# Module III – Table of Contents

## III. Production Issues for Bt Crops

### BACKGROUND INFORMATION FOR EDUCATORS

- Economic trade-offs ................................................................. 91
- Refuges .................................................................................... 91

### TEACHING RESOURCES

- **Lesson plan:** The Economics of Growing Bt corn .................................................. 95
- Internet ideas ........................................................................... 108
- Student handout: Learning More About the Economics of Growing Bt Crops .................................................. 109
- Student handout: See For Yourself – Example: Consider the Costs ......................... 111
- Student handout: See For Yourself – Consider the Costs ........................................ 115
- Overhead transparency masters ........................................................................ 131

- **Lesson plan:** Refuge Roundtable .................................................. 173
- Internet ideas ........................................................................... 176
- Student handout: Learning More About Insect Resistance to Bt .......................... 177
- Student handout: See For Yourself – The Mating Game .................................. 179

- **Lesson plan:** Locating Refuges – Insect Hotels ................................................. 183
- Internet ideas ........................................................................... 184
- Student handout: Learning More About Locating Refuges .................................. 187
- Student handout: See For Yourself – Locating Refuges: Insect Hotels .............. 191
- Overhead transparency masters ........................................................................ 197

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Production Issues for Bt Crops

BACKGROUND INFORMATION

Economic Tradeoffs
Bt crops were developed to reduce insect damage in corn from European corn borers (ECB), in cotton from bollworms and budworms, and in potatoes from the Colorado potato beetle. Predicting how much insect damage will occur in any one year is difficult, at best, because the weather and other factors can influence crop planting dates and insect populations from year to year. The growth stage of the crop when the insect begins feeding significantly affects the yield reduction, as can the harvest date.

Economic Thresholds
Economic thresholds are used to help agricultural producers determine when it is to their financial advantage to adopt a certain technology or practice. In the case of insect control practices, the economic threshold is the point at which the cost of an insect control practice equals the estimated cost in yield loss of not using the control practice. If the insect infestation is bad enough that the value of the yield loss is greater than the cost of applying the control practice, producers usually decide to treat the problem.

Agricultural producers can monitor (scout) their crops throughout the growing season for evidence of insect infestation. If the number of insects per plant exceeds a certain number or the visible damage to the crop plants exceeds a certain level, the producer may make the decision to apply insecticides. Economic threshold tables for crop pests have been developed by entomologists and agronomists to help producers make their decisions. The economic threshold tables take into account a range of market prices for the crop, the infestation level, the cost of the control practice, the effectiveness of the control practice, and the expected yield of the crop. Examples of scouting guides and economic threshold tables are listed in the Internet Ideas section on p. 108.

Bt Crops and Economic Thresholds
Because the insect resistance of Bt crops is genetically built into the seed, agricultural producers must decide whether paying the added cost charged for Bt seed is worth it before the crops are planted. Instead of relying on crop scouting data for one growing season, producers considering Bt crops look at insect damage over a number of years at their location. The economic decisions agricultural producers make about whether to plant Bt crops are based largely on the likelihood (probability) of insect damage rather than the certainty of damage.

The following excerpt from a 1997 University of Minnesota Extension Service publication regarding ECB damage in that state from 1988-1995 is a good example of the insect variability associated with all Bt crops.

“European corn borer populations fluctuate over the years and from one field to the next. Similarly, corn yields and market prices often are volatile. This variability raises concerns about fluctuations in yearly economic benefits of Bt corn. To illustrate this point, the risk of investing in Bt corn was scrutinized for southern Minnesota over an eight-year period 1988-1995. This period included three outbreak (high) years for European corn borer and five endemic (low) years. The average benefit for this period, $17.24 per acre, was very close to the national estimate of Bt value, but returns varied considerably between endemic and outbreak years. During the endemic years, the yield protection offered by Bt corn barely covered the price premium for seed, currently $7 to $10 per acre. During outbreak years, yield savings of $28 to $50 per acre were four to five times the added seed cost. The bottom line: Do not expect an economic return every year or in every field. As with any type of natural resistance, Bt corn only delivers an economic benefit when European corn borer outbreaks occur. Unfortunately, no predictive tools for European corn borer outbreaks are currently available.”

Refuges
The Environmental Protection Agency (EPA) has mandated practices that reduce the potential for insects to become resistant to the Bt proteins produced in Bt crops such as corn, cotton, and potatoes. Scientists believe that exposing insects to high doses of the proteins and planting refuges of non-Bt crops will slow the development of resistance. A high dose, as defined by the EPA’s Science Advisory Panel Subpanels, is 25 times the Bt protein concentration necessary to kill susceptible larvae.
**The Assumptions Behind Refuges**

The high dose/refuge strategy assumes that resistance to the Bt protein is controlled by a recessive allele of the insect, \( r \), and susceptibility is controlled by a dominant allele, \( S \). Insects can be susceptible homozygotes (SS), susceptible heterozygotes (Sr), or resistant homozygotes (rr). The high dose/refuge strategy also assumes that there will be very few resistant (rr) insects to begin with and that extensive random mating will occur between resistant and susceptible adult insects.

Ideally, only rare rr insects will survive a high dose of Bt endotoxin produced by a Bt crop. All the SS and all of the Sr individuals should be killed by the Bt protein. The non-Bt refuge will provide a place for susceptible SS individuals to feed and mate with the rare rr resistant individuals. When their Sr offspring are killed by the Bt crop, resistant r alleles are removed from the insect population. This should delay the development of resistance.

![Diagram showing mating of resistant survivor moths from Bt corn with susceptible moths from the refuge slows the development of resistance.](image)

The EPA has established resistance reporting requirements and monitoring procedures for companies who have registered Bt crops with the federal agency. Industry registrants, in turn, provide educational information about refuges and require agricultural producers to sign grower contracts.

**Insect Resistance Management Plans**

The EPA is addressing insect resistance to Bt by (1) trying to reduce the potential for insect resistance development in the field by mandating that industry registrants of Bt crops develop insect resistance management (IRM) plans and by (2) better understanding the mechanisms that cause resistance to develop. The EPA has identified seven elements, including refuges, that should be part of a Bt crop insect resistance plan:

- knowledge of insect biology and ecology
- appropriate dose expression strategy
- appropriate refuge
- resistance monitoring and a remedial action plan should resistance occur
- employment of integrated pest management
- communication and education strategies on use of the product
- development of alternative modes of action

The IRM plans also must include ways to measure how well the plans are being followed. IRM plans change as more scientific data become available, so the EPA makes research data requirements part of the terms and conditions of registration of Bt crops.

**Crop-Specific Refuge Requirements**

Each Bt crop has specific requirements for refuges. The EPA’s scientific advisory panels recommend that refuges for Bt corn, cotton, and potatoes be sized and located so that 500 susceptible insects are produced for every resistant insect. These requirements are updated for each new crop year according to the most recent scientific information. The activities in this module are based on the refuge information available for the 2002 crop year. Resources for updating refuge information for future years are given on p. 184-185. The requirements as stated below are not meant to be a complete presentation of all requirements that growers should follow when planting Bt crops. For complete information, view the EPA or industry sources listed on p. 184-185.

**Refuge Requirements for Growing Bt Corn in the Northern Corn Belt (Non-Cotton Growing Areas) in 2002**

In areas of the United States where no cotton is grown, the following requirements apply:

- On each farm, producers can plant up to 80% of corn acres with Bt corn. The other 20% of corn acres must be planted to a structured refuge of non-Bt corn.

- The non-Bt corn refuge must be placed within, adjacent to, or near the Bt corn field. The refuge must be within 1/2 mile of the Bt corn field (1/4 mile or closer preferred) to help provide a population of susceptible moths with which the resistant moths can mate.

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*Figure by Glenda Webber, ISU Office of Biotechnology.*
• Insecticide treatments for control of ECB, corn earworm, or Southwestern corn borer may be applied to the refuge only if economic thresholds are reached for one or more of the target pests. Microbial Bt insecticides may not be applied to non-Bt corn refuges.

• Refuge planting options include:
  - Separate fields
  - Blocks within fields along the edges or end rows
  - Strips across the field alternating four rows or more (six preferred) of non-Bt corn with Bt corn

Examples of acceptable refuges for Bt corn include:

- Adjacent Block
- Block Within Field
- Perimeter
- Strips
- Pivot Corners (irrigated fields)
- Separate Field

Refuge Requirements for Growing Bt Cotton in 2002
Growers can choose one of four refuge options when growing Bt cotton:

• 95:5 external structured unsprayed refuge:
  At least 5 acres of non-Bt cotton must be planted for every 95 acres of Bt cotton. The refuge must be at least 150 feet wide and may not be treated with insecticides for controlling tobacco budworm, cotton bollworm, or pink bollworm. The refuge must be planted within 1/2 linear mile from the edge of the Bt cotton field. The refuge must be managed (fertility, weed control, and management of other pests) similarly to the Bt cotton.

• 80:20 external sprayed refuge:
  At least 20 acres of non-Bt cotton must be planted for every 80 acres of Bt cotton. Both Bt and non-Bt cotton may be treated with insecticides, except for foliar B.t.k. (Bacillus thuringiensis, subspecies kurstaki) products labeled for the control of tobacco budworm, cotton bollworm, or pink bollworm. The refuge must be maintained within 1 linear mile (preferably 1/2 mile or closer) from the edge of the Bt cotton.

• 95:5 embedded refuge:
  At least 5 acres of non-Bt cotton must be planted for every 95 acres of Bt cotton. The non-Bt cotton must be planted as a block within the Bt cotton field. Multiple blocks across the field may be used for very large fields.

For fields that are small or irregularly shaped, neighboring fields farmed by the same grower can be grouped into a field unit block. The field unit block must be at least 150 feet wide and all fields grouped into it must be located within one square mile of the Bt cotton. Within the larger field unit, a smaller field planted to non-Bt cotton may serve as the embedded refuge.

Whether the refuge is embedded within a single Bt cotton field or is a smaller field that is grouped into a field unit block, the refuge acres can be treated with any insecticide (except foliar B.t.k. products for tobacco budworm, cotton bollworm, or pink bollworm) whenever the entire field is treated. The refuge acres cannot be treated with insecticides unless the Bt cotton acres also are treated.

• A group of cotton growers whose farmland is contiguous can establish a community refuge that meets the requirements of either the 95:5 or 80:20 option.
Examples of acceptable refuges for Bt cotton include:

- **5% Unsprayed Refuge (95:5)**
  - 95 Acres
  - 5 Acres

- **20% Sprayed Refuge (80:20)**
  - 80 Acres
  - 20 Acres

- **5% Embedded Refuge (95:5)**
  - 95 Acres
  - 5 Acres

- **5% Embedded Refuge for Very Large Fields (95:5)**
  - 95 Acres
  - 5 Acres

**Refuge Requirements for Growing Bt Potatoes in 2002**

Starting with the 2001 growing season, Monsanto decided to no longer market its NatureMark potatoes due to concern about consumer reaction and the reluctance of some major processors to buy genetically modified potatoes. However, as this is written, the EPA registration for the Cry3A Bt potato product with the trade name NewLeaf® is still in effect. Therefore, information about the refuge requirements is included in case the product is marketed in future years.

The current Insect Resistance Management (IRM) plan for Bt potatoes includes the following requirements for growers:

- Bt potatoes should be planted in rotation with other crops to reduce the numbers of Colorado potato beetle.
- At least 20% of the total potato acreage should be planted to non-Bt potato varieties as a refuge.
- Growers must not use a foliar Bt application to control the Colorado potato beetle in the refuge. Growers may treat Colorado potato beetles in the refuge with non-Bt foliar insecticides to prevent damage only when insect populations reach damaging levels, according to local integrated pest management recommendations.
- Plant every Bt potato field within 1/2 mile of the current year refuge or within 1/2 mile of land that was the designated refuge last year.
- Use every available method to reduce insect populations such as crop rotation, propane flaming, trench trapping, and destruction of overwintering habitat.

**Credit Notes**


5. Ibid., p. IID70-IID74.

6. Ibid., p. IID131-IID133.

NewLeaf® is a registered trademark of the Monsanto Company.
Lesson Module III – Production Issues for Bt Crops

TEACHING RESOURCES

Lesson Plan: The Economics of Growing Bt Corn

Science Content
Students will understand how natural variability of insect populations can impact the economics of crop planting decisions.

Science Education Standards

Life Science, Content Standard C
– Molecular basis of heredity (p. 185)
– Biological evolution (p. 185)
– Interdependence of organisms (p. 186)
– Matter, energy, and organization in living systems (p. 186)

Life Science, Content Standard F
– Population growth (in insect populations) (p. 198)
– Environmental quality (ecosystems) (p. 198)


Science Process Skills
– Observing
– Comparing and measuring
– Relating
– Inferring

Life Skills
– Learning
– Decision making
– Science processing

Time
Copying optional handouts: 10 minutes
Optional Internet research by students: variable
Doing activity: 40 minutes

Materials
If using the handouts, make enough copies of the optional student handout III-a, Learning More About the Economics of Growing Bt Crops, and III-b Example: Consider the Costs for the entire class. Make enough copies of student handouts III-c, d, e, and f so each member of a group has a copy of that group's handout. For example, all members of the group doing handout c should have a copy of it. Photocopying the first page of handouts b-f on one side of the paper only will make it easier for students to refer to the yield loss table. Ask students to bring calculators or provide calculators for each student.

Lesson Plan

Before the Activity
Teachers may use student handout III-a on p. 109 and/or the overhead masters III-a through III-u on p. 131-171 to introduce information about the economics of Bt corn production. If preferred, teachers may ask their students to research the economics of Bt corn production themselves by using some of the online publications listed in the Internet Ideas section or other resources. Because of the amount of math involved in this activity, teachers may wish to collaborate with a math teacher for this activity.

The Day of the Activity

Step One – Set the Scene
Tell students the following scenario:
“A farmer has purchased Midwest farmland. The farmer is going to plant 625 acres of corn on the land and is trying to determine whether planting Bt corn would be worth the extra cost. The farmer knows that Bt corn seed costs more than regular seed corn. The farmer also knows that the Bt corn being considered is nearly 100% effective against European corn borers (ECB).

“The former landowner kept no records on damage caused by ECB in previous years. However, with the help of the local USDA Extension office, the farmer collected crop information on ECB outbreaks for the past 20 years in the county where the land is located. Use the statistics and the chart "Percentage Yield Loss from ECB by Generation and Planting Date” to answer the questions for each year’s production. Decide if you can determine whether planting Bt corn probably would or would not be profitable for this farmer in the future.”
Step Two – Do an Example (optional)
Teachers may wish to do the example below with the students before asking them to do the activity. Students will need to use the corn yield loss chart1 below (also appears on the student handouts and on overhead masters III-g and III-u, p.143 and 171) to calculate the percentage of yield loss to ECB for each crop year. Yield percentages are rounded to nearest tenth, yield bushels to nearest hundredth, and dollars to nearest cent.

