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The Economics of Bt Corn: Adoption Implications

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Introduction

The European Corn Borer (ECB), *Ostrinia nubilalis (Hübner)*, is a major corn insect pest. Estimates of damage in the United States due to ECB range between $1-$2 billion per year from yield loss and control costs (Russnogle). A common rule of thumb states that one borer per plant can cause a 5% yield loss if the attack occurs during the corn's critical early development stages (see sidebar).

Control Options

While transgenic or Bt corn (see sidebar on page 2) is the latest approach to ECB control, historically there are several management tools that farmers have used. Cultural practices such as planting early, harvesting early, or destroying stalks after harvest have been used. Such practices are used to kill overwintering ECB larvae or to try to plant or harvest the corn at times that historically have lower expected infestation levels. Also, corn varieties that have been bred for resistance to ECB may be selected. These types of plants rely on a chemical called DIMBOA to kill ECB and are only effective in the very early plant growth stages (Rice and Ostlie). These options provide small measures of control.

Three more effective control options used by farmers are granular insecticides, liquid insecticides, and transgenic corn. Granular insecticides can be delivered

About the European Corn Borer

Corn borer damage can vary greatly from year to year. ECB may produce up to three generations per year in the Central Midwest (Edwards, Foster, and Obermeyer). Each generation differs in its feeding habits. First generation borers normally feed on leaves in the whorl area before tunneling into the stalk. These borers damage the plant by impeding the flow of nutrients to the ears. The tunneling weakens the stalk, increasing the potential for lodging in the fall prior to harvest. Tunneling also creates avenues for the introduction of plant pathogens, which may produce stalk rots that have further negative yield impacts.

Second and third generation borers can generally be found feeding on pollen, leaves, ears, and ear shanks. This feeding may cause ears to drop if the ear shank is significantly weakened. Later generations also tunnel into the stalk. Later generation larvae may overwinter if they develop enough to survive the winter. Typically, overwintering takes place in the leftover stalk of the harvested corn plant. These ECB will emerge the next year if they survive.

ECB development occurs in four stages. First, eggs are laid on the undersides of leaves near the midrib of the corn plant. Second, larvae emerge several days later. This is the stage when feeding occurs. After tunneling into the plant, the larvae develop into pupae, the third stage. Fourth, adults emerge to reproduce and begin another cycle.

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About Bt Corn

Several varieties of transgenic corn have recently become available. The term "transgenic" refers to corn, or any other organism, that contains a gene from a different plant or organism. In this case, the gene is taken from a naturally occurring soil bacterium known as *Bacillus thuringiensis* (Bt). The genes produce Cry proteins, which are the active substances that kill ECB. Bt has been used for many years, both in liquid and granular forms, to control ECB. However, with modern biotechnology techniques, the insecticidal trait can now be expressed, or produced, in corn plants. When the borer larvae feed, the Cry protein produced by the transgenic corn plant is transformed into a toxin which kills the insects within a day or two.

either through aerial or ground applications. Aerial applications are broadcast, while ground applications can be directed onto the plant, where the insecticide is most effective when it falls into the whorl or leaf axils.

Like granular insecticides, liquid insecticides can be applied as either aerial or ground applications or through an irrigation system. Liquids are generally not as effective as granular insecticides because they are more difficult to place where ECB harbor and feed (Edwards, Foster, and Obermeyer).

Neither liquid nor granular applications are 100% effective in killing ECB. Estimates of efficacy are about 80% against first generation borers and 67% against second generation (Ostlie, Hutchison, and Hellmich). The difference in efficacy between generations is due to the location of the borers on the corn plant. Later generations are found behind leaves and ear sheaths as well as on the ear, under the husks. Therefore, the borers are less likely to come in contact with the insecticide.

The decision to spray for ECB must be based on scouting results and economic criteria, which include expected yield benefits and costs of spraying. Many farmers do not scout for ECB (Ostlie, Hutchison, and Hellmich). Without scouting, spraying is generally not economical because timing of the spraying activity is crucial to its success (Edwards, Foster, and Obermeyer). Therefore, scouting and spraying for ECB must go hand-in-hand to be cost effective. The combination of the two activities will be referred to here as an ECB-Scout and Spray Pest Management (ECB-SSPM) program.

