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Genetically Modified Crops and Biological Conservation on Farmlands

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ABSTRACT
The human population is forecasted to approach 11 billion people by 2100 and increased demands for agricultural production are expected. A sustainable approach to agriculture will need to balance increased production with conservation of biodiversity and ecosystem services. Genetically modified (GM) crops designed for pest resistance and herbicide tolerance, among other traits, have been rapidly adopted since their introduction in 1996. Their widespread use represents a profound change in global agriculture. This case study explores how GM crops may influence agricultural management practices, and the subsequent effects on diversity and ecosystem function on farmlands. The case study describes the distinguishing features of GM crops, what GM traits and crops are available for commercial use, and adoption patterns. The exercise then presents the following three hypothetical scenarios taking place on a corn farm in Iowa in which users are asked to infer potential effects on biological conservation: 1) converting natural areas to farmland; 2) adopting insect-resistant Bt corn; and 3) adopting herbicide-tolerant corn. The exercise poses questions that require interpretation of data and critical thinking skills to address complex issues. Upon completion of the exercise, users should have a more nuanced understanding of GM crops and their role in biological conservation.

LEARNING OBJECTIVES

In light of the rapid changes in agriculture due to advancements in plant biotechnology, completing this exercise will allow you to:

1. Identify the factors that distinguish GM crops from other crops.
2. Describe how management practices change when GM crops are introduced into an agro-ecosystem.
3. Consider how GM crops and associated management practices influence biological diversity and ecosystem services and think critically to make a decision based on the evidence provided.

This exercise is designed to foster the practice of critical thinking—a habit of mind characterized by the comprehensive exploration of issues and evidence before accepting or formulating an opinion or conclusion (Rhodes 2010). Throughout this exercise you will be asked to apply your critical thinking skills in the context of genetically modified crops and biological conservation on farmlands.

INTRODUCTION

Genetically Modified Crops: A New Revolution In Agriculture

In the mid-20th century, widespread changes in agricultural practices led to what was known as the Green Revolution. During this time, advancements in farm management techniques, development of high-yielding crop varieties, and distribution and use of fertilizers and pesticides increased agricultural production worldwide, greatly reducing hunger (Tilman et al. 2002). Since then, the global human population has more than doubled from approximately 3 billion to 7 billion people, due in part to these advancements in agriculture. However, it is estimated that about 14% of our population is malnourished (Sanchez and Swaminathan 2005), and the number of people facing chronic food deprivation has increased to nearly 821 million as of 2017 (FAO et al. 2018). In addition, the United Nations (2017) predicts that the human population is expected to continue to grow and possibly exceed 11 billion people by the year 2100.

Meeting the energy and food demands of such a large human population will be one of the main challenges of this century. However, these needs must be balanced with the wise management of biodiversity[1] and ecosystem services[2] that are essential to our own survival. Since more than one third of the usable land on the planet is already appropriated for human needs (Vitousek et al. 1997), agricultural expansion will need to be increasingly aligned with conservation efforts and make use of scientific advances in farm management practices that are more sustainable and less intensive with regards to environmental impact (Godfray et al. 2010).

Recently there has been a new revolution in agriculture—the development of genetically modified (GM) crops. Using advancements in biotechnology, scientists have been creating GM crops that are resistant to pests and disease and are more tolerant of adverse environmental conditions, in addition to other traits related to improved nutrition and storage capabilities. When these GM crops are introduced into an agro-ecosystem[3], they can influence farm management practices, such as tillage[4] of the soil or pesticide use, which may indirectly or directly affect biodiversity (Amman 2005). GM crops may be attractive to many farmers, as they can often simplify the pest management process, which can be difficult and time-consuming (Hellmich and Hellmich 2012). Indeed, since their commercial introduction in 1996, GM crops have been widely and rapidly adopted in the US and elsewhere.

What Are GMOs?

Nearly all of the food crops we enjoy today have undergone extensive genetic modification over many years. Traditionally, these crops have been modified over time through selective breeding for desired traits. For example, consider an ear of sweet corn that you buy in the store: It has a large cob covered in many soft sweet kernels. However, the ancestor of modern corn—a type of wild grass native to Mexico, called teosinte—has hard small seeds and virtually no cob (Figure 1). By selectively breeding plants with desired traits, a process known as artificial selection, the evolution of corn occurred quite rapidly and involved relatively few genetic changes (Beadle 1980).

In addition to selective breeding[5], other crop modification techniques are also used (Figure 2). Mutagenesis[6] involves exposing seeds to radiation or chemical mutagens in order to produce a greater number of genetic mutations from which new traits can arise and be selected. The deep red color associated with some popular cultivars of ruby red grapefruits is actually a trait produced by exposure to radiation (Broad 2007). There is no way to know how many genes are affected by mutagenesis and extensive safety testing is not always required for these

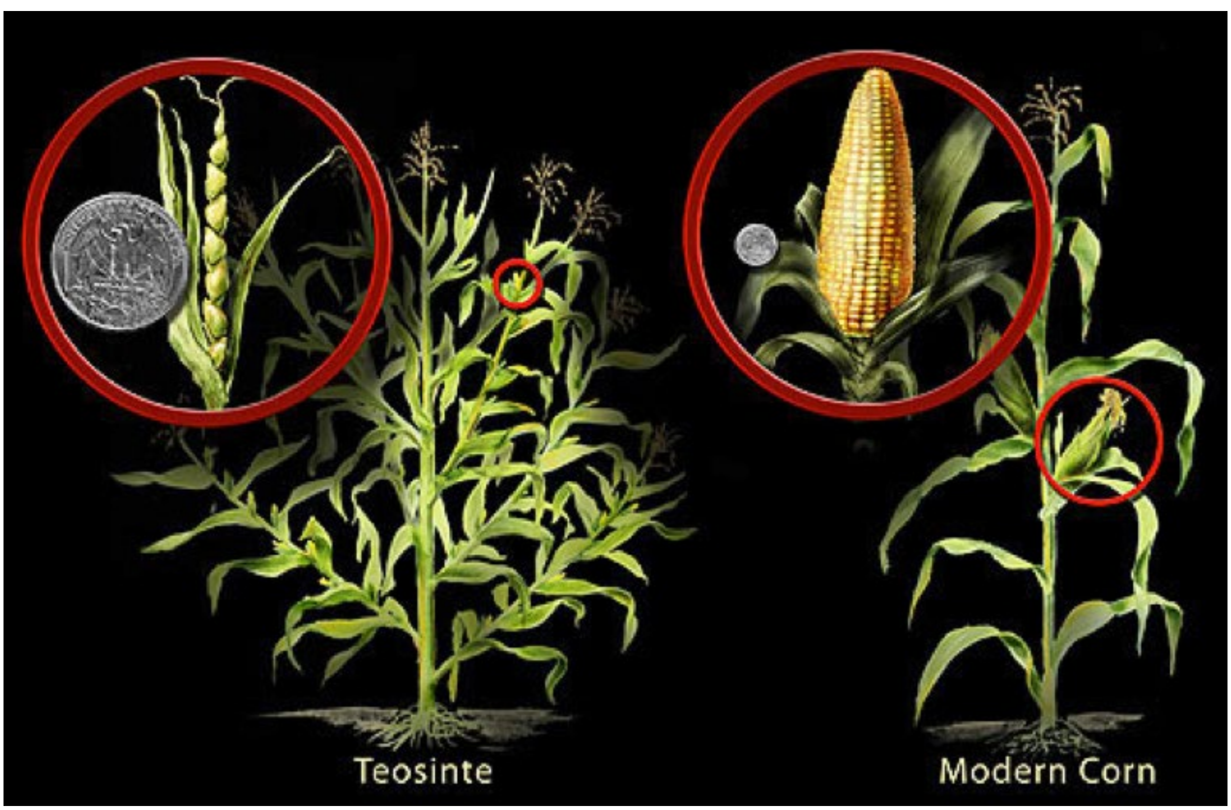

Figure 1. The evolution of corn occurred through artificial selection. Image credit: Nicolle Rager Fuller, National Science Foundation (Flickr/US government work).

