# CHAPTER 6

# Corn Under Construction

# Corn Under Construction

As the local farmers waited for the DeWitt County Extension monthly meeting to begin, they began discussing the surprising news that corn containing a new *Bt* gene not approved for human consumption had been found in a grain elevator in neighboring Macon County.

"I just don't understand it," Emmet said. "Now those growers have to sell all the corn in that elevator as animal feed. How did this happen if no one in that county planted the new *Bt* seed?"

"Well, they may not plant it in Macon County, but we certainly grow all types of *Bt* corn here," John replied.

"I always get some volunteer corn from the year before," Sam offered. "Do you think someone planted new acreage and didn't check for volunteers from the prior owner's crop?"

"I'm pretty sure the new *Bt* seed only became available this year," Emmet responded. "Do you think the seed company might have packaged some of the new *Bt* seed with the wrong label?"

"I know that new *Bt* corn hybrid was planted in at least two fields just north and west of the Macon County border," John declared. "So, what about pollen drift? Remember how windy it was this summer? Why, some of my late-planting corn seedlings in the flood plain were knocked down just about the same time the higher-ground corn was tasseling."

The conversation was interrupted as Roger, the county extension agent, signaled for the meeting to start. "Let's get down to today's business—new alternatives for planting European corn borer refuges—always a popular topic," he announced with a tentative smile.

**Figure 6.1** Mature corn plants with tassels and silks present.

## CASE ANALYSIS

1. **Recognize potential issues and major topics in the case.** What is this case about? Underline terms or phrases that seem to be important to understanding this case. Then list 3 or 4 biology-related topics or issues in the case.

2. **What specific questions do you have about these topics?** By yourself, or better yet, in a group, list what you already know about this case in the "What Do I Know?" column. List questions you would like to learn more about in the "What Do I Need to Know?" column.

| What Do I Know? | What Do I Need to Know? |
|---|---|
| | |

3. Put a check mark by 1–3 questions or issues from the "What Do I Need to Know?" list that you think are most important to explore.

4. **What kinds of references or resources would help you answer or explore these questions?** Identify two different resources and explain what information each resource is likely to give that will help you answer the question(s). Choose specific resources.

# Core Investigations

## I. Critical Reading

To complete this investigation, you should have already read Chapter 38: Angiosperm Reproduction and Biotechnology.

**A. Reproduction in Corn: Flowers and Pollination.** Like the majority of angiosperms, rose family plants have complete flowers. Their floral structure includes sepals, petals, stamens, and carpels (Figure 6.2). If you compare corn flowers to the rose flower, you can observe striking differences. Corn, known globally as *maize,* has unisexual flowers and is monoecious—both male (staminate) and female (carpellate) flowers are found on the same plant. The staminate flowers are located in the tassels produced at the top of the plant. The carpellate flowers are produced in rows on upright ears found lower on the cornstalk.

**Figure 6.2** Complete flowers such as this *Rosa* species have both male and female reproductive parts. Maize flowers, however, contain either male or female reproductive parts.

1. Is there any advantage for the corn plant to having its staminate flowers higher than its carpellate flowers? Explain.

2. Each tassel produces 2–5 million pollen grains. One acre of a cornfield may contain 20,000 to 30,000 corn plants, producing up to 68 kg (approximately 150 pounds) of pollen in a single growing season. Each ear has about 1,000 carpellate flowers, although only about 400 seed-containing kernels are produced on the average ear.

The pollen ovule ratio (P/O) in wind-pollinated plants is often greater than 1,000 (1,000 pollen grains:1 ovule). For example, horse chestnut has a P/O of 450,000 and oak has a P/O of 600,000. If 4 million grains of pollen are produced per tassel, what is the ratio of pollen to ovules in an average corn plant bearing one tassel and one ear?

3. Pollen grain size is significant (see Figure 6.3). If a pollen grain is too large, it may not disperse well; however, if it is too small, there will be insufficient resources to produce a pollen tube long enough to reach the ovules. Corn pollen averages 120 μm in diameter, which is much larger than either horse chestnut or oak pollen. Unlike either of these tree pollens, corn has to support the growth of a pollen tube up to 15 cm long.