Example
Corn acres: 625
Planting date: May 12
Potential yield/acre: 150 bushels
Average corn price received by farmers: $2.20/bushel
(If desired, teachers may wish to have students research the current corn price on the day of the activity. If the current price is used, the answers for the example will change accordingly.)
Average no. of first generation ECB per/plant: 1
Average no. of second generation ECB per/plant: 2

1. By what percentage did first generation borers probably lower the yield potential of non-Bt corn during this crop year?

3.8%  Look at row 1 for first generation ECB and follow it to where it intersects with the column labeled “May 10-16.” The planting date was May 12, which falls between May 10-16.

2. By what percentage did second generation borers probably further lower the yield potential of non-Bt corn during this crop year?

6.5%  Look at row 2 for second generation ECB and follow it to where it intersects with the column labeled “May 10-16”

3. What was the total percentage of yield loss of non-Bt corn that was likely caused by the two generations of ECB during this crop year?

The answer is 10.1%. Before the ECB damage began, the yield potential was 100%. After the first generation ECB damage, the yield potential was reduced to 96.2% because 100% - 3.8% damage from the first generation ECB = 96.2%. When the second generation ECB arrived and caused another 6.5% of damage, that damage was applied to the corn yield potential of 96.2%. To find out how much additional percentage yield loss was caused by the second generation ECB, the percentage of second generation damage is multiplied by the current yield potential of 96.2%: 0.065 x 0.962 = 0.06253, which can be rounded off to 0.063 x 100 = 6.3%. Therefore, the total damage caused by the two generations is 3.8% + 6.3% = 10.1%.

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### Percentage Yield Loss from ECB by Generation and Planting Date

<table>
<thead>
<tr>
<th>No. of ECB Per Plant</th>
<th>Before May 1</th>
<th>May 1-9</th>
<th>May 10-16</th>
<th>May 17-23</th>
<th>May 24-30</th>
<th>After May 30</th>
</tr>
</thead>
<tbody>
<tr>
<td>First Generation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>4.7</td>
<td>5.2</td>
<td>3.8</td>
<td>2.7</td>
<td>0.2</td>
<td>0.0</td>
</tr>
<tr>
<td>2</td>
<td>7.1</td>
<td>7.9</td>
<td>5.8</td>
<td>4.2</td>
<td>0.5</td>
<td>0.0</td>
</tr>
<tr>
<td>3</td>
<td>8.8</td>
<td>9.7</td>
<td>7.2</td>
<td>5.2</td>
<td>0.7</td>
<td>0.0</td>
</tr>
<tr>
<td>Second Generation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
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<td>2.0</td>
<td>3.7</td>
<td>4.2</td>
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<td>8.0</td>
<td>8.5</td>
<td>10.9</td>
<td>11.2</td>
</tr>
</tbody>
</table>

Table 4
The chart used in this activity was adapted from a similar one contained in *The Economics of BT Corn: Adoption Implications*, Table 4, p. 6. Jeffrey Hyde, Marshall A. Martin, Paul V. Preckel, C. Richard Edwards. Percentages were adjusted for the purposes of this activity, so results may differ from data reported in the peer-reviewed, scientifically-based publication. Purdue University Cooperative Extension Service, West Lafayette, Indiana, ID-219, Rev. 10/2001. Available at [http://www.ces.purdue.edu/extmedia/ID/ID-219.pdf](http://www.ces.purdue.edu/extmedia/ID/ID-219.pdf). Used with permission.
Another way to explain this is by using the formula:

\[ (1 - (1-Y_1)(1-Y_2)) \times 100 = \text{Total \% of Yield Loss} \]

where \( Y_1 \) is the percentage loss from first generation ECB and \( Y_2 \) is the loss from second generation ECB. Percentages are converted to their decimal equivalents before using in the formula. For example, 3.8% = 0.038.

Using the values for the example gives:

\[ (1 - (1-0.038)(1-0.065)) \times 100 = 10.1\% \]

If students ask for more detail about how the formula is solved, tell them first to do the subtraction problems inside each parenthesis. The next step is multiplying the answer to one subtraction problem times the other answer. The answer from the multiplication step should be subtracted from 1 and the result multiplied by 100 to arrive at a percentage.

Teachers may or may not want to tell students that if they simply add the two percentages of yield loss together (3.8% + 6.5%), they will get an approximate answer, but not the correct answer.

4. Use your answer from number 3 to calculate the probable yield/acre of non-Bt corn that the former landowner received for this crop year.

100% - 10.1\% yield loss = 89.9\% yield
150 bu/acre potential x 0.899 = 134.85 bu/acre

5. Assuming that the former landowner sold the non-Bt corn from the 625 acres for the average price for this year, how much money (gross income) would the landowner have received per acre? How much would the landowner have received for the entire crop?

134.85 bu/acre x $2.20/bu = $296.67/acre
$296.67 x 625 acres = $185,418.75 for the crop

Students’ answers may differ a little, depending on whether they rounded off some answers.

6. If Bt corn had been available and planted by the former landowner for this crop year, how much money (gross income) would the landowner have received per acre for the Bt corn? For the non-Bt refuge corn? How much money would the landowner have received for the entire corn crop?

(Assume that the former landowner would have divided his 625 acres of corn into 80% Bt corn and 20% non-Bt refuge. Also assume that the Bt corn was 100% effective against first and second generation borers, and the refuge corn had the yield/acre that you calculated for question 4.)

150 bu/acre x $2.20/bu = $330/ac for Bt corn
134.85 bu/acre x $2.20/bu = $296.67/acre for refuge corn

625 acres x 0.80 = 500 acres of Bt corn
500 acres Bt corn x $330/acre = $165,000 received for Bt corn

625 acres x 0.20 = 125 acres of refuge corn
125 acres refuge corn x $296.67/acre = $37,083.75 received for refuge corn

$165,000 + $37,083.75 = $202,083.75 for entire corn crop

7. If the former landowner had to pay $10/acre added cost for Bt corn seed for this particular crop year, would the added cost have been worth it? Why or why not?

Students can use the answers they calculated for questions 5 and 6 to help them answer this question. The added cost of the Bt seed would have been $10/acre x 500 acres = $5,000. The difference in the gross return from planting only non-Bt corn ($185,418.75) and the gross return from planting Bt corn ($202,083.75) would have been $16,665, which is more than the $5,000 extra cost of Bt seed.

Step Three – Divide Class into Four Groups and Distribute the Handouts

Divide the class into four groups. Give the members of each group one of the four handouts III-c, -d, -e, or -f on p. 115-130. Each student in the group should be given the same handout. Each handout contains crop statistics for five consecutive years of the past 20 years for the land the farmer bought. Ask students to look at the statistics provided and write down their predictions about the profitability of planting Bt corn for the five years before doing the handout. Teachers might suggest that students in a group divide responsibility for the five years so each group member calculates only one or two years.

Step Four – Report the Results

After the four student groups have completed their calculations, either the teacher or the group members should check their answers using the appropriate answer key on the following pages. The answer key for each five-year period is self-contained on a separate page for easy photocopying.
Teachers may want the groups to devise a chart, overhead transparency, or other way to present their results. If so, allow an extra class period for students to prepare their presentations. As the class is listening to the results from each group, ask the students to keep track of how many years it would have been more profitable to grow Bt corn and how many years it would have been less profitable.

**Step Five – Reflect and Apply**
Discuss the “Reflect and Apply” questions on p. 107.

**Credit Notes**

1 The chart used in this activity was adapted from a similar one contained in *The Economics of BT Corn: Adoption Implications*, Table 4, p. 6. Jeffrey Hyde, Marshall A. Martin, Paul V. Preckel, C. Richard Edwards. Percentages were adjusted for the purposes of this activity, so results may differ from data reported in the peer-reviewed, scientifically-based publication. Purdue University Cooperative Extension Service, West Lafayette, Indiana, ID-219, Rev. 10/2001. Available at http://www.ces.purdue.edu/extmedia/ID/ID-219.pdf. Used with permission.

Answers to Years 1-5 Handout

Yield percentages are rounded to nearest tenth, yield bushels to nearest hundredth, and dollars to nearest cent.

Year 1

Data
Corn acres: 625
Planting date: April 30
Potential yield/acre: 150 bushels
Average no. of first generation ECB per/plant: 0
Average no. of second generation ECB per/plant: 0
Average corn price received by farmers: $2.23/bu
Estimated added cost for Bt corn seed: $12/acre

Note: Zero ECB/plant does not mean that no ECB were present in the fields. It means that there were so few ECB that any damage caused was insignificant. The variation in potential yield/acre from year to year reflects the probable yield reduction for corn planted after May 1.

Answers
1. First generation ECB lowered yield by: 0%
2. Second generation ECB lowered yield by: 0%
3. Total yield loss due to ECB: 0%
4. Probable yield: 150 bu/acre
5. Money received/acre: $334.50
   Money received for entire crop: $209,062.50
6. If Bt corn had been available and planted:
   $334.50 received/acre for the Bt corn
   $334.50 received/acre for the refuge corn
   $209,062.50 received for entire crop
7. Profitability of planting Bt corn: No. The former landowner would have paid an extra $12/acre added cost for 500 acres of Bt seed ($6,000), but would not have received any benefit due to a low ECB infestation. This means that the landowner would have obtained $6,000 less profit from Bt corn than from non-Bt corn.

Year 2

Data
Corn acres: 625
Planting date: May 18
Potential yield/acre: 136 bu
Average no. of first generation ECB per/plant: 0
Average no. of second generation ECB per/plant: 0
Average corn price received by farmers: $2.93/bu
Estimated added cost for Bt corn seed: $10/acre

Answers
1. First generation ECB lowered yield by: 0%
2. Second generation ECB lowered yield by: 0%
3. Total yield loss due to ECB: 0%
4. Probable yield: 136 bu/acre
5. Money received/acre: $398.48
   Money received for entire crop: $249,050
6. If Bt corn had been available and planted:
   $398.48 received/acre for the Bt corn
   $398.48 received/acre for the refuge corn
   $249,050 received for entire crop
7. Profitability of planting Bt corn: No. The former landowner would have paid an extra $11/acre added cost for 500 acres of Bt seed ($5,500), but would not have received any benefit due to a low ECB infestation. This means that the landowner would have obtained $5,500 less profit from Bt corn than from non-Bt corn.

Year 3

Data
Corn acres: 625
Planting date: May 7
Potential yield/acre: 148 bu
Average no. of first generation ECB per/plant: 2
Average no. of second generation ECB per/plant: 3
Average corn price received by farmers: $2.94/bu
Estimated added cost for Bt corn seed: $10/acre

Answers
1. First generation ECB lowered yield by: 7.9%
2. Second generation ECB lowered yield by: 7.1%
3. Total yield loss due to ECB: 14.4%
4. Probable yield: 126.69 bu/acre
5. Money received/acre: $372.47
   Money received for entire crop: $232,793.75
6. If Bt corn had been available and planted:
   $435.12 received/acre for the Bt corn
   $372.47 received/acre for the refuge corn
   $264,188.75 received for entire crop
7. Profitability of planting Bt corn: Yes. The added cost of the Bt seed would have been $10/acre x 500 acres = $5,000. The difference in the gross return from planting only non-Bt corn ($232,793.75) and the gross return from planting Bt corn ($264,188.75) would have been $31,325, which is more than the $5,000 extra cost of Bt seed.

Year 4

Data
Corn acres: 625
Planting date: April 25
Potential yield/acre: 150 bu
Average no. of first generation ECB per/plant: 0
Average no. of second generation ECB per/plant: 0
Average corn price received by farmers: $2.39/bu
Estimated added cost for Bt corn seed: $10/acre

Answers
1. First generation ECB lowered yield by: 0%
2. Second generation ECB lowered yield by: 0%
3. Total yield loss due to ECB: 0%.
Answers
1. First generation ECB lowered yield by: 0%
2. Second generation ECB lowered yield by: 0%
3. Total yield loss due to ECB: 0%.
4. Probable yield: 150 bu/acre
5. Money received/acre: $358.50
   Money received for entire crop: $224,062.50
6. If Bt corn had been available and planted:
   $358.50 received/acre for the Bt corn
   $358.50 received/acre for the refuge corn
   $224,062.50 received for entire crop
7. Profitability of planting Bt corn: No. The former landowner would have paid an extra $10/acre added cost for 500 acres of Bt seed ($5,000), but would not have received any benefit due to a low ECB infestation. This means that the landowner would have obtained $5,000 less profit from Bt corn than from non-Bt corn.

Year 5
Data
Corn acres: 625
Planting date: May 13
Potential yield/acre: 141 bu
Average no. of first generation ECB per/plant: 0
Average no. of second generation ECB per/plant: 0
Average corn price received by farmers: $1.82/bu
Estimated added cost for Bt corn seed: $9/acre

Answers
1. First generation ECB lowered yield by: 0%
2. Second generation ECB lowered yield by: 0%
3. Total yield loss due to ECB: 0%.
4. Probable yield: 141 bu/acre
5. Money received/acre: $256.62
   Money received for entire crop: $160,387.50
6. If Bt corn had been available and planted:
   $256.62 received/acre for the Bt corn
   $256.62 received/acre for the refuge corn
   $160,387.50 received for entire crop
7. Profitability of planting Bt corn: No. The former landowner would have paid an extra $9/acre added cost for 500 acres of Bt seed ($4,500), but would not have received any benefit due to a low ECB infestation. This means that the landowner would have obtained $4,500 less profit from Bt corn than from non-Bt corn.

Five-Year Summary for Years 1-5
1. If Bt corn had been available for these five consecutive years and the former landowner had planted it in 80% of his total corn acreage each year, how much would he/she have paid for the added cost of Bt corn seed over the five years?

   Answer

   Added cost paid for Bt corn seed for the five years
   Year 1 = $6,000
   Year 2 = 5,500
   Year 3 = 5,000
   Year 4 = 5,000
   Year 5 = 4,500
   Total 26,000

2. Even though the only year with a significant ECB outbreak was year 3, would it have been financially worth it to the landowner to plant Bt corn all five years? Remember that currently there is no way to predict which years will have ECB outbreaks.

   Answer

   Yes.

   Extra gross return from Bt seed for the five years
   Year 1 = $ 0
   Year 2 = 0
   Year 3 = 31,325
   Year 4 = 0
   Year 5 = 0
   Total 31,325

$31,325 extra gross return from Bt corn in year 3 - 26,000 total added cost of Bt corn seed for five years
$ 5,325 extra gross return from Bt corn for five years
Answers to Years 6-10 Handout
Yield percentages are rounded to nearest tenth, yield bushels to nearest hundredth, and dollars to nearest cent.

**Year 6**

Data
- Corn acres: 625
- Planting date: May 16
- Potential yield/acre: 137 bu
- Average no. of first generation ECB per/plant: 1
- Average no. of second generation ECB per/plant: 1
- Average corn price received by farmers: $1.45/bu
- Estimated added cost for Bt corn seed: $9/acre

Answers
1. First generation ECB lowered yield by: 3.8%
2. Second generation ECB lowered yield by: 4.2%
3. Total yield loss due to ECB: 7.8%.
4. Probable yield: 126.30 bu/acre
5. Money received/acre: $183.14
6. If Bt corn had been available and planted:
   - $198.65 received/acre for the Bt corn
   - $183.14 received/acre for the refuge corn
   - $122,217.50 received for entire crop
7. Profitability of planting Bt corn: Yes. The added cost of the Bt seed would have been $9/acre x 500 acres = $4,500. The difference in the gross return from planting only non-Bt corn ($114,462.50) and the gross return from planting Bt corn ($122,217.50) would have been $7,755, which is more than the $4,500 extra cost of Bt seed.

