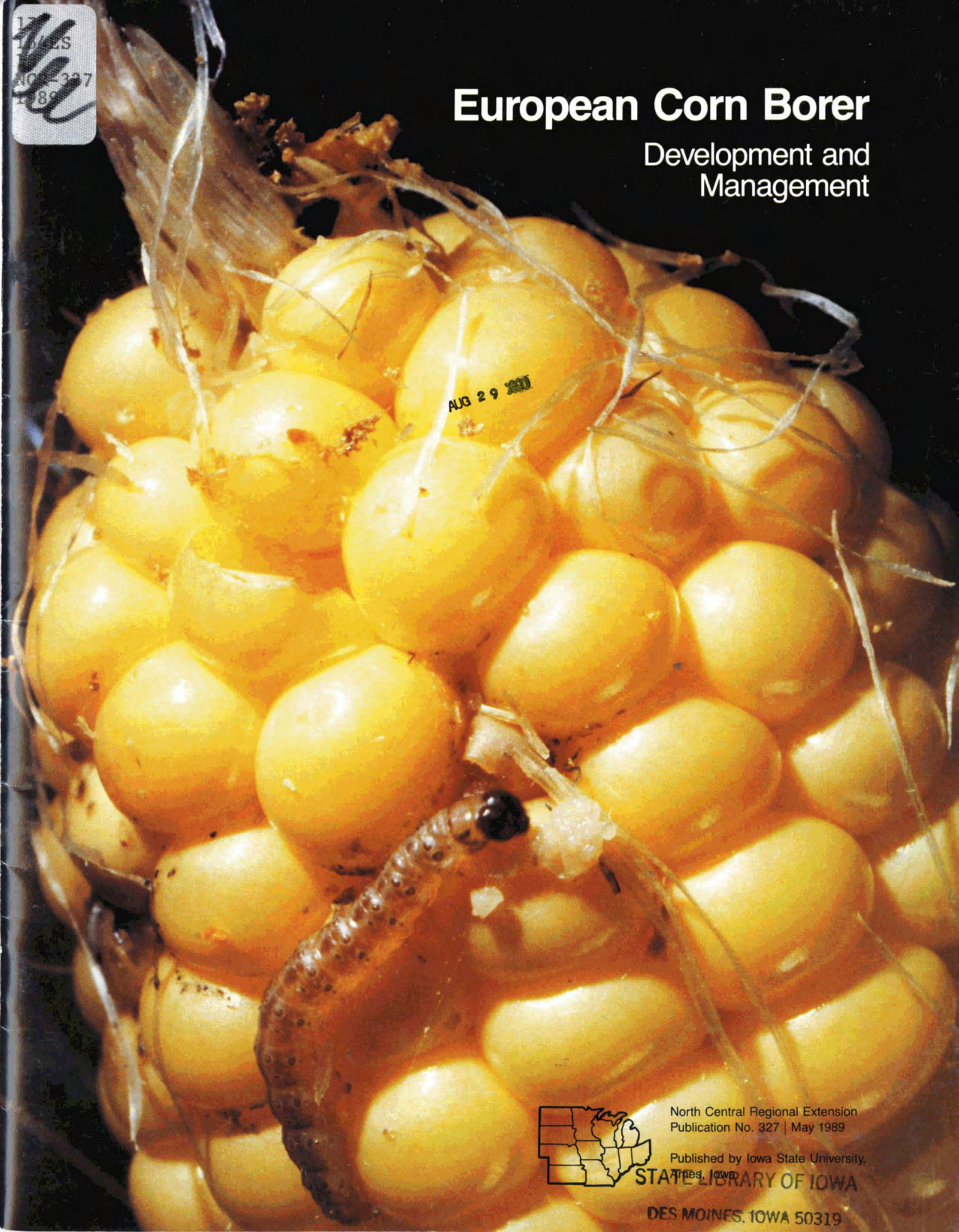

European Corn Borer

Development and Management

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In recognition of his numerous contributions to insect ecology, the authors affectionately dedicate this interregional bulletin to Dr. Huai C. Chiang, emeritus lifetime member, NC-180 Research Committee.

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[1]North Central Regional Project NC-180; Impact of Integrated Crop Management Practices on European Corn Borer and Related Stalk-boring Insects. Interregional Committee as of June, 1987.

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Introduction

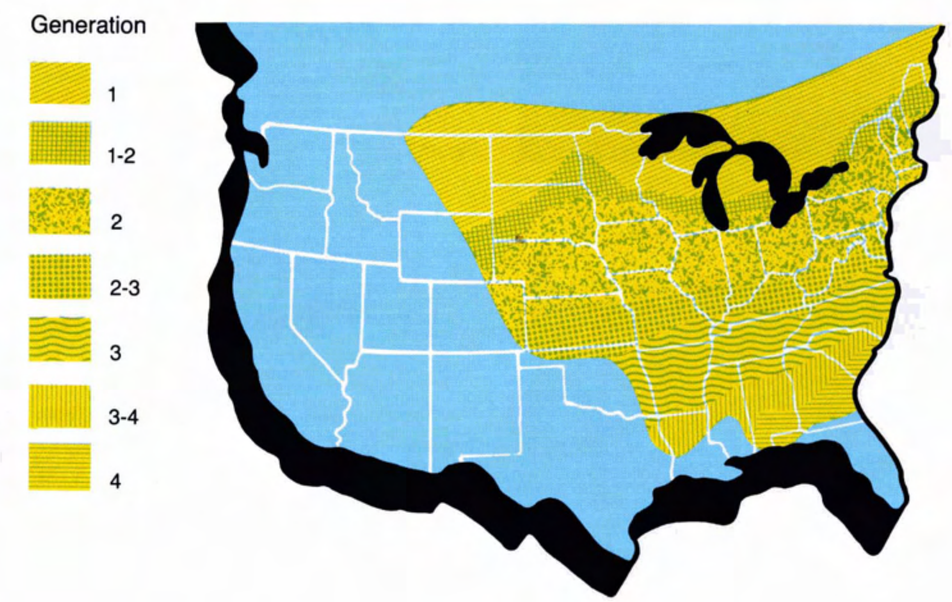
The European corn borer (ECB), *Ostrinia nubilalis* (Hübner), significantly affects production of *Zea mays* L. (field corn, popcorn, and sweet corn), as well as other commercial host plant species including sorghum, cotton, and many vegetables.

European corn borer is an introduced insect species that belongs to the order Lepidoptera. It came to North America during the early 1900s, possibly in broom corn imported from central Europe. It was first found in the north central states in 1921. It spread slowly from southern Michigan and northern Ohio. By the end of 1938, it was only as far west as the Wisconsin shore of Lake Michigan.

During most of this early history, the insect had one generation per year. In the late 1930s, a two-generation per year population began to appear in the north central states. This two-generation per year borer spread rapidly and soon became dominant in the region. It reached Illinois in 1939, Iowa in 1942, Nebraska in 1944, and South Dakota in 1946. Meanwhile, the single-generation borer spread northward into northern Minnesota, North Dakota, and the Canadian provinces of Quebec, Manitoba, and Saskatchewan.

Three- and four-generation per year populations of European corn borer dispersed southward along the Atlantic Coast and southwestward into Missouri, Arkansas, Kansas, Oklahoma, and the Gulf states. Figure 1 shows the approximate current range of the European corn borer in the United States and Canada.

Figure 1. Approximate distribution of generations of European corn borer in the United States and Canada.



The Insect

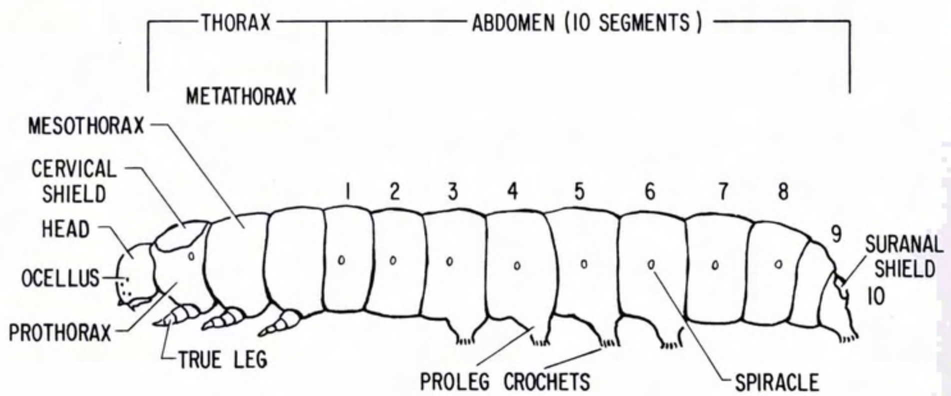
Identification

Several species of caterpillars (larvae) commonly found in the southern and western portions of the north central states might be confused with the European corn borer. Occasionally these caterpillars are found in the northern portion of the region. Important characteristics are illustrated in a simple key developed to assist with field identification (table 1).

Table 1. A simple key for identifying some common late-instar caterpillars found on corn. (G. L. Godfrey, Illinois Natural History Survey, University of Illinois)

1. Prolegs on abdominal segments 3, 4, 5, 6, and 10 (anal) (figure A) go to . . . 2
 - Fully developed prolegs present only on abdominal segments 5, 6, and 10 (figure B), or on 6 and 10 (figure C) . . . semiloopers or loopers

Figure A.



Fibure B.

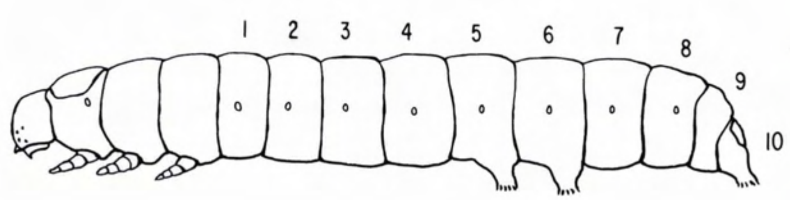
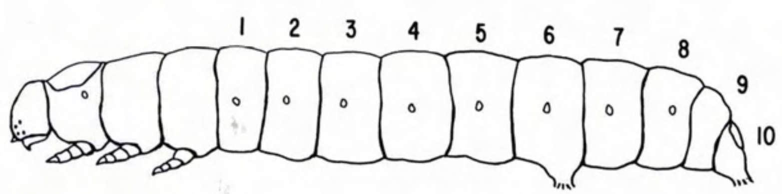


Figure C.



Figures A, B, C, H, I, J, L, M, P, R, U, and W, G. L. Hedburg, illustrator, National Animal Disease Center, USDA-ARS, Ames, Iowa; figures D, K_1, K_2, Q, T, V, and X, Dr. R. G. Weber, entomologist, Department of Entomology and Applied Ecology, University of Delaware, Newark, Del.; figures G, N, O, and T, Dr. G. L. Godfrey, associate professor, figure E, Dr. D. E. Kuhlman, professor, figure F, W. D. Zehr, photographer and figure S, C. MacMonegle, assistant scientist, all of the Illinois Natural History Survey, University of Illinois, Champaign, Ill.; figure Y, Dr. T. O. Holtzer, associate professor, Department of Entomology, University of Nebraska, Lincoln, Neb.

2. Body without obvious, dense, "hair-like" covering (figure D) go to . . . 3
 - Body obviously "hairy" (figures E, F, G) . . . woollyworms, cattail caterpillar, io moth caterpillar

Figure D.