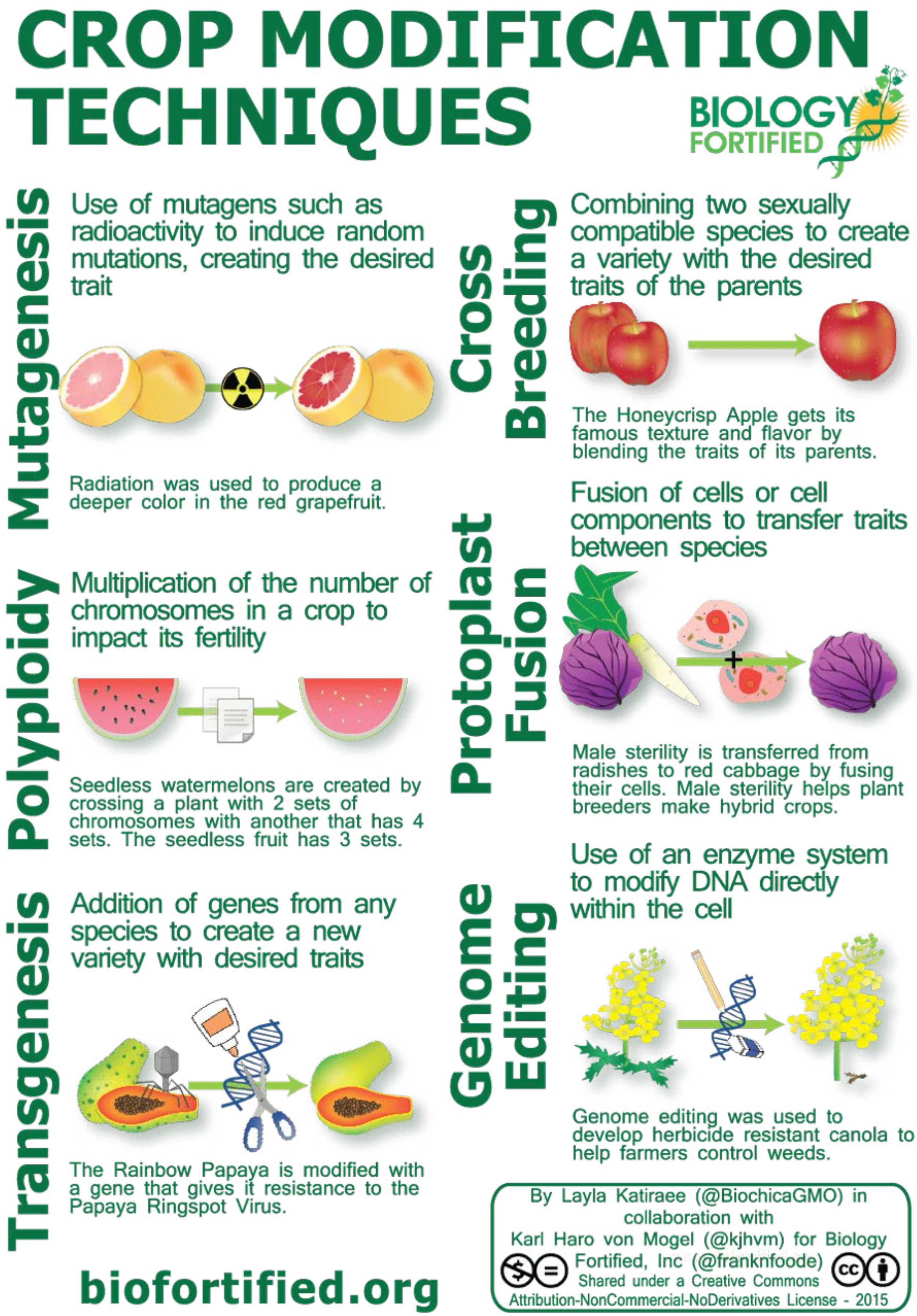

Figure 2. Examples of crop modification and development techniques. Image credit: Biology Fortified, Inc. (CC BY-NC-ND).

crops. Polyploidy[7] is a condition in which an organism has more than the typical two sets of chromosomes due to abnormal cell division. This is especially common in plants. Crossing plants with different numbers of chromosomes results in infertile offspring. For example, this is how seedless watermelons are produced. Protoplast fusion[8] is a hybridization technique that combines somatic cells and fuses nuclei of different plant species by removing their cell walls and exposing the cells to electric shock or chemicals. Recently, new advances in genome editing[9] also have great promise for crop production (Georges and Ray 2017). Genome editing involves the alteration of specific locations in the genome using DNA nucleases (i.e., "molecular scissors") in order to modify gene expression for desired traits, such as disease resistance. This approach is more precise and controlled than mutagenesis and has grown in prominence due to the development of the CRISPR/Cas9 system[10] and other gene editing tools.

Approaches such as selective breeding, mutagenesis, polyploidy, protoplast fusion, and genome editing are undoubtedly forms of genetic modification since they involve changes in gene expression and DNA manipulation driven by humans. However, the use of the term genetically modified organism[11], or GMO, more commonly refers to a transgenic, or genetically engineered, organism (i.e., transgenesis in Figure 2). Transgenic organisms have genes from a different species artificially incorporated into their genetic makeup using recombinant DNA[12] technology. In GM crops, these transgenes[13] confer traits that are deemed beneficial for agricultural production. Transgenic crops are tested for safety with regards to human health and the environment and are regulated by multiple governmental agencies.

Question 1

People often use the phrase "genetically modified organism", or GMO, when referring to a food crop that contains one or more genes that have been artificially introduced from another species. Based on the information given above, why might "genetically engineered" or "transgenic" be better terms than simply "genetically modified" to distinguish these crops from other crops?

WHAT GM CROPS EXIST AND TO WHAT EXTENT HAVE THEY BEEN ADOPTED?

Since the commercial introduction of GM crops in 1996, research on and development of GM crops has increased dramatically. Hundreds of different types of GM crops are tested annually. GM crop traits are related to pest resistance, herbicide tolerance, and improved agronomic traits and product quality (Sawaya 2014). Additionally, pollination control traits have been developed to reduce the risk of weed species acquiring GM traits via hybridization with GM crops (Daniell 2002, ISAAA 2017). At least 28 different crops now contain commercial GM traits (Table 1). Of these, the most widely adopted GM crops are insect-resistant or herbicide-tolerant corn, cotton, and soybean. These crops are staple commodities, and the GM traits have provided farmers with new options for management of pests.