Spraying is a control option available to all farmers, regardless of the type of seed planted. Therefore, although unlikely, spraying could be used with Bt corn if infestation is bad enough and if the Bt corn variety does not provide 100% protection. This possibility is further discussed later in this publication. However, few farmers, if any, in the Midwest have implemented such a program (Ostlie, Hutchison, and Hellmich).

Bt corn is the latest ECB management tool (see sidebar). Scientists have used molecular biology and genetic engineering to develop this tool. It should be noted that all Bt corn is not the same (Table 1).

As of April 1998, the Environmental Protection Agency (EPA) had registered four unique types of Bt corn. Each type is the result of a different "event." An event is a successful insertion of the Bt gene into the corn DNA. Each event is tested in the lab and field for desired agronomic traits. There are four events currently on the market. Some result in expression of the Bt protein throughout the above-ground portion of the plant. Others express the protein only in the green tissue and pollen, causing the protection against ECB to diminish with the end of photosynthesis.

The Economic Problem

Corn borer infestations do not occur every season in every field. In a recent study in Iowa and Minnesota, Rice and Ostlie estimated that a field is likely to have infestation levels of at least one ECB per

Table 1. Four Types of Bt Corn on the Market

Event	Brand Name	Developed by	1st/2nd Generation Control[a]
176	Knock*Out*®(Ciba/Novartis) or NatureGard®(Mycogen)	Ciba/Novartis & Mycogen	Excellent / Fair
Bt11	YieldGard®[b]	Northrup King/Novartis Seed	Excellent / Excellent
Mon810	YieldGard®[b]	Monsanto	Excellent / Excellent
DBT418	DEKALBt® or Bt-Xtra®	Dekalb Seeds	Excellent / Good[c]

[a] Obermeyer and Bledsoe
[b] Events Bt11 and Mon810 are both sold under the YieldGard®brand name.
[c] The efficacy of DBT418 Bt seed is being field tested. Early indications are that it will fall somewhere between the efficacy levels of YieldGard® and KnockOut® or NatureGard® seeds. This seed type can be evaluated using our model once the efficacy level is determined.

plant in only one in four to eight years. For Indiana farmers, one in four years is the basis for the analysis in this study (Bledsoe). Furthermore, the level of ECB pressure during an infestation year is variable. Pressure could arise from any combination of first, second, or third generation infestations. Also, the number of ECB per plant can vary in each generation. One borer per plant on average is typical in an infestation year, but there may be as many as three per plant in particularly bad years.

Due to the inherent protection from ECB infestations and additional development costs, seed companies charge more for Bt seed than for identical or similar varieties of non-Bt seed. Currently, the premium on Bt seed ranges from $6 to $12 per acre (about $18 to $36 per seed unit). Companies selling YieldGard® (referred to here as BtYG) are currently charging premiums in the $8-$12 range. Those companies selling Knock*Out*® or NatureGard® seeds (referred to here as Bt*KO*), charge a premium of around $6 (Beeler; Marking). The Bt*KO* premium is lower than the BtYG premium because Bt*KO* is expressed in less of the plant (only pollen and green tissue) and because it becomes less effective later in the growing season.

To get an idea of the economic benefits of protection against ECB infestation, consider the following example. Suppose a farmer expects 150 bushels per acre and a price of $2.50 per bushel. If ECB cause a 6.5% yield loss with no insecticide treatment, the farmer loses $24.37 per acre (i.e., $2.50/bu x 150 bu/acre x 6.5%). Assuming the farmer expects a loss of $24.37 per acre every fourth year, or an average of $6.10 per acre per year, it follows that the farmer should be willing to pay up to, but no more than, a $6.10 per acre premium ($18.30 per unit) for Bt corn that provides 100% protection.

The analysis presented above is an over-simplified version of the economic problem associated with planting Bt corn in Indiana. The situation is more complex due to several factors, including the effects of the planting date, timing and intensity of ECB infestation, and the effectiveness of a spraying program. Each of these factors affects the premium a farmer can afford to pay for Bt seed.