Figure E.

Figure F.

Figure G.

3. Crochets (minute hooks) on end of prolegs 3, 4, 5, and 6 form circle or nearly complete circle (figures H, I) go to . . . 4
 - Crochets on end of prolegs 3, 4, 5, and 6 form straight line or arc of less than 270° (figure J) go to . . . 6

Figure H.

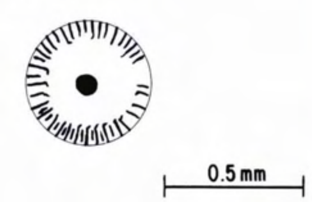


Figure I.

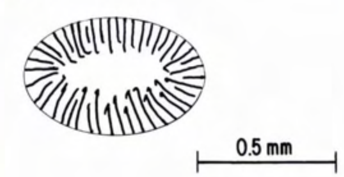
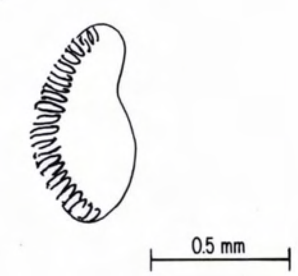


Figure J.



4. Black central dots in tips of fully extended prolegs on abdominal segments 3 through 6 (figure H), visible at 10 power, body pale brown or pinkish gray with dark gray middorsal line on abdominal segments (figure D) . . . European corn borer
 - No black central dots in tips of fully extended prolegs on abdominal segments 3 through 6 (figure I); body off-white go to . . . 5

5. Body with large, black tubercles (figure K_1) . . . southwestern corn borer (summer form)
 - Body with pale brown tubercles or tubercles inconspicuous (figure K_2) . . . southwestern corn borer (winter form)

Figure K_1.

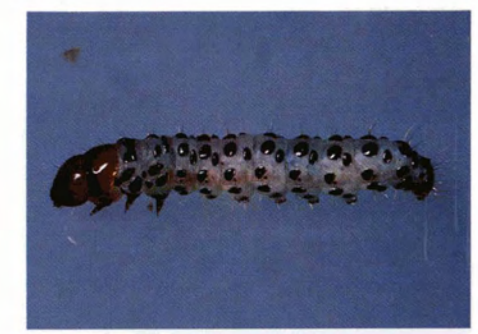
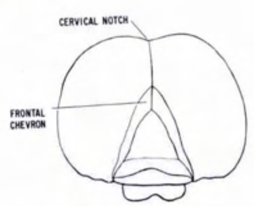


Figure K_2.

6. Tip of chevron mark (Λ) on head usually reaching cervical notch (figure L) . . . subterranean cutworms (black, claybacked, dingy, sandhill)
- Tip of chevron mark (Λ) on head usually not reaching cervical notch (figure M) go to . . . 7

Figure L.

Figure M.

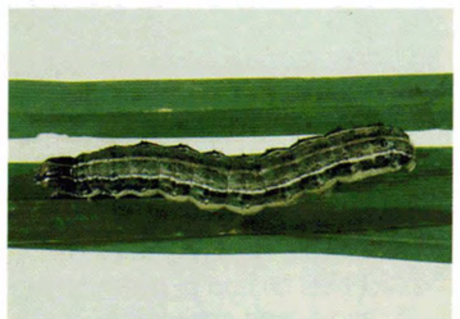


7. Body gray or black, marked with distinct yellow stripes along each side of back (figure N) . . . yellow-striped armyworm
- No distinct yellow stripes along sides of back go to . . . 8

Figure N.

8. Distinct white or pale yellow, middorsal dots on anterior abdominal segments (figure O) . . . variegated cutworm
- No distinct middorsal dots on abdominal segments go to . . . 9

Figure O.



9. Body covered with spinules (figure P) visible at 10 power, body surface mat-like (figure Q) . . . corn earworm
- Body not covered with spinules, appearing smooth or glossy go to . . . 10

Figure P.

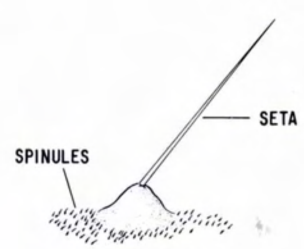
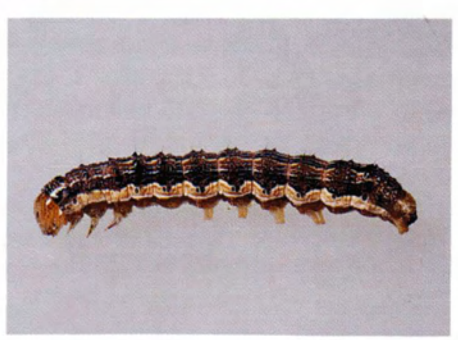


Figure Q.



10. Black bar on side of head (figure R); body purple or lavender with white longitudinal lines (figure S) . . . stalk borer
- Head and body not marked as above go to . . . 11

Figure R.

Figure S.

11. Head orange-brown, lacking black side bar; patches on back and sides of body appear to form pale lavender band across the back of each segment (figure T); feed on plant roots and plant crowns . . . hop vine borer
- Head and body not marked as above; feed on other plant parts go to . . . 12

Figure T.

12. Cutting edge of mandible smooth or with 2 medial teeth (figure U); larva as in figure V . . . armyworm
- Cutting edge of mandible with more than 2 teeth (figure W) go to . . . 13

Figure U.

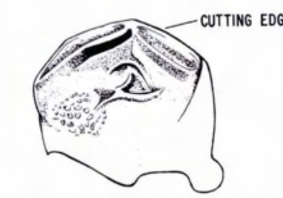
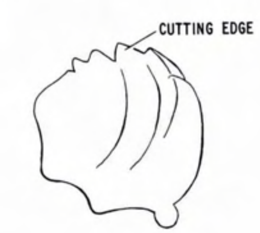


Figure V.

Figure W.



13. Head with contrasting white to cream, frontal chevron mark (figure M); distinct hairs on back of body arise from dark tubercles (figure X) . . . fall armyworm
- Head lacking contrasting white, frontal chevron mark; hairs and tubercles on body inconspicuous (figure Y) . . . western bean cutworm

Figure X.

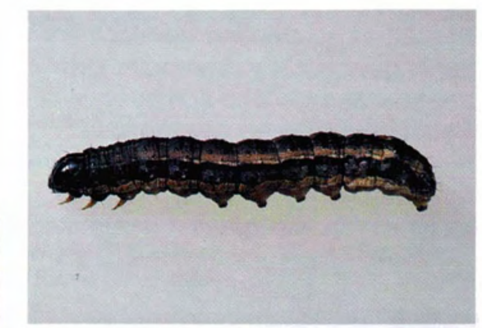


Figure Y.

Life Cycle and Generational Ecotypes

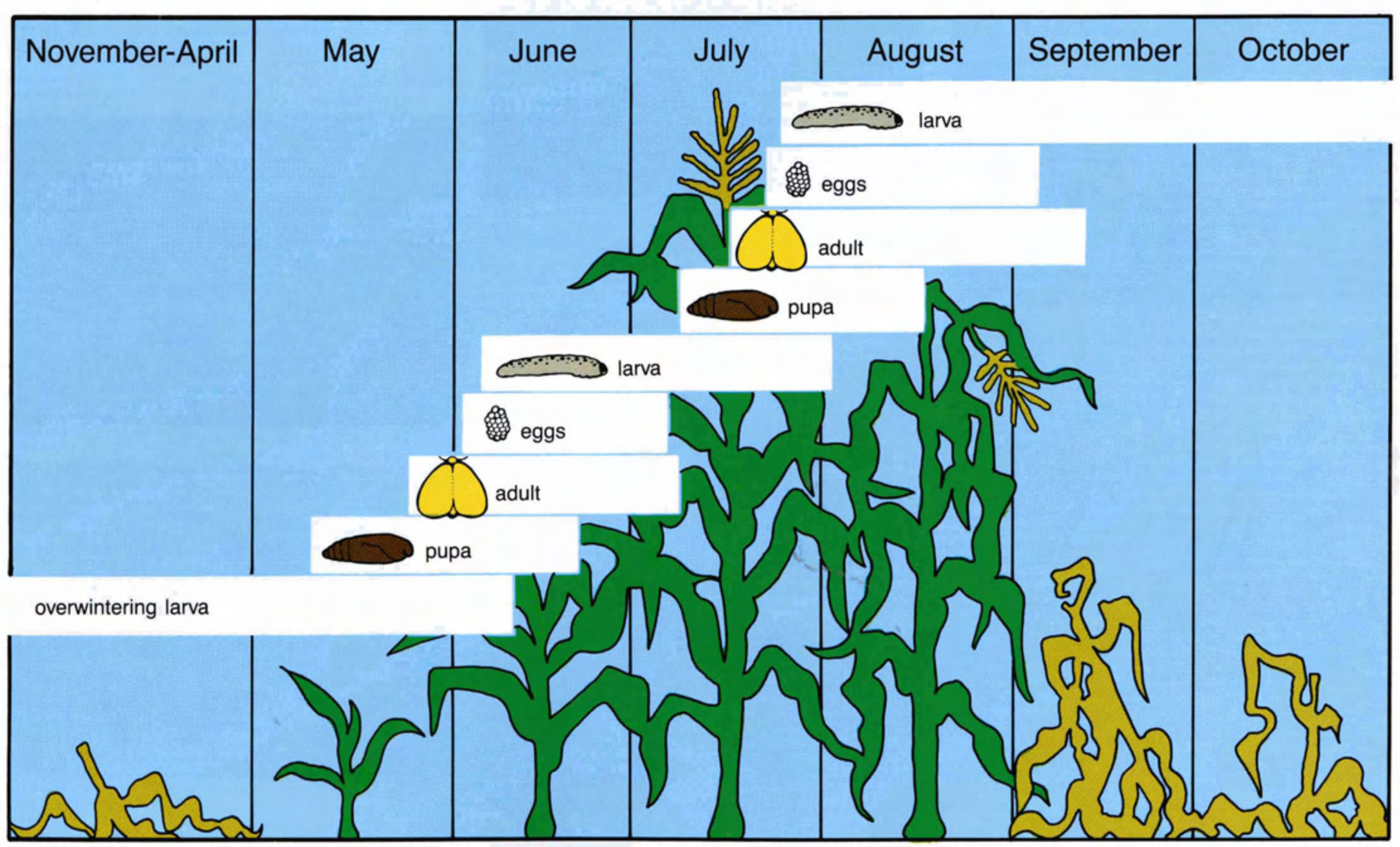
During its lifetime, the ECB goes through four stages of development (figure 2): egg, larva (borer), pupa (transition stage), and moth. The succession of these four stages constitutes a generation. The larva goes through five stadia of growth (first through fifth instar). During the fifth instar, all individuals either prepare to pupate and become adults (moths) or enter diapause. Diapause is a physiological condition expressed as suspended development that is governed by daylength, temperature, and genetic composition of a population. Based on diapause, the borer populations of North America have been partitioned into three ecotypes (an ecotype is a group of populations with most individual insects having similar environmental tolerances): northern (one generation per year), central (two generations per year), and southern (three or more generations per year).