Insect (pest)-resistant crops

Bacillus thuringiensis (Bt) is a common bacterium that is known to have insect-killing properties. This bacterium produces over 250 different kinds of insecticidal toxins, including crystalline (Cry) proteins that target the digestive tract of insects (Schnepf et al. 1998). Different Cry proteins are specific to different types of insects, many of which are crop pests during their larval stage. For example, some Cry toxins target certain species of moths, whereas others are specific to certain species of beetles. The larvae of these insects can be especially damaging to crops, as they feed on plants prior to pupation. Since *B. thuringiensis* is naturally occurring, effective, selective, and safe for humans, it is one of the most popular types of biopesticides[14] and frequently used in both organic and conventional agricultural systems (Hellmich and Hellmich 2012).

Through genetic engineering, some Bt cry genes have been incorporated into crops such as corn and cotton, and these plants are often referred to as Bt crops[15]. Since crops with these transgenes produce Cry proteins as part of their own genetic expression, the target insect pests are exposed to the toxins when feeding on the plant. Bt cotton targets bollworm, a moth pest, and Bt corn targets European corn borer (moth) or corn rootworm (beetle). These are some of the most notorious

Table 1. List of commercial genetically modified (genetically engineered) crops and traits (ISAAA 2017).

CROP	TRAIT						
	Insect resistance	Herbicide tolerance	Disease resistance	Abiotic stress tolerance	Altered growth/yield	Modified product quality	Pollination control
Alfalfa		x				x	
Apple						x	
Bean			x				
Bentgrass		x					
Canola		x				x	x
Carnation		x				x	
Chicory		x					x
Cotton	x	x					
Eggplant	x						
Eucalyptus					x		
Flax		x					
Maize	x	x		x	x		
Melon						x	x
Papaya			x			x	
Petunia							
Plum			x			x	
Poplar	x						
Potato	x	x	x				
Rice	x	x				x	
Rose						x	
Soybean	x	x		x	x	x	
Squash			x			x	
Sugar beet		x					
Sugarcane				x			
Tobacco		x					
Tomato	x		x			x	
Wheat		x				x	

pests of these crops, annually causing billions of dollars of yield loss. With Bt crops, a farmer only has to plant the crop in order to control these pests, as opposed to having to scout for them and apply insecticides. As a result, the increased use of Bt crops has been linked to decreases in insecticide use (Brookes and Barfoot 2012). In addition, due to the narrow target range of Cry toxins, Bt crops have minimal effect on non-target organisms as compared to crops in which insecticides are used to control the same target pest (Naranjo 2009).

One concern related to Bt crops—as with all pest management techniques—is the development of resistance within pest populations. Since Bt crops are so effective at controlling their target pests, farmers are required by the US Environmental Protection Agency to devote 5%–50% of farm acreage to non-Bt versions of the crop (Fleischer et al. 2014). These non-Bt areas, or refugia, are used to proactively prevent or slow the development of resistance, by preserving susceptible alleles within the pest population (Gould 1998, Bates et al. 2005). This approach is analogous to the judicious use of antibiotics by health care professionals to slow the development of drug-resistant bacterial pathogens. After more than two decades of Bt crop use, incidences of resistance have emerged in some areas and resistance management remains an important focus of study (Tabashnik and Carrière 2017).

Herbicide-tolerant (HT) crops

Herbicides are chemicals applied to a field to kill weeds, with the main aim to limit crop competition by weeds, which have been shown to cause up to 34% crop loss if unmanaged (Oerke 2006). Broad-spectrum herbicides kill a wide variety of weeds and can also cause damage to crops, so growers are limited to using them at times when they do not have a crop in the field. Narrow-spectrum herbicides, in contrast, kill some plants but not others, requiring more in-depth understanding by applicators regarding which herbicides target which plants. Herbicide-tolerant crops (HT crops) have been developed through genetic engineering (and also conventional breeding methods) to create crops that can survive being sprayed with broad-spectrum herbicides. Thus, growers are able to spray a crop field after the crop begins growing, killing the weeds that are in the field without damaging their crops. This provides growers with an effective, efficient way to manage weeds during the season. The most popular herbicide-tolerant crops are genetically engineered varieties that are resistant to glyphosate, a common, broad-spectrum herbicide. Glyphosate kills plants by inhibiting synthesis of some essential amino acids in plants. All herbicides carry risks, whether to the people applying the herbicides, non-target organisms such as wildlife or bees, or consumers (see Henderson et al. 2010 for information on glyphosate specifically). These risks vary widely depending on the toxicity and amount of the active ingredient, formulation, and other factors. Compared to other herbicides commonly used in agriculture, glyphosate has low mammalian toxicity and binds tightly to the soil, limiting leaching into groundwater (Henderson et al. 2010, Duke and Powles 2008). While glyphosate use has increased dramatically since the release of glyphosate-tolerant crops, there is also evidence of a decrease in toxicity associated with herbicide use on some of the major crops in the United States (Kniss 2017).

Adoption of herbicide-tolerant crop varieties occurred more quickly in crop types that had limited cost-effective weed management options prior to this technology, like soybeans and sugarbeets. The herbicide options available for soybeans were more costly or more complicated, for instance relying on narrow-spectrum products, than the simplicity presented by herbicide-tolerant crops. Corn, in contrast, had several effective approved herbicides for use in that system, thus growers were slower to adopt this technology in corn (Figure 3). For example, narrow-spectrum herbicides that only target broadleaf plants can be used on corn, which is a grass, but not on broadleaf crops such as soybeans and sugarbeets. Herbicide-tolerant crops can also be referred to as herbicide-resistant crops, or by the common phrase used in the press—“Roundup Ready”—which refers to crops that are resistant to applications of the herbicide “Roundup” the original trade name for glyphosate.

Adoption of genetically modified crops

Bt and HT crops provide growers with new options for managing pests. However, this technology can be expensive as GM seeds cost more than their conventional counterparts. Because of regulations, growing GM crops may also prevent growers from selling to certain foreign markets. These expenses may be counteracted by greater yields, reductions in pesticide applications, and lower fuel and labor costs, however this may depend on the severity of the pest/weed problem and other local factors. To illustrate the response of farmers to this technology, Figure 3 shows the trends in adoption rates of the main types of GM crops in the United States.

Question 2

What can you conclude from Figure 3? Summarize in three points the main information being presented.

AGRICULTURE AND GM CROPS: CONSERVATION SCENARIOS

Clearly, GM crops have been widely and rapidly adopted in the United States. At a global scale, they are now planted in 28 countries and on over 170 million hectares each year (ISAAA 2017). Over the first two decades since their commercial release, this represents billions of acre-