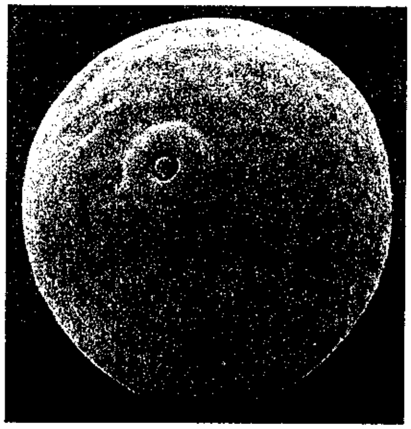


**Figure 6.3** A corn pollen grain (~90 μm).

Western ragweed pollen averages 21 μm in diameter and produces a pollen tube length of about 1 cm. Consider the differences in pollen production by corn (4 million grains per plant) and western ragweed (75 million pollen grains per plant). (Western ragweed pollen per stem was calculated from data presented in Wan, S., T. Yuan, S. Bowdish, L. Wallace, S. D. Russell, and Y. Luo, Response of an allergenic species, *Ambrosia psilostachya* [asteraceae], to experimental warming and clipping: Implications for public health. *American Journal of Botany,* 89[11]:1843–846, 2002.) Speculate how the characteristics of each plant's pollen benefit the reproduction of its species.

4. If you didn't know that corn is wind-pollinated, what characteristics of corn flowers could point you toward this conclusion?

5. How do you think a rose is pollinated? Consider your own experience with roses as well as the image provided in Figure 6.2. List two personal observations to support your answer.

6. Roses belong to the clade of flowering plants called eudicots. Corn belongs to the monocot clade. Using your knowledge of eudicot and monocot traits, answer "monocot" or "eudicot" for the following features observed in plants from one of these two clades:
   a. Parallel venation in the leaves
   b. Vascular bundles in the stem arranged in a ring
   c. The seedling produces a single cotyledon

**B. Reproduction: Fertilization and the Seed.** See Figures 38.3 and 38.8 in the text to help you with this investigation.

1. If you were to slice open a kernel of corn and apply iodine solution to the interior, which part of the kernel do you predict would turn the darkest blue? What is the function of this part of the seed?

2. Do the embryo and endosperm contain genetic information from the female gamete, the male gamete, or both?

3. Do both the embryo and the endosperm have the same number of chromosomes? Explain.

## II. Considering *Bt* Corn

**A. Misplaced *Bt* Corn.** Recall from the case that something strange happened in Macon County. Some of the corn stored in the major grain elevator tested positive for new *Bt* genes. These genes are found in some kinds of genetically modified corn, but this corn was not planted in Macon County according to the cooperative records. (*Note:* Macon County shares some of its north and west borders with DeWitt County.)

1. List the hypotheses posed by the DeWitt County growers as to how new *Bt* corn found its way into the Macon County growers' grain elevators.

2. Consider how the *Bt* genes turned up in the Macon County corn according to John's hypothesis. Within the seeds, would *Bt* genes be found in the embryo, the endosperm, or both? Explain.

3. Farms are spread out all around Macon County. Two members of the growers' cooperative had samples of seed from corn left in their fields that tested for the presence of *Bt* genes. Compare the test results of field A and field B in Figure 6.4.

4. Which field results would tend to support John's explanation of how pollen traveled from DeWitt County to Macon County? Why?

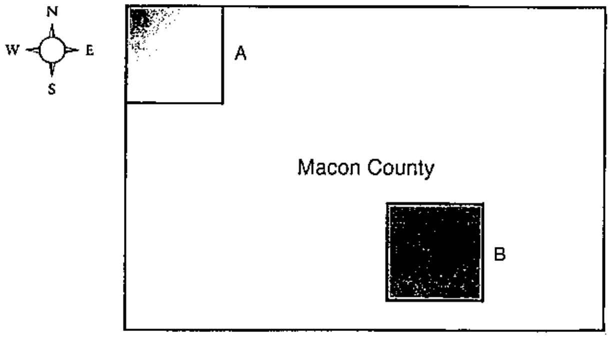


**Figure 6.4** Two fields with Bt test results in Macon County. Gray indicates the presence of *Bt* genes in the field. The more corn that tested positive for *Bt* genes, the darker the gray scale.

5. Which field results would tend to support Emmet's explanation? Why?

6. Draw a new rectangle to represent field C with results that would support Sam's hypothesis. Explain the significance of the pattern of *Bt* genes in your sketch.