Beginning midsummer to autumn, daylengths shorten and temperatures begin to cool. These environmental changes trigger one or more genes sex-linked to the male that allow the larval portion of the population to go into diapause, thus preparing the population for survival during the cold winter. The more heat-sensitive ECB populations of the southern portions of North America are less affected by shorter daylengths and cooler temperatures than their northern counterparts; so, more generations are completed by members of the southern ecotype before diapause begins.

The species passes the winter as full-grown larvae (figure 2) in cornstalks, corn cobs, weed stems, or spun up in other cornfield debris. Surviving, or overwintering, ECB become active in April or May in the central Corn Belt and begin development as outlined in figure 2.

Spring development of the European corn borer begins when temperatures exceed 50°F (10°C). During the 1950s, researchers began predicting the biological events of ECB by using accumulated temperature units called degree-days. Accumulations were arbitrarily started after January 1 of each year whenever 50°F (10°C) occurred. However, because of population diversity and environmental factors, these degree-day predictions have not been accurate. Recently, researchers began the degree-day accumulations with the capture of the first spring moth in either synthetic pheromone traps or light traps. Predictions of subsequent borer activity based on degree-day accumulation following spring flight have been relatively successful. Table 2 presents the accumulated degree-days using 50°F (10°C) as the threshold temperature after the initial capture of a spring European corn borer moth.

Figure 2. Typical life history of European corn borer in the Corn Belt of the United States.



Degree-days are the number of degrees above the threshold temperature occurring each 24-hour period. A simple way of calculating degree-days follows.

1. (Maximum temperature + minimum temperature) divided by 2 = mean temperature
2. Mean temperature − threshold temperature (50°F or 10°C) = daily degree-days
3. Sum of daily degree-days = accumulated degree-days.

Blacklight traps placed in the field before spring moth emergence during late April (Missouri) to early June (Wisconsin) should capture moths shortly after they begin to emerge. The moths (figure 3) will leave the emergence sites in cornfield debris and fly to patches or strips of dense vegetation, usually grasses, in conservation lanes or near fencerows. The vegetation in these habitats collects rain droplets and retains dew droplets more effectively than do the leaves of corn plants, so the proper microclimate exists for feeding, resting, and mating.

Table 2. Predictions of selected European corn borer activity based on degree-day accumulation following initial capture of spring moths (minimum developmental threshold—50°F [10°C]), begin degree-day accumulation—first significant moth flight).

Degree-days (°F) from event	Stage	Activity
First generation		
0	Spring moth flight[1]	
100	Peak egg hatch	
200+	1st-2nd instar	Leaf feeding
350+	3rd instar	Stalk boring
400+	4th instar	Stalk boring
550+	5th instar	Stalk boring
900+	Pupation	
1150-1700	Adult moths	Egg laying
Second generation		
1260	Peak egg hatch	
1350+	1st instar	Sheath feeding
1500+	2nd instar	Sheath feeding
1600+	3rd instar	Sheath feeding
1650		(initial stalk boring)

[1]Initiate degree-day accumulation when extended corn leaf height is 17 inches (43 cm) or greater.

Once in one of these action sites, the female moths drink rain or dew droplets and begin emitting a sex attractant (pheromone) composed of two isomers of 11-tetradecenyl acetate. This activity usually begins by 10 p.m. and peaks at 1 a.m. The combination of the habitat's microclimate and the emission of pheromone draws large aggregations of European corn borer moths into relatively small areas of dense vegetation.

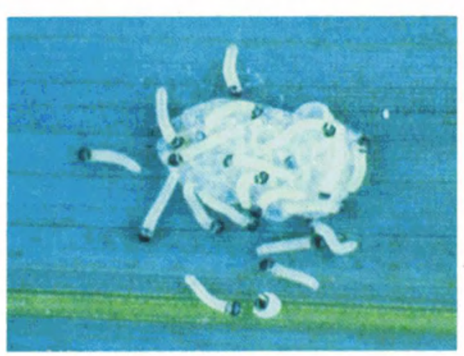
Female moths normally mate when 48 hours old, then leave the action sites to deposit eggs in the target crops. On warm, calm evenings, these egg-laying activities will begin shortly after sundown and cease by midnight. The females will leave the target crop and return to action sites to feed, rest, possibly remate (less than 5 percent), and to await another suitable evening for egg laying.

Figure 3. European corn borer moths: male, left; female, right.

If the target crop is corn, females of the spring flight are attracted to the tallest fields. Egg masses consist of 15 to 30 white eggs (figure 4), overlapping like fish scales, and are normally deposited near the midrib on the underside of corn leaves. Egg masses are flat and approximately ¼ inch (6 millimeters) in diameter. Eggs about to hatch have distinct black centers. This is the black head of the larva visible through the translucent egg shell. The eggs hatch (figure 5) in 3 to 7 days, depending on weather conditions. Each mated female is capable of depositing an average of two egg masses per night for 10 nights. The majority of the masses, however, will be deposited during the first 6 nights after mating.

Figure 4. European corn borer egg masses on underside of a corn leaf.

Figure 5. Recently hatched larvae.

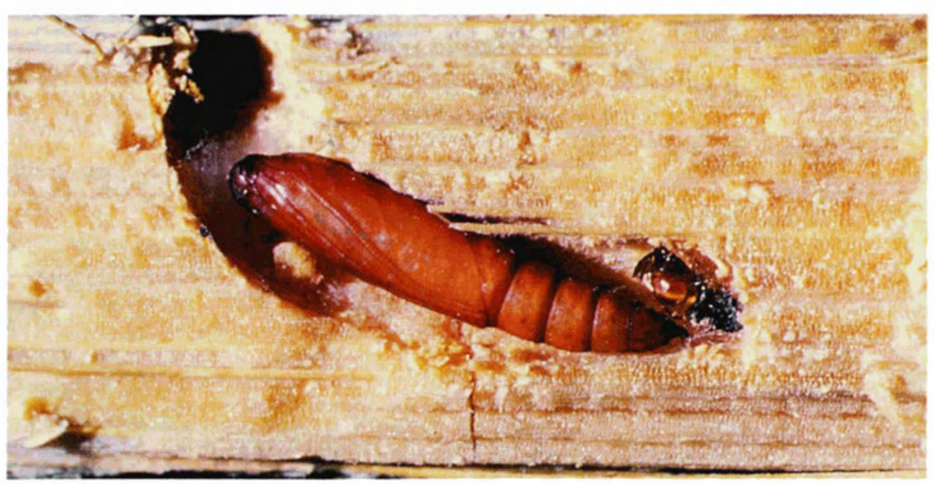


If the corn is small, less than 16-inch (40-centimeter) extended leaf height, when the eggs hatch, most of the small larvae fail to become established because they wander off and die. In many corn hybrids, a primary factor for this behavioral response is a plant aglucone, 2-4 dihydroxy-7-methoxy-1, 4-benzoxazin-3-one (DIMBOA). The concentrations of DIMBOA in a given corn hybrid usually decrease proportionally with plant growth. A greater proportion of larvae survive on corn in mid-to-late whorl stage, 22- to 36-inch (55- to 80-centimeter) extended leaf height. Usually corn plants are mid-to-late-whorl when most of the eggs are deposited during the spring borer flight. But, even in the presence of optimal corn plant stage, temperature-related climatic variables, such as moisture stress and evaporation, will kill 22 to 68 percent of the freshly hatched larvae. Those that live move to the whorl to feed and develop. Eventually, they burrow into the stalk of the corn plant where they change to pupae during the summer (figure 6).

The moths that emerge in midsummer fly to dense vegetation, primarily foxtail grass in the Corn Belt, to feed, rest, and mate. These mated females prefer succulent, recently tasseled corn plants on which to deposit eggs that will produce the second generation of European corn borer. If corn plants in commercial vegetable areas have progressed beyond the silking and tasseling stage, the moths will lay eggs on pepper plants or other economically important hosts.

During the silking and tasseling stage of corn growth, 90 percent of the egg masses will be laid on the undersides of the three leaves above the ear, on the ear husk, on the undersides of the ear leaf, and the three leaves below the ear. During this time of year, depending on weather conditions, the eggs will hatch in 3 to 5 days. About 75 percent of the small larvae will move to the leaf axils and the remaining 25 percent to the ear to feed on sheath and collar tissue, or on pollen collected in these sites. Late in summer, particularly in the southern portions of the north central region,

Figure 6. European corn borer pupa in a turgid cornstalk.



second-generation (third flight) moths will deposit eggs that produce a third generation. These eggs will be laid on tasseled corn plants when the kernels of the ears have not matured beyond the milk stage. These ECB (second or third generation) will attain the last larval stage (figure 7), diapause, and spend the winter.

How Corn Is Damaged by the European Corn Borer

Bear in mind that yield losses from both first- and second-generation borers are primarily because of physiological losses rather than ear droppage. The corn plants fail to yield well as a result of corn borer damage. Hybrids with resistance to the first generation (leaf-feeding resistance) can reduce the amount of loss; but, to date, these hybrids do not have the yield potential of more susceptible hybrids. Full-season hybrids tend to be more susceptible to the second-generation and third-generation borer; but, they typically have a greater yield potential that compensates for the increased susceptibility. Yield losses during all stages of corn development can be extremely high during severe infestations, especially if damage begins just before the tassel emerges (see Economic Injury Levels).

Damage results from:

1. Leaf feeding (from the first generation);

2. Stalk tunneling (from the first and second generation);

3. Leaf sheath and collar feeding (from the second and third generation); and

4. Ear damage (from the second and third generation).

European corn borer damage results in poor ear development, broken stalks, and dropped ears. The majority of the yield loss is because of the inability of the plants to produce as a result of damage. With persistent autumn winds and dry weather, however, tunneling in the stalks and ear shanks increases stalk breakage and dropped ears, respectively. Recent research has shown there is close association between second- and third-generation ECB infestation and incidence of stalk rot. The disease is caused primarily by two species of fungi, *Fusarium moniliforme* (Sheld) and *Gibberella zene* (Schw.). Corn yield losses from this disease average 4 to 5 percent per rotted internode. Only one ECB egg mass per plant, however, can increase the numbers of rotted internodes by an average of four per plant. This increase in stalk rot is directly related to boring into stalks and ear shanks by ECB larvae. Losses will increase the longer the corn harvest is delayed.

Damage because of direct feeding by ECB on the kernels of the ear in inbred seed cornfields can be significant. This type of feeding on sweet corn is especially important to canners and market gardeners (see Sweet Corn).

Components of Management

Reaching the proper management decision is dependent on many biological and economic factors. The following simple management model is effective. More complex microcomputer-based management models are available from Kansas State or Pennsylvania State Universities.

Researchers from several states, cooperating and coordinating their investigations through NC-180, are rapidly accumulating the data necessary to localize the European corn borer management model. Presently, research is under way to validate the latest ECB management model across the north central region of the United States and in member states outside the region. For more information, acquire a copy of Volume 1, Number 1, of the *NCCI Software Journal;* or, contact a representative of the NC-180, Technical Committee on Stalk-boring Insects (listed on inside front cover).

Figure 7. Fifth-stage European corn borer larva. Ready to spin silk and go into diapause.

Scouting Techniques

Scouting is recommended to assess field populations of pests. The key to good scouting is representative sampling. Where possible, five random samples of 20 consecutive plants should be examined for every 40 to 50 acres (16.2 to 20.2 hectares). Although less precise, as a practical compromise for very large fields, 80 acres (32.4 hectares) or more, growers and consultants may have to limit their surveys to five or more random samples of 25 consecutive plants per field. As sampling intensity decreases, the chances of making a wrong decision increase greatly. Considering the cost of control strategies, if there is any doubt as to the seriousness of the infestation, more samples should be taken.