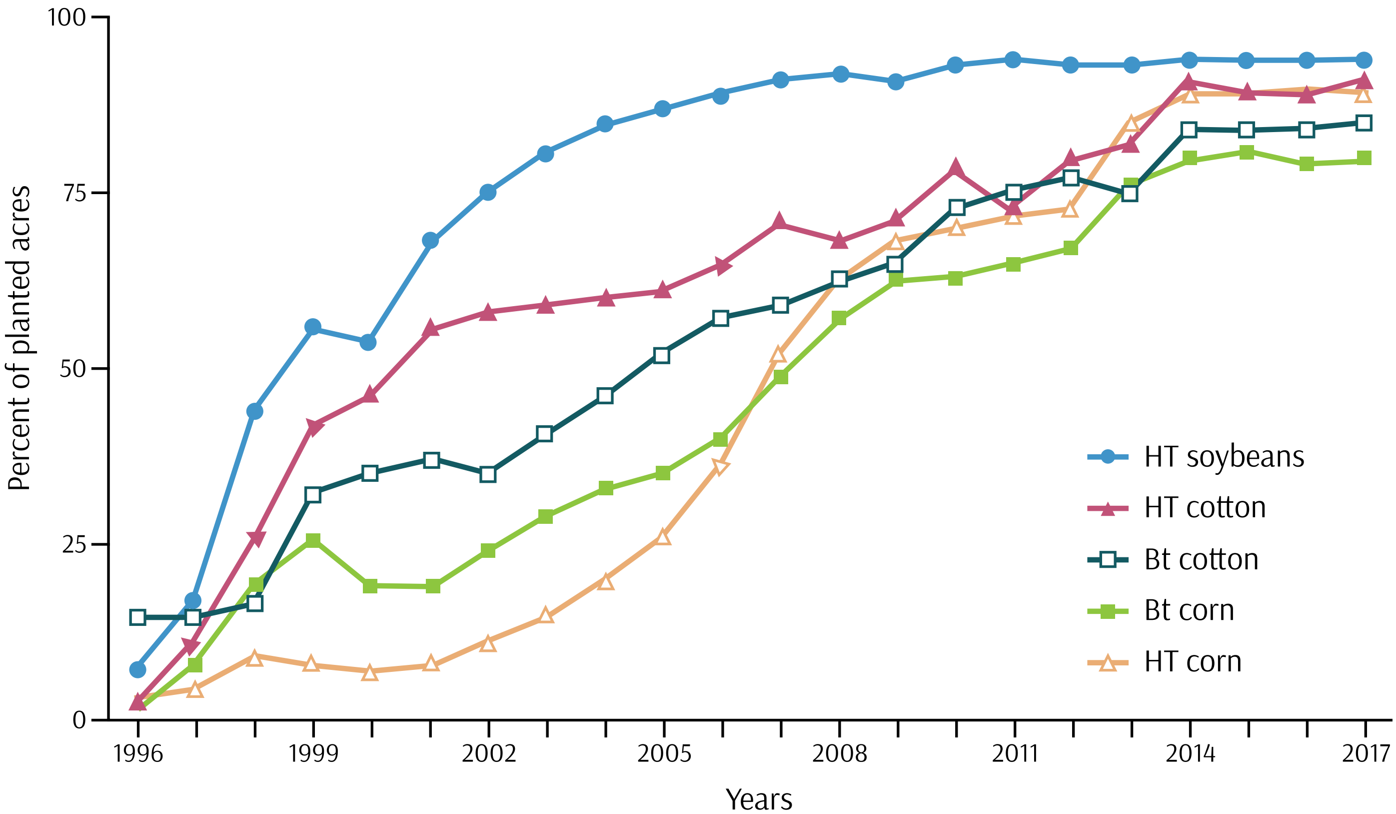

Figure 3. Adoption of genetically engineered crops in the United States, 1996–2017. Image credit: USDA Economic Research Service (US government work); adapted by Nadav Gazit.

years of GM crop production. In this case study, you will be asked to consider how the adoption of GM crops may affect farm management inputs and biological conservation on farmlands. Use the following scenario of Greta Greenthumb, a (fictional) farmer in Iowa, to explore these effects and to draw conclusions about this important topic in agriculture and conservation.

Greta Greenthumb grew up on a corn farm in Iowa that was about 300 acres—a little smaller than the average farm size in the state. Iowa is in the heart of the Midwestern United States, and agriculture plays an important role in these communities of people and in the ecosystems present there. Greta's parents grew field corn and soybeans to be used as feed for livestock and Greta was happy to chip in with farm chores when she wasn't in school. After graduation, Greta moved to Des Moines for a job, but often missed her life back on the farm. She decided she wanted to return home to run the farm when her parents got older. That time had finally come and she was back at the old farmhouse. It was winter and she was planning for the upcoming field season. She was excited but also a little bit nervous about all the decisions she would need to make.

Conservation Scenario #1: From Prairie to Agriculture

The north central part of the US is one of the most agriculturally productive regions in the world. Greta was always proud of her family's history of farming in this region. Her family valued hard work, common sense, and a connection to the land. Greta had always been interested in the history of the area and enjoyed looking at old maps and books in the local library. She had learned that this part of the country was historically prairie land (Figure 4), containing numerous species of grasses and wildflowers that, in turn, supported diverse communities of arthropods, birds, and mammals. These prairie plants and their complex root systems, in combination with the climate and geology in this region, resulted in deep, fertile soils, rich in organic matter—perfect for growing food. As such, many of the native prairies were eventually converted into agricultural lands and a family farm culture emerged as more settlers moved into the area in the late 19th and early 20th century. Over time, and with economic diversification, many of these smaller mixed-use family farms have given way to larger specialized grain production farms.

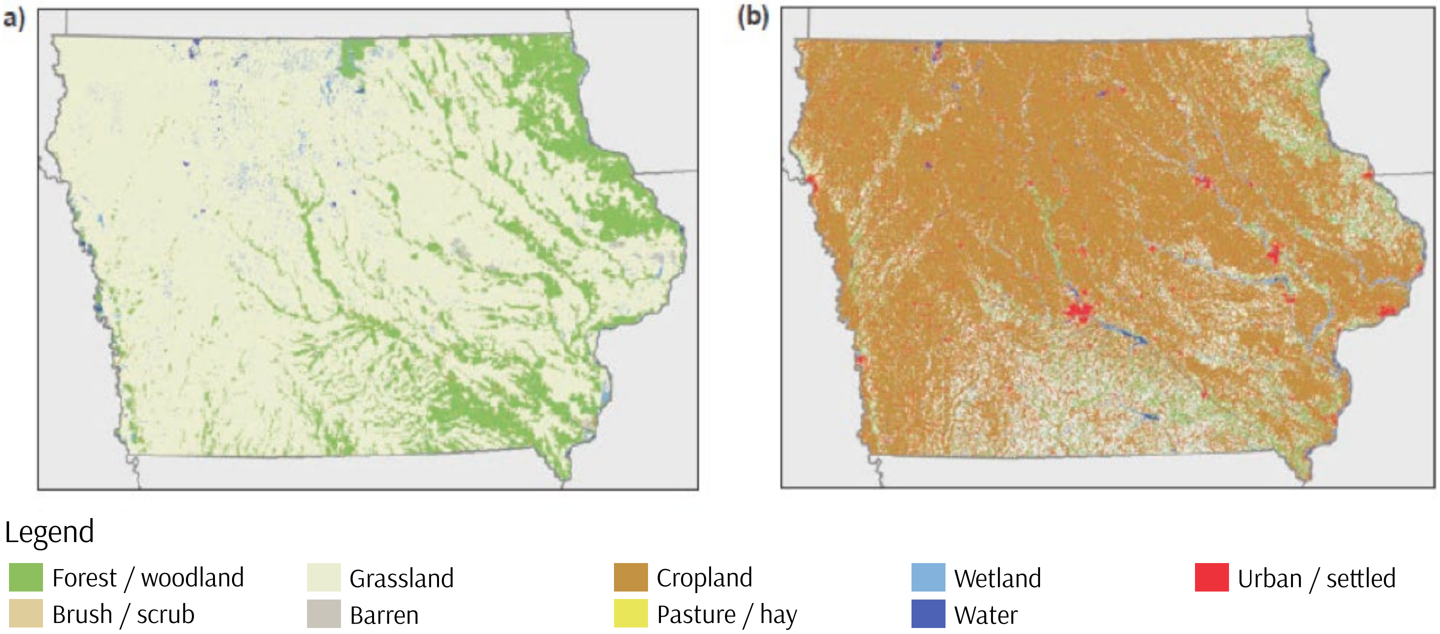

Figure 4. Iowa land cover in the mid-1800s (a) and in 2001 (b). Image credit: Gallant, A.L., W. Sadinski, M.F. Roth, and C.A. Rewa. 2011. Changes in historical Iowa land cover as context for assessing the environmental benefits of current and future conservation efforts on agricultural lands. Journal of Soil and Water Conservation 66(3):67A-77A, doi:10.2489/jswc.66.3.67A.