This publication analyzes the value of the protection offered by BtYG and Bt*KO* corn. The analysis employs a computer spreadsheet model that provides a flexible framework for analyzing the value of Bt seed relative to non-Bt seed. Important factors which must be considered include: the impact of planting date on yields, probabilities of alternative levels of infestation for each of the ECB generations and associated yield losses; base yields for Bt and non-Bt varieties; corn prices; and the efficacy of different Bt varieties in controlling ECB.

Figure 1. Dates of Key Crop Production Events and Decisions

Winter	May 9	May 31	June 7	Aug. 6	Sept. 2	Fall
Seed Choice?	*Normal Planting*	*Late Planting* **Spray?**	*First Generation* **Spray?**	*Second Generation* **Spray?**	*Third Generation*	Harvest

Note: Critical decision points are printed in bold, while random events are in italics.

The Model

Time Line

The time horizon for the analysis is a single crop year, beginning with the seed-buying decision and ending with harvest. Between these two events, several things occur. First, the planting date is important because expected yields are greatly reduced for late planted corn and because first generation ECB often strike before late-planted corn is sufficiently developed to serve as a host. The representative date associated with “normal” planting is May 9 and with “late” planting is May 31. These dates reflect the averages of actual planting dates realized from 1985 to 1996 (USDA); realized actual planting date means that approximately half of the Indiana corn crop has been planted by that date. For 10 of those 12 years, the realized actual planting date for the year was near the May 9 date. For the other two years, it occurred much later, around May 31.

Second, the potential occurrence of a first generation ECB infestation is important. In the model, this is assumed to occur on June 7. Infestation dates were calculated from ECB peak flight data provided by Purdue University’s Department of Entomology. The extent of the infestation may be zero, one, two, or three borers per plant in any of the three generations. In an ECB-SSPM framework, once the extent of the infestation has been realized, the decision of whether or not to spray is made based on expected yield, the expected price of corn, and the efficacy and cost of spraying.

Table 2. ECB Infestation Probability Distribution by Generation and Planting Date
(Total Probability of Zero ECB = 75%)

	Normal Planting (Probability = 83%)		**Late Planting** (Probability = 17%)	
	No. of ECB	**Probability**[a]	**No. of ECB**	**Probability**[a]
First Generation	0	83.9	0	98.7[b]
	1	9.7	1	0.8
	2	5.2	2	0.4
	3	1.3	3	0.1
Second Generation	0	90.6	0	83.9
	1	5.6	1	9.7
	2	3.0	2	5.2
	3	0.8	3	1.3
Third Generation	0	98.7[c]	0	90.6
	1	0.8	1	5.6
	2	0.4	2	3.0
	3	0.1	3	0.8

[a] See Hyde, Martin, Preckel, and Edwards, “Analyzing the Risks Associated with Bt Corn” for a more detailed description of how these probabilities were calculated.
[b] In late planted corn, first generation infestation occurs very shortly after emergence, so that ECB usually cannot establish themselves in the plant.
[c] In normal planted corn, third generation infestation occurs when the corn is well developed and turning brown, making it unattractive.

About the Likelihood of Key Events

The following assumptions about the probabilities of planting dates and ECB infestations were used in this analysis.

- The probability of planting at the normal time is 0.83, or five out of six years. The probability of a late planting year is 0.17 (USDA).
- The probability of infestation is 25% (Bledsoe).
- If infestation occurs in a year when corn is planted at the normal time, then the likelihood of first generation infestation is 0.6. The likelihood of second generation is 0.35. And the likelihood of third generation is 0.05, or one in 20 years (Bledsoe).
- If infestation occurs in a year when corn is planted late, then the likelihood of first generation infestation is 0.05. The likelihood of second generation infestation is 0.6. And the likelihood of a third generation infestation is 0.35 (Bledsoe).
- If infestation occurs in any year, regardless of planting date, then the likelihood of there being one ECB per plant is 0.6, or six out of ten. The likelihood of two ECB per plant is 0.32, or one in three. The likelihood of three ECB per plant is 0.08 (Bledsoe).

Similar cycles of realized infestation levels, followed by decisions to spray or not, occur for second and third generations as well. Assumed dates for second and third generations are August 6 and September 2, respectively, again based on Purdue University peak flight data. A time line helps summarize the key crop production events and ECB control decisions (Figure 1).