To eliminate the edge effect, the first sample should be taken after walking 100 feet (30.4 meters) or more into the field. The remaining sample sites should be taken randomly across the entire field, using care to consider all representative topographical, environmental, and cultural features that may influence plant height, plant maturity, and plant density. If more than one variety is planted in the same field, consider each variety as a separate field for scouting purposes.

Treatment guidelines for first-generation ECB are based on whorl feeding (figure 8). Examine plants for fresh whorl feeding and record the number of plants damaged. If the margins of the damaged area are brown to black, then the damage is old. Dissect two infested plants per sample of 20 or 25 plants and look for live borers. It is important to check for live larvae because borer mortality in the first 3 to 5 days following hatch is normally very high. Major causes of mortality in the whorl are adverse environmental conditions (temperatures and moisture) and the resistance of the plant. Table 3 shows a comparison of survival expressed in cavities per plant using a susceptible hybrid (B73 X Mo17) and two hybrids

Table 3. Mean numbers of cavities/plant in 3 varieties of corn at different plant heights 35 days following manual infestation (June 21) of ca. 60 European corn borer larvae/plant. (Concord, Nebraska, 1980 J. F. Witkowski).

Hybrid[1]	Planting date	Extended leaf ht. (in.)	Whorl ht. (in.)	Number of leaves	Cavities per plant[2]
B73 × Mo17	May 1	65	46	12	3.0 a[3]
A619 × A632		64	49	12	1.6 b
A619 × H99		67	67	12	1.4 b
B73 × Mo17	May 15	52	27	10	2.5 a
A619 × A632		49	29	10	1.7 b
A619 × H99		49	28	10	1.3 b
B73 × Mo17	May 30	17	11	6	1.3 a
A619 × A632		19	10	6	1.0 a
A619 × H99		19	12	6	0.9 a

[1]B73 × Mo17 = Susceptible
A619 × A632 = Intermediate resistance
A619 × H99 = Intermediate resistance
[2]Each mean made up of 80 observations (10 plants split per replication × 8 replications).
[3]Means followed by a common letter are not significantly different at the 0.05 level of probability.

Figure 8. Whorl feeding by European corn borer larvae.

Figure 9. Leaf axil feeding by European corn borer larvae.

showing an intermediate level of resistance (A619 X H632 and A632 X H99). Plants were manually infested with first-instar ECB larvae at three different plant heights achieved by planting corn at 2-week intervals in May.

Scouting for first generation should begin when plants with extended leaves are 17 inches (43 centimeters). This normally occurs in middle May in southern Illinois, Kansas, Kentucky, and Missouri, during early June in Delaware, Iowa, northern Illinois, Indiana, Maryland, Nebraska, and Ohio, and mid-June in central Wisconsin, central Michigan, southern Minnesota, southern Ontario, Pennsylvania, and South Dakota. The moths become active in late June to early July in Alberta, Manitoba, northern Minnesota, Quebec, and North Dakota. Consult table 2, which lists degree-day accumulations beginning with the appropriate moth capture during the spring of the year.

Treatment guidelines for second- or third-generation European corn borer in most states have been based on 35 to 50 percent of the plants in the pre- to post-tasseling stage of corn development having an egg mass. Based on model simulations, personnel in Kansas have lowered the threshold to 10 to 20 egg masses per 100 plants. The problem with using a standard economic injury level for ECB across the entire geographic range is that the synchrony of insect and plant development differs between regions and fields. Larvae that initiate feeding earlier in a plant's development have a greater potential to cause yield reduction than those initiating feeding nearer to physiological maturity of the corn plant. Plant developmental stage during ECB egg laying must be known to account for differences in yield loss caused by leaf axil feeding (figure 9) and subsequent stalk boring. This information will result in more economically accurate decisions. Research in Kansas and discussions with specialists in other states indicated that egg laying takes place over a 20-day period, with peak egg deposition 10 days after the first eggs are deposited (figure 10a). If the egg-laying period is approximated as a symmetric 20-day triangle, the entire egg-laying period can be determined by locating initiation of egg laying.

Initiation of egg laying can be determined by observing the date when first moths are collected in a nearby blacklight trap. When a blacklight trap is not available, frequent egg mass sampling (2 to 3 days apart) is necessary. When no other informa-

Figure 10a. The proportion of the total egg complement deposited by the time the sample was taken 8 days after oviposition began.

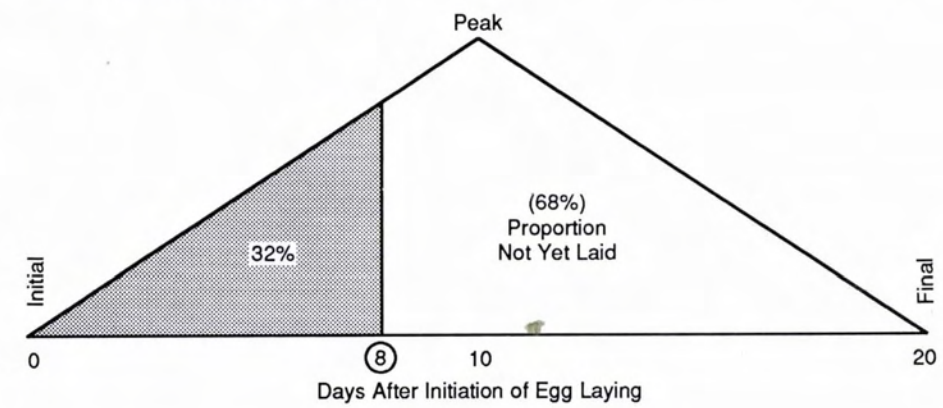
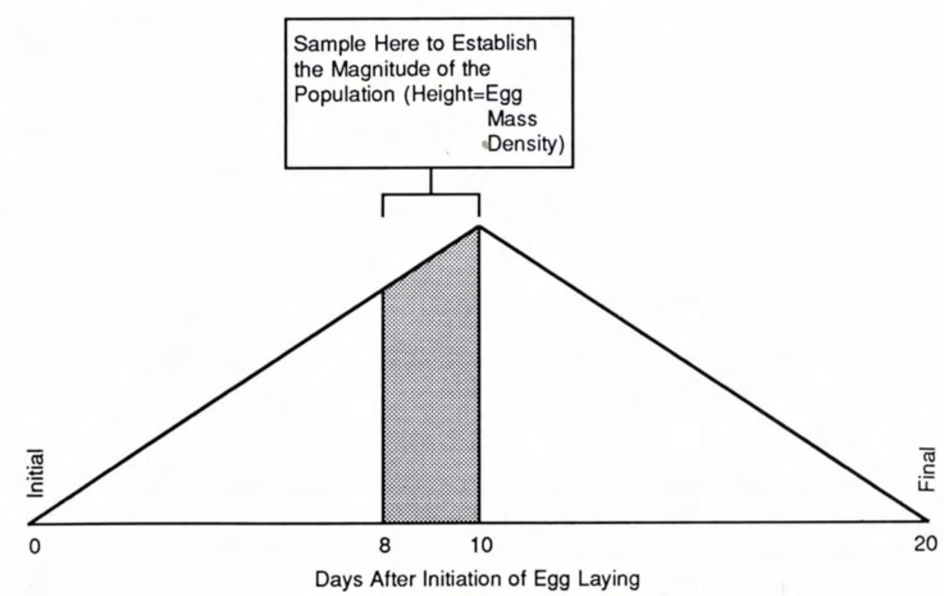


Figure 10b. Key dates that must be established with reasonable certainty to evaluate the seriousness of European corn borer infestations in field corn.



tion is available, begin sampling when the most advanced cornfield in the area has reached the pretassel stage.

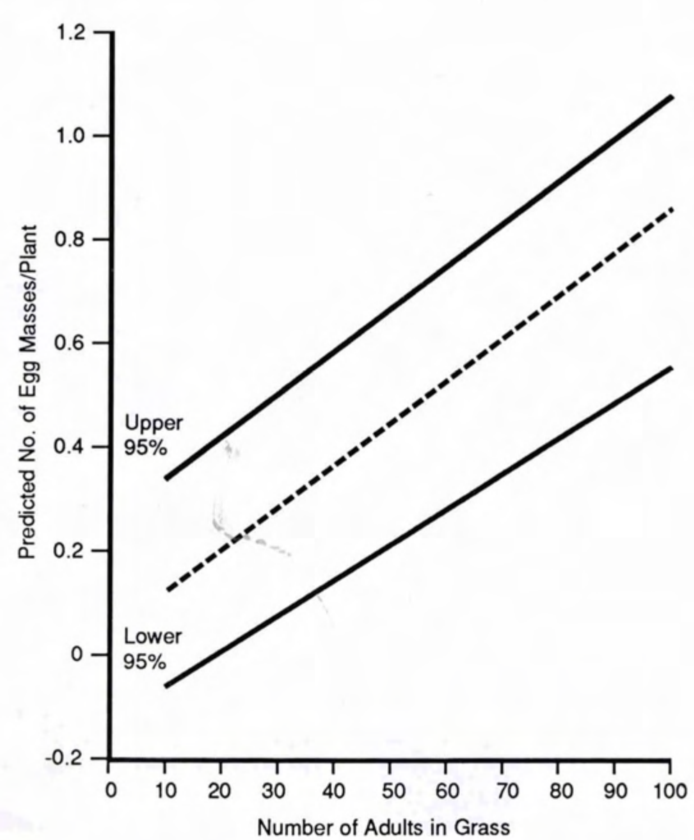
Researchers believe that locating an egg mass is unlikely before 5 percent of the eggs have been deposited in the field. Based on the 20-day symmetric egg-laying period, initiation of egg laying would occur 3 days before detection of the first egg masses if regular intensive sampling has been conducted at 2-day intervals. For example, if the first egg mass was observed on July 4, then egg laying probably was initiated on July 1. Timely sampling will reduce discrepancies between adult flight and egg deposition in nearby fields.

Once the initiation of egg laying has been established, an additional egg mass sample should be taken 8 to 10 days after the initiation of egg laying to determine the density of the egg population (figure 10b). Sampling at this time minimizes sampling errors caused by low egg mass densities and allows time to instigate a control procedure if needed. To determine the egg mass population, the sample should be taken at random.

Research indicates that about 91 percent of the total egg mass complement on 25 consecutive plants at four locations within a field can be accounted for on the middle seven corn leaves (three leaves above and below the ear leaf). These seven leaf samples can be corrected to whole plant samples without loss in the accuracy of the control decision. An estimated whole plant count can be calculated by multiplying the total number of egg masses found on the seven leaf count by 100 and dividing by 91. The resulting full plant egg mass density estimate per 100 plants serves as the egg population input into the ECB management model. For instance, if six egg masses per 100 plants are detected 9 days after egg laying begins, we estimate that 40.5 percent of the eggs have already been laid. A final density of 0.69 larva per plant will develop if insecticides are not used.