**B. The Economics of *Bt* Corn.** The seed for *Bt* corn hybrids costs approximately $14 more per bag than the seed for conventional corn hybrids. This "biotechnology premium" varies from year to year and depends on the type of transgenic seed purchased. The following table describes the potential savings (or losses) of using *Bt* corn under various levels of corn borer populations and corn pricing.

1. Using Table 6.1, estimate the net loss or net gain for a farmer with 2,000 acres in the following scenarios.
   a. Corn prices are low ($1.50) and so are the corn borer populations (about 1 for every 4 corn plants, or 0.25).

## Table 6.1 Potential Savings (or Loss) per Acre of *Bt* Corn Versus No Corn Borer Control[1]

| **Average Number of Borers/Plant[2]** | **Corn Price per Bushel** | | | |
|---|---|---|---|---|
| | **$1.50** | **$2.00** | **$2.50** | **$3.00** |
| 0.00 | ($4.55) | ($4.55) | ($4.55) | ($4.55) |
| 0.25 | ($1.99) | ($1.13) | ($0.27) | $0.58 |
| 0.50 | $0.58 | $2.29 | $4.00 | $5.71 |
| 1.00 | $5.71 | $9.13 | $12.55 | $15.97 |
| 1.50 | $10.84 | $15.97 | $21.10 | $26.23 |
| 2.00 | $15.97 | $22.81 | $29.65 | $36.49 |

[1] This table assumes: a yield potential of 144 bushel per acre; *Bt* corn costs $14 extra per bag; a seeding rate of 26,000/acre.

[2] The number of corn borers that would complete development in a non-*Bt* hybrid.

b. Corn prices are high ($2.50) and so are the corn borer population sizes (about 1 for every plant, or 1.00).

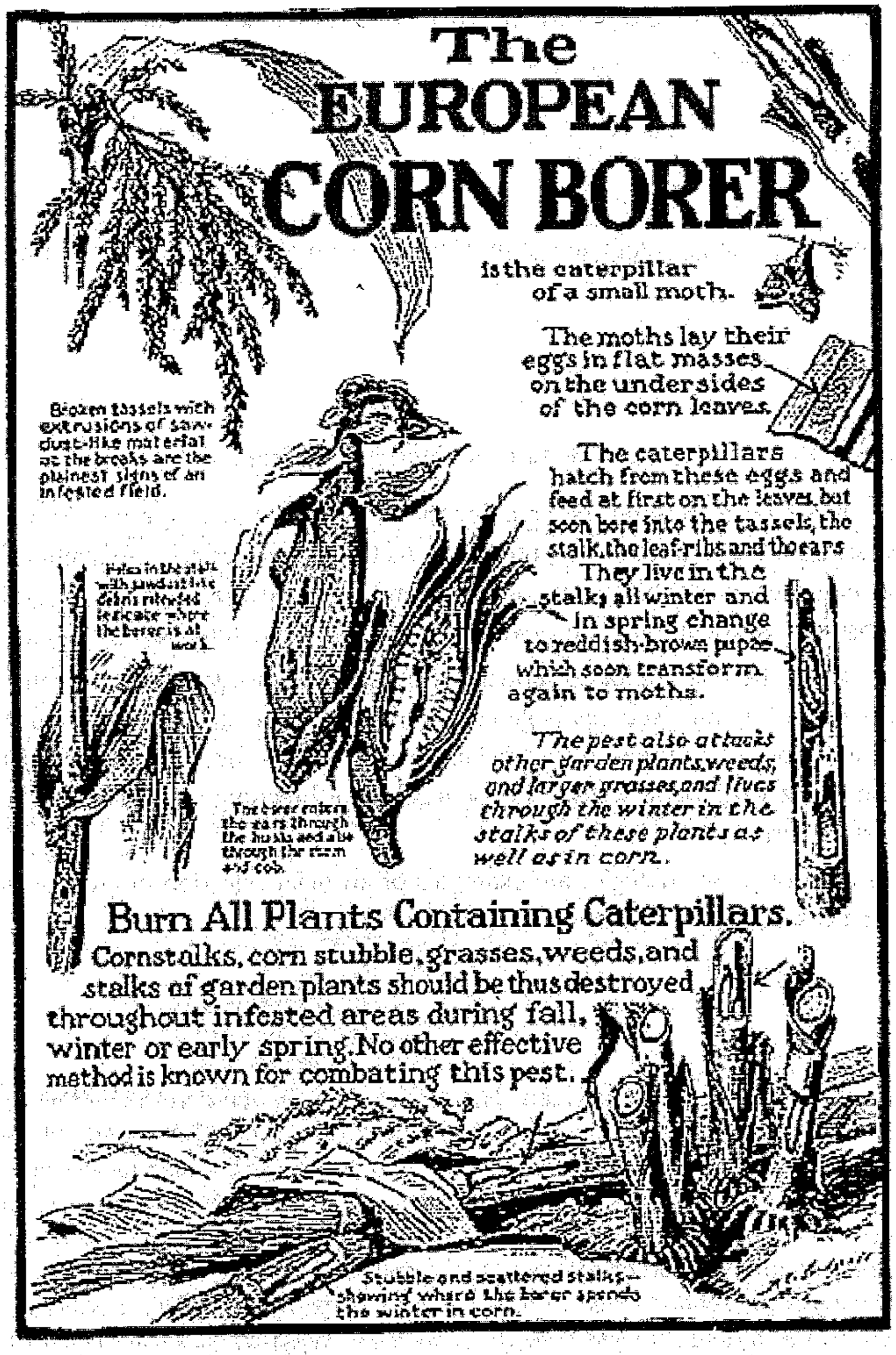
2. What other factors might enter into a grower's decision about whether to plant *Bt* corn?

