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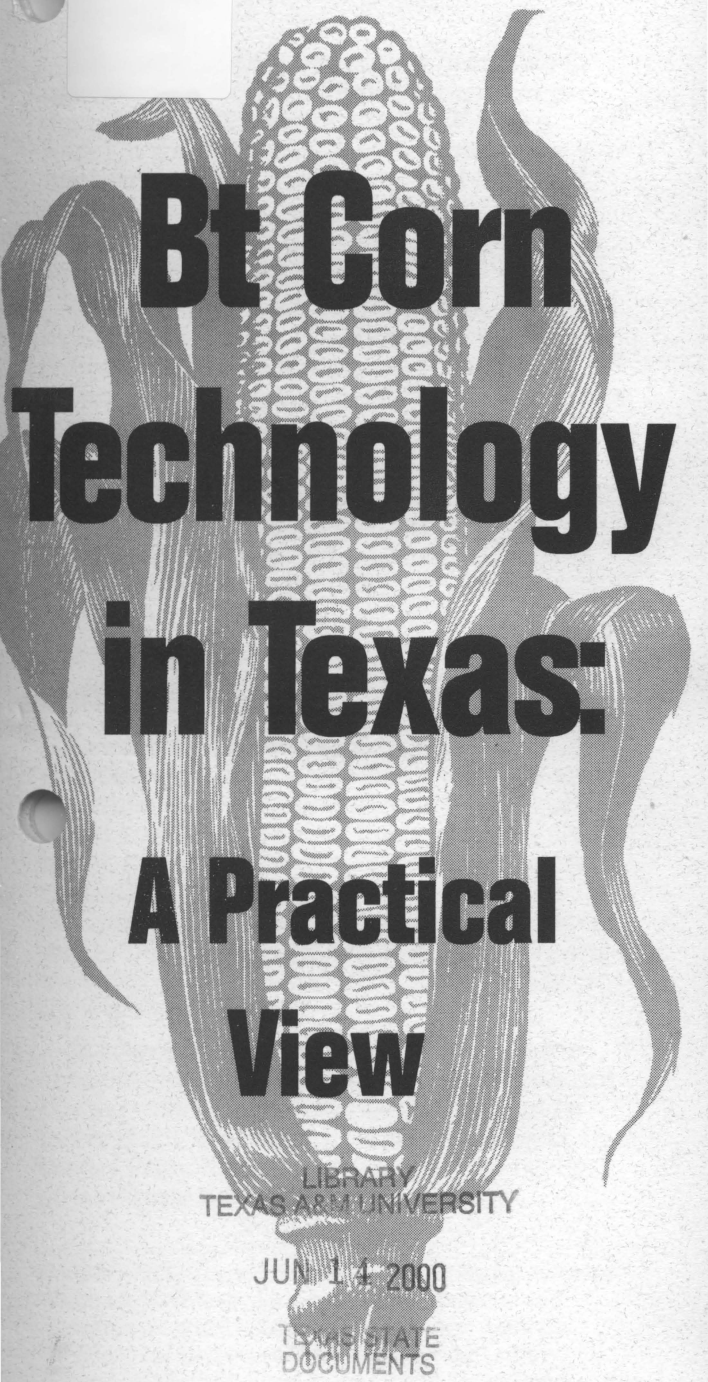

Bt Corn Technology in Texas: A Practical View

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Since 1996, corn growers have been able to purchase genetically enhanced corn that produces some of the insecticidal endotoxins found in the bacterium *Bacillus thuringiensis kurstaki* (Bt). These toxins are highly toxic to certain insect pests, but have little or no effect on humans, livestock, most beneficial insects, and other nontarget organisms.

Benefits of transgenic corn include potential reduction in human exposure to pesticides, reduced incidence of some plant diseases, reduction of insecticide application costs, and a reduction in environmental consequences due to pesticide use.

The following information on scouting and management of Bt corn has been developed from university research and Extension trials and answers some frequently asked questions.

Pests Controlled and Not Controlled by Bt Corn

Extensive field testing indicates that Bt corn varieties provide excellent control of first and sometimes second generation European corn borers, southwestern corn borers, and sugarcane borers. Bt corn varieties also may be effective in controlling or suppressing some other lepidopterous (caterpillar) pests, including corn earworm. There are significant differences among the types of Bt corn and their ability to control these pests (Table 2).