Egg mass densities also can be approximated by monitoring moth activity in action sites. Walking through an action site will cause moths to flush. This adult flushing technique is a useful way to determine whether scouting for egg masses should be initiated. Moths may be seen during the early morning by disturbing grassy field margins, weedy fencerows, and unmowed waterways extending through the field. These action sites of dense vegetation are necessary "stopping off" points for female moths before egg deposition begins in the cornfield. Research using a l-meter bar brushed through the grass canopy for 10 meters at several places around field edges, in waterways, and between rows of weedy fields has shown that the number of moths flushed per 10 meters correlates with the number of egg masses deposited on the corn plant (figure 11).

Figure 11. Predicted number of European corn borer egg masses per corn plant, based on number of European corn borer moths per 10 meters of dense grass (M. E. Derrick and W. B. Showers).



Economic Injury Levels, Economic Thresholds, and Reaching a Management Decision

The economic injury level (EIL) is the pest population density at which the value of actual or potential damage equals the cost of preventing the damage (table 4). The economic threshold (ET) is the population density at which control measures should be initiated to prevent the pest density from surpassing the EIL.

To apply EIL and ET to the European corn borer, the concept of a treatment "window" must be introduced and understood. Only larvae that have not bored into the plant can be killed. Consequently, there is a specific time period, or "window," during which pesticides must be applied if they are to be effective. Egg deposition in a given field may last 3 weeks. Available insecticides kill larvae over a relatively short period of time; therefore, they must be applied before all eggs are deposited. If the treatment is delayed, larvae from eggs deposited early in the egg-laying (oviposition) period will succeed in entering the plant. The decision to treat, therefore, should be based on an estimate of the potential European corn borer population density expected to establish within the stalks.

For a single application, an insecticide should be applied from 10 to 14 days after initiation of egg laying, which would be 0 to 4 days after the peak. Two applications are frequently required for suppression of second or third generation populations because timing with one application is seldom perfect. If two applications are used, then the first should be applied at 25 to 30 percent completion of egg laying and the second about 7 days later (see Timing Insecticide Treatment, table 7). Note re-entry restrictions on some pesticide labels that would preclude rescouting the field without adequate protective equipment.

One of the greatest values of the EIL and ET concepts is in monitoring the build-ups of potentially damaging pest populations and reaching a control or management decision before economically important grain yield reductions occur. The ET for first generation ECB in the Corn Belt has been well researched. As a general rule during whorl stage corn growth, there is a 5 percent yield reduction for each of the first three larvae (table 4) that bore into the stalk. When numbers of larvae exceed three per plant, however, the actual loss caused by each additional larva will not be linear. Control measures for ECB vary across the species distribution, but for suppression of ECB during the whorl stage of corn growth granular formulations usually outperform liquids, 80 to 50 percent, respectively. The proportion of ECB population killed (PC) used in the formula for the EIL presented in table 4 is an average (0.67) developed from these percentages.

Table 4. Corn loss caused by European corn borer and calculated economic injury level (EIL) for various corn growth stages (R. A. Higgins, R. E. Lynch, and F. L. Poston).

Plant stage	Loss bu./A (ECB/plant)	% loss (ECB/plant)	Calculated EIL[1] 1 application	Calculated EIL[1] 2 applications
Early whorl	7.7	5.5	1.45	2.90
Late whorl	6.2	4.4	1.81	3.62
Pretassel	9.2	6.6	1.21	2.41
Pollen shedding	6.2	4.4	1.81	3.62
Kernels initiated	4.2	3.0	2.65	5.31

[1]$EIL = \frac{CC}{PL \times MV \times EY \times PC}$

Cost of control (CC) = $16.00/A, 1 application; CC = $32.00/A, 2 applications. Proportion of yield lost per ECB (PL) = based on percentage loss per plant stage (column three). Market value (MV) = $2.00/bu. Expected yield (EY) = 150 bu./A. Proportion of ECB population killed (PC) = 0.67.

Table 5. EIL table.

____________ % of 100 (125) plants infested × ____________ average number larvae per infested plant = ____________ larvae per plant (from checking whorls of 2 plants from each sample site)

____________ larvae per plant × 5% loss per larva = ____________ % yield loss

____________ % yield loss × ____________ expected yield (bushels) = ____________ bushels per acre loss

____________ bushels per acre loss × $ ____________ price per bushel = $ ____________ loss per acre

$ ____________ loss per acre × 67% control (from table 4) = $ ____________ preventable loss per acre

$ ____________ preventable loss per A − $ ____________ cost of control per acre = $ ____________ benefit or loss from treatment

A relatively precise decision-making guide for control of ECB during whorl stage corn now is being used in much of the Corn Belt. To determine the need for treatment after scouting for damaged plants and live larvae, the following must be considered: the cost of treatment, expected yield per acre (hectare), value of the grain, percentage control achieved, potential yield loss, and pest population. These data may be used by calculating an EIL table (table 5).

Treatment guidelines for second- and third-generation European corn borer are frequently made when a predetermined percentage of plants in the pre- and post-tasseling stage of corn development are infested with egg masses. Computer software for a dynamic decision model for second generation European corn borer has recently been developed. Using the same factors that govern calculation of the EIL, both the cost (dollars per acre) of each insecticide application and the benefit (dollars per acre) derived from the control action are calculated and compared to assess the value of insecticide application. Thus, a comparison of dollars spent for larval suppression (cost) and dollars gained by initiating control measures (benefit) can be used to formulate management decisions. Using the model, egg population density is predicted before completion of oviposition and a timely control decision is made using a straightforward cost/benefit analysis.

Control Costs (CC) are calculated using the following equation.

$$CC = NA \times (AC + IC)$$

where:
NA = Number of insecticide applications
AC = Application cost (dollars per acre)
IC = Insecticide cost per application (dollars per acre)

The benefit (B) derived from a control action is calculated as follows.

$$B = PC \times PL \times MV \times EY \times PPD$$

where:
PC = Proportion of the ECB population killed by the insecticide (PC = 1.0 if 100 percent are killed; PC = .80 if 80 percent are killed, etc.)
PL = Proportion of yield lost per borer per plant (table 4) (proportional loss per borer per plant)
MV = Anticipated corn market value in dollars per bushel (dollars per bu)
EY = Expected corn yield in bushels per acre (bushels per acre) without ECB infestation
PPD = Predicted potential ECB population density (ECB per plant)

For the second generation, the following equation is used to calculate the potential population density (PPD) per plant.

$$PPD = \frac{SV \times EPM \times EM}{PO}$$

where:
SV = The average proportion of individuals surviving to cause damage. If no other information is available, based on studies conducted in Kansas and Iowa, a value of 0.2 is recommended. Environmental conditions may warrant research in other regions to establish more appropriate local values.
EPM = Eggs per mass. If more specific local information is not available, suggested value is 23 (eggs per egg mass).
EM = The average number of egg masses per plant, based on the latest scouting reports. Count both hatched and unhatched egg masses (egg masses per plant).
PO = The proportion of the total egg complement deposited by the time the sample egg mass collection (EM) was taken.

Correct estimation of PO is essential to accurately predict the PPD of the ECB. This is necessary to arrive at the proper management decision. To calculate PO, the shape and length of the ECB egg-laying period must be estimated as described in the scouting section (see also the window for second-flight moths, table 2). Assuming that the values presented above for eggs per mass, and length and shape of the oviposition period are reasonable, PO for any sample date during the oviposition period can be calculated. Table 6 is a compilation of estimated PPDs using these assumptions. Columns represent the number of days into the oviposition period that the most recent egg mass sample was taken. Column one depicts the average number of egg masses per plant counted in the sample. Each cell in table 6 is the calculated PPD for a given observed density of egg masses per plant and sample date. For example, if eight egg masses per 100 corn plants (egg mass density = 0.08/plant) were counted 8 days into the oviposition period, the predicted PPD would be 1.16 larvae per plant. The recommended sampling date of egg masses to estimate PPD is from 8 to 10 days after initiation of egg laying (table 6). This allows the user to optimize sampling precision and if needed, still leave time for applying insecticides while larvae are exposed.

The formulae for estimating PO are given so they can easily be programmed on a microcomputer.

Case 1: If the sample date is later than or equal to the termination of oviposition then PO = 1.0.

Case 2: If the egg mass sample date (for density estimation) is earlier than, or equal, to the peak in oviposition and after initiation of oviposition, then $PO = x^2/a(a+b)$.

Case 3: If the egg mass sample date (for density estimation) is later than the peak of oviposition but before the termination of oviposition, then $PO = 1-(a+b-x)^2/b(a+b)$.

where:
x = (Sample date) − (initiation of oviposition date)
a = Days from initiation of oviposition to peak of oviposition
b = Days from peak to termination of oviposition.

Incorrectly defining the oviposition distribution through time has the following effects: shortening the oviposition period from 20 days greatly alters the predicted PPD, lengthening the oviposition period beyond 20 days has only a slight effect on the PPD and accuracy of the final control decision.

The same variables used to calculate the cost per benefit ratio can be used to calculate the EIL for any set of economic and biological conditions. The EIL is calculated using the following equation.

$$EIL = \frac{CC}{PL \times MV \times EY \times PC}$$

All variables are defined as for the cost per benefit approach presented earlier. The EIL is the PPD value when the cost per benefit ratio equals 1.

For example, a field of corn is shedding pollen when the majority of egg masses are deposited. The anticipated yield without European corn borer damage is 150 bushels per acre. Corn has an anticipated market value of $2.50 per bushel and the total control cost for one application is $12.50 per acre. The application is expected to kill 67 percent of the larvae (PC=0.67).

Thus,

$$EIL = \frac{\$12.50}{0.044 \times \$2.50 \times 150 \times 0.67}$$

$$EIL = \frac{\$12.50 \text{ per acre}}{\$11.05 \text{ per acre}}$$

EIL = 1.13 borers per plant at season's end.

Table 6. Predicted potential population densities of ECB larvae for various egg mass densities per whole corn plant (or corrected egg mass densities if 7-leaf count used[1]) collected on different dates during the oviposition period.