### C. Simulations: Hybridization and Genetic Engineering of Crops

1. *Bt* corn is made by replicating the gene for the *Bt* toxin found in the bacterium *Bacillus thuringiensis* and inserting the gene into corn. Techniques described in Chapter 20 enable the plant engineer to identify plants that have incorporated the *Bt* gene. Go to the Case Book website to run a simulation for engineering transgenic tomatoes.
2. Figure 38.16 in the text compares modern corn with its ancestral plant, teosinte. Neolithic farmers selected for traits such as large cobs and kernel size as well as a tough husk encasing the entire cob. Over time, this artificial selection led to the development of modern maize. Go to the Case Book website to use a selective breeding simulation for engineering bigger, better corn.
3. Although both of these strategies are examples of artificial selection of crop plants, describe two differences between these approaches.

**D. Alternatives for Controlling European Corn Borers.** The European corn borer (ECB) was introduced into the United States in the early 1900s, most likely arriving with imported European plant products. Without predators to keep the population in check, ECBs spread rapidly. In most of the United States this moth produces multiple generations in a single year. Various environmental factors influence the population sizes from year to year. Isolating infested fields and burning the plant material was the only method of control until the mid-1920s (Figure 6.5) when the bacterium *Bacillus thuringiensis* was discovered to have pesticidal properties. By 1930, growers were spraying their crops with a mixture containing live *B. thuringiensis,* which was effective against ECB for as long as the pesticide-producing bacteria survived—several days at most. Although chemical pesticides became widely available after World War II, the majority of growers continued to use the *B. thuringiensis* mixture.

1. Many farmers growing corn using conventional methods still choose to apply *B. thuringiensis* sprays. What are the advantages of this strategy for controlling ECB?



The EUROPEAN CORN BORER

is the caterpillar of a small moth.

The moths lay their eggs in flat masses on the undersides of the corn leaves.

The caterpillars hatch from these eggs and feed at first on the leaves, but soon bore into the tassels, the stalk, the leaf-ribs and the ears. They live in the stalks all winter and in spring change to reddish-brown pupae which soon transform again to moths.

*The pest also attacks other garden plants, weeds, and larger grasses, and lives through the winter in the stalks of these plants as well as in corn.*

Broken tassels with extrusions of saw-dust-like material at the breaks are the plainest signs of an infested field.

Holes in the stalk with sawdust-like debris extruded indicate where the borer is at work.

The borer enters the ears through the husks and also through the stem and cob.

**Burn All Plants Containing Caterpillars.**

Cornstalks, corn stubble, grasses, weeds, and stalks of garden plants should be thus destroyed throughout infested areas during fall, winter or early spring. No other effective method is known for combating this pest.

Stubble and scattered stalks — showing where the borer spends the winter in corn.

**Figure 6.5** In 1919, the only method of controlling corn borers was crop destruction.

2. What are the disadvantages of applying sprays?

## III. Investigating Corn Morphology and Growth with a Model of Insect Damage

**A. Corn Morphology.** Maize is a member of the grass family. As you may recall from Chapter 35, grasses contain meristematic tissue in each node along the length of their shoots as well as in a basal meristem. Although most other plants produce new growth from apical meristems, grass leaves and shoots grow up from the base. Mowing is the equivalent of a "haircut" for grasses, which grow back quickly. Nongrass plants recover from mowing much more slowly, because new apical meristems must form.