Probability

The probability distributions used in the computer model (Table 2) were generated using several assumptions (see sidebar). Note that from this point on the term “no infestation” does not mean the total absence of ECB in a field. It simply means that their impact is negligible.

The probabilities in Table 2 reflect the likelihood of infestation levels of zero to three ECB per plant for a given calendar date associated with a particular ECB generation, given either normal or late planting. Suppose, for example, that the field was planted late, that the current date is August 1, and that a second generation infestation is about a week away. The farmer wants to know the probability of second generation infestation in that field. The likelihood of no significant ECB infestation is 83.9%, or about eight out of 10 years (Table 2, “Late Planting” column, “Second Generation” row). The likelihood of an infestation of one borer per plant is about one in 10 years. For two borers per plant, the likelihood is one in 20 years. And for three borers per plant, the likelihood is about one in 80 years.

Scouting

The computer model requires key revenue and cost components as well as assumed levels of spraying effectiveness (Table 3). “Scouting costs” are the difference between the cost of a scouting program which includes ECB scouting and one that is identical in every way except that it does not include ECB scouting. Costs of scouting for other pests are assumed to be unchanged whether ECB scouting is performed or not. The ECB scouting cost in the computer model is $3.00 per acre. Scouting is assumed to be 100% effective in determining the presence and level of infestation.

Yield Losses

Estimates of yield losses across ECB generations are also critical (Table 4). Loss estimates reflect both physiological and mechanical damage. Physiological losses occur when ECB destroy the stalk and ear shanks, impeding the flow of nutrients to the ears. ECB may cause yield loss by other indirect means, referred to as mechanical losses. Weakened stalks from ECB tunneling may result in lodging in strong winds, or the combine may break the stalk before the ears are removed. It is also possible that significantly weakened ear shanks will cause ears to drop during harvest. For more

Table 3. Assumed per Acre Cost and Revenue Parameters

Parameter	Value
Scouting Costs	$3.00[a]
Labor and Machinery Costs	$4.00[b, e]
Insecticide Cost	$10.00[c, e]
Corn Price	$2.50[c]
Base Yield	132 bu./acre
First Generation Spraying Efficacy	80%[c]
Second Generation Spraying Efficacy	60% [c]
Third Generation Spraying Efficacy	50% [c]
YieldGard Bt Effectiveness (All Gens.)	100% [c]
First Generation Event 176 Bt Effectiveness	100% [c]
Second Generation Event 176 Bt Effectiveness	75% [c]
Third Generation Event 176 Bt Effectiveness	60% [c]

[a] Larson. This is the marginal cost of scouting for ECB.
[b] Doster.
[c] Based on published trade, extension, and journal articles. See Ostlie, Hutchison, and Hellmich for example.
[d] Average Indiana Yield, 1992-96, Indiana Agricultural Statistics.
[e] Equals zero when scouting or spraying is not performed.

detail on these loss estimates, see the Note in Table 4.

The losses in Table 4 are for non-Bt corn relative to the base yield with no infestation. The losses can be found by multiplying relevant yield loss estimates rather than adding them. For example, the yield adjustment if the corn is planted at the normal time and there is one ECB per plant in first generation, one in the second, and none in the third is 9.6%, or (1 – (1 - .058) (1 - .04)) x 100.

The loss estimates are multiplied because earlier generations decrease the yield potential faced by later generations. In the above example, the one first generation borer decreases yield potential by 5.8%. Therefore, the yield potential faced by the one second generation borer is 94.2%. The second generation ECB lowers that yield by 4%. So the total effect is that yield potential is now only 90.4%, or 100 - 9.6%.

Contribution Margins

The computer model calculates the differences in average contribution margins for the different types of seed. The per acre contribution margin in this analysis is defined as revenue (price times yield per acre) less per acre seed, scouting, labor, machinery, and insecticide costs required in an ECB-SSPM program. In a non-ECB-SSPM framework, no costs related to scouting and spraying (labor, machinery, and insecticide) are incurred. The differences in calculated contribution margins can be compared directly to the actual premiums charged for Bt seed. If the actual premium is less than the expected extra value afforded by the protection from ECB, the profit maximizing farmer should adopt the Bt seed technology. If the premium is greater than the value of protection, the farmer should not adopt the Bt technology.