**Year 7**

Data
- Corn acres: 625
- Planting date: April 28
- Potential yield/acre: 150 bu
- Average no. of first generation ECB per/plant: 0
- Average no. of second generation ECB per/plant: 0
- Average corn price received by farmers: $2.18/bu
- Estimated added cost for Bt corn seed: $8/acre

Answers
1. First generation ECB lowered yield by: 0%
2. Second generation ECB lowered yield by: 0%
3. Total yield loss due to ECB: 0%.
4. Probable yield: 150 bu/acre
5. Money received/acre: $345
6. If Bt corn had been available and planted:
   - $345 received/acre for the Bt corn
   - $345 received/acre for the refuge corn
   - $215,625 received for entire crop
7. Profitability of planting Bt corn: No. The former landowner would have paid an extra $8/acre added cost for 500 acres of Bt seed ($4,000), but would not have received any benefit due to a low ECB infestation. This means that the landowner would have obtained $4,000 less profit from Bt corn than from non-Bt corn.

**Year 8**

Data
- Corn acres: 625
- Planting date: April 26
- Potential yield/acre: 150 bu
- Average no. of first generation ECB per/plant: 0
- Average no. of second generation ECB per/plant: 0
- Average corn price received by farmers: $2.30/bu
- Estimated added cost for Bt corn seed: $8/acre

Answers
1. First generation ECB lowered yield by: 0%
2. Second generation ECB lowered yield by: 0%
3. Total yield loss due to ECB: 0%.
4. Probable yield: 150 bu/acre
5. Money received/acre: $345
6. If Bt corn had been available and planted:
   - $345 received/acre for the Bt corn
   - $345 received/acre for the refuge corn
   - $215,625 received for entire crop
7. Profitability of planting Bt corn: No. The former landowner would have paid an extra $8/acre added cost for 500 acres of Bt seed ($4,000), but would not have received any benefit due to a low ECB infestation. This means that the landowner would have obtained $4,000 less profit from Bt corn than from non-Bt corn.

**Year 9**

Data
- Corn acres: 625
- Planting date: May 10
- Potential yield/acre: 141 bu
- Average no. of first generation ECB per/plant: 0
- Average no. of second generation ECB per/plant: 0
- Average corn price received by farmers: $2.27/bu
- Estimated added cost for Bt corn seed: $8/acre

Answers
1. First generation ECB lowered yield by: 0%
2. Second generation ECB lowered yield by: 0%
3. Total yield loss due to ECB: 0%.
4. Probable yield: 141 bu/acre
5. Money received/acre: $320.07
6. If Bt corn had been available and planted:
   - $320.07 received/acre for the Bt corn
   - $320.07 received/acre for the refuge corn
   - $204,375 received for entire crop
7. Profitability of planting Bt corn: No. The former landowner would have paid an extra $8/acre added cost for 500 acres of Bt seed ($4,000), but would not have received any benefit due to a low ECB infestation. This means that the landowner would have obtained $4,000 less profit from Bt corn than from non-Bt corn.
6. If Bt corn had been available and planted:
   $320.07 received/acre for the Bt corn
   $320.07 received/acre for the refuge corn
   $200,043.75 received for entire crop

7. Profitability of planting Bt corn: No. The former landowner would have paid an extra $8/acre added cost for 500 acres of Bt seed ($4,000), but would not have received any benefit due to a low ECB infestation. This means that the landowner would have obtained $4,000 less profit from Bt corn than from non-Bt corn.

**Year 10**

**Data**
- Corn acres: 625
- Planting date: May 5
- Potential yield/acre: 148 bu
- Average no. of first generation ECB per/plant: 0
- Average no. of second generation ECB per/plant: 0
- Average corn price received by farmers: $2.23/bu
- Estimated added cost for Bt corn seed: $8/acre

**Answers**
1. First generation ECB lowered yield by: 0%
2. Second generation ECB lowered yield by: 0%
3. Total yield loss due to ECB: 0%.
4. Probable yield: 148 bu/acre
5. Money received/acre: $330.04
   Money received for entire crop: $206,275
6. If Bt corn had been available and planted:
   $330.04 received/acre for the Bt corn
   $330.04 received/acre for the refuge corn
   $206,275 received for entire crop
7. Profitability of planting Bt corn: No. The former landowner would have paid an extra $8/acre added cost for 500 acres of Bt seed ($4,000), but would not have received any benefit due to a low ECB infestation. This means that the landowner would have obtained $4,000 less profit from Bt corn than from non-Bt corn.

**Five-Year Summary for Years 6-10**

1. If Bt corn had been available for these five consecutive years and the former landowner had planted it in 80% of his total corn acreage each year, how much would he/she have paid for the added cost of Bt corn seed over the five years?

**Answer**
- Added cost paid for Bt corn seed for the five years:
  - Year 6 = $4,500
  - Year 7 = 4,500
  - Year 8 = 4,000
  - Year 9 = 4,000
  - Year 10 = 4,000
  - Total 21,000

2. Even though the only year with a significant ECB outbreak was year 6, would it have been financially worth it to the landowner to plant Bt corn all five years? Why or why not? Remember that currently there is no way to predict which years will have ECB outbreaks.

**Answer**
- No.

- Extra gross return from Bt seed for the five years:
  - Year 6 = $7,755
  - Year 7 = 0
  - Year 8 = 0
  - Year 9 = 0
  - Year 10 = 0
  - Total 7,755

- $7,755 extra gross return from Bt corn in year 6
- $21,000 total added cost of Bt corn seed for five years
- $13,245 gross loss from Bt corn for five years
Answers to Years 11-15 Handout

Yield percentages are rounded to nearest tenth, yield bushels to nearest hundredth, and dollars to nearest cent.

Year 11

Data
Corn acres: 625
Planting date: April 27
Potential yield/acre: 150 bu
Average no. of first generation ECB per/plant: 2
Average no. of second generation ECB per/plant: 1
Average corn price received by farmers: $2.16/bu
Estimated added cost for Bt corn seed: $10/acre

Answers
1. First generation ECB lowered yield by: 7.1%
2. Second generation ECB lowered yield by: 2.0%
3. Total yield loss due to ECB: 9.0%
4. Probable yield: 136.50 bu/acre
5. Money received/acre: $294.84
    Money received for entire crop: $184,275
6. If Bt corn had been available and planted:
    $324.00 received/acre for the Bt corn
    $294.84 received/acre for the refuge corn
    $324.00 received for the entire crop
7. Profitability of planting Bt corn: Yes. The added cost of the Bt seed would have been $10/acre x 500 acres = $5,000. The difference in the gross return from planting only non-Bt corn ($184,275) and the gross return from planting Bt corn ($198,855) would have been $14,580, which is more than the $5,000 extra cost of Bt seed.

Year 12

Data
Corn acres: 625
Planting date: May 3
Potential yield/acre: 148 bu
Average no. of first generation ECB per/plant: 0
Average no. of second generation ECB per/plant: 0
Average corn price received by farmers: $2.13/bu
Estimated added cost for Bt corn seed: $9/acre

Answers
1. First generation ECB lowered yield by: 0%
2. Second generation ECB lowered yield by: 0%
3. Total yield loss due to ECB: 0%
4. Probable yield: 148 bu/acre
5. Money received/acre: $294.84
    Money received for entire crop: $184,275
6. If Bt corn had been available and planted:
    $339 received/acre for the Bt corn
    $339 received/acre for the refuge corn
    $339 received for the entire crop
7. Profitability of planting Bt corn: No. The former landowner would have paid an extra $9/acre added cost for 500 acres of Bt seed ($4,500), but would not have received any benefit due to a low ECB infestation. This means that the landowner would have obtained $5,000 less profit from Bt corn than from non-Bt corn.

Year 13

Data
Corn acres: 625
Planting date: April 29
Potential yield/acre: 150 bu
Average no. of first generation ECB per/plant: 0
Average no. of second generation ECB per/plant: 0
Average corn price received by farmers: $2.26/bu
Estimated added cost for Bt corn seed: $10/acre

Answers
1. First generation ECB lowered yield by: 0%
2. Second generation ECB lowered yield by: 0%
3. Total yield loss due to ECB: 0%
4. Probable yield: 150 bu/acre
5. Money received/acre: $339
    Money received for entire crop: $211,875
6. If Bt corn had been available and planted:
    $339 received/acre for the Bt corn
    $339 received/acre for the refuge corn
    $339 received for the entire crop
7. Profitability of planting Bt corn: No. The former landowner would have paid an extra $10/acre added cost for 500 acres of Bt seed ($5,000), but would not have received any benefit due to a low ECB infestation. This means that the landowner would have obtained $5,000 less profit from Bt corn than from non-Bt corn.

Year 14

Data
Corn acres: 625
Planting date: May 17
Potential yield/acre: 136.5 bu
Average no. of first generation ECB per/plant: 0
Average no. of second generation ECB per/plant: 0
Average corn price received by farmers: $2.47/bu
Estimated added cost for Bt corn seed: $9/acre

Answers
1. First generation ECB lowered yield by: 0%
2. Second generation ECB lowered yield by: 0%
3. Total yield loss due to ECB: 0%
4. Probable yield: 136.50 bu/acre
5. Money received/acre: $315.24
    Money received for entire crop: $197,025
6. If Bt corn had been available and planted:
    $315.24 received/acre for the Bt corn
    $315.24 received/acre for the refuge corn
    $315.24 received for the entire crop
    $197,025 received for the entire crop
7. Profitability of planting Bt corn: No. The former landowner would have paid an extra $9/acre added cost for 500 acres of Bt seed ($4,500), but would not have received any benefit due to a low ECB infestation. This means that the landowner would have obtained $4,500 less profit from Bt corn than from non-Bt corn.
6. If Bt corn had been available and planted:
   $337.16 received/acre for the Bt corn
   $337.16 received/acre for the refuge corn
   $210,725 received for entire crop
7. Profitability of planting Bt corn: No. The former landowner would have paid an extra $9/acre added cost for 500 acres of Bt seed ($4,500), but would not have received any benefit due to a low ECB infestation. This means that the landowner would have obtained $4,500 less profit from Bt corn than from non-Bt corn.

**Year 15**

**Data**
Corn acres: 625
Planting date: May 6
Potential yield/acre: 148 bu
Average no. of first generation ECB per/plant: 3
Average no. of second generation ECB per/plant: 2
Average corn price received by farmers: $3.63/bu
Estimated added cost for Bt corn seed: $9/acre

**Answers**
1. First generation ECB lowered yield by: 9.7%
2. Second generation ECB lowered yield by: 5.7%
3. Total yield loss due to ECB: 14.8%.
4. Probable yield: 126.10 bu/acre
5. Money received/acre: $457.74
   Money received for entire crop: $286,087.50
6. If Bt corn had been available and planted:
   $537.24 received/acre for the Bt corn
   $457.74 received/acre for the refuge corn
   $325,837.50 received for entire crop
7. Profitability of planting Bt corn: Yes. The added cost of the Bt seed would have been $9/acre x 500 acres = $4,500. The difference in the gross return from planting only non-Bt corn ($286,087.50) and the gross return from planting Bt corn ($325,837.50) would have been $39,750, which is more than the $4,500 extra cost of Bt seed.

**Five-Year Summary for Years 11-15**
1. If Bt corn had been available for these five consecutive years and the former landowner had planted it in 80% of his total corn acreage each year, how much would he/she have paid for the added cost of Bt corn seed over the five years?

   **Answer**
   Added cost paid for Bt corn seed for the five years
   - Year 11 = $5,000
   - Year 12 = $4,500
   - Year 13 = $5,000
   - Year 14 = $4,500
   - Year 15 = $4,500
   Total 23,500

2. Even though the only years with significant ECB outbreaks were years 11 and 15, would it have been financially worth it to the landowner to plant Bt corn all five years? Why or why not? Remember that currently there is no way to predict which years will have ECB outbreaks.

   **Answer**
   Yes.

   Extra gross return from Bt seed for the five years
   - Year 11 = $14,580
   - Year 12 = 0
   - Year 13 = 0
   - Year 14 = 0
   - Year 15 = $39,750
   Total 54,330

   $54,330 extra gross return from Bt corn in years 11, 15 - $23,500 total added cost of Bt corn seed for five years
   $30,830 extra gross return from Bt corn for five years
Answers to Years 16-20 Handout
Yield percentages are rounded to nearest tenth, yield bushels to nearest hundredth, and dollars to nearest cent.

Year 16
Data
Corn acres: 625  
Planting date: May 1  
Potential yield/acre: 148 bu  
Average no. of first generation ECB per/plant: 0  
Average no. of second generation ECB per/plant: 0  
Average corn price received by farmers: $2.45/bu  
Estimated added cost for Bt corn seed: $9/acre

Answers
1. First generation ECB lowered yield by: 0%  
2. Second generation ECB lowered yield by: 0%  
3. Total yield loss due to ECB: 0%  
4. Probable yield: 148 bu/acre  
5. Money received/acre: $362.60  
   Money received for entire crop: $226,625  
6. If Bt corn had been available and planted:  
   $362.60 received/acre for the Bt corn  
   $226,625 received for entire crop  
7. Profitability of planting Bt corn: No. The former landowner would have paid an extra $9/acre added cost for 500 acres of Bt seed ($4,500), but would not have received any benefit due to a low ECB infestation. This means that the landowner would have obtained $4,500 less profit from Bt corn than from non-Bt corn.

Year 17
Data
Corn acres: 625  
Planting date: May 19  
Potential yield/acre: 135 bu  
Average no. of first generation ECB per/plant: 0  
Average no. of second generation ECB per/plant: 0  
Average corn price received by farmers: $2.06/bu  
Estimated added cost for Bt corn seed: $9/acre

Answers
1. First generation ECB lowered yield by: 0%  
2. Second generation ECB lowered yield by: 0%  
3. Total yield loss due to ECB: 0%  
4. Probable yield: 135 bu/acre  
5. Money received/acre: $362.60  
   Money received for entire crop: $226,625  
6. If Bt corn had been available and planted:  
   $362.60 received/acre for the Bt corn  
   $226,625 received for entire crop  
7. Profitability of planting Bt corn: No. The former landowner would have paid an extra $9/acre added cost for 500 acres of Bt seed ($4,500), but would not have received any benefit due to a low ECB infestation. This means that the landowner would have obtained $4,500 less profit from Bt corn than from non-Bt corn.