1. How does this type of growth in the leaves help grasses survive being eaten by herbivores such as bison?

2. When corn is infested with ECB, several types of damage can occur. Late-season borers may invade the corn ears. Not only does this result in an unsightly appearance and decrease in yield, but the damaged sites are also likely to be colonized by bacteria and fungi. Production of toxic by-products from certain species of fungi such as aflatoxin can result in the entire crop being rejected at the mill.

   Another kind of damage occurs when ECBs tunnel into the solid stalks and create hollow spaces that weaken the plant, which may collapse. Like the damaged ears, damaged stems are also inviting to bacteria and fungi.

   Considering what you have learned about stem structure and function, describe an additional problem that is likely to result from ECB stem tunneling.

   To get a better understanding of the structure and growth of grasses like corn, we will study yet a different type of damage from the ECB, called "shot holes."

3. Using Figure 6.6, note the position of each leaf and fill in Table 6.2. Row D is filled in for you.

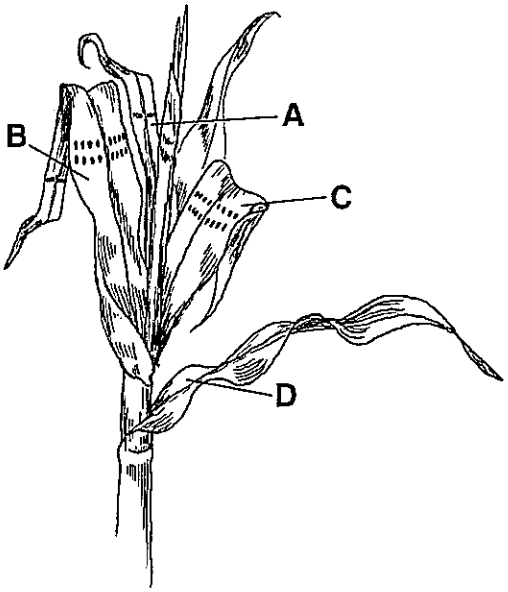


**Figure 6.6** A corn plant with early-season damage from European corn borers.

## Table 6.2 Damage Done to the Leaves by Corn Borers

| Leaf | Damage | Comparative Age |
|---|---|---|
| A | | |
| B | | |
| C | | |
| D | None observed | Older than A, B, and C |

When the ECB caterpillars first emerge, corn is in an early stage of growth that farmers describe as the *whorl* stage. The new leaves are tightly wrapped around each other at first. Then, as the stem elongates, they separate. The leaves dramatically expand as their cells mature and elongate.

4. Do you think that the damage in Figure 6.6 was caused by several caterpillars feeding on the leaves successively or by one or two feeding at the same time? Explain.

**B. Making a Model of Shot Hole Damage to Explore Growth.** Models are often useful in exploring complex phenomena by limiting the number of factors involved. Models allow us to simulate interactions, test hypotheses, and ask new questions.

To examine the cause of shot hole damage, you need to first construct a physical model of a young corn plant in whorl stage with three leaves. Then use this model to simulate the feeding activity of corn borers. You need a sheet of ruled notebook paper (8½″ × 11″), a ruler, scissors, a writing instrument, and a straight pin.

### Part 1: Making the Leaves

Step 1: With the pen or pencil, draw a vertical line at 4 inches and another at 7 inches from the left edge of the paper (Figure 6.7a).

Step 2: Cut the paper lengthwise along the two lines you have drawn so that you have three vertical strips to represent three leaves (Figure 6.7b).

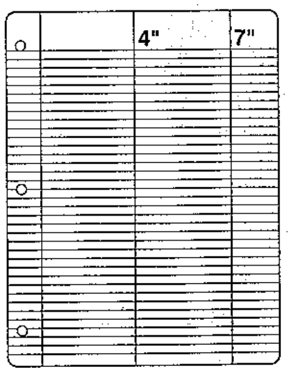


**Figure 6.7a**

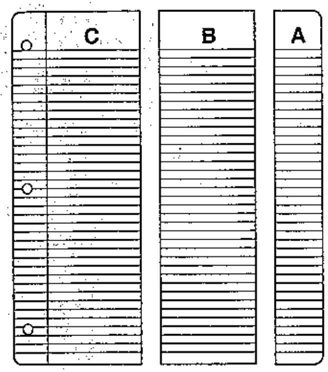


**Figure 6.7b**

Step 3: Mark the top of the thinnest strip as leaf A, the next widest as leaf B, and the widest as leaf C.