Bt corn currently marketed is intended to control some species of lepidoptera. It does not directly affect corn rootworm, aphids, spider mites, grubs, wireworms, seedcorn maggots, flea beetles, chinch bugs, grasshoppers, sap beetles, or vertebrate pests (birds, rodents, etc.).

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Because pollen from most Bt corn varieties contains the endotoxin, it is possible that wind dispersed pollen may accumulate on noncorn host plants of some nonpest caterpillar species like the monarch butterfly. The possible impact on nonpest species is being investigated.

Differences and Similarities Between Bt Corn and Conventional Corn

Q. Without pest pressure, will I get a yield increase with Bt corn?

A. The presence of Bt does not enhance yield; it simply protects the yield against insect damage. Without the presence of pests, there is no yield difference when compared to the same variety without Bt. However, many Bt hybrids are put into "elite" hybrids and these may or may not yield more than older hybrids.

Seed companies market both conventional (nontransgenic) corn and transgenic (Bt toxin-containing) corn hybrids. These hybrids are selected for yield and other favorable agronomic traits including stalk strength, days to maturity, etc. Bt corn lines contain the positive agronomic traits of their nontransgenic counterparts, but they also contain genes for production of a protein that is toxic to certain insects.

In general, transgenic corn hybrids yield as well as or better than conventional hybrids under low pest pressure, and may yield significantly more under high pest pressure. Field trials have shown no significant "yield drag" associated with production of protein toxins in the plant. In practical terms, there is no appreciable yield difference between Bt and non-Bt varieties when Bt-susceptible pests are absent or present at low numbers. Under more intense pest pressure, Bt hybrids have shown a yield advantage over unsprayed non-Bt hybrids.

Some growers have noted that even when pests are not present, or are present in very low numbers, some Bt hybrids seem to look better and out-perform non-Bt hybrids. This may be because seed companies are introducing Bt genes into their "elite" hybrids, many of which might have agronomic qualities superior to those of older hybrids. In this case, the difference in appearance or yield has no direct link to the presence or absence of the Bt gene.

Differences Between Types of Bt Corn

Q. What is the difference between the different types of Bt corn?

A. All currently registered Bt-transgenic corn hybrids produce insecticidal toxins, but these hybrids vary in their ability to control insects. These variations result from differences in toxins produced, location of toxins in the plant, and/or concentration of toxin(s) in plant tissues.

In broad terms, there are currently five different groups of Bt corn, divided according to gene insertion event, toxin and regulatory region. Regulatory regions are the genetic material that controls the expression of toxins in the tissues. Table 1 highlights some differences among different types of Bt corn.

Table 2 presents general information on each gene insertion event and its effectiveness in controlling different pest species. Gene insertion events differ in their abilities to control common caterpillar pests of corn.

Regulatory Requirements for Planting Bt Corn

Q. How is the planting of Bt corn regulated in Texas?

A. Because Bt corn is a transgenic organism, and because it contains some of the insecticidal toxins that are available as sprayable Bt insecticides, Bt corn is regulated by the Environmental Protection Agency (EPA).

As part of the registration process, EPA required all Bt corn registrants to develop a plan to delay or prevent the development of insect resistance to Bt toxins. EPA has developed different regulations for each of the five genetic events. Growers should follow the resistance management guidelines provided on seed bags and brochures or printed

Table 1. Types of Bt Corn in Commercial Use (2000).