Seed Choices

Three seed choices were analyzed: non-Bt (regular corn), BtYG (YieldGard®), and Bt*KO* (Knock*Out*® or NatureGard®). For purposes of comparison, the three seed corn varieties are assumed to be identical except for their different Bt characteristics. That is, each has the same base yield, 132 bushels per acre (average Indiana yields, 1992-96), in the absence of ECB pressure. For each of these three seed choices, the farmer could implement an ECB-SSPM program. Analysis of the economic value of such a program under each seed choice is presented below.

Table 4. Percentage Yield Losses Due to ECB Infestation Levels by Generation

	No. of ECB	Normal Planted Losses (%) Phys.[a]	Mech.[b]	Total	Late Planted Losses (%) Phys.[a]	Mech.[b]	Total
First Generation	1	5.5	0.3	5.8	5.5	0.3	5.8
	2	8.2	0.4	8.6	8.2	0.4	8.6
	3	10.0	0.5	10.5	10.0	0.5	10.5
Second Generation	1	2.9	1.1	4.0	6.6	0.3	6.9
	2	4.3	1.7	6.0	9.9	0.4	10.3
	3	5.3	2.1	7.4	12.1	0.5	12.6
Third Generation	1	2.0	0.9	2.9	2.5	0.7	3.2
	2	3.0	1.3	4.3	3.8	1.0	4.8
	3	3.7	1.7	5.4	4.6	1.2	5.8

[a] Phys. - physiological losses (Edwards, Foster, and Obermeyer).
[b] Mech. - Mechanical losses (Lynch).
Note: Losses were calculated by mapping a timeline with plant growth and expected infestation dates. If expected infestation dates fell between stages of plant growth, then the losses between the two growth stages were assumed to change linearly. For example, if planted late, the model assumes that the corn reaches the blister stage on Aug. 26 and the dough stage on Sept. 10. Third generation ECB hit on Sept. 2, about halfway between the two growth stages. So losses with third generation ECB in late planted corn are calculated as 1/2 dough losses plus 1/2 blister losses. The six growth stages used in the model are early whorl, late whorl, pre-tassel, pollen shedding, blister, and dough.

Analyses of third generation impacts are not reported because the probability of a third generation infestation is so small that its impact is negligible, on average.

Results

Cost Effectiveness of ECB-SSPM

A base case was developed to serve as a benchmark for analyzing the changes in expected values of each seed, under ECB-SSPM and no ECB-SSPM assumptions, given changes in other factors. (See Tables 2 through 4 for the base case levels of probabilities, cost and revenue components, and yield losses.) Recall that an ECB-SSPM program includes scouting and spraying.

ECB-SSPM practices are not economical based on the computer model and assumptions. With non-Bt corn, implementing an ECB-SSPM program results in an average loss of $2.49 per acre. (Three dollars per acre is the ECB scouting cost. However, spraying adds $0.51 per acre in increased expected revenue, resulting in a net loss of $2.49 per acre.) It is important to note that these figures are based on average costs and benefits. There are some years in which scouting and spraying would be economical in non-Bt corn. However, the likelihood of that situation is so small that, more often than not, scouting costs are much greater than the economic benefits from spraying.

With Bt corn (either BtYG or Bt*KO*) spraying is not cost effective for any generation or infestation level, even if there are no scouting costs. Therefore, ECB-SSPM programs would result in a $3.00 per acre loss of net revenue because of scouting costs. Spraying is never chosen because the costs of materials, labor, and machinery operating expenses are greater than the value of saved yields in every case.

Given that ECB-SSPM practices result in lower contribution margins for each seed type analyzed, the best choice for the average farmer is not to scout or spray for ECB. Only if the marginal cost of scouting for ECB is less than $0.51 per acre would an ECB-SSPM program be economical for farmers growing non-Bt corn. Thus, $0.51

Table 5. ECB Infestation Probability Distribution by Generation and Planting Date

(Total Probability of Infestation = 40%)

	Normal Planting (Probability = 83%)		**Late Planting** (Probability = 17%)	
	No. of ECB	**Probability**	**No. of ECB**	**Probability**
First Generation	0	72.9	0	97.7
	1	16.3	1	1.4
	2	8.7	2	0.7
	3	2.2	3	0.2
Second Generation	0	84.2	0	72.9
	1	9.5	1	16.3
	2	5.1	2	8.7
	3	1.3	3	2.2
Third Generation	0	97.7	0	84.2
	1	1.4	1	9.5
	2	0.7	2	5.1
	3	0.2	3	1.3

per acre represents a breakeven cost of scouting to make an SSPM program economical in non-Bt corn.

