in agriculture.

Committee members drafted these white papers as a service to the public for the purpose of providing information from several scientific perspectives. These papers have been reviewed by all committee members and are intended to help inform public conversations about genetically engineered organisms in agriculture.

IMPLICATIONS OF GENE FLOW AND NATURAL SELECTION IN GENETICALLY ENGINEERED CROPS

OSU-CAS Committee
September 30, 2014

WHAT IS GENE FLOW?

Gene flow is the change in gene frequency in a population due to movement of genetic material, individuals, or groups of individuals from one place to another. Gene flow was one of the first issues raised about the introduction the genetically engineered (GE) crops.

In plant crops, gene flow occurs via pollen and seed movement. Gene flow happens to some degree in all plant crops, whether genetically engineered or bred traditionally; it even happens in predominantly self-pollinated crops, such as wheat and rice. Gene flow is not generally considered to be an issue in crops using traditional breeding, unless the crops are being grown for seed and genetic purity is neecessary.

Gene flow via pollen requires genetic compatibility between species; the species must occur in the same area and their flowering periods must overlap. It is difficult to predict how far a pollen grain will move. Most pollen is viable for only a matter of hours. Gene flow via pollen cannot be prevented with the technology that is now being used to breed crops, whether through biotechnology or traditional breeding.

Gene flow via seed dispersal happens through natural dispersal, such as water and wind ,and through operations in the agricultural production system, such as planting, harvest, and transport. Gene flow via seed cannot be prevented and mitigation is difficult.

Adventitious presence is the unintended presence of genetically engineered material in an agricultural commodity and can occur through pollen or seed movement. Adventitious presence is also referred to as *low level presence*.

WHY ARE PEOPLE CONCERNED ABOUT GENE FLOW?

Gene flow from GE crops to organic and conventional crops is a big agricultural concern, primarily market driven and based on consumer preference. USDA organic regulations do not permit the planting of GE crops but do not preclude the sale of a crop as organic if there was pollen flow from a neighboring GE crop. However, organic markets may refuse to accept the product if, during testing, it is found to contain a GE trait. There are conventional growers who are producing guaranteed non-GE crops who share the same concerns about *adventitious presence* that would prevent the sale of their products.

Non-agricultural issues of gene flow are related to the consequences of genes flowing from GE crops to native or naturalized species. For example, there are concerns that gene flow would reduce biodiversity, or that increased weediness of non-native species would negatively impact native or endangered species. In the U.S., GE cotton and canola are the only commercialized genetically engineered crops that have related species that occur outside of agricultural cultivation.

Creeping bentgrass has several sexually compatible native or naturalized species. Hybrids between GE creeping bentgrass and redtop and rabbitfoot grass were identified outside of cultivated fields of GE creeping bentgrass, grown for seed in Oregon but never approved for commercial sale. Gene flow between GE alfalfa and feral populations is likely if the plants are within the range of pollinator movement. Other GE crops under development, for example wheat and rice, have compatible species that occur in the areas of production. Depending on the trait, gene flow might expand the area where these species occur. For example, a gene that imparts disease resistance, or drought or salt tolerance, might lead to a weed that would survive in a new environment and could therefore negatively impact the species in that environment.

HOW CAN GENE FLOW BE REDUCED?

Gene flow via pollen can be reduced using separation in time and space so that compatible species are not flowering at the same time or are located far apart so the opportunity for cross pollination is reduced. Biological barriers such as male sterility or, in an outcrossing species, placing the transgene only in the maternal parent, can reduce gene flow via pollen. Mapping systems have been used to address isolation distances for production of some crops. Field locations are marked and growers can determine the proximity of a compatible crop.

Gene flow via seed can be reduced by monitoring each operation, cleaning equipment such as planters and combines, producing crops where volunteers are easily identified and controlled, or producing crops where there is a reduced chance of seed mixing to occur.
It is important to recognize that gene flow *will* occur. The only way that coexistence between GE and non-GE crops can be achieved is to set tolerances for adventitious presence, because it is impossible to guarantee zero gene flow.

GE CROPS AND NATURAL SELECTION OF RESISTANT BIOTYPES

The widespread planting of GE crops resistant to glyphosate and Bt (*Bacillus thuringiensis*) has led to the evolution of resistant weeds and insects because of increased selection pressure.

The increased use of glyphosate on so many acres quickly selected resistant weeds. In particular, two glyphosate-resistant pigweed species, Palmer and waterhemp, are widespread in fields where GE glyphosate-resistant crops were produced. The resistant weeds have resulted in changes in production systems, increased cost of weed control, and in some cases, growers reverting to tillage and hand weeding to manage the weeds. Glyphosate-resistant weeds are not always associated with the GE crops but have evolved under conventional production, especially in orchards where glyphosate has been used for many years and was often applied multiple times during a given year. However, the number of acres infested with glyphosate-resistant weeds is much greater in association with glyphosate-resistant crops.

Genetically engineered Bt-resistant corn contains a gene or genes from a soil bacterium that allows it to produce a toxin that kills specific insect pests. Initially. in order to delay resistance, the U.S. Environmental Protection Agency required that growers of Bt-resistant corn plant 20% of their corn acres to non-Bt-resistant corn. This area was referred to as a 'refuge.' The refuge was planted to maintain susceptible individuals that could mate with resistant individuals that might be selected within the Bt corn fields and thus reduce the number of resistant offspring. Western corn rootworm with resistance to one of the Bt toxins used in GE corn was identified in 2009 (Gassman et al. 2011) and subsequently western corn rootworm with cross-resistance to multiple Bt toxins were identified (Gassman et al. 2014). The delay in evolution of Bt resistance as compared to glyphosate resistance was likely due to the requirement for the refuge. However, EPA has relaxed the acreage requirement for the refuge, which could lead to the evolution of more resistant populations .

Insects with resistance to Bt toxins have the potential to limit the usefulness of spraying Bt on non-GE crops including organic crops where Bt is one of the few approved insecticides. Although not common, other insect species resistant to Bt toxins evolved which were not associated with the use of GE crops.

REFERENCES (PENDING)