Year 18
Data
Corn acres: 625  
Planting date: May 2  
Potential yield/acre: 148 bu  
Average no. of first generation ECB per/plant: 0  
Average no. of second generation ECB per/plant: 0  
Average corn price received by farmers: $1.85/bu  
Estimated added cost for Bt corn seed: $9/acre

Answers
1. First generation ECB lowered yield by: 0%  
2. Second generation ECB lowered yield by: 0%  
3. Total yield loss due to ECB: 0%  
4. Probable yield: 148 bu/acre  
5. Money received/acre: $273.80  
   Money received for entire crop: $171,125  
6. If Bt corn had been available and planted:  
   $273.80 received/acre for the Bt corn  
   $171,125 received for entire crop  
7. Profitability of planting Bt corn: No. The former landowner would have paid an extra $9/acre added cost for 500 acres of Bt seed ($4,500), but would not have received any benefit due to a low ECB infestation. This means that the landowner would have obtained $4,500 less profit from Bt corn than from non-Bt corn.

Year 19
Data
Corn acres: 625  
Planting date: April 24  
Potential yield/acre: 150 bu  
Average no. of first generation ECB per/plant: 0  
Average no. of second generation ECB per/plant: 0  
Average corn price received by farmers: $1.71/bu  
Estimated added cost for Bt corn seed: $8/acre

Answers
1. First generation ECB lowered yield by: 0%  
2. Second generation ECB lowered yield by: 0%  
3. Total yield loss due to ECB: 0%  
4. Probable yield: 150 bu/acre  
5. Money received/acre: $256.50  
   Money received for entire crop: $160,312.50
6. If Bt corn had been available and planted:
   $256.50 received/acre for the Bt corn
   $256.50 received/acre for the refuge corn
   $160,312.50 received for entire crop
7. Profitability of planting Bt corn: No. The former landowner would have paid an extra $8/acre added cost for 500 acres of Bt seed ($4,000), but would not have received any benefit due to a low ECB infestation. This means that the landowner would have obtained $4,000 less profit from Bt corn than from non-Bt corn.

Year 20

Data
Corn acres: 625
Planting date: April 22
Potential yield/acre: 150 bu
Average no. of first generation ECB per/plant: 1
Average no. of second generation ECB per/plant: 1
Average corn price received by farmers: $1.73/bu
Estimated added cost for Bt corn seed: $8/acre

Answers
1. First generation ECB lowered yield by: 4.7%
2. Second generation ECB lowered yield by: 2.0%
3. Total yield loss due to ECB: 6.6%.
4. Probable yield: 140.10 bu/acre
5. Money received/acre: $242.37
   Money received for entire crop: $151,481.25
6. If Bt corn had been available and planted:
   $259.50 received/acre for the Bt corn
   $242.37 received/acre for the refuge corn
   $160,046.25 received for entire crop
7. Profitability of planting Bt corn: Yes. The added cost of the Bt seed would have been $8/acre x 500 acres = $4,000. The difference in the gross return from planting only non-Bt corn ($151,481.25) and the gross return from planting Bt corn ($160,046.25) would have been $8,565, which is more than the $4,000 extra cost of Bt seed.

Five-Year Summary for Years 16-20
1. If Bt corn had been available for these five consecutive years and the former landowner had planted it in 80% of his total corn acreage each year, how much would he/she have paid for the added cost of Bt corn seed over the five years?

Answer
Added cost paid for Bt corn seed for the five years
Year 1 = $4,500
Year 2 = 4,500
Year 3 = 4,500
Year 4 = 4,000
Year 5 = 4,000
Total 21,500

2. Even though the only year with a significant ECB outbreak was year 20, would it have been financially worth it to the landowner to plant Bt corn all five years? Why or why not? Remember that currently there is no way to predict which years will have ECB outbreaks.

Answer
No.

Extra gross return from Bt seed for the five years
Year 16 = $0
Year 17 = 0
Year 18 = 0
Year 19 = 0
Year 20 = 8,565
Total 8,565

$8,565 extra gross return from Bt corn in year 20
-21,500 total added cost of Bt corn seed for five years
-12,935 gross loss from Bt corn for five years
Reflect and Apply

1. Judging from the history of European corn borer infestations in this area, would you advise the new owner to plant Bt corn every year in 80% of his corn acreage? Why? Does your answer differ from the predictions you made?

Students may point to the summary section of the handouts for each five-year period as evidence that the new owner should plant Bt corn every year. In this activity, the extra costs for Bt corn seed for the 500 acres that could have been planted to Bt corn were

- $26,000 for years 1-5
- $21,000 for years 6-10
- $23,500 for years 11-15
- $21,500 for years 16-20
- $92,000 total extra Bt seed cost for years 1-20

The total extra gross return that could have been derived from planting Bt corn on 500 acres for the last 20 years would have been

- $31,325 for years 1-5
- $7,755 for years 6-10
- $54,330 for years 11-15
- $8,565 for years 16-20
- $101,975 total extra gross return for years 1-20

$101,975 extra gross return from Bt corn for years 1-20
- $92,000 added cost of Bt corn seed for years 1-20
- 9,975 extra gross return from Bt corn for years 1-20

Other students may point out that the history of ECB outbreaks is not an accurate predictor of what will actually occur in the future. Also, other variables that can change are the price premiums companies charge for Bt seed, the prices for which farmers can sell their corn, and when the weather allows farmers to plant their crops. Students may mention environmental issues, export markets that will or will not accept Bt crops, and other issues.

Because the timing and severity of ECB outbreaks cannot be accurately predicted at planting time, farmers are working with probabilities, not certainties.

2. This activity correlated yield loss from ECB damage solely to the numbers of ECB present in the field and the planting date. Remembering what you have learned about the ECBs life cycle, what other factors could affect the amount of damage done by ECB?

Students might mention weather conditions such as dry weather and windy days that lead to stalk breakage, whether the corn plants were under moisture stress, and early vs. late harvest.

3. In this activity, the cost of Bt corn seed and the cost of damage caused by ECB were the only two production costs considered. In real life, farmers have many other production costs that must be subtracted from the selling price of the crop before they know their profit. What do you think some of these costs would be?

Students may point out the cost of farm equipment for tilling the soil, planting, and harvesting; fuel and maintenance costs for the equipment; transportation costs to move the crop to market; storage costs if grain is stored on- or off-farm; salary and benefit costs if the farmer has employees; and yearly property taxes or rent, depending on whether the farmer owns or rents cropland.

4. Bt corn has been referred to by some people as “an insurance policy.” How are insurance and Bt corn alike? How are they different?

Students may suggest that insurance and Bt corn both cost money to have, but only pay off when a loss is incurred. Insurance often protects against more than one type of loss, but Bt corn protects only against loss caused by ECB.

5. What factors other than cost or profit might influence the decision to plant or not plant Bt corn?

Students may mention the possibility of pollen drift to a neighbor’s non-Bt corn or other ethical concerns about GMO crops. Module IV deals with these types of issues.

Beyond this activity:
To obtain a clearer picture of the economic considerations that affect the decision to grow or not to grow Bt corn, students could investigate the variability of the corn market over the past few months, the current marketing restrictions placed on Bt corn in foreign
countries, the weather outlook for the next corn growing season, and the history of ECB outbreaks in their own geographical area. They could use what they find to make a prediction about whether it would be profitable to plant Bt corn during the next crop season. Possible Internet sources for this information are given in the next section.

Internet Ideas

THE ECONOMICS OF GROWING BT CORN

The Economics of Bt Corn: Adoption Implications

Students could use this publication to further explore the real-life production issues involved in deciding whether to adopt Bt corn. The publication was written specifically for Indiana farmers by Jeffrey Hyde, Marshall A. Martin, Paul V. Preckel, and C. Richard Edwards, Purdue University Cooperative Extension Service, West Lafayette, Indiana, ID-219, Rev. 10/2001.

Bt Corn and European Corn Borer


EUROPEAN CORN BORER SCOUTING GUIDES AND ECONOMIC THRESHOLD TABLES/WORKSHEETS

The Economics of Bt Corn: Adoption Implications

Scouting for European Corn Borer
http://ianrwww.unl.edu/ian/triad/scoutecb.htm

No.4 - European Corn Borer: Ostrinia nubilalis Hubner
http://www.ipm.uiuc.edu/publications/infosheets/4-ecb/ecb.html#scouting

Field Crops: European Corn Borer in Field Corn
http://www.entm.purdue.edu/entomology/ext/targets/e-series/EseriesPDF/E-17.pdf


EUROPEAN CORN BORER TRACKING INFORMATION

Iowa – http://www.ent.iastate.edu/pest/cornborer/

Minnesota – http://www.mnipm.umn.edu/bugweb/ecbmainmenu.htm (BugWeb® has moth flight info. for Iowa, Minnesota, North Dakota, South Dakota, and Wisconsin.)

North Dakota – http://www.ndsu.nodak.edu/entomology/ecb/

South Dakota – http://www.abs.sdstate.edu/plantsci/ext/ent/ent.htm

Wisconsin – http://www.mnipm.umn.edu/bugweb/bugbase/flight/ecbnetwork/currentstatuswi.htm

GENERAL INFORMATION ABOUT CORN PRODUCTION

The Maize Page
http://maize.agron.iastate.edu/production.html

KingCorn.org: The Corn Growers’ Guidebook
http://www.agry.purdue.edu/ext/corn/

National Corn Handbook
http://www.agcom.purdue.edu/AgCom/Pubs/agronomy.htm#4 Each fact sheet title is listed separately and linked to an HTML file.

STATE AGRICULTURAL STATISTICS SITES

Students could use these sites to investigate the variability of crop prices and the costs of production.

Iowa – http://www.agriculture.state.ia.us/historic.html or http://www.nass.usda.gov/ia/

Minnesota – http://www.nass.usda.gov/mn/

North Dakota – http://www.nass.usda.gov/nd/


WEATHER OUTLOOKS

The National Weather Service’s Climate Prediction Center
http://www.cpc.ncep.noaa.gov/

U.S. Government’s Weekly Weather and Crop Bulletin
http://www.usda.gov/oe/weather/wcb.html
The Economics of Growing Bt Crops

Economic Uncertainties
Bt crops were developed to reduce insect damage in corn from European corn borers (ECB), in cotton from bollworms and budworms, and in potatoes from the Colorado potato beetle. Farmers would like to be able to predict how much insect damage will occur in any one year so they can use the right control practices to prevent the damage. Control practices like Bt crops or insecticides are expensive. Losing crop yields due to insect damage is also expensive. Farmers try to make the best decisions they can to protect the economic investment they have made in their crops.

There are many factors that determine how much insect damage occurs in any one year. Insect populations increase or decrease as weather conditions, their food supply, and habitat change. For example, ECB damage to corn is greatly affected by weather conditions.

- Weather that is too wet or cold can delay crop planting dates.
- Weather affects when ECB larvae hatch and begin feeding. The growth stage of the crop when feeding begins affects how much the yield is reduced.
- Delayed harvesting of the crop, especially during a dry and windy fall, allows more breakage of the corn stalks damaged by ECB. When stalks break, their ears of corn fall to the ground where harvesting equipment cannot reach them.

Economic Thresholds
Economic thresholds are used to help farmers determine when it is to their financial advantage to adopt a certain insect control practice. The economic threshold is the point at which the cost of an insect control practice equals the estimated cost in yield loss of not using the control practice. The farmer tries to determine the break-even point. If the insect infestation is bad enough that the value of the crop that will be lost is more than the cost of insect control, the farmer usually decides to use the control practice.

Economic threshold tables for crop pests have been developed by entomologists and agronomists to help producers make their decisions. The economic threshold tables take into account a range of market prices for the crop, the infestation level, the cost of the control practice, the effectiveness of the control practices, and the expected yield of the crop.

Bt Corn
Farmers who use insecticides to control ECB can scout their corn crop during the growing season. They look for ECB larvae or plant damage by sampling their corn crop. If the number of insects on a plant exceeds a certain number or the visible damage to the crop plants exceeds a certain level, the farmer may make the decision to apply insecticides.

Farmers must decide whether to plant Bt corn at the beginning of the growing season before it is known how serious ECB damage will be that year. They can only make a prediction or best guess about how much ECB damage will occur during that year.
Because the insect resistance of Bt crops is genetically built into the seed, agricultural producers must decide whether paying the added cost charged for Bt seed is worth it before the crops are planted. Producers considering Bt crops consider insect damage over a number of years at their location. The economic decisions agricultural producers make about whether to plant Bt crops are based largely on the likelihood (probability) of insect damage rather than the certainty of damage.

The following excerpt from a 1997 University of Minnesota Extension Service publication about corn borer damage in that state from 1988-1995 is a good example of the variability in insect damage from one year to the next.

“European corn borer populations fluctuate over the years and from one field to the next. Similarly, corn yields and market prices often are volatile. This variability raises concerns about fluctuations in yearly economic benefits of Bt corn.

“To illustrate this point, the risk of investing in Bt corn was scrutinized for southern Minnesota over an eight-year period 1988-1995. This period included three outbreak (high) years for European corn borer and five endemic (low) years. The average benefit for this period, $17.24 per acre, was very close to the national estimate of Bt value, but returns varied considerably between endemic and outbreak years. During the endemic years, the yield protection offered by Bt corn barely covered the price premium for seed, currently $7 to $10 per acre. During outbreak years, yield savings of $28 to $50 per acre were four to five times the added seed cost.

“The bottom line: Do not expect an economic return every year or in every field. As with any type of natural resistance, Bt corn only delivers an economic benefit when European corn borer outbreaks occur. Unfortunately, no predictive tools for European corn borer outbreaks are currently available.”

Learn the Language

**Economic threshold**
The point at which the cost of an insect control practice equals the cost of the yield loss from insect damage

**Economic threshold table**
Numerical tables that take into account a number of variables to determine at what point using an insect control practice becomes profitable

**Sampling**
Examining a representative number of individual plants to determine the number of insects present or amount of insect damage

**Scout**
Examining a field for the presence of insects or insect damage

Credit Notes

Example: Consider the Costs

A farmer has purchased Midwest farmland. The farmer is going to plant 625 acres of corn on the land and is trying to determine whether planting Bt corn would be worth the extra cost. The farmer knows that Bt corn seed costs more than regular seed corn. The farmer also knows that the Bt corn being considered is nearly 100% effective against European corn borers (ECB). The former landowner kept no records on damage caused by ECB in previous years. However, with the help of the local USDA Extension office, the farmer collected crop information on ECB outbreaks for the past 20 years in the county where the land is located. Use the statistics and the chart “Percentage Yield Loss from ECB by Generation and Planting Date” to answer the questions for each year’s production. Decide if you can determine whether planting Bt corn probably would or would not be profitable for this farmer in the future.

Statistics
Corn acres: 625
Planting date: May 12
Potential yield/acre: 150 bushels
Average corn price received by farmers: $2.20/bushel
Average no. of first generation ECB per/plant: 1
Average no. of second generation ECB per/plant: 2

<table>
<thead>
<tr>
<th>Percentage Yield Loss from ECB by Generation and Planting Date</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="chart.png" alt="Chart of Percentage Yield Loss from ECB by Generation and Planting Date" /></td>
</tr>
</tbody>
</table>

The chart used in this activity was adapted from a similar one contained in The Economics of BT Corn: Adoption Implications, Table 4, p. 6. Jeffrey Hyde, Marshall A. Martin, Paul V. Preckel, C. Richard Edwards. Percentages were adjusted for the purposes of this activity, so results may differ from data reported in the peer-reviewed, scientifically-based publication. Purdue University Cooperative Extension Service, West Lafayette, Indiana, ID-219, Rev. 10/2001. Available at http://www.ces.purdue.edu/extmedia/ID/ID-219.pdf. Used with permission.
Round the yield percentages to the nearest tenth of a percent (6.67% = 6.7%). Round the yield bushels to the nearest hundredth of a bushel (140.353 bu = 140.35 bu). Round dollar amounts to the nearest cent ($353.109 = $353.11). In all cases, if the number in the rounding position is a 5, round up ($133.485 = $133.49).