One of the primary crops being grown is maize, or field corn, used for livestock feed and biofuel production. Thus, this region is often called the "Corn Belt" due to this crop's predominance in the landscape along with other cash-grain crops. Such farms are often described as relying on monocultures[16] of corn, since at times it is the only thing being grown over a very large area. Corn is typically rotated annually with soybean, another very common crop in Iowa.

Question 3

1. Compare the land use maps of Iowa from the mid-1800s and 2001 (Figure 4).
2. In 2–3 sentences, describe the major changes in Iowa land cover between the two maps.
3. Take a moment to identify and write down how an agricultural field differs from natural habitat it replaces (in this case, a corn monoculture versus a prairie). For example, in terms of disturbance, habitat heterogeneity, and anything else that jumps to mind. Then briefly explain below in the table what effects these differences may have on the biodiversity of three different groups of organisms: 1) plants, 2) soil arthropods and microorganisms, and 3) above-ground animals (arthropods, birds, mammals).

ORGANISMS	AGRICULTURAL FIELD VS. NATURAL HABITAT: EFFECT ON BIODIVERSITY
1. Plants	
2. Soil arthropods/ microorganisms	
3. Above-ground animals	

Conservation Scenario #2: Adopting Bt Corn

Despite the changes to the natural environment that agriculture may present, food production is necessary and more agricultural production will likely be needed for the growing human population. Knowing this, Greta was committed to managing her farm in a sustainable fashion, from both from an economic and environmental standpoint. Therefore, she was open to considering multiple tactics for controlling crop pests, as long as they assured the economic viability of the farm. For example, she was keen on using biological and cultural control tactics that could reduce pest populations; this may include supporting or introducing organisms that naturally kill pests, or using tillage and crop rotation[17] patterns to reduce pest pressure and maintain healthy soils. Ideally, pesticides would be used as a last resort, however she understood that pesticides often need to be used, especially when pest densities are high.

Like Greta's family farm, most of the neighboring farms were also over 100 acres in size and many of these farms were devoted to corn production. Corn was typically planted in late April/early May and harvested in October. Although various insect pests present a challenge for growing corn, one of the major pests in the region was the European corn borer, a moth whose larvae feed on corn and other crops. In the Corn Belt, European corn borers go through at least two generations a year (Figure 5). The larvae of the first generation will feed on the leaves of the young corn plants. The second-generation larvae can damage the leaves, stalk and ears of corn, before overwintering in the corn stalks and residue. Both generations only feed on the surface of the plant for a

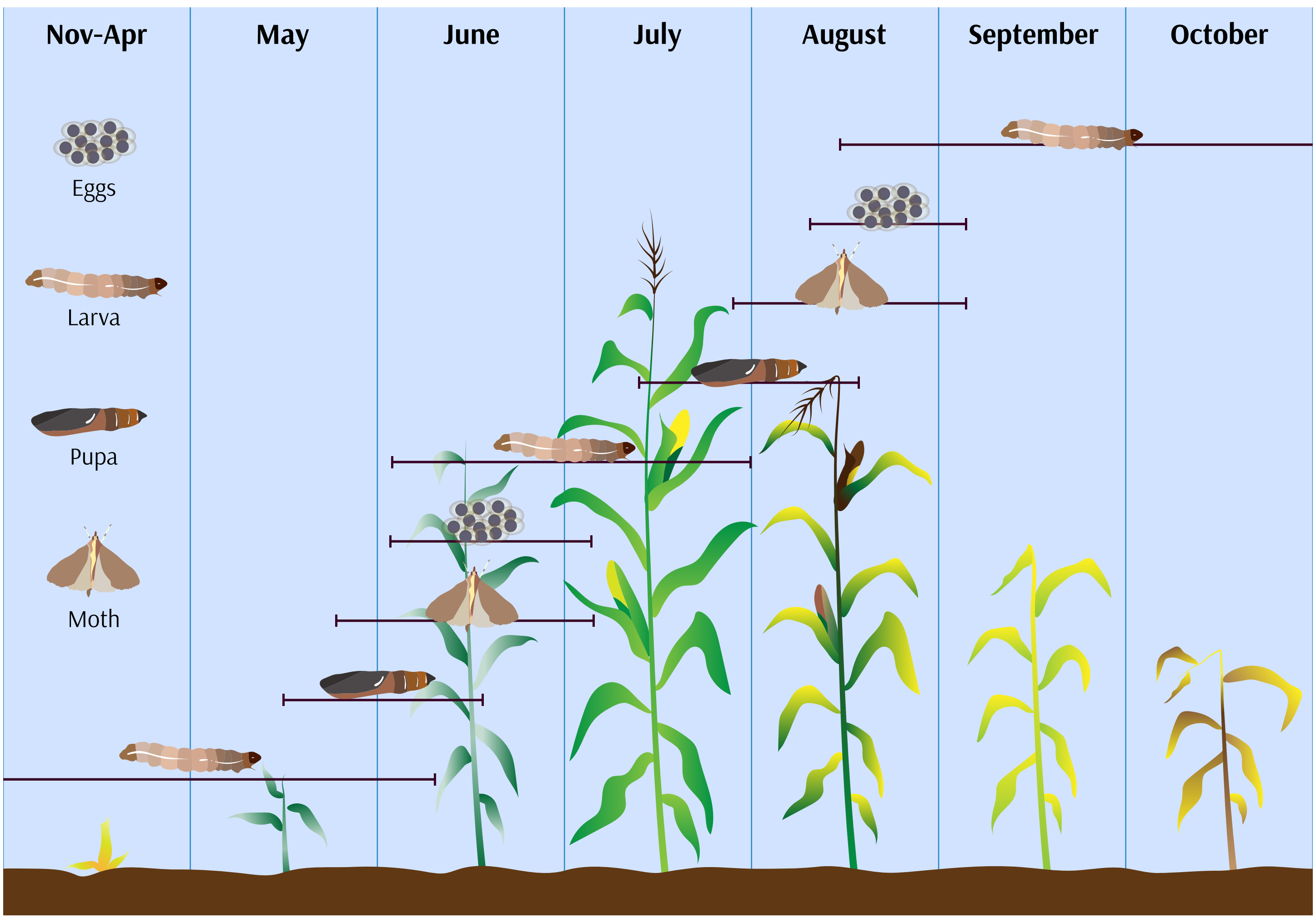

Figure 5. European corn borers typically go through two full life cycles during the growing season of corn in Iowa. Larval corn borers will spend the winter in the senescent corn stalks before emerging as flying adults the following year. Image credit: reprinted with permission from Iowa State University Extension and Outreach; Edwards, E., editor, European Corn Borer Ecology and Management, NCR 327, 1996; adapted by Nadav Gazit.

short period of time before tunneling into the stalks or ears of the corn.