Because ECB-SSPM programs are not considered best practices based on the data used in this analysis, the proper base to use to compare Bt seed values is non-Bt seed without an ECB-SSPM program. When compared to this base, BtYG and Bt*KO* seeds are worth $4.99 and $4.49 per acre more, respectively. It may seem surprising that the values of BtYG and Bt*KO* are only $0.50 apart. However, the low probabilities of second and third generation infestations drive this result (see Table 2), because both BtYG and Bt*KO* provide 100% protection against first generation ECB infestations.

Sensitivity to Likelihood of Infestation

The probability of ECB infestations across the state of Indiana has been assumed to be 25%. However, there are some areas of the state, particularly the Northern portion, in which the probability of infestation of at least one borer per plant in any generation may be as high as 40% (Bledsoe). Therefore, the sensitivity of Bt seed values to the probability of infestation (probabilities in Table 5) is analyzed.

The probability of infestation has a strong impact on the value of Bt to farmers. By increasing the probability of infestation from 25 to 40%, the economic value of BtYG increases from $4.99 to $8.35 per acre, while for Bt*KO* it increases from $4.49 to $7.52 per acre. Both of the new Bt values are now within the ranges of the premiums currently charged by the various seed companies for Bt seed.

The increase in infestation probability has little impact on a scouting and spraying program. The breakeven scouting cost increases from $0.51 per acre in the initial base case to $0.84 per acre when the likelihood of ECB infestation is 40%. Hence, scouting and spraying for ECB do not pay, but adopting Bt corn does. Although it may seem that Bt values are affected much more than the value of spraying, the two are actually very similar in percentage terms. The values all increase by about 65%.

Bt Effectiveness

The true level of protection against ECB is yet unknown for BtYG and Bt*KO* seeds. However, it is well accepted that the Bt in BtYG is highly active during the growing season, throughout the corn plant. The Bt in Bt*KO* is considered to be highly active against first generation ECB, with protection declining as the corn develops (Ostlie, Hutchison, and Hellmich). Second and third generation protection is still being evaluated. Given this uncertainty, it is important to analyze a range of potential levels to determine the value of protection over that range (Table 6).

The results of this analysis, in percentage terms, are the same regardless of whether the probability of infestation is 25 or 40%. As the ECB protection in BtYG decreases from the base assumption of 100% to 90%, the value of the protection decreases by 10%. This decrease pushes its value below the current premium range with a 40% probability of infestation.

For Bt*KO*, protection differs with respect to each ECB generation. Therefore, each must be analyzed individually, with the efficacy level of the other generation held at its base case level (100% for first generation and 75% for second). When first generation protection is 90% and the probability of infestation is 40%, its value is $7.00. This compares to a value of $7.52 when the effective protection level is 100%. When the seed offers 60% protection against second generation borers, the value of Bt*KO* is $7.11. At 85% protection, the value of Bt*KO* is $7.80.

As field tests clarify the ECB protection issue, the value can be more precisely defined. However, the ranges analyzed here are large enough to provide an indication of the value of ECB protection with Bt seed.

Yield Drag

It has been suggested in several trade publications (e.g., Bechman, *Soybean Digest*) that the insertion of the Bt gene may reduce the yield potential of the transgenic corn plant relative to the non-Bt plant. This is called yield drag. However, to date field tests for yield drag have been inconclusive. Nonetheless, the potential presence of yield drag has important consequences for the value of ECB infestation protection.

To determine what the loss in value of Bt seed is for a given base yield, yield drag level, and corn price, apply the following formula: (83% x Base Yield x Corn Price x Yield Drag level) + (17% x (Base Yield x 60%) x Corn Price x Yield Drag Level)

This formula reflects the probability of normal planting of 83%, the probability of late planting of 17%, and the yield adjustment factor of 60% for late planting. Suppose a farmer expects 132 bushels per acre yield at a corn price of $2.50 and Bt seed exhibits a 1% yield drag. Then the loss in value of the Bt corn is (83% x 132 bu/acre x $2.50/bu x 1%) + (17% x (132 bu/acre x 60%) x $2.50/bu x 1%), which equals $3.08. Thus, if the premium for a Bt variety were $6.00, then a yield drag level of only 2% (or 2.6 bushels per acre in this example) would completely offset the added benefit of the Bt trait.