1. By what percentage did first generation borers probably lower the yield potential of non-Bt corn during this crop year?

2. By what percentage did second generation borers probably further lower the yield potential of non-Bt corn during this crop year?

3. What was the total percentage of yield loss of non-Bt corn that was probably caused by the two generations of ECB during this crop year?

4. Use your answer from number 3 to calculate the probable yield/acre of non-Bt corn that the former landowner received for this crop year.

5. Assuming that the former landowner sold the non-Bt corn from the 625 acres for the average price for this year, how much money (gross income) would the landowner have received per acre? How much would the landowner have received for the entire crop?

   Per acre:

   Entire crop:
6. If Bt corn had been available and planted by the former landowner for this crop year, how much money (gross income) would the landowner have received per acre for the Bt corn? For the non-Bt refuge corn? How much money would the landowner have received for the entire corn crop? (Assume that the former landowner would have divided his 625 acres of corn into 80% Bt corn and 20% non-Bt refuge. Also assume that the Bt corn was 100% effective against first and second generation borers, and the refuge corn had the yield/acre that you calculated for question 4.)

Money per acre for Bt corn:

Money per acre for non-Bt corn:

Money for the entire crop:

7. If the former landowner had to pay $10/acre added cost for Bt corn seed for this particular crop year, would the added cost have been worth it? Why or why not?
See for yourself . . .

Consider the Costs

Years 1 through 5

A farmer has purchased Midwest farmland. The farmer is going to plant 625 acres of corn on the land and is trying to determine whether planting Bt corn would be worth the extra cost. The farmer knows that Bt corn seed costs more than regular seed corn. The farmer also knows that the Bt corn being considered is nearly 100% effective against European corn borers (ECB). The former landowner kept no records on damage caused by ECB in previous years. However, with the help of the local USDA Extension office, the farmer collected crop information on ECB outbreaks for the past 20 years in the county where the land is located. Use the charts below to answer the questions for each year's production. Decide if you can determine whether planting Bt corn probably would or would not be profitable for this farmer in the future.

<table>
<thead>
<tr>
<th>Data for 625 Acres</th>
<th>Planting Date</th>
<th>Potential Yield/Acre in Bushels</th>
<th>Average No. 1st Gen. ECB</th>
<th>Average No. 2nd Gen. ECB</th>
<th>Average Corn Price Per Bushel</th>
<th>Estimated Per Acre Added Cost of Bt Seed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year 1</td>
<td>April 30</td>
<td>150</td>
<td>0</td>
<td>0</td>
<td>$2.23</td>
<td>$12.00</td>
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<td>Year 2</td>
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<td>136</td>
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<td>$11.00</td>
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<td>$10.00</td>
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<td>0</td>
<td>0</td>
<td>$1.82</td>
<td>$9.00</td>
</tr>
</tbody>
</table>

| Percentage Yield Loss from ECB by Generation and Planting Date |
|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|
|                   | Planting Date     | Before May 1      | May 1-9           | May 10-16         | May 17-23         | May 24-30         | After May 30      |
|                   | No. of ECB Per Plant |                   |                   |                   |                   |                   |                   |
| First Generation  | 1                  | 4.7               | 5.2               | 3.8               | 2.7               | 0.2               | 0.0               |
|                   | 2                  | 7.1               | 7.9               | 5.8               | 4.2               | 0.5               | 0.0               |
|                   | 3                  | 8.8               | 9.7               | 7.2               | 5.2               | 0.7               | 0.0               |
| Second Generation | 1                  | 2.0               | 3.7               | 4.2               | 4.5               | 5.8               | 6.0               |
|                   | 2                  | 3.1               | 5.7               | 6.5               | 6.9               | 8.8               | 9.1               |
|                   | 3                  | 3.9               | 7.1               | 8.0               | 8.5               | 10.9              | 11.2              |

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For crop year number ____________
(1, 2, 3, 4, or 5)

Round the yield percentages to the nearest tenth of a percent (6.67% = 6.7%). Round the yield bushels to the nearest hundredth of a bushel (140.353 bu = 140.35 bu). Round dollar amounts to the nearest cent ($353.109 = $353.11). In all cases, if the number in the rounding position is a 5, round up ($133.485 = $133.49).

1. By what percentage did first generation borers probably lower the yield potential of non-Bt corn during this crop year?

2. By what percentage did second generation borers probably further lower the yield potential of non-Bt corn during this crop year?

3. What was the total percentage of yield loss of non-Bt corn that was probably caused by the two generations of ECB during this crop year?

4. Use your answer from number 3 to calculate the probable yield/acre of non-Bt corn that the former landowner received for this crop year.

5. Assuming that the former landowner sold the non-Bt corn from the 625 acres for the average price for this year, how much money (gross income) would the landowner have received per acre? How much would the landowner have received for the entire crop?

Per acre:

Entire crop:
6. If Bt corn had been available and planted by the former landowner for this crop year, how much money (gross income) would the landowner have received per acre for the Bt corn? For the non-Bt refuge corn? How much money would the landowner have received for the entire corn crop? (Assume that the former landowner would have divided his 625 acres of corn into 80% Bt corn and 20% non-Bt refuge. Also assume that the Bt corn was 100% effective against first and second generation borers, and the refuge corn had the yield/acre that you calculated for question 4.)

Money per acre for Bt corn:

Money per acre for non-Bt corn:

Money for the entire crop:

7. If the former landowner had paid the added cost for Bt corn seed for this particular crop year, would the added cost have been worth it? Why or why not?
Reflect and Apply

After hearing all the group reports, answer the following questions as your teacher directs.

1. Judging from the history of European corn borer (ECB) infestations in this area, would you advise the new owner to plant Bt corn every year in 80% of his corn acreage? Why? Does your answer differ from the predictions you made?

2. This activity correlated yield loss from ECB damage solely with the number of ECB present in the field and the planting date. Remembering what you have learned about the ECBs life cycle, what other factors could affect the amount of damage done by ECB?

3. In this activity, the cost of Bt corn seed and the cost of damage caused by ECB were the only two production costs considered. In real life, farmers have many other production costs that must be subtracted from the selling price of the crop before they know their profit. What do you think some of these costs would be?

4. Bt corn has been referred to by some people as “an insurance policy.” How are insurance and Bt corn alike? How are they different?

5. What factors other than cost or profit might influence the decision to plant or not plant Bt corn?
See for yourself . . .

Consider the Costs

Years 6 through 10

A farmer has purchased Midwest farmland. The farmer is going to plant 625 acres of corn on the land and is trying to determine whether planting Bt corn would be worth the extra cost. The farmer knows that Bt corn seed costs more than regular seed corn. The farmer also knows that the Bt corn being considered is nearly 100% effective against European corn borers (ECB). The former landowner kept no records on damage caused by ECB in previous years. However, with the help of the local USDA Extension office, the farmer collected crop information on ECB outbreaks for the past 20 years in the county where the land is located. Use the charts below to answer the questions for each year’s production. Decide if you can determine whether planting Bt corn probably would or would not be profitable for this farmer in the future.

### Data for 625 Acres

<table>
<thead>
<tr>
<th>Year</th>
<th>Planting Date</th>
<th>Potential Yield/Acre in Bushels</th>
<th>Average No. 1st Gen. ECB</th>
<th>Average No. 2nd Gen. ECB</th>
<th>Average Corn Price Per Bushel</th>
<th>Estimated Per Acre Added Cost of Bt Seed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year 6</td>
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<td>137</td>
<td>1</td>
<td>1</td>
<td>$1.45</td>
<td>$9.00</td>
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<tr>
<td>Year 7</td>
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<td>Year 9</td>
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<td>0</td>
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<tr>
<td>Year 10</td>
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<td>148</td>
<td>0</td>
<td>0</td>
<td>$2.23</td>
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### Percentage Yield Loss from ECB by Generation and Planting Date

<table>
<thead>
<tr>
<th>No. of ECB Per Plant</th>
<th>Before May 1</th>
<th>May 1-9</th>
<th>May 10-16</th>
<th>May 17-23</th>
<th>May 24-30</th>
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</tr>
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<tbody>
<tr>
<td>First Generation</td>
<td></td>
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<td>1</td>
<td>4.7</td>
<td>5.2</td>
<td>3.8</td>
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<td>0.2</td>
<td>0.0</td>
</tr>
<tr>
<td>2</td>
<td>7.1</td>
<td>7.9</td>
<td>5.8</td>
<td>4.2</td>
<td>0.5</td>
<td>0.0</td>
</tr>
<tr>
<td>3</td>
<td>8.8</td>
<td>9.7</td>
<td>7.2</td>
<td>5.2</td>
<td>0.7</td>
<td>0.0</td>
</tr>
<tr>
<td>Second Generation</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>2.0</td>
<td>3.7</td>
<td>4.2</td>
<td>4.5</td>
<td>5.8</td>
<td>6.0</td>
</tr>
<tr>
<td>2</td>
<td>3.1</td>
<td>5.7</td>
<td>6.5</td>
<td>6.9</td>
<td>8.8</td>
<td>9.1</td>
</tr>
<tr>
<td>3</td>
<td>3.9</td>
<td>7.1</td>
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For crop year number ___________
(6, 7, 8, 9, or 10)

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3. What was the total percentage of yield loss of non-Bt corn that was probably caused by the two generations of ECB during this crop year?

4. Use your answer from number 3 to calculate the probable yield/acre of non-Bt corn that the former landowner received for this crop year.

5. Assuming that the former landowner sold the non-Bt corn from the 625 acres for the average price for this year, how much money (gross income) would the landowner have received per acre? How much would the landowner have received for the entire crop?

   Per acre:

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Money per acre for non-Bt corn:

Money for the entire crop:

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Reflect and Apply

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Consider the Costs

Years 11 through 15

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<tr>
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<th>Potential Yield/Acre in Bushels</th>
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<th>Average No. 2nd Gen. ECB</th>
<th>Average Corn Price Per Bushel</th>
<th>Estimated Per Acre Added Cost of Bt Seed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year 11</td>
<td>April 27</td>
<td>150</td>
<td>2</td>
<td>1</td>
<td>$2.16</td>
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<td>3</td>
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</table>

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Percentage Yield Loss from ECB by Generation and Planting Date

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For crop year number __________
(11, 12, 13, 14, or 15)

Round the yield percentages to the nearest tenth of a percent (6.67% = 6.7%). Round the yield bushels to the nearest hundredth of a bushel (140.353 bu = 140.35 bu). Round dollar amounts to the nearest cent ($353.109 = $353.11). In all cases, if the number in the rounding position is a 5, round up ($133.485 = $133.49).

1. By what percentage did first generation borers probably lower the yield potential of non-Bt corn during this crop year?

2. By what percentage did second generation borers probably further lower the yield potential of non-Bt corn during this crop year?

3. What was the total percentage of yield loss of non-Bt corn that was probably caused by the two generations of ECB during this crop year?

4. Use your answer from number 3 to calculate the probable yield/acre of non-Bt corn that the former landowner received for this crop year.

5. Assuming that the former landowner sold the non-Bt corn from the 625 acres for the average price for this year, how much money (gross income) would the landowner have received per acre? How much would the landowner have received for the entire crop?

Per acre:

Entire crop:
6. If Bt corn had been available and planted by the former landowner for this crop year, how much money (gross income) would the landowner have received per acre for the Bt corn? For the non-Bt refuge corn? How much money would the landowner have received for the entire corn crop? (Assume that the former landowner would have divided his 625 acres of corn into 80% Bt corn and 20% non-Bt refuge. Also assume that the Bt corn was 100% effective against first and second generation borers, and the refuge corn had the yield/acre that you calculated for question 4.)

Money per acre for Bt corn:

Money per acre for non-Bt corn:

Money for the entire crop:

7. If the former landowner had paid the added cost for Bt corn seed for this particular crop year, would the added cost have been worth it? Why or why not?
Reflect and Apply

After hearing all the group reports, answer the following questions as your teacher directs.

1. Judging from the history of European corn borer (ECB) infestations in this area, would you advise the new owner to plant Bt corn every year in 80% of his corn acreage? Why? Does your answer differ from the predictions you made?

2. This activity correlated yield loss from ECB damage solely with the number of ECB present in the field and the planting date. Remembering what you have learned about the ECB's life cycle, what other factors could affect the amount of damage done by ECB?

3. In this activity, the cost of Bt corn seed and the cost of damage caused by ECB were the only two production costs considered. In real life, farmers have many other production costs that must be subtracted from the selling price of the crop before they know their profit. What do you think some of these costs would be?

4. Bt corn has been referred to by some people as “an insurance policy.” How are insurance and Bt corn alike? How are they different?

5. What factors other than cost or profit might influence the decision to plant or not plant Bt corn?
See for yourself . . .
Consider the Costs

Years 16 through 20

A farmer has purchased Midwest farmland. The farmer is going to plant 625 acres of corn on the land and is trying to determine whether planting Bt corn would be worth the extra cost. The farmer knows that Bt corn seed costs more than regular seed corn. The farmer also knows that the Bt corn being considered is nearly 100% effective against European corn borers (ECB). The former landowner kept no records on damage caused by ECB in previous years. However, with the help of the local USDA Extension office, the farmer collected crop information on ECB outbreaks for the past 20 years in the county where the land is located. Use the charts below to answer the questions for each year's production. Decide if you can determine whether planting Bt corn probably would or would not be profitable for this farmer in the future.

### Data for 625 Acres

<table>
<thead>
<tr>
<th>Year</th>
<th>Planting Date</th>
<th>Potential Yield/Acre in Bushels</th>
<th>Average No. 1st Gen. ECB</th>
<th>Average No. 2nd Gen. ECB</th>
<th>Average Corn Price Per Bushel</th>
<th>Estimated Per Acre Added Cost of Bt Seed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year 16</td>
<td>May 1</td>
<td>148</td>
<td>0</td>
<td>0</td>
<td>$2.45</td>
<td>$9.00</td>
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<td>Year 17</td>
<td>May 19</td>
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<td>$2.06</td>
<td>$9.00</td>
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<td>148</td>
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<td>$1.85</td>
<td>$9.00</td>
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<td>Year 19</td>
<td>April 24</td>
<td>150</td>
<td>0</td>
<td>0</td>
<td>$1.71</td>
<td>$8.00</td>
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<td>April 22</td>
<td>150</td>
<td>1</td>
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<td>$1.73</td>
<td>$8.00</td>
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### Percentage Yield Loss from ECB by Generation and Planting Date

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Economic Uncertainties of Bt Crops

Bt crops were developed to reduce insect damage from:
- European corn borers in corn
- Bollworms and budworms in cotton
- Colorado potato beetles in potatoes

Estimating how much insect damage will occur over a period of years deals with the likelihood (probability) of damage, not the certainty of damage.
Factors Affecting Yearly Insect Damage

Weather conditions

- Could delay planting
- Could impact when larvae hatch and begin feeding
- Could delay harvesting

Food supply for insects

Change in habitat, ex. how field is tilled, which affects the crop residue available to insects for over-wintering
Economic Thresholds

Economic threshold is the break-even point for use of an insect control practice.