### Part 2: Modeling the Age of the Leaves

Step 1: Mark leaf A 10 lines from the bottom (Figure 6.7c). Roll the strip tightly from the bottom until you reach the 10-line mark. Press firmly to fold the rolled paper in place. Leaf A is the youngest leaf. It is the thinnest and the shortest. Much of its maturation and elongation has not occurred.

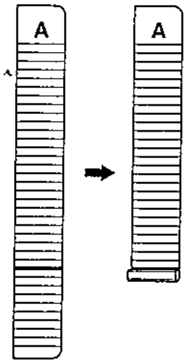


Figure 6.7c

Step 2: Mark leaf B at 5 lines from the bottom. Repeat the roll-and-fold process from step 1. Leaf B is the middle leaf and should be longer and wider than leaf A.

Step 3: Leaf C does not require folding. Leaf C is the oldest leaf and should be the widest and longest. It has completed most of its maturation and elongation.

### Part 3: Assembling the Whorl

Step 1: Mark leaf C in the center of the strip 5 lines from the bottom. Label this mark "node 1." Mark leaf B in the center of the strip at 5 lines from the bottom. Label this mark "node 2" (Figure 6.7d).

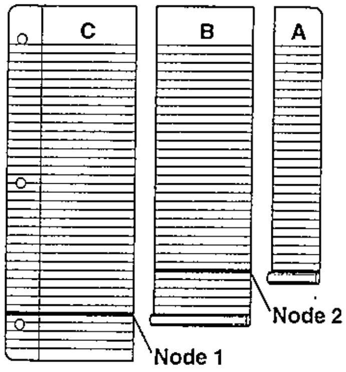


Figure 6.7d

Step 2: Take the folded leaf B and center its base on node 1. Take the folded leaf A and center its base on node 2. The three leaves should now be stacked (Figure 6.7e).

Step 3: Carefully keep the three strips in place (you could use a small piece of tape to secure leaf B and leaf A) as you roll the leaves as one unit from the side around your writing instrument.

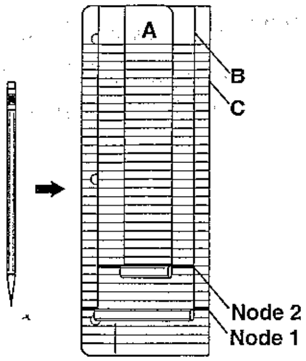


**Figure 6.7e**

Step 4: Carefully ease out the pencil by pulling it from the center while firmly holding the strips. Then flatten the roll of strips lengthwise for easier handling.

### Part 4: Simulating the Corn Borer Damage

Step 1: The resulting model of a corn plant whorl should look tubelike. If you feel along the tube, there will be a noticeable thickening where leaf B begins and another where leaf A begins. These represent nodes on the stem, where the meristems that produce the leaves are located.

Step 2: Locate the flattened area between the node for leaf B and the node for leaf A 2.5 inches or so from the bottom. Take the pin and push it once through the whorl at this location. This simulates the path a borer makes while eating, or "boring," its way straight through the leaves.

Step 3: Locate the flattened area above the node for leaf A 3.5 inches or so from the bottom. Take the pin and push it once through the whorl at this location. This simulates a new path the same borer or a second borer makes while eating its way straight through the leaves.

### Part 5: Modeling Growth After the Damage

Step 1: Unroll the model of the damaged whorl and separate leaf A from leaf B and leaf B from leaf C.

Step 2: Unroll the shortened strips of leaf A and leaf B. Carefully replace or reattach the bottom of the unrolled leaves to the nodes that they were attached to before you unrolled them. This repositioning of the leaves models the elongation of both the stem and the leaves during normal growth.

1. Describe the pattern of damage you see on the leaves by filling in Table 6.3.

## Table 6.3 Pattern of Damage Seen in Simulated Borer Activity

| Leaf | Damage |
|---|---|
| A | |
| B | |
| C | |

2. Look again at Figure 6.6 of shot hole damage. Are your model results consistent with this picture?

3. What do you consider to be the limitations of this model of corn growth?

4. What do you consider to be the strengths of this model of corn growth?

5. Do you think making a physical model was helpful in understanding this pattern of damage by European corn borers? Explain.