Although a farmer will use a variety of tactics to best avoid or minimize corn borer infestations (e.g., alter planting dates), controlling this pest may require insecticide applications. Insecticides are usually applied in mid-summer and late summer when larvae are present (Figure 5). Since the larvae are able to quickly tunnel into the plant, there is only a brief window of time in which insecticide applications are effective. Therefore, growers must devote time and resources to scouting for the pest to identify the best times for insecticide applications. European corn borer adults lay eggs over several weeks, so sometimes a single insecticide application is not sufficient to control emerging larvae, and a second application may be needed. Insecticides may be applied in granular or liquid form using tractors with spray tanks or overhead sprinkler systems. These insecticides often have long residual times to control emerging larvae over longer periods of time, and most are nerve poisons that are toxic to many organisms other than the pests.

Due to the tunneling activities of corn borer larvae, managing this pest with conventional foliar applications of insecticides, as described above, can be difficult and expensive. An alternative pest control option for the farm would be to plant Bt corn that specifically targets European corn borer. When speaking with her neighbors, Greta learned that since the commercial introduction of Bt corn in 1996, more than half of her neighbors had chosen to adopt Bt corn for corn borer control. Greta wondered how this may have influenced corn borer populations in the Corn Belt and came across a long-term study led by Dr. Bill Hutchison at the University of Minnesota that examined how the introduction of Bt maize (corn) in the Midwestern United States has influenced European corn borer densities (summarized in Figure 6).

Question 4

Carefully inspect Figure 6 (including the caption, the legend, and the axis titles) and answer the following questions.

1. What do the vertical gray bars represent?
2. What general trend do you see over time for this variable?
3. Why are there no values for this variable prior to 1996?
4. What do the white dots represent?
5. What pattern(s) do you see for this variable prior to 1996?

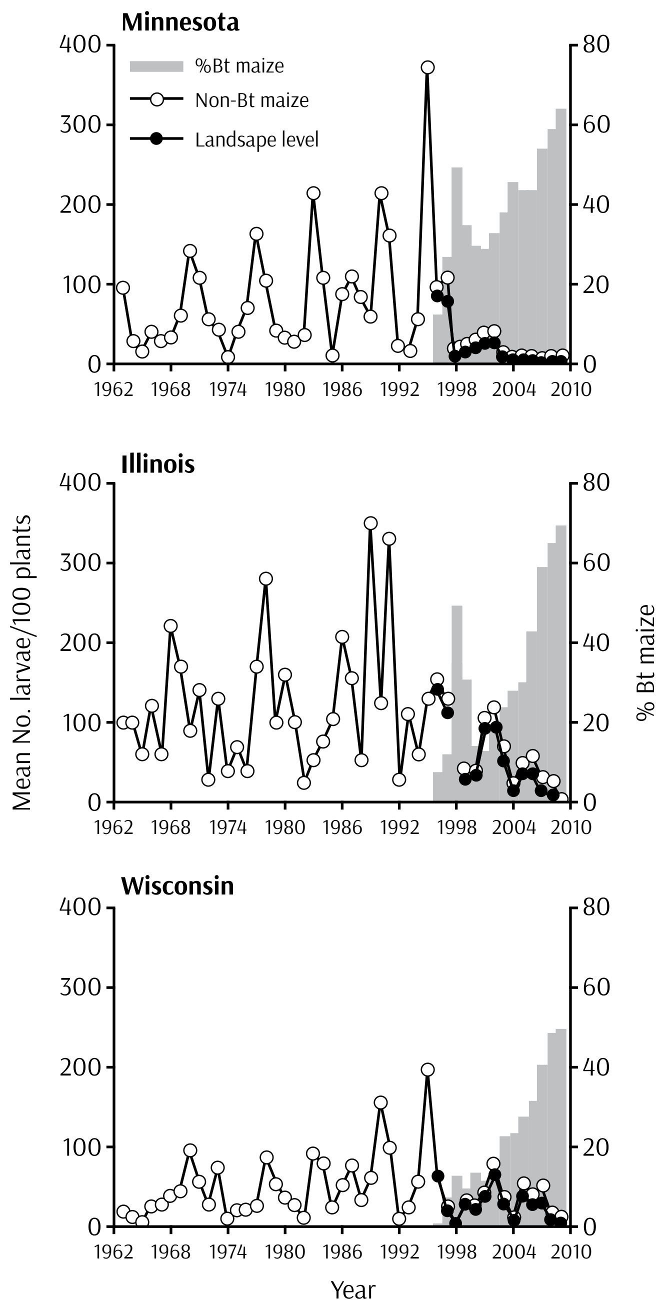

Figure 6. European corn borer densities (mean number of larvae per 100 plants, in both Bt maize field and the whole landscape, which comprises Bt and non-Bt combined) and Bt maize adoption over time in three states of the US Corn Belt. European corn borer larvae overwintering in corn stalks were counted annually from 1962–2010. Image credit: Hutchison et al. 2010 (Science/US government work); adapted by Nadav Gazit.

6. What may have caused such patterns?
7. What happens to these values after 1996?
8. If you were to plot only two variables—% Bt maize against European corn borer densities (using data from 1996-present)—what might the graph look like? Label the axes, write a caption and draw a hypothetical trend line.

Greta realized that transitioning from a conventional insecticide-based pest management program to Bt corn-based system may not only influence pest densities, but may also influence insecticide use patterns and ultimately the diversity of organisms in and around the farm. Greta started doing some research and soon realized that numerous studies (e.g., O'Callaghan et al. 2005, Romeis et al. 2008, Naranjo 2009) had examined the effects of Bt crops on non-target organisms[18], or those organisms not being targeted by a pesticide. In general, due to the target specificity of Cry toxins, Bt crops do not seem to have substantial effects on non-target organisms, especially as compared to the effects of using insecticide applications to control the same pest on non-Bt crops (Naranjo 2009). On a farm, non-target organisms may include birds and mammals that feed, nest, or simply pass through these farm fields. However, since Bt corn specifically targets insect pests, non-target effects are more often assessed for arthropods. Non-target arthropods may include other pests of the crop, however most non-target studies have looked at effects on crop-beneficial arthropods. These organisms include arthropods that are predators and parasitoids[19] of pests. Predators and parasitoids of pests may also be referred to as natural enemies[20], or biological control[21] agents. These arthropods are considered integral parts of the agro-ecosystem and how they are affected by changes in farm management practices is an important component of ecologically-based farming. Some of these beneficial arthropods, such as ladybugs/ladybird beetles (Figure 7A), feed on a wide range of pests and are known as generalist predators. Others, such as some parasitoid wasps (Figure 7B), will exclusively target a single species; these natural enemies are known as specialists.

Question 5

Consider two farming scenarios: one with Bt corn and one using conventional pest management options to control European corn borer. In the table below, choose answers to indicate how you think insecticide applications, the abundance of pests, and the abundance of non-target organisms would compare between Bt corn (targeting European corn borer) and conventionally-managed corn. Below the table, provide a brief justification for your answers.