The economic threshold is the point at which insect control cost = cost of yield loss when insect control is not used.

Agronomists have developed economic threshold tables based on

- range of market prices for the crop
- infestation level
- cost and effectiveness of insect control
- expected yield per acre
Insecticide Decisions

Farmers who use insecticides can determine infestation levels by scouting fields.

A representative sample of the plants are examined for

- number of insects per plant
- visible damage to plant

Farmer determines if economic threshold has been reached.
Bt Seed Decisions

- Decisions are made at planting time.

- No reliable way exists yet to predict insect outbreaks for any one year.

- Farmers can look at long-term probabilities of outbreaks.
Consider the Costs – An Example

Statistics

• Corn acres: 625

• Planting date: May 12

• Potential yield/acre: 150 bushels

• Average corn price received by farmers: $2.20/bushel

• Average no. of first generation ECB per/plant: 1

• Average no. of second generation ECB per/plant: 2
Consider the Costs – An Example

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Consider the Costs – An Example

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Consider the Costs – Example Questions

Planted May 12

1. By what percentage did 1st generation borers probably lower the yield potential of non-Bt corn during this crop year?

2. By what percentage did 2nd generation borers probably further lower the yield potential of non-Bt corn during this crop year?
Consider the Costs – Example Questions

3. What was the total percentage of yield loss of non-Bt corn that was probably caused by the two generations of ECB during this crop year?

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Consider the Costs – Example Questions

Calculating 1st generation damage
1st generation damage = 3.8% (from table)

Calculating 2nd generation damage
100% - 3.8% = 96.2% yield remaining after damage by 1st generation

2nd generation damage = 6.5% (from table)

0.962 yield x 0.065 damage = 0.063 yield loss caused by 2nd generation

Calculating total damage to yield
0.038 + 0.063 = 0.101 total damage
1st gen. 2nd gen.

Multiply by 100 to convert to 10.1%.
Consider the Costs – Example Questions

Mathematical formula for answering question 3:

\[ [1 - (1 - Y_1)(1 - Y_2)] \times 100 = \text{total } \% \text{ of yield loss} \]

\[ Y_1 = \% \text{ loss from 1st generation} = 3.8\% \]
\[ Y_2 = \% \text{ loss from 2nd generation} = 6.5\% \]

\[ [1 - (1 - 0.038)(1 - 0.065)] \times 100 = 10.1\% \]

Consider the Costs – Example Questions

4. Use your answer from number 3 (10.1%) to calculate the probable yield/acre of non-Bt corn received for this crop year.

Potential yield/acre: 150 bushels
Consider the Costs – Example Questions

Answer for question 4:

100% potential yield
- 10.1% yield loss
  89.9% remaining yield

150 bu/acre x 0.899 = 134.85 bu/acre
Consider the Costs – Example Questions

5. Assume that the non-Bt corn from the 625 acres was sold for $2.20/bu.

How much money (gross income) would have been received:

Per acre?

For the entire crop?
Consider the Costs – Example Questions

Answers for question 5:

**Per acre**
134.85 bu/acre x $2.20/bu = $296.67

**Entire crop**
$296.67/acre x 625 acres = $185,418.75
Consider the Costs – Example Questions

6. If Bt corn had been planted on 80% of the 625 acres and non-Bt corn had been planted as a 20% refuge, how much money (gross income) would have been received:

Per acre for the Bt corn?

Per acre for the non-Bt corn?

For the entire corn crop?

(Assume that the Bt corn was 100% effective against ECB, and the non-Bt refuge corn had the yield/acre that you calculated for question 4.)
Consider the Costs – Example Questions

Answers for question 6:

**Per acre for the Bt corn**
150 bu/acre x $2.20/bu = $330

**Per acre for the non-Bt corn**
134.85 bu/acre x $2.20/bu = $296.67

**For the entire crop**
625 acres x 0.80 = 500 acres x $330 =
$165,000 for Bt corn

625 acres x 0.20 = 125 acres x $296.67 =
$37,083.75 for non-Bt corn

$165,000 + $37,083.75 = $202,083.75
for entire crop
Consider the Costs – Example Questions

7. If the added cost for Bt corn seed was $10/acre for this year, would the extra cost have been worth it?
Consider the Costs
Example Questions

Answer for question 7:

**Difference in gross return**

\[
\begin{align*}
\text{for planting Bt corn and non-Bt refuge} & \quad \$202,083.75 \\
\text{for planting only non-Bt corn} & \quad -185,418.75 \\
\end{align*}
\]

\[
\begin{align*}
\text{extra cost of Bt seed} & \quad \$16,665.00 \\
\text{extra return from Bt corn} & \quad -5,000.00 \\
\end{align*}
\]

\[
\begin{align*}
\text{for planting Bt corn} & \quad $11,665.00 \\
\end{align*}
\]

Yes, for this year, planting Bt corn would have been worth it.
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<td>5.8</td>
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<td>3.1</td>
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<td>6.9</td>
<td>8.8</td>
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<tr>
<td>3</td>
<td>3.9</td>
<td>7.1</td>
<td>8.0</td>
<td>8.5</td>
<td>10.9</td>
<td>11.2</td>
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</table>

The chart used in this activity was adapted from a similar one contained in *The Economics of BT Corn: Adoption Implications*, Table 4, p. 6. Jeffrey Hyde, Marshall A. Martin, Paul V. Preckel, C. Richard Edwards. Percentages were adjusted for the purposes of this activity, so results may differ from data reported in the peer-reviewed, scientifically-based publication. Purdue University Cooperative Extension Service, West Lafayette, Indiana, ID-219, Rev. 10/2001. Available at http://www.ces.purdue.edu/extmedia/ID/ID-219.pdf. Used with permission.
Production Issues for Bt Crops

TEACHING RESOURCES

Lesson Plan: Refuge Roundtable

Science Content
- Students will visualize the genetic probability of insect resistance to insecticides.
- Students will understand the term “refuge” and how it relates to insect resistance.

Science Education Standards

Life Science, Content Standard C
- Molecular basis of heredity (p. 185)
- Biological evolution (p. 185)
- Behavior of organisms (p. 187)


Science Process Skills
- Observing
- Ordering
- Categorizing
- Comparing and measuring
- Applying

Life Skills
- Learning
- Making decisions
- Science processing

Time
Preparing larvae/moths: 20 minutes
Optional Internet research by students: variable
Doing activity: 40 minutes

Materials
If using the student handouts, make enough copies of optional student handout III-g, Learning More About Insect Resistance to Bt, p. 177-178, and III-h See For Yourself – The Mating Game, p. 179-182, for the entire class. You also will need:

- 48 lids (flats) used for sealing glass canning jars when preserving home garden produce or 48 plastic cups in either 3 oz. or 5 oz. size
- 24 spring-type clothespins
- Pen or magic marker
- 48 small sticky-backed labels that can be made by cutting blank address labels or cutting strips of masking tape
- Paper bag, shoebox, or other container large enough to hold 40 lids or 40 plastic 3-5 oz. cups and large enough for students to reach into
- Flat surface like a table, counter, or lab bench
- Strip of masking tape as long as necessary to extend across the width of the flat surface
- 1 pair of scissors

For each group of students:
- Pens or pencils
- 10 of the lids or cups labeled as directed in the next section
- 5 of the spring-type clothespins labeled with group number

Lesson Plan

Before the Activity
Teachers may use student handout III-g on p. 177-178 and/or the overhead masters III-v through III-z on p. 197-205 to introduce information about refuges. If preferred, teachers may ask their students to research the refuge requirements for Bt corn and cotton themselves for one or more class periods by using some of the online publications listed in the Internet Ideas section on p. 176 or by using other resources. If the
student research option is used, ask students to report
their findings to the class before the day of the activity.

To prepare European corn borer (ECB) larva/moths:

1. Label 20 lids or cups with the letter “r” that stands
   for a resistant allele and 20 with the letter “S” for
   susceptible allele. Set aside the remaining 8 lids or
cups. Because ink tends to rub off the metal
surface of the canning lids, labels can be made from
blank address labels or from short pieces of
masking tape. If you are using cups, you may be
able to write directly on the cups.

2. Using a pen or marker, write “Group 1” on five of
   the spring-type clothespins, “Group 2” on another
   five, “Group 3” on another five, and “Group 4” on
   another five.

3. Take the remaining 8 lids or cups that you set aside
   in step 1, and label them with “r” for the resistance
allele. Use the remaining four clothespins to attach
them in pairs. You may need to use these four
resistant larvae/moths during the game. See step 4
of the “Doing the Activity” section.

4. Put the 20 lids or cups with the letter “r” and the
   20 lids or cups with the letter “S” that you prepared
   in step 1 into the paper bag, shoe box, or other
   container. Shake or stir to mix up the lids or cups.

**Doing the Activity**

1. Tell the class that one way to better understand
   how refuges operate is to explore how the genotype
   (genetic makeup) of an ECB moth affects its larva’s
   phenotype (resistance to Bt). Tell students that, in
   this activity, the flat surface represents a Bt corn
   field. The lids or cups represent all the alleles that
   a population of mating ECB moths contribute to
   the next generation of larvae.

2. Divide the class into four groups, Group 1, 2, 3,
   and 4. Give each group the five spring-type
   clothespins that you labeled with the group’s
   number.

3. Ask the members of each group to reach into the
   container and draw out two lids at random and clip
   (mate) the pair of lids or cups together to form one
   larva. Tell students that the two lids or cups
   represent one allele from a female ECB moth and
   one allele from a male ECB moth.

4. Repeat step 3 until all groups have assembled five
   larvae.

5. Ask each group to place their larva in the Bt corn
   field (on the flat surface).

6. After all the groups’ larvae have been placed in
   the Bt corn field, check to see if there are at least four
   larvae with the “rr” gene type. If not, add to the
   corn field one or more of the larvae you assembled
   and set aside in step 3 of the “Before the Activity”
   section so there are four “rr” larvae in the corn
   field. You can tell the students that these new
   larvae came from moths that flew in from the
   neighboring corn field.

7. Ask each group to revisit the Bt corn field and
   remove all of their group’s larvae that would not
   survive in the Bt corn field. When this step is done
   only the “rr” larvae should be left in the corn field.

8. Ask the class what type of offspring these larvae
   will produce when they mature into moths and
   mate. Use a Punnett square to illustrate this.

   \[
   \begin{array}{cccc}
   r & r & r & r \\
   r & r & r & r \\
   \end{array}
   \]

   The only offspring that these moths can produce
   would be “rr” genotypes with the resistant pheno-
type.

9. Ask the class how well Bt would work to control
   the offspring of “rr” larvae mated to each other.
   Help students to understand that Bt would not
   control these offspring and resistance would
   quickly develop.

10. Return the “rr” larvae to each group. Place a line of
   masking tape on the flat surface about 1/5 of the
   way in from one of the sides. Tell students that in
this corn field, 20% of the acreage is planted to non-Bt corn as a refuge and 80% is planted to Bt corn.

11. Ask each group to put four of their larvae at random on the Bt side of the corn field and the remaining larvae on the refuge side. If you used some of the extra rr larvae that you prepared, you can place one on the refuge side and the rest on the Bt side.

12. Ask each group to revisit the Bt corn field and remove all of their group's larvae that would not survive in the Bt corn field or in the refuge. When this step is done, only the rr larvae should be left in the Bt corn field. All larvae will survive in the refuge and should be left there.

13. Ask the groups to complete “The Mating Game” student handout on p. 179-182 to determine the mating possibilities for the moths that grow from the larvae in the refuge and the Bt corn field. Inform students that in writing the genotype for heterozygotes (Sr), the dominant allele (S) is always written first. If your students are not familiar with Punnett squares, explain that the allele letters representing one parent's genotype are written to the left of the square and the allele letters representing the genotype of the other parent are written above the square. The possible genotypes of the offspring are written inside the smaller squares.

Answers to “The Mating Game” handout

1. Genotype Phenotype
   rr resistant

2.
   \[
   \begin{array}{cc}
   r & r \\
   \text{resist} & \text{resist} \\
   r & r \\
   \text{resist} & \text{resist}
   \end{array}
   \]

3. Genotype Phenotype
   rr resistant
   Sr susceptible
   SS susceptible

4.
   \[
   \begin{array}{ccc}
   r & r & r \\
   r & r & \text{resist} & \text{resist} \\
   r & r & \text{resist} & \text{resist} \\
   r & r & \text{resist} & \text{resist}
   \end{array}
   \]

Reflect and Apply

These questions are on the student handout “See for Yourself – The Mating Game” on p. 179.

1. Scientists who developed the high dose/refuge strategy for slowing the development of insect resistance to Bt crops assumed that very few resistant (rr) insects existed in nature. Do you think this was a valid assumption? Why or why not?

   It probably was a valid assumption. If Bt resistance is recessive and is conferred by a single locus with two alleles (r and S), then only the rr individuals of the three possible genotypes (SS, Sr and rr) would carry resistance to Bt.

2. To slow the development of insect resistance to Bt, which allele would you try to reduce in the insect population? How could a refuge help you accomplish your goal?
The resistant r allele would be the one to reduce. A refuge would provide food and mating habitat for susceptible SS individuals to mate with the rare rr insects. As the resulting Sr individuals die from the Bt crop, resistant r alleles are dropped from the insect population.

3. You and a friend are both scientists working on slowing the development of insect resistance to Bt. Your friend asks you to evaluate a plan for developing a crop that expresses a low level of Bt and planting it next to a refuge. How would you respond to your friend?

The friend’s plan likely will speed up insect resistance to Bt instead of slowing it. The low-level of Bt may kill some of the susceptible SS and Sr individuals, but a greater number of individuals will probably survive. Over time, an increasing number of susceptible individuals are likely to develop tolerance to Bt.

4. Microorganism resistance to antibiotics is a phenomenon that is concerning the medical community. In response, doctors are telling patients for whom they prescribe antibiotic pills to take every one in the bottle, even if they feel better. Why? How does this relate to the strategy discussed above in question 3?

Doctors tell patients to take all the pills so that the disease-causing microorganisms are exposed to a high enough dose to completely kill all of them. The microorganisms that survive a low dose of antibiotic tend to become resistant to even high doses. Eventually, that particular antibiotic becomes useless for curing the disease. This relates to the EPA’s high-dose requirement for Bt crops that mandates 25 times the Bt protein concentration needed to kill susceptible larvae.

Internet Ideas

Biopesticides Registration Action Document – Bacillus thuringiensis (Bt) Plant-Incorporated Protectants
http://www.epa.gov/pesticides/biopesticides/pips/bt_brad.htm
This document was issued by the U.S. Environmental Protection Agency, Office of Pesticide Programs, Biopesticides and Pollution Prevention Division, October 15, 2001. The high dose/refuge strategy for Bt is discussed on p. IID2-IID3.