Number of egg masses/plant	Days after initiation of egg laying and proportion of egg laying complete (in parentheses)															
	5 (0.125)	6 (0.180)	7 (0.245)	8 (0.320)	9 (0.405)	10 (0.500)	11 (0.595)	12 (0.680)	13 (0.755)	14 (0.820)	15 (0.875)	16 (0.920)	17 (0.955)	18 (0.980)	19 (0.995)	20 (1.00)
0.02	0.72	0.50	0.37	0.28	0.22	0.18	0.15	0.13	0.12	0.11	0.10	0.10	0.09	0.09	0.09	0.09
0.04	1.44	1.00	0.74	0.56	0.44	0.36	0.30	0.26	0.24	0.22	0.21	0.20	0.19	0.18	0.18	0.18
0.06	2.24	1.56	1.14	0.88	0.69	0.56	0.47	0.41	0.37	0.34	0.32	0.30	0.29	0.29	0.28	0.28
0.08	2.96	2.06	1.51	1.16	0.91	0.74	0.62	0.54	0.49	0.45	0.42	0.40	0.39	0.38	0.37	0.37
0.10	3.68	2.56	1.88	1.44	1.14	0.92	0.77	0.68	0.61	0.56	0.53	0.50	0.48	0.47	0.46	0.46
0.12	4.40	3.06	2.24	1.72	1.36	1.10	0.92	0.81	0.73	0.67	0.63	0.60	0.58	0.56	0.55	0.55
0.14	5.12	3.56	2.61	2.00	1.58	1.28	1.08	0.94	0.85	0.78	0.73	0.70	0.67	0.55	0.64	0.64
0.16	5.92	4.11	3.02	2.31	1.83	1.48	1.24	1.09	0.98	0.90	0.85	0.80	0.77	0.76	0.74	0.74
0.18	6.64	4.61	3.39	2.59	2.05	1.66	1.40	1.22	1.10	1.01	0.95	0.90	0.87	0.85	0.83	0.83
0.20	7.36	5.11	3.76	2.88	2.27	1.84	1.55	1.35	1.22	1.12	1.05	1.00	0.96	0.94	0.92	0.92
0.22	8.08	5.61	4.12	3.16	2.49	2.02	1.70	1.49	1.34	1.22	1.10	1.10	1.06	1.03	1.02	1.01
0.24	8.80	6.11	4.49	3.44	2.72	2.20	1.85	1.62	1.46	1.34	1.26	1.20	1.15	1.12	1.11	1.10
0.26	9.60	6.67	4.90	3.75	2.96	2.40	2.02	1.76	1.59	1.46	1.37	1.30	1.26	1.22	1.21	1.20
0.28	10.32	7.12	5.27	4.03	3.19	2.58	2.17	1.90	1.71	1.57	1.47	1.40	1.35	1.32	1.39	1.29
0.30	11.04	7.67	5.63	4.31	3.41	2.76	2.32	2.03	1.83	1.68	1.58	1.50	1.45	1.41	1.39	1.38
0.50	18.40	12.78	9.39	7.19	5.68	4.60	3.87	3.38	3.05	2.80	2.63	2.50	2.41	2.35	2.31	2.30
0.75	27.60	19.17	14.08	10.78	8.52	6.90	5.80	5.07	4.57	4.21	3.94	3.75	3.61	3.52	3.47	3.45
1.00	36.80	25.56	18.78	14.38	11.36	9.20	7.73	6.76	6.09	5.61	5.23	5.00	4.82	4.69	4.62	4.60
1.25	46.00	31.94	23.47	17.97	14.20	11.50	9.66	8.46	7.62	7.01	6.57	6.25	6.02	5.87	5.78	5.75
1.50	55.20	38.33	28.16	21.56	17.04	13.80	11.60	10.15	9.14	8.41	7.89	7.50	7.46	7.23	6.93	6.90

[1]Whole plant count = $\frac{\text{7-leaf count}}{91} \times 100$

Figures 12a through 12e illustrate the effect of control cost, crop value (MV × EY), and corn stage when eggs are deposited (PL) on the EIL (expressed as a PPD). Percentage control (PC) is assumed to be 67 percent. If percentage control is believed to differ from 67 percent, the alternative value can be substituted in the EIL formula. EIL values can be easily determined using the figures, if the 67 percent control is acceptable. Select the figure for the corn growth stage when the majority of egg deposition is noticed. Next, determine the crop value by multiplying the expected yield (bushels per acre) by the anticipated market value (dollars per bushel). Locate the calculated crop value on the horizontal axis of the figure. Now follow a straight line vertically up the figure until the appropriate control cost curve is intersected. Move horizontally to the vertical axis. The PPD value where the axis is intersected represents the calculated EIL value.

Because a control action must be taken when eggs are present, it is more useful to express the EIL in terms of egg masses per plant that will result in an economic larval density at season's end. By converting back to egg masses per plant, the user would have time to respond before larvae bore into the plant and become protected from the action of contact insecticides. Therefore, under these assumptions, the number of egg masses per plant that result in the EIL is the ET.

Using the information from the example above, refer again to table 6. Within the body of the table, locate all the values in each column that are closest to 1.13. Because PPD and the number of live borers per plant at the season's end are equivalent, critical egg mass density that should cause the user immediate concern can now be determined. For instance, if sampling to establish the current egg mass density did not occur until 10 days after oviposition started (approximately the peak in egg laying), then somewhere between 0.12 and 0.14 egg masses (hatched and unhatched) per plant (12 to 14 per 100 plants) would be the ET. Eight days after initiation of oviposition (2 days before the peak in egg laying) 32 percent of the eggs have been laid. At that time, an average of one egg mass on 8 percent of the plants is potentially economic (table 6). If we sample 5 days into the egg-laying period only 12.5 percent of the eggs have probably been laid and about three egg masses per 100 plants would be enough to indiciate that economic problems are very likely without well timed insecticide treatments. Sampling early in the oviposition period, however, greatly increases the chance of reaching an improper decision.

Both of the approaches described above (cost per benefit and EIL) assume that the damage inflicted is largely restricted to borers entering the stalk over one plant growth stage. Figure 12f shows that this is an oversimplification. More refined computer-based models that account for the correlation between oviposition, phenology of stalk entry by the surviving larvae, plant development, and grain yield loss vulnerability are under development.

Timing Insecticide Treatment

Previously in the Corn Belt, early-planted corn was most attractive to moths that produced first-generation European corn borers. These plantings were frequently severely damaged. Early-planted corn, however, escaped the second generation because the plants were no longer attractive for egg laying. But, late-planted corn was highly attractive for egg laying and these plantings sustained large numbers of second generation ECB.

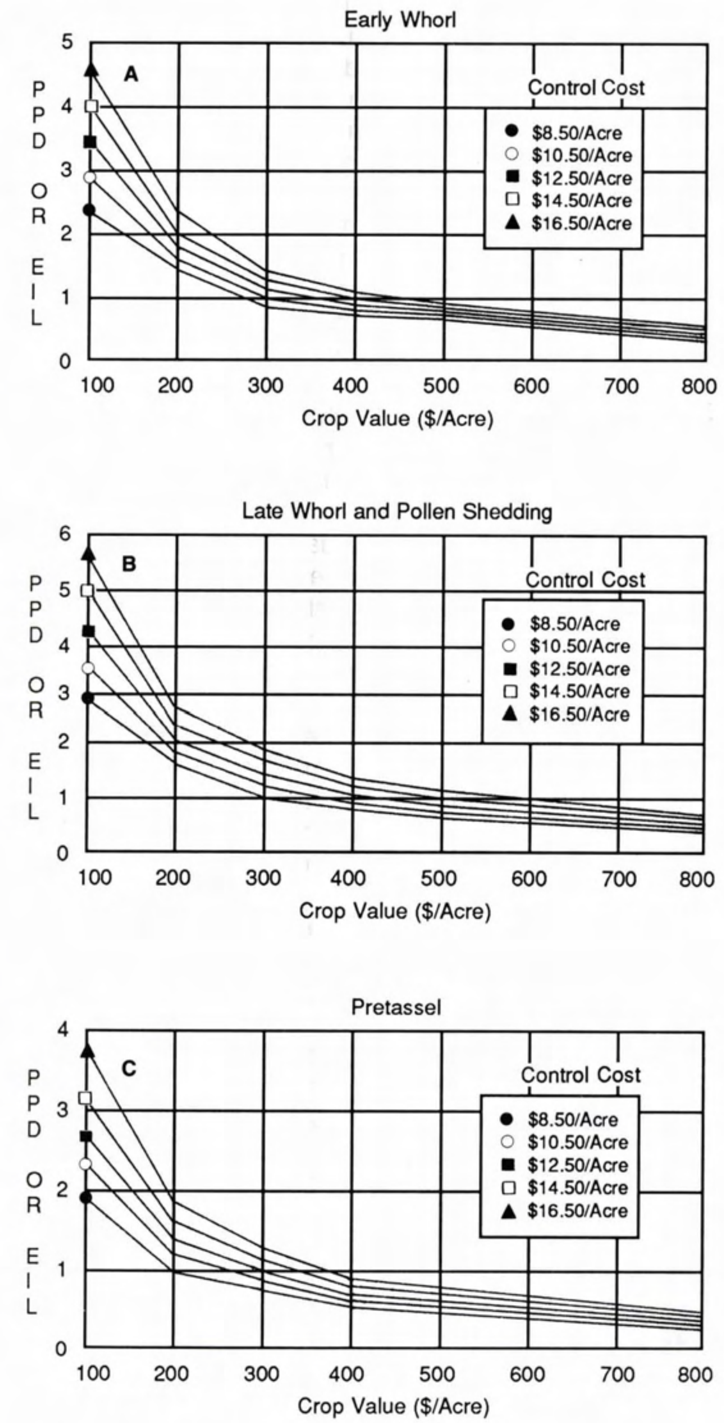
Currently, there is a trend to plant long-season corn with heavy fertilization. When planted early, this corn can be attacked by the first generation and may still be attractive to the second generation. This is particularly true in those areas of the Corn Belt where irrigation is available and used throughout the growing season. The corn hybrids planted in these areas are usually long-season, planted very early, and planted at a higher population than their neighboring nonirrigated cornfields.

In some areas of the Corn Belt, reduced tillage practices are being used in corn production. Most reduced tillage systems, especially those that do not include plowing, permit increased survival of the overwintering population of borers. Proper weather during the spring increases the probability of subsequent attack by the first generation.

If weather favors survival of the borer when long-season corn is grown, it may be necessary to treat the field for more than one generation. When light traps show heavy moth flight and the corn is shedding pollen, green silks are present, or the ear is in the milk stage (table 4), treatment may be needed to control the second or third generation.

Timing is one of the most critical aspects of European corn borer control with insecticides. The number and timing of whorl-stage

Figure 12a-e. Calculated Economic Injury Level (EIL or PPD) values when control cost, crop value, and corn stage during egg deposition are varied.



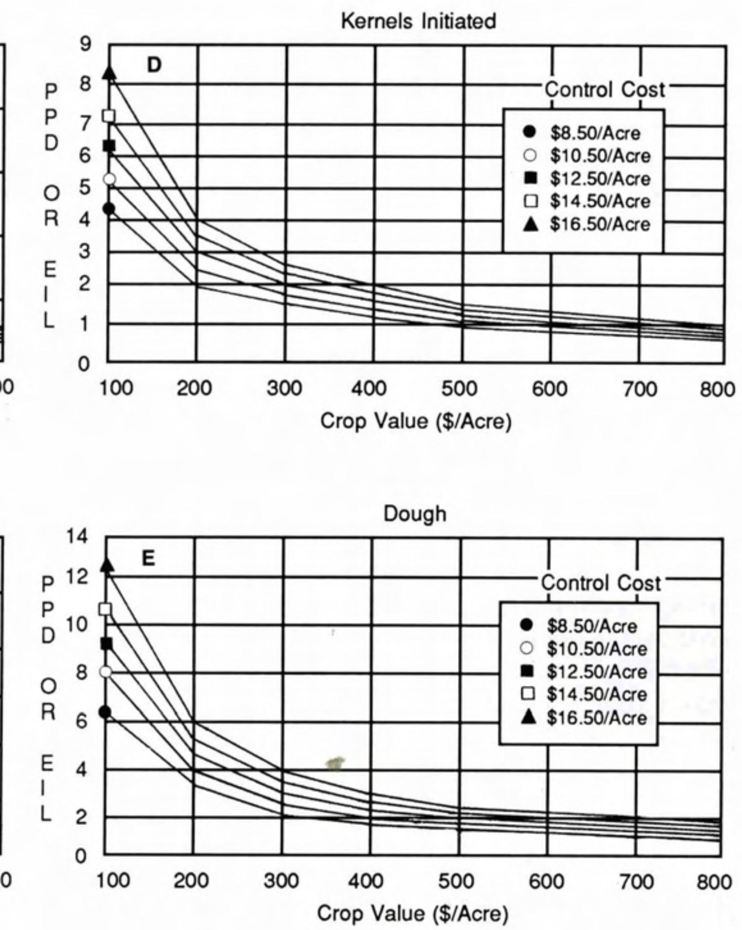
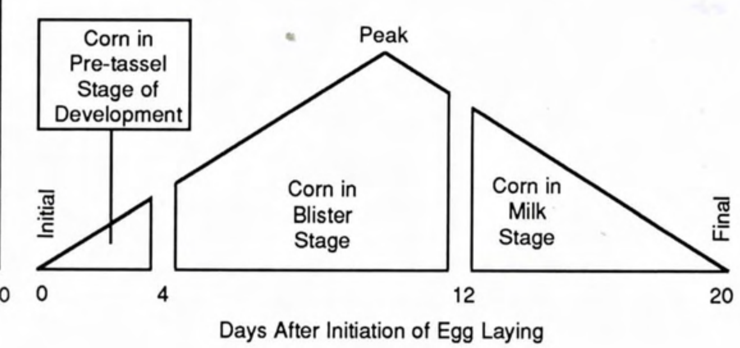


Figure 12f. Oviposition and subsequent damage over three stages of corn development.



treatments depend upon the severity of the infestation and the degree of control desired. Except under very heavy infestation, one treatment is usually sufficient on field corn during the whorl stage of corn development. Seed corn or other extra-value crops may profitably receive two or more treatments.