Insertion Event	Registrant	Bt Toxin	Trade Name	Toxic Tissues
176	Ciba (Mycogen)	CryIA(b)	NatureGard®	leaves and pollen
MON 810	Monsanto	CryIA(b)	YieldGard®	leaves, stalk, shuck, silk, pollen, kernels
Bt 11	Novartis (NK)	CryIA(b)	YieldGard®	stalk, shuck, silk, pollen, kernels
DBT 418	DeKalb	CryIA(c)	Bt-Xtra®	not available in Texas
CBH 351	AgrEvo	Cry9C	StarLink®	leaves, stalk, shuck, silk, pollen, kernels

Table 2. Pests Controlled or Suppressed by Bt C[illegible]

Event	First Generation Corn Borer	Second Generation Corn Borer	Corn Earworm	Fall Armyworm	Beet Armyworm	Common Stalk Borer	Sugarcane Borer
176	fair/excellent	poor	poor	poor	poor	poor	poor
MON 810	excellent	excellent	suppression	suppression	unknown	supression	excellent
Bt 11	excellent	excellent	suppression	suppression	fair	unknown	excellent
DBT 418	not available in Texas						
CBH 351	excellent	excellent	none	poor	unknown	unknown	unknown

materials. In the past, the EPA has had different regulations for Texas growers, depending on whether Bt corn is planted north or south of I-40 on the Texas High Plains. Additionally, neighboring states have different regulations than Texas. The easiest way to determine what regulations apply to a particular farm is to contact your seed dealer. EPA will simplify these regulations for the 2000 crop year.

Resistance Management

Q. Why do we need a resistance management plan for Bt corn?

A. *B. thuringiensis* and insects have coexisted in nature for a very long time. Recent studies have demonstrated that genes for resistance to Bt already exist in populations of European corn borer and other lepidopterous insects. Resistance management plans are intended to keep resistance genes rare for as long as possible and extend the effective life of transgenic Bt technology.

Fundamentally, development of resistance to the Bt toxins in transgenic corn is no different than development of resistance to synthetic insecticides. The rate of resistance development depends on many genetic factors including the initial frequency of resistance genes in the population, functional dominance of these genes, fitness of resistant individuals on both Bt and non-Bt plants, and the number of genes involved in resistance. Recent research from Kansas State University indicates that resistance genes are dominant. Other factors that influence resistance development include aspects of insect biology such as host range of the pest, number of generations per year on Bt and non-Bt crops, synchrony of mating between insects developing on Bt and non-Bt crops, biological control agents, and other mortality factors such as weather and insecticide use. Other factors include, but are not limited to, the dose of Bt expressed in the crop, the plant parts that express the toxin, the number of different toxins expressed in the crop, synchrony of pest emergence between Bt and non-Bt crops, and pest movement between Bt and non-Bt crops.

Growers cannot influence many of these factors, especially the genetic ones. Because European corn borer and possibly other pests already have the genes for resistance to Bt, it is likely that field-level resistance will be observed in future years. However, careful management of Bt crops can extend the number of years until resistance becomes a problem. The most important practice growers can use to delay resistance is to plant a refuge of non-Bt corn.

An excellent source of more information is the regional publication "Bt Corn and European Corn Borer: Long Term Success Through Resistance Management" available from the University of Minnesota at http://www.extension.umn.edu/distribution/ cropsystems/ DC7055.html or (612) 625-2787.

Refuge Considerations

Q. Why is the refuge important?

A. The refuge is the best way to slow the development of resistance to Bt and help ensure that Bt corn will continue to control insects for several years into the future. When resistance develops, Bt corn will become ineffective and growers will lose a valuable pest control tool.

Refuges are areas where insects are not exposed to Bt toxins during the course of their development. The frequency of Bt resistance genes will not increase in refuges, and the vast majority of insects emerging from these refuges will not have genes for resistance. These insects will be available to mate with the few insects that survive and emerge from Bt corn and are presumably resistant to the Bt toxin. This intermating will help "dilute" the resistance genes.

The EPA mandates that growers plant non-Bt corn as a refuge. The EPA has established regulations for minimum refuge sizes and the maximum distance that refuges can be from Bt corn fields. Minimum refuge sizes are set to provide an adequate number of susceptible moths to mate with the few moths emerging from Bt corn. Maximum distances between refuges and Bt corn fields are set to increase the likelihood of mating between these moths. For example, European corn borer adults move an average of 1/4 mile to mate and lay eggs. Therefore, the refuge should be within 1/4 mile of the Bt corn, otherwise mating of moths that emerge from these two types of corn is unlikely to occur.

The size of a mandated refuge might vary depending on the corn hybrid being grown and the genetic event that hybrid possesses. Refuge size may also be impacted by the number of acres of cotton being grown in the county.