Decision Tools

Table 6. Impact of Bt Efficacy on Bt Values

		Bt Value (25%)[a]		**Bt Value (40%)**[b]	
	Efficacy Range[c]	Range		Range	
BtYG	90-100%	$4.48	$4.99	$7.51	$8.35
First Generation Bt*KO*	90-100%	$4.18	$4.49	$7.00	$7.52
Second Generation Bt*KO*	60-85%	$4.25	$4.66	$7.11	$7.80

[a] Probability of infestation is 25%.
[b] Probability of infestation is 40%.
[c] This is the percent of ECB killed by the Bt toxins in the corn. Due to lack of published data on efficacy ranges, these cover a significant range spanning the base case levels.
Note: "Bt Value" is the value to the farmer afforded by the extra protection from Bt corn relative to non-Bt varieties.

The results of this analysis indicate that "typical" Indiana farmers (those operating under the base case levels of corn yields and output prices) may not benefit by adopting Bt technology under "average" infestation levels. This does not mean that Bt corn is economically a poor choice for every farmer. By the same argument, under some conditions, it may be economical for some farmers to implement an ECB-SSPM program. Tables 7, 8, and 9 provide guidelines to decide if either spraying or Bt technologies are economical given a farmer's expected yield, price, and ECB infestation level.

While it is economical to implement an ECB-SSPM program at the $3.00 per acre scouting cost for some farmers with both high expected per acre revenues and high infestation expectations (Table 7), for most farmers, ECB-SSPM does not pay when scouting costs are $3.00 per acre. Table 7 shows breakeven scouting costs for each revenue-probability combination.

The base case suggests that Bt corn is not economical. However, both BtYG and Bt*KO* are profitable under conditions of higher than average expected revenues and higher likelihoods of ECB infestation (Tables 8 and 9). Almost all farmers would benefit from BtYG, at an $8.00 per acre premium level, when the likelihood of ECB infestation is 40% or greater (Table 8). For Bt*KO*, the threshold premium level, $6.00 per acre in this case, is reached sooner with lower expected revenues and lower likelihood of ECB infestation (Table 9).

Table 7. Breakeven Scouting Costs for Different Revenue and Infestation Levels

	Probability of Infestation			
Revenue	**20%**	**25%**	**30%**	**40%**
$250	$0.13	$0.16	$0.20	$0.36
$300	$0.29	$0.36	$0.43	$0.77
$350	$0.52	$0.66	$0.80	$1.41
$400	$0.83	$1.06	$1.28	$2.27
$450	$1.17	$1.49	$1.81	$3.20*
$500	$1.51	$1.93	$2.34	$4.14*
$550	$1.86	$2.37	$2.87	$5.10*
$600	$2.20	$2.81	$3.41*	$6.06*
$650	$2.60	$3.32*	$4.02*	$7.15*
$700	$3.01*	$3.84*	$4.65*	$8.28*
$750	$3.42*	$4.36*	$5.28*	$9.40*

* Indicates that an ECB-SSPM program is economical at the assumed scouting cost of $3.00 per acre.
Note: Revenue is measured as expected price times expected yield. For example, the revenue for a farmer expecting a yield of 140 bushels per acre at a price of $2.50 per bushel is $350 per acre.

Table 8. Estimated Value of YieldGard® Corn for Different Revenue and Infestation Levels

	Probability of Infestation			
Revenue	**20%**	**25%**	**30%**	**40%**
$250	$2.96	$3.78	$4.59	$6.32
$300	$3.27	$4.53	$5.50	$7.59
$350	$4.15	$5.29	$6.42	$8.85*
$400	$4.74	$6.04	$7.34	$10.12*
$450	$5.33	$6.80	$8.25*	$11.38*
$500	$5.92	$7.55	$9.17*	$12.65*
$550	$6.52	$8.31*	$10.09*	$13.91*
$600	$7.11	$9.06*	$11.00*	$15.18*
$650	$7.70	$9.82*	$11.92*	$16.44*
$700	$8.29*	$10.57*	$12.84*	$17.71*

* Indicates that BtYG is economical at the assumed minimum premium level of $8.00 per acre.