Various procedures are available to determine the time of application for control on whorl stage corn. These procedures include tassel-to-bud ratio, a certain percentage moth emergence, accumulated egg masses per 100 plants, and percentage whorl feeding. Percentage fresh whorl feeding and the presence of live larvae in the whorl have proven to be the best criteria for treatment timing. See the previous section for cost versus benefit in table 5 for whorl stage corn. Treatment after the borers have invaded the stalk will not be satisfactory.

Intensive scouting is necessary to determine the time of application for control during the tasseling and silking stage of corn development. Without scouting and development of an economic threshold (ET) for suspect fields, control of the second- or third-generation borer is more difficult. More than one insecticide application may be necessary. The best information to date indicates that the first application should be applied over the grassy action sites (for moth control) and the cornfield when eggs begin to hatch and larvae are visible in leaf axils (table 7). Choose an insecticide that will control moths and hatching borers over several days. Nonresidual insecticides are not suitable for control during corn tasseling and silking. If fresh eggs are still observed 7 to 10 days following the first application, treat a second time. Borers in the ear tip and collar area of field corn cannot be controlled by an insecticide application (see Sweet Corn).

Application Equipment
Most applications for control of European corn borer are aerially applied. In those areas with a history of European corn borer problems, granules are the preferred formulation, particularly for control during the whorl stage of corn development. Fortunately, most aerial operators are usually equipped to apply either a granule or a liquid formulation. Although not true for all compounds, efficacy comparisons between granules and liquids of the same compound applied over whorl stage corn usually favor the granules. Granules have additional advantages: (1) no mixing or water is needed, (2) there is less drift, (3) personal hazard is usually less, and (4) there is less hazard to honeybees and other beneficial insects. Liquid insecticides, however, give better control of ECB moths and larvae during the tasseling and silking stage of corn development. Also, liquid formulations are advantageous later in the crop development because European corn borer may not be the only target insect pest species.

When high-clearance equipment is available, it can be modified to apply either granules or liquids. To control leaf feeding, granules need to be directed into the whorl of the plant. To control sheath-collar feeding during the pre- and post-tassel stages of corn development, granules need to be directed over the entire plant and into leaf axils. This is usually accomplished by using 7 to 10 inch (18 to 25 centimeter) spreader banders attached to delivery tubes extending from each insecticide box.

For liquid applications to reduce leaf feeding, use one or two nozzles per row. Adjust the nozzles to deliver the spray above and into the whorl. To control sheath-collar and ear feeding, use four nozzles per row and direct the spray at the ear zone. Thorough coverage is important. Ground applications should be applied with a minimum of 10 gallons (37.9 liters) of water per acre. To control whorl feeding, these same granular or liquid delivery systems can be mounted on a tool bar and used with cultivation layby equipment. Generally corn is too tall and already cultivated when decisions are made to control whorl feeding. Although there are distinct advantages to ground application, equipment availability and the time required to complete application over large acreages often necessitate the use of aerial equipment.

Table 7. Effectiveness of ground-applied Furadan 10% granules at 1.0 lb. A.I./A against second-generation European corn borer in field corn. Variety Acco 2901 planted June 6, 1978. (Cedar County, Nebraska, J. F. Witkowski).

Treatment timing and date	Mean borers/plant: Number[1]	% reduction
1. At 25% egg hatch (Aug. 14)	2.0 ab[2]	65
2. At 25% egg hatch + 4 days	1.6 a	72
3. At 50% egg hatch (Aug. 16)	3.4 e	40
4. At 50% egg hatch + 5 days	2.3 bc	60
5. At 75% egg hatch (Aug. 18)	3.0 de	47
6. At 75% egg hatch + 5 days	2.7 cd	53
7. At 95% egg hatch (Aug. 21)	3.7 e	35
8. At 95% egg hatch + 4 days	3.4 e	40
9. No treatment	5.7 f	—

[1]Each mean made up of 40 observations (10 plants × 4 replications).
[2]Mean separation by Duncan's multiple range test; P = 0.05.

In those areas where insecticides are commonly applied at planting or cultivation for control of rootworm larvae, application of a systemic insecticide seemingly controls whorl-feeding European corn borer. ECB control with this method, however, has been inconsistent and therefore it is not recommended.

The application of insecticides via injection into irrigation water (insectigation), particularly with overhead center pivot irrigation systems, is an effective method and is rapidly becoming common in some irrigated areas of the Corn Belt. Because it is relatively new, the technology is changing rapidly. Federal and state legislation governing its use is also changing rapidly. Before using this method of application, consult your local Cooperative Extension Service and the respective regulatory agencies. Some states have very specific rules and regulations regarding the injection of chemicals into irrigation water.

One of the primary concerns of insectigation is potential contamination of underground water. If insectigation is used, comply with all laws and regulations, including those promulgated by the Environmental Protection Agency, the manufacturer of the insecticide, and local regulatory agencies. At a minimum, make sure the well is equipped with a check valve to eliminate the possibility of reverse flow, or back siphoning, in the event the system loses pressure and shuts down during the insecticide application process. The check valve will eliminate the possibility of contamination of the well with the insecticide.

Resistant Varieties
Selections of inbred dent corn lines resistant to leaf feeding by first-generation borers have been made during the past six decades. Today most seed corn companies have hybrids available with intermediate resistance to leaf feeding (figure 13). It was estimated that 21 million acres of corn in 1969 were planted to hybrids whose pedigree contained at least one inbred line with an intermediate degree of resistance.

Since the mid-1970s, however, the acreage planted to hybrids resistant to leaf feeding has decreased dramatically. This is because the inbred line B73, large yielding but susceptible to leaf feeding, has become widely used in hybrid combinations.

Germ plasm resistant to sheath-collar feeding by second- or third-generation borer has been difficult to locate. There has been, however, a considerable decrease in sheath-collar feeding on inbred lines and hybrids grown during the 1970s, compared with genotypes grown during the 1930s. Although most hybrids grown today are susceptible to sheath-collar feeding (figure 14), they vary in degree of susceptibility. Progress also has been made during the past 45 years in developing hybrids with better root systems, stalk strength, and ear shank strength. Hybrids are available today with some tolerance to late summer borer attack. These hybrids stand well and retain ears despite heavy infestation.

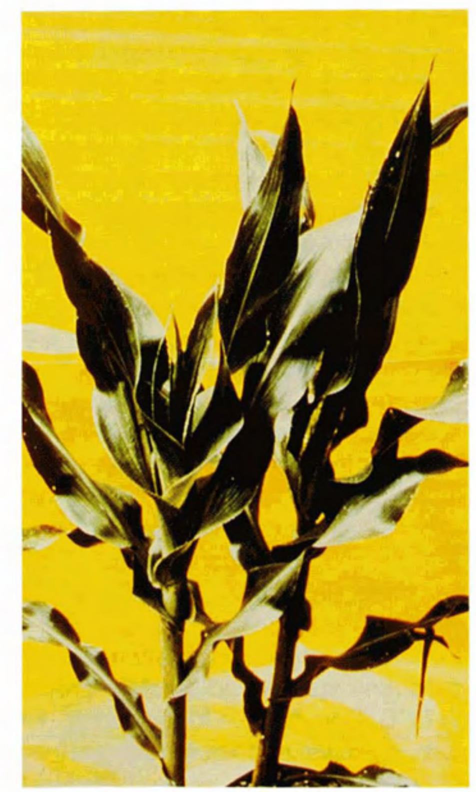


Figure 13. Corn hybrid displaying resistance to whorl feeding by European corn borer.

Figure 14. Corn hybrid displaying resistance to sheath-collar and leaf axil feeding by European corn borer, left. Susceptible hybrid, with few remaining leaves, right.

In the future, hybrids with resistance to both leaf and sheath-collar feeding should be available. Several seed corn companies have extensive breeding projects and all companies can use germ plasm resistant to European corn borer released by U.S. Department of Agriculture, Agricultural Research Service-State Experiment Station joint corn breeding projects. This germ plasm can be used directly in hybrid combination or as genetic stocks for breeding purposes.

Biological Agents

The European corn borer is attacked by many natural enemies throughout its life. Lady beetles and other insects and predacious mites feed on the eggs and young larvae. Picnic beetles, which enter the borer tunnels to feed on plant sap, will injure borers and crowd them out of the tunnels. The downy woodpecker, ringneck pheasant, and other birds dig overwintering borers out of their chambers in cornstalks and plant debris. Parasitic flies and wasps have been imported from Europe and released in the United States to control the borer. Some wasp species, *Macrocentrus grandii* and *Eriborus terebrans,* are well established and are responsible for suppressing borer populations to varying extents in different locations and years. A parasitic fly, *Lydella thompsoni,* also imported and established in the United States some years ago, disappeared in the north central region in the mid-1960s. The fly is presently reestablished in the Middle Atlantic states and attempts are being made to reintroduce the fly in the north central states.

A parasitic protozoan, *Nosema pyrausta,* weakens the borer so that infected larvae suffer heavier winter kill and infected moths lay fewer eggs than normal moths. This protozoan plays a moderate-to-significant role in reducing borer populations.

Two additional parasitic protozoa, *Vairimorpha necatrix* and *Vairimorpha* sp., will infect the borer under laboratory conditions. *V. necatrix* is extremely virulent and is promising as a microbial control agent.

Beauveria bassiana, a widespread fungus, can kill more than 50 percent of the overwintering populations of the borer in a given year. Conidia of *B. bassiana* remain in the soil and on/in corn plant debris. Epizootics, therefore, occur most readily during periods of ample rainfall with temperatures in the mid-80s°F (about 28°C).