While different refuge sizes might be a bit more trouble to keep track of and implement, it is important to remember that refuge sizes are chosen according to the best scientific estimates for each genetic event. These estimates are based on many factors, and since each Bt event influences resistance development differently, each event may require a different refuge size. Scientists determine refuge sizes with complex computer models.

Current refuge recommendations are intended to prevent widespread resistance to Bt crops for at least 10 years. Growers who plant a smaller refuge than is recommended, and/or place refuges too far away from Bt corn are seriously increasing the risk that resistance will develop more rapidly.

A corn refuge should be grown under agronomic practices similar to those for the Bt corn. Most corn pests lay eggs on corn based on growth stage and overall health of the plant. Refuge corn that is not at the same growth stage as the Bt corn it is protecting probably will not be equally attractive to moths that are laying eggs. Thus, it will not produce an adequate number of moths to dilute resistance genes. Likewise, refuge corn that is not adequately fertilized or watered will not attract egg-laying moths and will not function as an effective refuge.

From a biological perspective, other types of refuges may be available depending on the specific pest and other nearby noncorn plants. For example, corn earworms (headworms) that develop on nearby grain sorghum are not exposed to Bt toxins. Functionally, the grain sorghum crop acts as a refuge.

Not all noncorn crops can serve as refuges. An example of a nonrefuge would be where Bt corn and Bt cotton are planted in close proximity. Insects surviving on Bt corn (such as the corn earworm) can mate and lay eggs on Bt cotton, where their offspring will again be exposed to the Bt toxin. In this case, two or three consecutive generations of the pest may be exposed to the Bt toxin without the "dilution" effect provided by refuges. Similarly, any non-Bt crop that is treated with a foliar Bt pesticide is no longer a refuge because the insects in the crop have been exposed to Bt toxins.

Because refuges must be assured in all corn production systems, the EPA has mandated that refuges of non-Bt corn be planted along with areas of Bt corn. Noncorn plants are not considered part of the mandated refuge. This is a prudent requirement; refuges are vital to maintaining susceptibility of target pests to Bt toxins and they cannot be left to chance.

Q. If my neighbor plants non-Bt corn, can I consider his field as my non-Bt refuge?

A. No. From a legal and regulatory standpoint, each grower must plant a refuge on his or her own farm, and the refuge must be planted in accordance with EPA guidelines.

igns of Resistance to Bt in the Field

Q. How can I tell if I have Bt resistant borers in my Bt corn field?

A. You can't tell directly, but one sign is if more than 5 percent of your plants have live insects in them. The situation is a little more complicated, as explained in the following.

It is common to find a few plants in a field of transgenic corn that have live corn borer larvae. In fact, because Bt corn is increased through conventional breeding techniques, it is common that about 5 percent of the plants do not contain the Bt toxin. Therefore, isolated plants with healthy corn borers should be no cause for alarm. However, several consecutive plants or many isolated plants with live corn borers could indicate a problem.

European and southwestern corn borers and sugarcane borer (ECB, SWCB and SCB respectively) lay eggs in clusters, and larvae often disperse, usually down the row, after hatching. If a moth passed resistance genes to her offspring, you would expect to see consecutive plants in the row with live larvae. (Of course, if 5 percent of the plants do not contain Bt, it is possible to have two or more of these side by side in the row. However, this is not likely. The odds of having two such plants side by side is 0.05 X 0.05, or 0.0025 [1 in 400]. The odds of having three such plants side by side is 1 in 10,000.) Two plants with live larvae should provoke interest. The presence of three or more such plants, or more than 5 percent of the field with live larvae (except in the case of gene insertion event 176) should make the field a candidate for the possible presence of resistant larvae.

Dealers are working with seed companies to detect resistance early. If resistance is suspected, a seed company representative will visit the field and test plants to make sure they do, in fact, contain the Bt toxin. If the plants contain toxin but are not killing target insects, the representative will collect the insects and ship them to a central laboratory for genetic testing. This is an expensive process, but companies want to detect resistance early so as to prevent its spread. Growers should contact their seed suppliers or local county Extension office if they suspect a resistance problem.