Bt Corn & European Corn Borer: Long-Term Success Through Resistance Management
http://www.extension.umn.edu/distribution/cropsystems/DC7055.html
Published by the University of Minnesota, this document has a comprehensive discussion of insect resistance.

A Grower’s Handbook: Controlling European Corn Borer with Bt Corn Technology
http://www.ontariocorn.org/btguide.html
This publication by the Canadian Corn Pest Coalition explains the high dose/refuge strategy.

Transgenic Crops: An Introduction and Resource Guide
http://www.colostate.edu/programs/lifesciences/TransgenicCrops/
This site by the Center for Life Sciences and Department of Soil and Crop Sciences at Colorado State University has an evaluation and regulation section that explains how transgenic crops, such as those with Bt, are regulated.
Insect Resistance

When an insect population is repeatedly exposed to high concentrations of certain insecticides, resistance can develop. When this happens, it takes more and more of the insecticide to kill the same percentage of insects. As each generation of the insect is exposed to the insecticide, a few more survive.

The survivors have a genetic makeup that enables them to better withstand exposure to the insecticide. As survivors mate with other susceptible insects, some of their offspring also will be susceptible and will die. But other offspring will receive the resistant gene and will survive. Over a number of generations of repeated exposure to the insecticide, the percentage of survivors in the insect population will increase until the insecticide kills so few of the insects that it no longer is useful.

The Environmental Protection Agency (EPA) has regulatory authority over plant pesticides. This agency of the federal government has established practices that seed companies and farmers must follow to reduce the potential for insects to develop resistance to the Bt proteins, also called endotoxins, produced in Bt crops. Scientists believe that the development of resistance can be slowed by

- exposing insects to high doses of the Bt proteins and
- planting refuges of non-Bt crops.

The EPA's Science Advisory Panel Subpanels have defined what a high dose must be. In the case of Bt corn, a high dose is defined as 25 times the Bt protein concentration necessary to kill susceptible European corn borers (ECB).

The Assumptions Behind Refuges

The high dose/refuge strategy assumes that resistance to the Bt protein is controlled by a recessive allele of the insect, r, and susceptibility is controlled by a dominant allele, S. Insects can be susceptible homozygotes (SS), susceptible heterozygotes (Sr), or resistant homozygotes (rr). The high dose/refuge strategy also assumes that there will be very few resistant (rr) insects to begin with and that extensive random mating will occur between resistant and susceptible adult insects.

Mating of resistant survivor moths from Bt corn with susceptible moths from the refuge slows the development of resistance. Figure by Glenda Webber, ISU Office of Biotechnology.

Mating of resistant survivor moths from Bt corn with other resistant moths speeds up the development of resistance. Figure by Glenda Webber, ISU Office of Biotechnology.
Ideally, only rare \( rr \) insects will survive a high dose of Bt protein produced by a Bt crop. All the SS and all of the Sr individuals should be killed by the Bt protein. The non-Bt refuge provides a place for susceptible SS individuals to feed and mate with the rare \( rr \) resistant individuals. When their Sr offspring are killed by the Bt crop, resistant \( r \) alleles are removed from the insect population. This delays the development of resistance.

The EPA has established resistance reporting requirements and monitoring procedures for companies who have registered Bt crops with the federal agency. Industry registrants, in turn, provide educational information about refuges and require agricultural producers to sign grower contracts.

**Insect Resistance Management Plans**

The EPA is addressing insect resistance to Bt by (1) trying to reduce the potential for pest resistance development in the field by mandating that industry registrants of Bt crops develop insect resistance management (IRM) plans and by (2) better understanding the mechanisms that cause resistance to develop. The EPA has identified seven elements, including refuges, that should be part of a Bt crop insect resistance plan:

- knowledge of pest biology and ecology
- appropriate dose expression strategy (how much Bt protein is produced by the plant)
- appropriate refuge
- resistance monitoring and a remedial action plan should resistance occur
- employment of integrated pest management
- communication and education strategies on use of the product
- development of alternative modes of action

The IRM plans also must include ways to measure compliance, which means how well the plans are being followed. IRM plans change as more scientific data become available, so the EPA makes research data requirements part of the terms and conditions of registration of Bt crops.

**Learn the Language**

**Alleles**

Different forms of a gene

**Endotoxin**

The Bt protein in crops that is sometimes referred to as Bt endotoxin, to distinguish it from other types of proteins produced by Bt bacteria

**Generation**

One completed life cycle of an organism

**Heterozygotes**

Organisms that contain two different forms of a gene

**Homozygotes**

Organisms that contain two identical forms of a gene

**Integrated pest management**

Utilizing a combination of different economically and environmentally sound practices to control a pest while minimizing pesticide use

**Mode of action**

Chemical process by which an insecticide kills an insect

**Recessive**

A gene that is expressed only when two copies of it occur together in an individual

**Resistance**

Ability to survive and reproduce when exposed to an insecticide or Bt protein

**Susceptible**

Unable to survive when exposed to an insecticide or Bt protein

**Credit Notes**


... and justice for all

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Issued in furtherance of Cooperative Extension work, Acts of May 8 and June 30, 1914 in cooperation with the U.S. Department of Agriculture. Stanley R. Johnson, director, Cooperative Extension
See for yourself . . .

The Mating Game

Names of Group Members ____________________________________________

One way to better understand how refuges operate is to explore how the genotype (genetic make-up) of European corn borer (ECB) moths affect the phenotype (resistance or susceptibility to Bt) of their larval offspring. A larva’s phenotype determines whether it can survive in a Bt corn field. Answer the following questions about the mating possibilities for ECB moths and fill in the blanks, as your teacher directs.

1. A corn field was planted entirely to Bt corn with no non-Bt corn refuge. Using “r” to represent an allele that is recessive and resistant to Bt and “S” to represent an allele that is dominant and susceptible to Bt, what would be the possible genotype(s) of the larvae that survive in this field? What would be their phenotypes (resistant or susceptible)? Use as many of the possible genotype and phenotype blanks as you need to answer this question.

   Larvae Surviving in Bt Corn Field        Phenotype
   Possible genotype:  _____  _____                    
   Possible genotype:  _____  _____                    
   Possible genotype:  _____  _____                    

2. When the surviving larvae develop into moths and mate in the Bt corn field with no non-Bt refuge, what genotype(s) would be possible for their offspring larvae? Fill in the Punnett square(s) below for the parent moths and the genotypes of their offspring. Write the abbreviation for the phenotype of each offspring under its genotype. Use as many squares as you need. See the example at the right.

   Moths Mating in Bt Corn Field        Moths Mating in Bt Corn Field        Moths Mating in Bt Corn Field

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Iowa State University Extension and ISU Office of Biotechnology
3. Suppose that 80% of a corn field was planted to Bt corn and 20% of the field was planted to a non-Bt corn refuge. What would be the possible genotype(s) and phenotype(s) of the larvae that survive in the refuge part of the field? Use as many of the possible blanks below as you need to answer this question.

<table>
<thead>
<tr>
<th>Larvae Surviving in Non-Bt Corn Field</th>
<th>Phenotype</th>
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<tr>
<td>Possible genotype: _____  _____</td>
<td>____________________</td>
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<td>Possible genotype: _____  _____</td>
<td>____________________</td>
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<tr>
<td>Possible genotype: _____  _____</td>
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4. Referring to the field in question 3, and considering moths that developed from surviving larvae, if any moth in the refuge could mate with any other moth in the refuge or Bt corn field, what genotype(s) would be possible for their offspring larvae? Fill in the Punnett square(s) below for the parent moths and the genotypes of their offspring. Write the abbreviation for the phenotype of each offspring under its genotype. Use as many Punnett squares as you need.

<table>
<thead>
<tr>
<th>Moths Mating Anywhere in Field</th>
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</table>
Reflect and Apply

1. Scientists who developed the high dose/refuge strategy for slowing the development of insect resistance to Bt crops assumed that very few resistant (rr) insects existed in nature. Do you think this was a valid assumption? Why or why not?

2. To slow the development of insect resistance to Bt, which allele would you try to reduce in the insect population? How could a refuge help you accomplish your goal?
3. You and a friend are both scientists working on slowing the development of insect resistance to Bt. Your friend asks you to evaluate a plan for developing a crop that expresses a low level of Bt and planting it next to a refuge. How would you respond to your friend?

4. Microorganism resistance to antibiotics is a phenomenon that is concerning the medical community. In response, doctors are telling patients for whom they prescribe antibiotic pills to take every one in the bottle, even if they feel better. Why? How does this relate to the strategy discussed above in question 3?
Lesson Plan: Locating Refuges – Insect Hotels

Science Content
Students will apply their knowledge from the previous activities to make scientifically sound decisions about the use of this crop technology.

Science Education Standards
Life Science, Content Standard C
  – Molecular basis of heredity (p. 185)
  – Behavior of organisms (p. 187)
  – Interdependence of organisms (p. 186)


Science Process Skills
• Observing
• Communicating
• Relating
• Inferring
• Applying

Life Skills
• Learning
• Making decisions
• Science processing

Time
Copying optional handouts: 20 minutes
Optional Internet research by students: variable
Doing activity: 40 minutes

Materials
If using the student handouts, make enough copies of optional student handout III-i, Learning More About Locating Refuges, p. 187-190, and III-j See For Yourself – Locating Refuges: Insect Hotels, p. 191-196, for the entire class.

Lesson Plan

Before the Activity
Teachers may use student handout III-i, p. 187-190, and/or the overhead masters on p. III-aa to III-ii, p. 207-223, to introduce information about refuge requirements. If preferred, teachers may ask their students to research the refuge requirements for Bt corn and cotton themselves for one or more class periods by using some of the online publications listed in the Internet Ideas section on p. 184 or by using other resources. If the student research option is used, ask students to report their findings to the class before the day of the activity.

Doing the Activity
1. The class may do this activity individually or in student groups. If using groups, divide the class into four groups. The four parts of the activity handout are on separate pages so teachers may give each group all or just one of the parts to complete.

2. Tell the students: “In this activity, you assume the role of a reviewer of insect resistance management (IRM) plans. You work for a seed company that produces Bt corn and Bt cotton seed. Your company requires farmers to submit IRM plans as part of the grower agreement they sign when they purchase Bt crop seed. Your job is to review the plans using the refuge regulations established by the Environmental Protection Agency (EPA). If a farmer's IRM plan meets the guidelines, you can approve the plan. If the plan does not meet the guidelines, you will need to reject the plan and recommend modifications.”

3. Give students handout III-j, See For Yourself – Locating Refuges: Insect Hotels, p. 191-196. Ask them to review each farmer's plan, accept or reject it, and suggest modifications to the plan, if necessary.

4. The teacher may choose to grade the activity individually or ask groups to share their answers in a class discussion. Note: The names and locations used in this activity are intended to be fictitious. Any resemblance to real individuals, living or dead, is purely coincidental.

Answers:
IRM Plan from Frank and Lila Brown
• Field 1 is an example of the adjacent block option and meets the EPA guidelines.
• Field 2 is an example of the strips option and violates two EPA guidelines. Refuge strips
must be a minimum of four rows wide (six preferred). The refuge must be a minimum of 20% of the field acreage, so 40 acres are needed and only 20 refuge acres (4 acres x 5 strips) are planned.

- Field 3 is an example of the pivot corners option for irrigated fields and violates one EPA guideline. The refuge must be a minimum of 20% of the field acreage, so 30 acres are needed and only 10 refuge acres are planned.

**IRM Plan from Margaret Fellows**
- Field 1 is an example of the adjacent block option and meets EPA guidelines. Teachers may need to remind students that refuge acreage greater than the 20% minimum is acceptable.
- Field 2 is an example of the perimeter option and violates one EPA regulation. Bt insecticide cannot be used on refuge acres.
- Field 3 is an example of the separate field option and meets EPA guidelines.

**IRM Plan from Tyler Thompson**
- Field 1 is an example of the 5% external, structured, unsprayed refuge (95:5) and violates three EPA guidelines. The refuge is not located within 1/2 mile from the edge of the Bt cotton field. The refuge is not at least 150' wide. The refuge cannot be sprayed with insecticide.
- Field 2 is an example of the 20% external sprayed refuge option (80:20) and meets EPA guidelines.
- Field 3 is an example of the 5% embedded refuge for very large fields option (95:5) and violates one EPA guideline. The refuge acres must be sprayed at the same time as the Bt cotton acres.

**IRM Plan from Jan and James Smith**
- Field 1 is an example of the 5% embedded refuge option (95:5) and meets EPA guidelines. Teachers may need to remind students that refuge acreage greater than the 5% minimum is acceptable.
- Field Unit is an example of the embedded refuge field unit block (95:5) option and violates one EPA guideline. The refuge acres cannot be treated differently than the Bt cotton acres when insecticide is applied.

5. Discuss the Reflect and Apply questions with the class.

**Reflect and Apply**

1. If the Environmental Protection Agency (EPA) did not require refuges for Bt crops, after a few years what type of insects would be available as mates for resistant insects? How would this affect the development of insect resistance to Bt?

   Without a refuge for susceptible insects, eventually only resistant insects would be available as mates for each other. The effect would be to increase the number of resistant alleles in the population and speed up the development of insect resistance to Bt.

2. Why do you think the EPA restricted the use of microbial Bt insecticides on Bt crop refuges?

   If Bt insecticides were used on the refuges, the susceptible insects would be killed and the effect would be the same as described in the answer for question 1.

3. Farmers who grow organic crops and home gardeners have used Bt insecticides for many years. If you were an organic farmer or a home gardener, would you support or oppose the use of Bt crops?

   Answers will vary. If Bt resistance develops in a certain insect population, Bt insecticides would no longer be effective in controlling that insect. Organic farmers and gardeners might lose an effective tool for controlling insects. Other students may point out that resistance to Bt probably will develop anyway, even if Bt crops were not used. Bt crops, they might argue, are just speeding up an inevitable process.

4. The EPA has decided that the companies selling Bt crop seeds are responsible for ensuring that their products are used correctly. Do you think this is fair? Why or why not?

   Answers will vary. Some students may take the position that the developer of a product is responsible for its use. Others may assert that the user of a product should bear the responsibility for how a product is used.

**Internet Ideas**

Biopesticides Registration Action Document – Bacillus thuringiensis (Bt) Plant-Incorporated Protectants
http://www.epa.gov/pesticides/biopesticides/pips/bt_brad.htm

This document was issued by the U.S. Environmental Protection Agency, Office of Pesticide Programs,
Biosticides and Pollution Prevention Division, October 15, 2001. Refuge requirements for Bt corn grown in non-cotton growing areas are on p. IID15-IID28. Refuge requirements for Bt cotton are on p. IID70-IID74. Refuge requirements for Bt potatoes are on p. IID131-IID133.

**Insect Resistance Management – National Corn Growers Association**
This site has a map of the United States that students can click on to learn about the refuge requirements for Bt corn grown in their state. There also is a PowerPoint® presentation about insect resistance management plans.