## IV. Refuges for Resistance Management

In the case, we saw that the farmers were going to discuss planting refuges for the European corn borer (ECB). The Environmental Protection Agency requires every grower who plants *Bt* corn to use a refuge so that some *Bt*-susceptible corn borers will survive. When *Bt*-susceptible corn borer moths mature, they are available in adequate numbers to mate with any rare *Bt*-resistant corn borer moth that survives in the *Bt* corn. The eggs produced from these matings are more likely to contain embryos that possess susceptibility genes to *Bt* toxin. In this way, refuges help maintain the gene frequencies for susceptibility in the ECB population and overcome the *Bt*-resistance selection effects found in the *Bt* cornfields. Although resistant populations of ECB are quite likely to develop in the future, the purpose of the refuges is to slow this process. (*Note:* You may wish to use the Hardy-Weinberg equilibrium model to look at the effect of migration on gene frequencies to justify the refuge concept. See the Investigation on the Campbell website in Chapter 23, *How Can Frequency of Alleles Be Calculated?*)

1. In the case, the growers meet to discuss planting refuges in order to reduce the chance that a population of corn borers resistant to *Bt* toxin will become established. Offer two explanations why the development of resistant bacteria is more difficult to control than the development of resistant corn borers. (Hint: See the heading “R Plasmids and Antibiotic Resistance” in Concept 27.2.)

2. All the refuge plans shown in Figure 6.8 provide an interface between *Bt* and non-*Bt* corn. Do you think the block refuge or the split planter refuge would be more likely to facilitate the opportunity for a rare *Bt*-resistant corn borer moth to mate with a moth that isn't *Bt*-resistant? Explain.

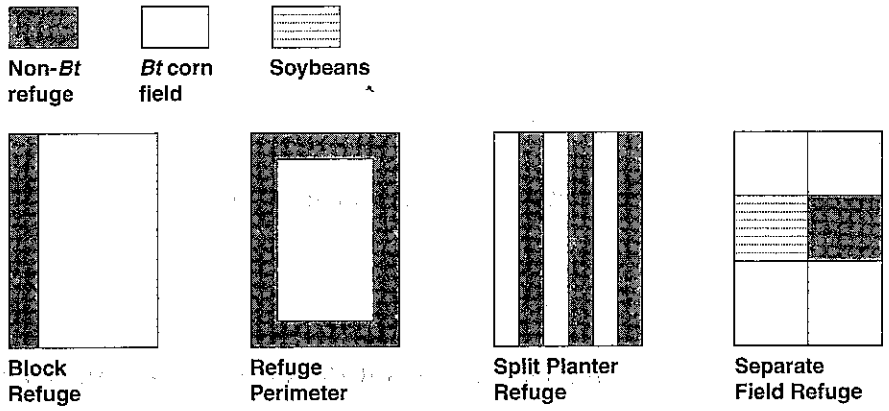


**Figure 6.8** Several options for planting refuges. Federal guidelines call for refuges to constitute at least 20% of field space.

# Additional Investigation

## V. Making Decisions About DNA Technology: Golden Rice

1. Complete the Web/CD Activity: Making Decisions About DNA Technology in Chapter 38. This activity raises a concern that transgenic crops may reduce biodiversity. In your own words, explain how this might occur and why it is significant.

2. Consider your explanation above. Do these risks only apply to transgenic seeds, or is this also true of the hybrid seed that farmers have been using for many years?

3. In developing nations, farmers generally depend on crops that produce both food and seed. Develop arguments both for and against the distribution of *Bt* corn seed to farmers in developing nations. Is a growing reliance on seed companies problematic, or do the benefits outweigh the risks?

   Before you answer this question, consider reading the following two position papers from *Action Bioscience* on the Case Book website:

   "The Ecological Impacts of Agricultural Biotechnology" by Miguel A. Altieri, February 2001.

   "Biotechnology and the Green Revolution," interview with Norman Borlaug, November 2002.

## VI. Open-Ended Investigations

A gene from Antarctic fish that allows the fish to avoid freezing has been put into tomatoes. These tomatoes also survive hard frosts.

Find another gene that might be valuable for crop management, enhanced growth, or nutritional quality and tell why. Identify the source of the gene and the target crop.