Scouting Bt Corn

Q. Do I still have to scout Bt corn?

A. Yes. Growers using a NatureGard® variety should scout all generations of ECB and SWCB. Growers using YieldGard® or StarLink® need to scout for later generations, but not first generation.

Transgenic corn still needs to be scouted for insects. Bt corn growers do not need to scout for first generation European and southwestern corn borers. However, growers using events 176 and DBT 418 do need to scout for the second generation of these pests as if they were not growing Bt corn. YieldGard® (genetic events MON 810 and Bt 11) and StarLink® (CBH 351) lines should provide adequate second generation control, but verify this with timely scouting. Additionally, Bt corn does not control many other corn pests, including rootworms, aphids, spider mites, grubs, wireworms, seedcorn maggots, flea beetles, chinch bugs, and grasshoppers. Therefore, these pests should be monitored in the same way as they would be in non-transgenic corn.

Bt Corn and the Incidence of Aflatoxin and Other Pathogens

Q. Will Bt corn influence the incidence of pathogens in my field?

A. Experimental data suggests that Bt corn can influence pathogen levels, but the relationships between Bt corn and pathogens are not yet clearly understood.

A major concern for corn growers is the occurrence of mycotoxins. These are toxins produced by pathogenic fungal organisms that can adversely affect both animals and humans. One of these organisms is the fungus *Aspergillus flavus,* which is responsible for producing the toxin aflatoxin. This toxin is a potential carcinogenic fungal by-product when ingested by animals and humans. Another group of toxin-producing pathogenic fungi is found in several *Fusarium* species, which produce the toxin fumonisin. Both of these by-products cause side effects that are toxic when consumed by animals and humans.

Recent university data have shown that high concentrations of fumonisin in non-Bt hybrids were associated with high ECB populations. Bt corn hybrids in the same trials produced less than 10 percent of the concentration of fumonisin than was found in the non-Bt hybrids. Because of their insect pest resistance, Bt hybrids have the potential to reduce the incidence of stalk rot diseases where ECB, SCB and SWCB infestations are moderate to heavy.

Bt hybrids can reduce feeding damage, reduce plant stress, and reduce the number of potential sites for pathogen infection. Numerous diseases are associated with corn borer feeding damage, and several of these may affect the final yield and quality of field corn. Annual yield losses of 10 percent or more can be attributed to stalk and ear rot diseases. Common stalk rot pathogens include *Fusarium*, *Gibberella* and *Colletotrichum*. Ear rot pathogens associated with plants that are stressed or damaged by insects include *Aspergillus*, *Diplodia*, *Fusarium*, *Cladosporium* and *Gibberella*. The incidence of corn diseases associated with insect damage has been shown to be reduced by Bt corn hybrids in field trials. However, other trials have shown an increase of some pathogens in some types of Bt corn hybrids. The relationship between Bt corn and plant pathogens is currently being investigated in Texas.

Economics of Bt Corn

Q. Will it pay to plant Bt corn even though the seed is more expensive?

A. The economic return on Bt technology depends on many factors including corn borer pressure, lodging, degree of corn dry down before harvest, and price paid for Bt corn vs. non-Bt corn at the elevator.

The need for Bt corn cannot be established prior to planting because corn borer populations vary from year to year. However, in areas of traditionally high corn borer pressure, growers might be comfortable planting Bt corn. In other areas where pressure is low, growers might choose to plant nontransgenic corn and rely on traditional insecticides if an economic infestation develops.

Bt corn costs more than nontransgenic corn, and this price difference is usually paid by growers as a technology fee. Current technology fees are approximately $10 per acre. An economic return on the technology fee is not guaranteed.

Iowa State University recently published a cost/benefit comparison guide (Table 3) for Bt corn under different European corn borer infestation levels.