**Insect Resistance Management – Pioneer Hi-Bred International, Inc.**
http://www.pioneer.com/biotech/irm/
This site has a number of insect resistance management resources for Bt corn.

**Refuge Acreage Calculator for Bt Corn – Pioneer Hi-Bred International, Inc.**
Students can enter their state and total planned corn acreage to have their maximum Bt acres and refuge acres calculated.

**Technology Use Guide – Monsanto Company**
http://WWW.FARMSOURCE.COM/TUG/tug2002_index.asp
The guidelines for the use of products such as Bt corn and Bt cotton can be accessed from this page. Watch the frame at the left for the “insect resistance management” link that appears when a Bt product is clicked.

**Credit Note**
PowerPoint® is a registered trademark of Microsoft.
Learning more about . . .
Locating Refuges

Refuges: Insect Hotels
When farmers plant a field of Bt corn, the Environmental Protection Agency (EPA) requires that they plant a refuge in or near it. These refuges are like insect hotels. They are places where insects can live safely and luxuriously for a while with plenty of non-Bt plant food and other insects to meet. In a refuge, the rare insects that are resistant to the Bt protein produced in Bt crops (rr genotype) and those that are susceptible (SS and Sr genotypes) can mate and produce mostly Sr offspring. Because resistance to Bt is carried by a recessive allele, only rr individuals are likely to survive exposure to the high doses of Bt protein that is produced by Bt crops. Susceptible Sr offspring will die before they mature and reproduce, effectively removing resistant r alleles from the insect population.

Location, Location, Location
In the real estate business, it is a long-standing saying that the three most important things that determine the value of property are location, location, and location. The value of a refuge is determined by its location, too.

Like all insects, the European corn borer, cotton bollworm, tobacco budworm, pink bollworm, and Colorado potato beetle vary in how far they travel during their lives. Insect mobility was considered by the EPA when it set guidelines for the location of refuges for different crops. If a refuge is located too far from a Bt crop field, the rare rr resistant insects surviving in the Bt field will not mate extensively with susceptible SS and Sr insects living in the refuge.

Crop-Specific Refuge Requirements
Each Bt crop has specific requirements for refuges. These requirements are updated for each new crop year according to the most recent scientific information. The size and location of the refuges are based on results from scientific studies about insect mating habits and how far insects travel during their lifetimes. The EPA's scientific advisory panels recommend that refuges for Bt corn, cotton, and potatoes be sized and located so that 500 susceptible insects are produced for every resistant insect. Here are the refuge locating requirements for a recent crop year.

Refuge Requirements for Growing Bt Corn in the Northern Corn Belt (Non-Cotton Growing Areas) in 2002
In areas of the United States where no cotton is grown, the following requirements apply.

- On each farm, producers can plant up to 80% of corn acres with Bt corn. The other 20% of corn acres must be planted to a structured refuge of non-Bt corn.
- The non-Bt corn refuge must be placed within, adjacent to, or near the Bt corn field. The refuge must be within 1/2 mile of the Bt corn field (1/4 mile or closer preferred) to help provide a population of susceptible moths with which the resistant moths can mate.
• Insecticide treatments for control of ECB, corn earworm, or Southwestern corn borer may be applied to the refuge only if economic thresholds are reached for one or more of the target pests. Microbial Bt insecticides may not be applied to non-Bt corn refuges.

• Refuge planting options include:
  - Separate fields
  - Blocks within fields along the edges or end rows
  - Strips across the field alternating four rows or more (six preferred) of non-Bt corn with Bt corn

Examples of acceptable refuges for Bt corn include:

- Adjacent Block
- Block Within Field
- Perimeter
- Strips
- Pivot Corners (irrigated fields)
- Separate Field

Refuge Requirements for Growing Bt Cotton in 2002

Growers can chose one of four refuge options when growing Bt cotton:

• 95:5 external structured unsprayed refuge:
  At least 5 acres of non-Bt cotton refuge must be planted for every 95 acres of Bt cotton. The refuge must be at least 150 feet wide and may not be treated with insecticides for controlling tobacco budworm, cotton bollworm, or pink bollworm. The refuge must be planted within 1/2 linear mile from the edge of the Bt cotton field. The refuge must be managed (fertility, weed control, and management of other pests) similarly to the Bt cotton.

• 80:20 external sprayed refuge:
  At least 20 acres of non-Bt cotton must be planted for every 80 acres of Bt cotton. Both Bt and non-Bt cotton may be treated with insecticides, except for foliar B.t.k. (Bacillus thuringiensis, subspecies kurstaki) products labeled for the control of tobacco budworm, cotton bollworm, or pink bollworm. The refuge must be maintained within 1 linear mile (preferably 1/2 mile or closer) from the edge of the Bt cotton.

• 95:5 embedded refuge:
  At least 5 acres of non-Bt cotton must be planted for every 95 acres of Bt cotton. The non-Bt cotton must be planted as a block within the Bt cotton field. Multiple blocks across the field may be used for very large fields.

For fields that are small or irregularly shaped, neighboring fields farmed by the same grower can be grouped into a field unit block. The field unit block must be at least 150 feet wide and all fields grouped into it must be located within one square mile of the Bt cotton. Within the larger field unit, a smaller field planted to non-Bt cotton may serve as the embedded refuge.

Whether the refuge is embedded within a single Bt cotton field or is a smaller field that is grouped into a field unit block, the refuge acres can be treated with any insecticide (except foliar B.t.k. products for tobacco budworm, cotton bollworm, or pink bollworm) whenever the entire field is treated. The refuge acres cannot be treated with insecticides unless the Bt cotton acres also are treated.

• A group of cotton growers whose farmland is contiguous area can establish a community refuge that meets the requirements of either the 95:5 or 80:20 option.

Examples of acceptable refuges for Bt cotton include:
The current Insect Resistance Management (IRM) plan for Bt potatoes includes the following requirements for growers:

- Bt potatoes should be planted in rotation with other crops to reduce the numbers of Colorado potato beetle.
- At least 20% of the total potato acreage should be planted to non-Bt potato varieties as a refuge.
- Growers must not use a foliar Bt application to control the Colorado potato beetle in the refuge. Growers may treat Colorado potato beetles in the refuge with non-Bt foliar insecticides to prevent damage only when insect populations reach damaging levels, according to local integrated pest management recommendations.
- Plant every Bt potato field within 1/2 mile or less of the current year refuge or within 1/2 mile of land that was the designated refuge last year.
- Use every available method to reduce insect populations such as crop rotation, propane flaming, trench trapping, and destruction of overwintering habitat.

**Learn the Language**

**Economic threshold**
The point at which the cost of an insect control practice equals the cost of the yield loss from insect damage

**Genotype**
Genetic makeup of an organism; the genes it contains

**Recessive allele**
A gene that is expressed only when two copies of it occur together in an individual

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Refuge Requirements for Growing Bt Potatoes in 2002

Starting with the 2001 growing season, Monsanto decided to no longer market its NatureMark potatoes due to concern about consumer reaction and the reluctance of some major processors to buy genetically modified potatoes. However, as this is written, the EPA registration for the Cry3A Bt potato product with the trade name NewLeaf® is still in effect. Therefore, information about the refuge requirements is included in case the product is marketed in future years.
Credit Notes


2 Ibid., p. IID70-IID74.

3 Ibid., p. IID131-IID133.

NatureMark® and NewLeaf® are registered trademarks of the Monsanto Company.
In this activity, you assume the role of a reviewer of insect resistance management (IRM) plans. You work for a seed company that produces Bt corn and Bt cotton seed. Your company requires farmers to submit IRM plans as part of the grower agreement they sign when they purchase Bt crop seed. Your job is to review the plans using the refuge regulations established by the Environmental Protection Agency (EPA). If a farmer's IRM plan meets the guidelines, you can approve the plan. If the plan does not meet the guidelines, you will need to reject the plan and recommend modifications.

**Insect Resistance Management Plan**

<table>
<thead>
<tr>
<th>Type of Crop:</th>
<th>Corn</th>
</tr>
</thead>
</table>

Submitted by: Frank and Lila Brown  
12300 346th Avenue  
Jasonville IA 50033

- Total crop acres: 850
- Acres to be planted to Bt crop: 720
- Acres to be planted as refuge: 130

The farmers’ proposed refuge plan is below. Refuge acres are shaded.

For Reviewer:

IRM plan is: _____ approved _____ rejected. If rejected, suggest modifications to plan in space below.

Signature of reviewer(s) ________________________________ Date __________________
Insect Resistance Management Plan

Type of Crop: Corn

Submitted by: Margaret Fellows
Route 2, Box 193
Echo ND 58111
Total crop acres: 450
Acres to be planted to Bt crop: 352
Acres to be planted as refuge: 98

The farmer’s proposed refuge plan is below. Refuge acres are shaded.

Field 2 perimeter totals 32 acres. Due to ECB problem in field 2 late last season, I plan to spray Bt corn and refuge with Bt insecticide early this season.

For Reviewer:
IRM plan is: ______ approved ______ rejected. If rejected, suggest modifications to plan in space below.

Signature of reviewer(s) _____________________________ Date _____________________________
Insect Resistance Management Plan

Type of Crop: Cotton

Submitted by: Tyler Thompson

Total crop acres: 1,000
Acres to be planted to Bt crop: 867.5
Acres to be planted as refuge: 132.5

The farmer’s proposed refuge plan is below. Refuge acres are shaded.

For Reviewer:
IRM plan is: ______ approved ______ rejected. If rejected, suggest modifications to plan in space below.

Signature of reviewer(s) ______________________________ Date ____________________________
Insect Resistance Management Plan

Type of Crop: **Cotton**

Submitted by: **Jan and James Smith**  
759 Western Road  
Sunny CA 99134  
Total crop acres: **320**  
Acres to be planted to Bt crop: **302**  
Acres to be planted as refuge: **18**

The farmers’ proposed refuge plan is below. Refuge acres are shaded.

For Reviewer:  
IRM plan is: _____ approved _____ rejected. If rejected, suggest modifications to plan in space below.

Signature of reviewer(s) ____________________________  Date ____________________
Reflect and Apply

1. If the Environmental Protection Agency (EPA) did not require refuges for Bt crops, after a few years what type of insects would be available as mates for resistant insects? How would this affect the development of insect resistance to Bt?

2. Why do you think the EPA restricted the use of microbial Bt insecticides on Bt crop refuges?

3. Farmers who grow organic crops and home gardeners have used Bt insecticides for many years. If you were an organic farmer or a home gardener, would you support or oppose the use of Bt crops? Why?
4. The EPA has decided that the companies selling Bt crop seeds are responsible for ensuring that their products are used correctly. Do you think this is fair? Why or why not?

Note: The names and locations used in this activity are intended to be fictitious. Any resemblance to real individuals, living or dead, is purely coincidental.
Insect Resistance

Insect populations repeatedly exposed to certain insecticides can develop resistance to the insecticide.

Survivors mate with each other, causing the number of resistant individuals to gradually increase.

To kill the same percentage of insects, increasingly higher amounts of insecticide are needed.
Bt Resistance

The Environmental Protection Agency (EPA) regulates plant pesticides.

EPA scientists believe Bt resistance can be slowed by

- exposing insects to high doses of Bt protein (25x the amount needed to kill susceptible insects)
- planting refuges of non-Bt varieties of crops
Bt Resistance

Scientists think

- Bt resistance is recessive (r) and susceptibility is dominant (S).

- The alleles for Bt resistance or susceptibility are located at one place (locus) on a chromosome.

- Each insect has two alleles at this locus.

The result is three possible genotypes

- rr resistant
- Sr susceptible (r is recessive)
- SS susceptible
Why Refuges?

- Rare rr insects should survive a high dose of Bt. The SS and Sr insects should die.

- Refuges provide a place near a Bt crop where susceptible insects can survive and mate with rare rr insects.
Why Refuges?

As their Sr offspring move into nearby Bt crops and die, resistant r alleles are removed from the insect population.

Result: Resistance development is delayed.
Refuge Requirements

Refuge requirements are established by the EPA.*

Requirements are updated each crop year as new scientific information becomes available.

EPA scientific advisory panels recommend that refuges for Bt corn, cotton, and potatoes be sized and located so susceptible insects outnumber resistant ones 500 to 1.

Refuge Requirements for Northern Corn Belt in 2002
(areas where no cotton is grown)

On each farm, up to 80% of corn acres can be planted to Bt corn if a minimum of 20% of corn acres are planted to structured non-Bt refuge.

Refuge must be placed within, adjacent to, or near the Bt corn field (no more than 1/2 mile away, 1/4 mile or closer preferred).

Insecticide treatments to control European corn borer, corn earworm, or Southwestern corn borer can be applied only if economic thresholds are reached for one or more of these pests. No microbial Bt insecticides are allowed in non-Bt corn refuges.
Refuge Examples
Northern Corn Belt in 2002

- Separate fields
- Blocks within fields
- Strips alternating 4 rows or more (6 preferred) non-Bt with Bt corn
Refuge Requirements for Cotton in 2002

Four options:

1. 95:5 external unsprayed refuge

   • At least 5 acres of non-Bt cotton must be planted for every 95 acres of Bt cotton.

   • Refuge must be at least 150 feet wide, and may not be treated with insecticides to control tobacco budworm, cotton bollworm, or pink bollworm.

   • Refuge must be planted within 1/2 linear mile from edge of Bt cotton field and managed similarly to Bt cotton field (fertility, weed control, and other pests).
Refuge Requirements for Cotton in 2002

80:20 external sprayed refuge

- At least 20 acres of non-Bt cotton must be planted for every 80 acres of Bt cotton.
- Refuge must be within 1 linear mile (1/2 mile or closer preferred) from edge of Bt cotton field.
- Both Bt and non-Bt cotton may be treated with insecticides (except foliar Bt products) for control of tobacco budworm, cotton bollworm, or pink bollworm.
Refuge Requirements for Cotton in 2002

95:5 embedded refuge

• At least 5 acres of non-Bt cotton must be planted for every 95 acres of Bt cotton.

• Refuge must be planted as a block in Bt cotton field or multiple blocks may be used for very large fields.

• Small or odd-shaped fields farmed by the same grower can be grouped as a field unit block that is at least 150 feet wide and within one square mile of the Bt cotton. One of the smaller fields planted to non-Bt cotton within the field unit block can be the refuge.
Refuge Requirements for Cotton in 2002
(95:5 embedded refuge continued)

- Whether refuge is embedded in one field or grouped into field unit block, refuge can be treated with insecticides (except foliar Bt products) for tobacco budworm, cotton bollworm, or pink bollworm when entire field is treated.

- Refuge cannot be treated differently than the Bt cotton.
Refuge Requirements for Cotton in 2002

Community refuge

Group of cotton growers with adjoining farmland can establish community refuge that meets requirements for either 95:5 external unsprayed or 80:20 external sprayed options.
Refuge Examples
Cotton in 2002

5% Unsprayed Refuge (95:5)

95 Acres

5 Acres

20% Sprayed Refuge (80:20)

80 Acres

20 Acres

5% Embedded Refuge (95:5)

95 Acres

5 Acres

5% Embedded Refuge for Very Large Fields (95:5)

Field Unit

1 mile

1 mile