Refuge Considerations

Scientists agree that ECB populations may develop resistance to Bt corn over time. However, planting a refuge can help slow that process. A refuge is an area of non-Bt corn planted in proximity to a Bt field. The refuge will allow non-resistant borers to survive and mate with resistant borers, thus keeping the non-resistant genes prevalent in the ECB gene pool. The goal of the refuge is to lengthen the useful life span of the Bt technology by slowing the resistance development process.

There are several important issues in the refuge debate. Scientists must come to a consensus on how resistance management should differ among Bt seed types. There are issues concerning the fraction of acreage that must be planted to refuge and where the refuge should be planted relative

Table 9. Estimated Value of KnockOut® or Maximizer® Corn for Different Revenue and Infestation Levels

	Probability of Infestation			
Revenue	**20%**	**25%**	**30%**	**40%**
$250	$2.67	$3.40	$4.13	$5.70
$300	$3.20	$4.08	$4.96	$6.84*
$350	$3.74	$4.77	$5.79	$7.98*
$400	$4.27	$5.45	$6.61*	$9.12*
$450	$4.81	$6.13*	$7.44*	$10.26*
$500	$5.34	$6.81*	$8.26*	$11.40*
$550	$5.87	$7.49*	$9.09*	$12.54*
$600	$6.41*	$8.17*	$9.92*	$13.68*
$650	$6.94*	$8.85*	$10.74*	$14.82*
$700	$7.48*	$9.53*	$11.57*	$15.96*

* Indicates that BtKO is economical at the assumed minimum premium level of $6.00 per acre.

to the Bt corn (i.e., how far away from Bt corn, planted as a separate block or interspersed with the Bt corn). Ostlie, Hutchison, and Hellmich recommend that 20 to 30% of corn acreage be planted to non-Bt corn as a refuge for non-resistant ECB when spraying is not performed on the refuge. If spraying is planned for the non-Bt refuge area, then a 40% refuge is recommended.

The refuge requirement should not change the decision to adopt Bt corn. The refuge will simply decrease the number of acres planted to Bt corn. If planting Bt corn is profitable for the expected yield and infestation levels on that field (Tables 8 and 9), then that field should be planted to Bt corn with an appropriate refuge planted to non-Bt corn.

Planting a refuge involves a tradeoff of current profits for future profits. Planting 100% of corn acres to Bt varieties may maximize farm profits in the first year, but a significant number of non-resistant ECB may die. If enough die, then Bt corn will be ineffective against the remaining resistant borers, and an important pest management tool will have been lost. The refuge is designed to lengthen the useful life of Bt corn as a crop protection tool. The proper amount and design of refuge to plant to maximize farm profits over time is being studied. However, it is the responsibility of all farmers planting Bt corn to plant refuge so that this important management tool can be maintained as long as possible for all farmers.

Management Implications

For the average Indiana farmer, the results of the study reported in this publication suggest that current premiums charged for Bt seed are higher than the expected value of the protection offered by the seed. Based on historical Indiana data and the assumption that ECB infestations occur one in four years, the value of BtYG seed is about $5.00 per acre greater than the value of non-Bt seed. The value of Bt*KO* seed is about $4.50 per acre greater. If ECB infestations occur more often and/or expected yields or prices are higher than the values assumed in this publication, then the expected value of Bt corn will cover the premiums currently being charged for Bt seed.

Even though the expected financial benefit may be slightly below the actual premium in most cases, Bt corn still may not be a bad investment for farmers. Each farmer must decide the value of the Bt seed in terms of risk management and peace of mind. Bt seed can be viewed much like insurance. It offers financial protection from yield losses in infestation years. In non-infestation years, the premium paid for Bt seed increases per acre costs while providing no financial benefits (assuming equal yield potential between Bt and non-Bt seeds). Each farmer must decide if the actual yield above the expected extra value of the Bt corn is worth the peace of mind of knowing that yields are protected in case of infestation.

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