Table 3. Projected return in dollars per acre with Bt corn under different European corn borer infestation levels.*

Yield/acre	Corn Price**	European Corn Borers per Plant				
		0	0.5	1.0	1.5	2.0
125 bu. (7,000 lbs.)	$2.00	-10.00	-3.75	2.50	8.75	15.00
	$2.50	-10.00	-2.19	5.63	13.44	21.25
	$3.00	-10.00	-0.63	8.75	18.13	27.50
150 bu. (8,400 lbs.)	$2.00	-10.00	-2.50	5.00	12.50	20.00
	$2.50	-10.00	-0.63	8.75	18.13	27.50
	$3.00	-10.00	1.25	12.50	23.75	35.00
175 bu. (9,800 lbs.)	$2.00	-10.00	-1.25	7.50	16.25	25.00
	$2.50	-10.00	0.94	11.88	22.82	33.75
	$3.00	-10.00	3.13	16.25	29.38	42.50

Source: Iowa State University, Marlin Rice.

*Assumptions: Bt corn technology fee is $10.00 per acre, each European corn borer per plant reduces yield by 5 percent, and Bt corn provides complete control.

** $2.00/bu prices and returns calculated by Texas A&M University to adjust for current low market prices.

Table 4. Projected return in dollars per acre with Bt corn under different southwestern corn borer infestation levels.*

		Southwestern Corn Borers per Plant				
Yield/acre	**Corn Price****	**0**	**0.25**	**0.5**	**0.75**	**1.0**
125 bu. (7,000 lbs.)	$2.00	-10.00	-3.75	2.50	8.75	15.00
	$2.50	-10.00	-2.19	5.63	13.44	21.25
	$3.00	-10.00	-0.63	8.75	18.13	27.50
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Source: Carl Patrick and Greg Cronholm, Texas Agricultural Extension Service.

*Assumptions: Bt corn technology fee is $10.00 per acre, each southwestern corn borer per plant reduces yield by 10 percent, losses from lodging are not included, and Bt corn provides complete control.

Southwestern corn borer is a serious pest in parts of Texas. The economic returns for growing Bt corn under different populations of southwestern corn borer are presented in Table 4.

These tables illustrate one important point: the technology fee is economically justified only when significant corn borer infestations are present. Without corn borers, the net loss for using Bt corn could be $10.00 per acre. With southwestern corn borers, there is a break even point at 0.5 borers per plant at 125 bushels per acre for $2.00 corn. With European corn borers, Bt corn will provide a net economic benefit at 0.5 borers per plant only when yields are about 150 bushels per acre and corn sells for $3.00 per bushel, or when yields are 175 bushels per acre and corn prices are $2.50 per bushel or higher. At one corn borer per plant, growers will profit from using Bt corn even when corn prices are only $2.00 per bushel.

One additional consideration relates to harvest date and percentage of moisture in the grain. Because most types of Bt corn provide nearly complete control of corn borers (except event 176 and DBT 418), corn stalks will not be damaged to any significant extent, and corn can be left in the field to dry down longer than might otherwise be the case with nontransgenic corn.

Considerations for Marketing Bt Corn

Recent corporate, national and international trade developments are restricting the sale of Bt corn, and perhaps are reducing its value in the marketplace. Some international trading partners will not allow the importation of some types of Bt corn. This has led some grain companies to require that Bt corn be kept separate from non-Bt corn from the time of harvest to the time of final sale. Additionally, some elevators now offer to pay more for non-Bt corn than for Bt corn, and a reduced price for Bt corn will affect its economic attractiveness. Growers should check with the buyers of their corn to determine if Bt corn will be purchased, whether Bt corn should be kept separate, and whether there will be a price difference between Bt and non-Bt corn. The American Seed Trade Association maintains a list of grain handlers willing to purchase Bt corn. This list can be found on the Web at http://asta.farmprogress. com/.

Future Developments

Each of the currently available Bt corn hybrids has only one type of Bt toxin in the plant (Table 1). Seed companies are preparing to introduce transgenic lines that contain two or more different Bt toxins in the same plant. These are called "stacked gene" lines, and they will either be toxic to a broader range of pests, or will potentially be toxic to insects that have become resistant to a single Bt toxin. It is important to note that there are no insect control stacked gene hybrids on the market at this time, and the EPA has not approved the introduction of such hybrids. The first commercially available stacked gene corn hybrids contain one gene for insect control and one gene for herbicide tolerance.

Several seed companies have announced the development of transgenic corn that is toxic to corn rootworms. These hybrids are under development and might reach the commercial market by 2001.

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