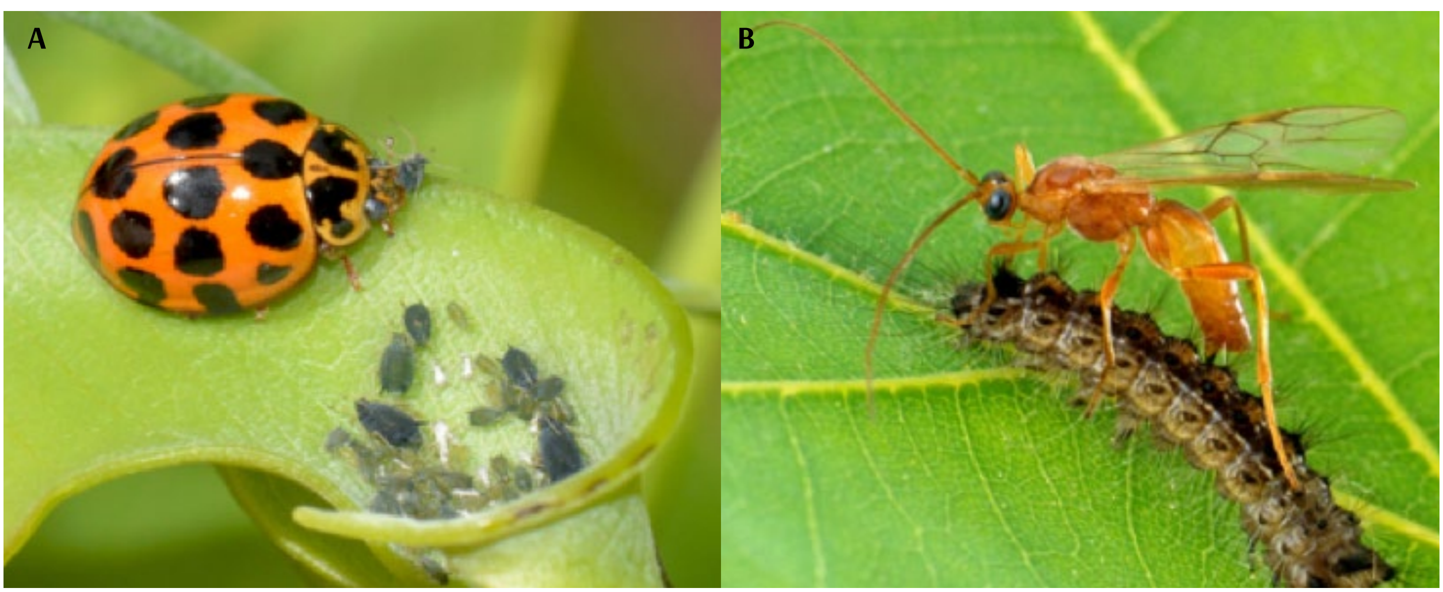

Figure 7. Natural enemies are organisms that kill crop pests. These include predators such as ladybird beetles (A) and parasitoid wasps (B). Image credit: 7A: Jean and Fred/Flickr (CC BY 2.0); 7B: Scott Bauer, Image Number K7659-1 (USDA/US government work).

COMPARED TO A CONVENTIONALLY-MANAGED CORN FIELD, A BT CORN FIELD WILL HAVE:			
☐ fewer	☐ the same number of	☐ more	insecticide applications
☐ fewer	☐ the same number of	☐ more	European corn borers
☐ fewer	☐ the same number of	☐ more	specialist parasitoids of European corn borers
☐ fewer	☐ the same number of	☐ more	generalist predators

Conservation Scenario #3: Adopting Herbicide-Tolerant Crops

Iowa farmers most often employ a corn-soybean rotation, planting corn and soybean in the same fields in alternate years. Crop rotation helps reduce pest populations in both crops since many insect pests and pathogens are specific to one crop or the other (Robertson et al. 2014). Greta, however, is still struggling with large populations of weedy plants that compete with both the corn and soy crops. Her current management strategies include narrow-spectrum herbicides that are approved for use on these crops, if the timing is right to use them, as well as tillage, which she completes prior to and after planting of her crops, between the crop rows.

Tillage, a term referring to some sort of soil disturbance (Figure 8A), is one way farmers kill weeds and other plant residues either after crop harvest or prior to planting. However, this practice is disruptive to the soil, alters the community of soil animals and microbes that live there (Stinner and House 1990, Lundgren et al. 2006), and destroys soil structure, making it much easier for soil to blow away or float away in wind or water erosion (Karlen et al. 1994). Soil is highly valuable as habitat for biodiversity and for ecosystem services such as carbon sequestration[22] and water filtration (Lavelle et al. 2006). Conservation tillage[23], also referred to as reduced or no-till practices, can improve soil quality through reduced disturbances and maintenance of crop residue on the soil surface (Figure 8B). Greta recently went to a farming conference where she heard other Iowa farmers talking about how much they support no-till farming and keeping their ground covered. She loves the idea of protecting her soil for generations to come. She couldn't believe it when she heard at the conference that in some parts of Iowa, topsoil is being lost at rates of 10–50 times faster than soil is being formed at those sites (Neuman 2011).

However, if Greta switches to no-tillage farming, she will have to change the way she manages weeds, because she won't be tilling the ground to kill the plants. Her neighbor tells her that's why he uses herbicide-tolerant crops. He can plant his soybeans and then go right over the whole field with a broad-spectrum herbicide that kills all the weeds but does not kill his crops.

A group of scientists led by Wade Givens were curious to find out if farmers who adopted herbicide-tolerant crops changed their tillage practices at all (Givens et al. 2009). Could switching over to herbicide-tolerant crops affect what type of tillage farmers use? If so, this could have implications for soil conservation.

Dr. Givens and his collaborators surveyed 1,195 growers from six states in the Midwestern United States. The results are presented in Table 2.

Question 6
Examine the data table below (Table 2) from their study. Did farmers change their tillage practices after adopting herbicide-tolerant (HT) crops? Explain how you came to your conclusion below.

Question 7
Do you think these changes have any impacts on biodiversity or ecosystem services provided by soil? Explain.

Figure 8. Conventional tillage of farm field (A). Under conservation tillage (B), crop residue is left on the soil surface. Image credits: 8A: Joevilliers, via Wikimedia Commons (Public Domain); 8B: USDA NRCS South Dakota/Flickr (CC BY-SA 2.0).

Table 2. Percent farmers using each type of tillage before and after adopting herbicide-tolerant (HT) crops.

TYPE OF TILLAGE	BEFORE HT CROPS ADOPTED	AFTER HT CROPS ADOPTED
Conventional till	37%	18%
Reduce till	38%	41%
No till	25%	41%

Adapted from Givens et al. 2009. Weed Science 23(1):150–155.

Question 8

Greta is wondering if switching to herbicide-tolerant crops means that she will change the amount of herbicide used on her farm. Based on what you have learned so far about herbicide-tolerant crops, predict whether herbicide use would increase, decrease, or neither following adoption of herbicide-tolerant crops. Justify your answer.

To compare the ecological effects of different agricultural management practices, including tillage, researchers at the Kellogg Biological Station in southwest Michigan started an experiment in 1989 called their "Main Cropping System Experiment" (Kellogg Biological Station 2017). This experiment is particularly valuable given its long-term nature (Robertson et al. 2008). The impacts of different crop management strategies can be very different over a long time-frame rather than in a single season.

For this experiment, scientists compared ecosystems along a management intensity gradient, including four annual cropping systems: 1) a "conventional" system (conventional tillage and use of GM crops since 2009), 2) "no-till" system (same as conventional except no tillage is used), 3) a "reduced-input" system (fewer synthetic fertilizers applied, cover crops included as nitrogen source), and 4) a "biologically based" system (certified organic, no GM crops, no synthetic fertilizers applied, includes tillage) (Robertson et al. 2014). For this exercise, we will focus on the comparison between conventional and no-till systems, given that GM crops have better enabled farmers to use no-till strategies if they wish. Scientists have studied various dimensions of the ecosystem in this experiment, including soil health, nutrient loss, and water storage capacity. Water is a conservation issue of concern to growers, as extreme conditions such as droughts considerably reduce food production (Lesk et al. 2016). The data shown below are from 24 years after the initiation of the experiment and focus on soil moisture, a rough indicator of how much water is available in the soil for plants to access.

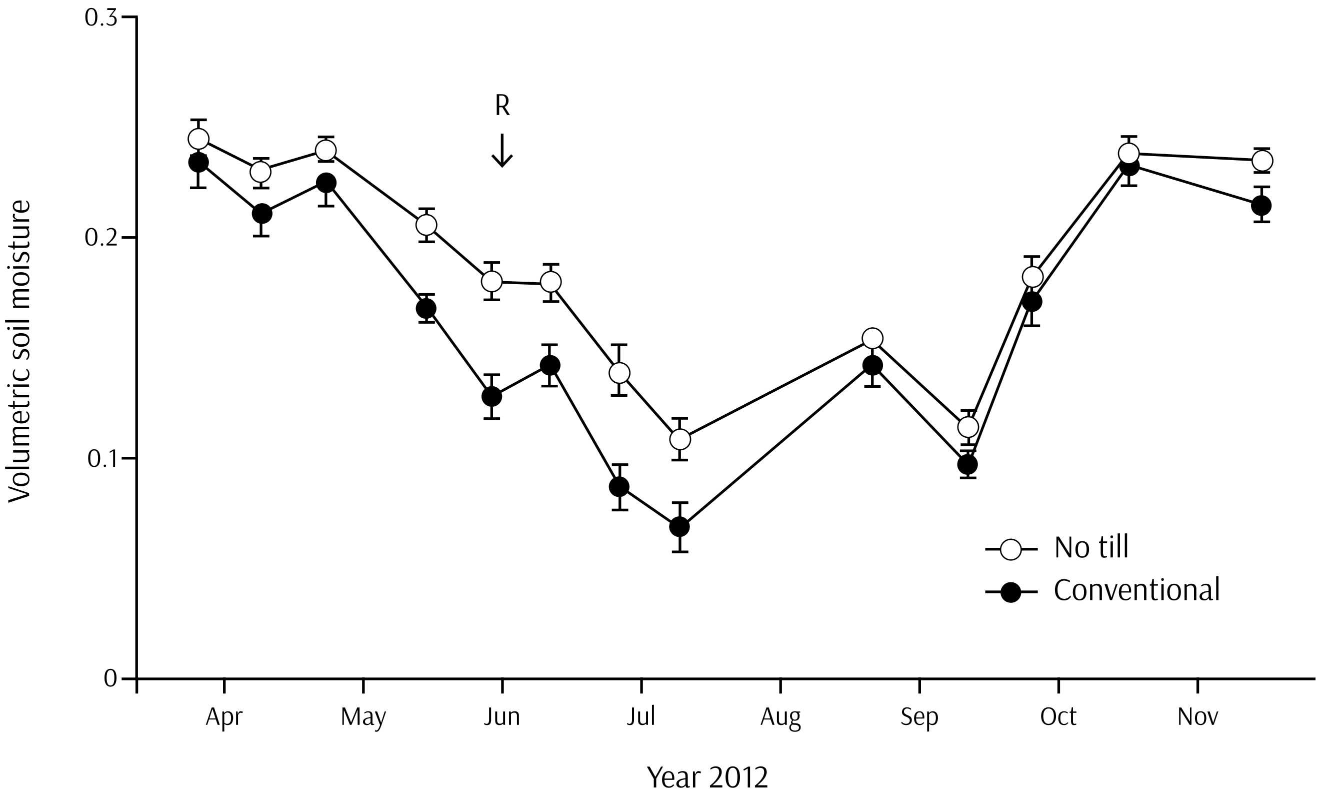

Figure 9. Mean soil moisture (in cubic cm per cubic cm) in no-till and conventional soybean systems during the 2012 soybean growing season. A 6-week drought began after the June rainfall event indicated with the R on the figure. Error bars represent the standard error (n = 6 soil moisture samples). Image credit: Robertson et al. 2014. Bioscience 64(2):404–415 (CC BY); adapted by Nadav Gazit.

Question 9

Examine data from the Kellogg Biological Station cropping systems experiment in Figure 9. What can you conclude from this graph? Please support your claims.

REFLECTION AND SYNTHESIS

This case study has highlighted several different management choices that Greta can make (using a GM crop that is insect resistant and/or herbicide tolerant, adopting no-till strategies, using crop rotation). If you were Greta, and were concerned about biodiversity and soil health, how would you manage your farm? Would you plant GM crops? Justify your answer. Include advantages and disadvantages to your decision.

GLOSSARY

1. **Biodiversity**: The variety of life on Earth at all its levels, from genes to ecosystems, and the ecological and evolutionary processes that sustain it. It usually is measured as the number and types of living organisms that reside in a particular area.
2. **Ecosystem services**: the direct and indirect contributions of ecosystems to human well-being.
3. **Agro-ecosystem**: an agricultural area considered as an ecosystem, which includes living and non-living components and their interactions.
4. **Tillage**: mechanical agitation of soil to aid crop production, can be used prior to and during crop production.
5. **Selective breeding**: choosing and mating parents with certain traits to produce offspring with more desired characteristics.
6. **Mutagenesis**: the process by which an organism's genetic makeup is changed due to natural mutations or by exposure to certain physical or chemical mutagens.
7. **Polyploidy**: a condition in which a normally diploid cell or organism has more than two sets of chromosomes.
8. **Protoplast fusion**: a type of genetic modification in which cells of two species are fused together to produce a somatic hybrid.

9. **Genome editing**: the modification of DNA at precise locations in the genome of an organism or cell, often using DNA nucleases.
10. **CRISPR/Cas 9 system**: Clustered Regularly Interspaced Short Palindromic Repeats (CRISPR) are a group of prokaryotic DNA sequences that contain viral DNA from previous infections. These embedded sequences, along with CRISPR-associated (Cas) enzymes that splice DNA, are used to recognize and destroy viruses in subsequent attacks. Using a synthetic RNA guide, the Cas9 nuclease can be used in laboratory settings to splice and edit genomes at specific locations complementary to the RNA guide.
11. **Genetically modified organisms**: organisms that contain genes from other organisms using inserted recombinant DNA methods.
12. **Recombinant DNA**: DNA combined from two or more sources.
13. **Transgene**: a gene that has been transferred from one organism to another.
14. **Biopesticide**: pesticide derived from natural materials.
15. **Bt crops**: genetically engineered crops that contain genes from the bacterium, *Bacillus thuringiensis* (Bt). Bt genes are expressed throughout the plant and encode for crystalline proteins that are toxic to certain insects.
16. **Monoculture**: the cultivation of single crop over a large area.
17. **Crop rotation**: the practice of growing different crops in succession on the same land, most commonly to increase crop yields, reduce pest pressure, and for soil nutrient management.
18. **Non-target organism**: species not specifically targeted by a pesticide.
19. **Parasitoid**: organisms that parasitize and kill their hosts; some are "specialists", in that they only target one host species.
20. **Natural enemies**: organisms such as predators, parasites and pathogens that contribute to control of pests.
21. **Biological control**: control of a pest by the introduction of predators, parasitoids, or pathogens.
22. **Carbon sequestration**: process by which carbon is removed from the atmosphere and held in solid or liquid form.
23. **Conservation tillage**: low intensity preparation of soil for growing crops that seeks to conserve soil, water, and energy and features retention of plant residues.

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