A group of tiny wasps, *Trichogramma* spp., attacks the eggs of many lepidopterous insects, including European corn borer. In Texas, parasitized lepidopterous eggs containing the larvae of a species of *Trichogramma* have been applied to cotton by airplane for control of the cotton bollworm, *Heliothis zea,* and the tobacco budworm, *H. virescens.* Unfortunately, there is so much variation associated with this technique that the results are inconsistent. But, several species of *Trichogramma* are used in Europe, Central and South America, and Asia to control ECB. A species, *Trichogramma nubilalae,* native to the United States has been found in Delaware. Use of this species, and exotic species of *Trichogramma,* for control of ECB are under study.

Bacillus thuringiensis, a bacterium, produces spores and crystals toxic to ECB. Commercial formulations, both granular and liquid, are efficacious against whorl feeding and sheath-collar feeding. This microbial agent is being extensively used through pivot irrigation (insectigation) to control ECB. It also is very attractive because of reduced environmental contamination.

Nuclear polyhedrosis viruses isolated from the alfalfa looper, *Autographa californica,* and a mint looper, *Rachiplusia ou,* will infect the borer. Recent field experiments suggest viruses might show promise as control agents. It is unlikely, though, that viruses will have a practical application for European corn borer control.

Weather

Changing crop rotation practices during the past 20 years (from corn-oats to corn-soybeans) and changing harvesting methods (from picker harvest-ear storage to combined harvest-shelled grain storage) have dramatically reduced overwintering populations of European corn borer in the Corn Belt. Reduction of overwintering populations might be important. But, research in Iowa and Minnesota shows that borer survivorship is independent of the size of the previous generation. Borer survivorship is quite dependent on the weather conditions during adult moth mating and egg laying and during borer development immediately following egg hatch.

Table 8 presents information showing the effects of moisture in combination with temperature-related factors (stress and evaporation) on the survivorship of first-generation larvae on a susceptible corn hybrid. Moisture stress caused relatively uniform mortality; by the twentieth day after hatch just 1.8 borers per plant survived (91.1 percent mortality). Inundation of the larvae, however, on days 0 to 2 and 4 to 6 by 1⅛ inches (2.6 centimeters) and ⅞ inch (2.2 centimeters) of rainfall, respectively, caused 87.5 percent mortality by the sixth day after hatch. Although the final survival under both moisture stress and inundation is similar (day 24), the amount of damage sustained by plants from borers stressed for moisture could be more severe because of the slower increase in larval mortality. Regardless of the precautions taken before planting, climatic variables will ultimately determine the number of ECB (table 8).

Cultural Practices

There are several management practices that may effectively reduce the severity of local infestations of European corn borer. But, to have significant impact some of these management practices must be conducted over a community or county-wide area.

1. Planting Time

The effect of planting date on borer infestations will vary depending on the number of borer generations in the corn production region.

a. One-generation regions. Early planting of borer-resistant corn hybrids will normally result in minimum infestation, borer tunnels, and broken stalks; but presently the yield potential will be lower than yield expected from susceptible hybrids. If a number of growers in a given location follow a comparable planting date, this will provide conditions needed for uniform dispersal of ovipositing female moths and thereby reduce the number of egg masses deposited in individual fields. Abundant action sites in and around a specific field, however, will allow larger aggregations of moths and will result in larger numbers of egg masses being deposited in that field. Fields planted extremely early by an individual grower will also provide conditions for concentration of ovipositing female moths with a resulting heavy infestation.

b. Two-generation regions. Early planting of resistant hybrids also is considered to be a practical management approach. Extremely early planting (or earlier than other producers) will result in heavier-than-average infestation of second-generation borers for that specific field if moths are present during the tasseling and silking period. Late planting also will be attractive to concentrations of ovipositing females and will result in above-normal infestations and damage by second-generation borers. Except for a few tolerant corn hybrids, heavy second-generation infestations in corn planted early or late will result in broken stalks, dropped ears, and reduced yields. It must be remembered that at present, resistant corn hybrids lose their resistance when the corn reaches tasseling and silking. Most hybrids are susceptible when second-generation borers are attacking. Early-planted corn that is in stage R2 (kernels initiated, table 4) when the second generation of borer is present has a better chance of avoiding serious loss.

c. Three- and four-generation regions. The benefits of early planting remain the same for one- and two-generation regions. In the three- and four-generation regions, however, all planting dates are subjected to a minimum of two generations of borers. Earlier plantings receive infestations from first and second generations. Later plantings receive infestations from second and third generations. But, similar to the two-generation regions, earlier planting is a viable and practical management option.

2. Grass-weed and Adult European Corn Borer Suppression

Recent research suggests that European corn borer larval populations can be kept below economic levels by combining grass-weed control and adult moth control. If cornfields are kept relatively free of

Table 8. Average number of larvae per plant and cumulative percentage mortality for first-generation European corn borer caused by moisture stress and inundation, Iowa studies (W. B. Showers).

	Moisture			
	Stress		Inundation	
Observation days after hatch[1]	No. larvae/ plant	% larval mort./plant	No. larvae/ plant	% larval mort./plant
0	20.0	0	20.0	0
2	15.7	21.5	6.5	67.5
4	9.0	55.0	6.5	67.5
6	8.7	56.7	2.5	87.5
8	5.1	74.6	2.5	87.5
12	4.25	78.8	1.25	93.8
14	3.5	82.4	1.25	93.8
17	2.5	87.6	1.25	93.8
20	1.8	91.1	0.8	96.0
22	0.9	95.6	0.5	97.5
24	0.6	97.2	0.45	97.8

[1]All leaves of 20 corn plants examined/observation.

grass and dense weeds, and the waterways and field edges are mowed, borer moths can be "herded" into predesignated patches of grass [minimum size, 99 ft. (30m) × 494 ft. (150m)] and killed with nonpersistent insecticides labeled for grasshopper control. The predesignated patches of treated grass are necessary at each field where most grassy areas have been mowed. These patches prevent the moth populations from seeking cover in untreated grass near neighboring fields and then returning to lay eggs in the fields with the borders and waterways mowed. Where corn is the predominate crop, this strategy is most effective on a section or more.

3. Early Harvesting

Early harvesting is a management option that will effectively reduce yield losses resulting from broken and lodged plants and dropped ears. Most corn produced in the Corn Belt is subjected to infestations by two generations of borers. After boring into the plant, the second-generation larvae feed primarily in the lower portion of the plant (table 9). It is this feeding that is responsible for stalk breakage and dropped ears. Early harvest, combined with early planting, will reduce yield losses. In the southern portion of the Corn Belt (Kansas, Kentucky, and Missouri), and in other southern regions where more than two generations occur, early harvesting of heavily infested fields is recommended. If the corn can be mechanically dried on the farm, it will probably be profitable to dry it. If no on-farm drying facilities are available, it will usually be better to harvest early and to sell the corn and take a relatively large moisture dockage.

Summary of Management Tactics

There are several stages during the corn production process where growers can influence ECB populations through their management decisions. Successful control of ECB usually can be achieved by integrating management components into comprehensive programs tailored to conditions for the particular location.

The design of a control program for a particular area is largely dependent on the number of generations per year. This section summarizes typical control programs in terms of generations of corn borer per year. Each narrative section below is accompanied by a table that shows the management action growers can take in successive phases of the annual production cycle. Detailed descriptions of these actions can be obtained by referring to the appropriate sections under Components of Management.

One-generation Regions (table 10)

Establishment of ECB larvae occurs after susceptible corn plants reach an extended leaf height of approximately 22 inches (55 centimeters). Infestations are indicated by larval feeding in the whorl and on the plant leaves. Leaf feeding has the appearance of "shot holes." Damage is inflicted by tunneling in the leaf midribs and in the stalk, thus reducing the flow of plant nutrients and water. Selection of resistant hybrids and early planting dates is important. During seasons with heavy populations, estimate the probability that economic injury levels (EIL) will be exceeded. Insecticidal controls may be necessary.

Two-generation Regions (table 11)

First generation. Seasonal management practices should be the same as for one-generation regions (see above).

Table 9. Location of second-generation, fifth-instar European corn borer on susceptible field corn in the Corn Belt (Iowa, W. B. Showers; Nebraska, J. F. Witkowski).

	Iowa[1]		Nebraska[2]	
Plant area	Borers/ plant	% of total	Borers/ plant	% of total
Above the ear	0.94	29	2.0	31
On ear and shank	0.29	9	1.12	18
Below the ear	2.02	62	3.21	51
Total per plant	3.25	100	6.33	100

[1]Iowa—Each mean composed of 360 observations (10 plants × 36 replications). August, 1968.
[2]Nebraska—Each mean composed of 80 observations (10 plants × 8 replications). August, 1978.

Table 10. Management options, one generation.

Corn hybrid	Planting time	Treatment 1st generation
Hybrid resistant to leaf feeding	Plant early	Scout during whorl stage; should not need to treat.
Hybrid susceptible to leaf feeding	Plant early	Scout starting with 22 in. (56 cm) extended leaf height during whorl stage; develop PPD and EIL and treat if necessary; 1 treatment should be sufficient.

Table 11. Management options, two generations.

		Treatment	
Corn hybrid	Planting time	1st generation	2nd generation
Hybrid resistant to leaf feeding; susceptible to sheath and collar feeding	Early as possible	Scout, starting with 22 in. (56 cm) extended leaf height during whorl stage; should not need to treat.	Scout, develop PPD and EIL after finding first egg mass on leaf or young larvae in leaf axils; 2 treatments may be necessary.
Hybrid susceptible	Early as possible	Scout, develop PPD and EIL after leaves show feeding and live larvae are present; 1 treatment should be sufficient.	Scout, develop PPD and EIL after finding first egg mass on leaf or young larvae in leaf axils; 2 treatments may be necessary.

Table 12. Management options, three or four generations.

		Treatment			
Hybrid	Planting time	1st generation	2nd generation	3rd generation	4th generation
Long-season hybrid resistant to leaf feeding; susceptible to sheath and collar feeding	Early as possible	3-generation area—scout, should not have to treat; 4-generation area—no concern	Scout, develop PPD and EIL and treat if necessary; 2 applications, 7-10 days apart	Scout, develop PPD and EIL and treat if necessary; harvest early	Harvest early
Long-season hybrid susceptible to leaf feeding; tolerant to sheath and collar feeding	Early as possible	3-generation area—scout and treat; 4-generation area—no concern	Scout, treat if necessary; 2 applications, 7-10 days apart	Scout, treat if necessary; harvest early	Harvest early
Long-season hybrid susceptible to all feeding	Early as possible	3-generation area—scout and treat if necessary; 4-generation area—no concern	Scout, treat if necessary; 2 applications, 7-10 days apart	Scout, treat if necessary; harvest early	Harvest early
Short-season hybrid resistant to leaf feeding; susceptible to sheath and collar feeding	Early as possible	3-generation area—scout, should not have to treat; 4-generation area—no concern	Scout, treat if necessary; 2 applications, 7-10 days apart	Should scout and treat if necessary in 4-generation areas	No concern
Short-season hybrid susceptible to leaf feeding; tolerant to sheath and collar feeding	Early as possible	3-generation area—scout and treat if necessary; 4-generation area—no concern	Scout, treat if necessary; 2 applications, 7-10 days apart	No concern in 3-generation area; scout and treat if necessary in 4-generation area	No concern
Short-season hybrid susceptible to all feeding	Early as possible	3-generation area—scout and treat if necessary; 4-generation area—no concern	Scout, treat if necessary; 2 applications, 7-10 days apart	No concern in 3-generation area; scout and treat if necessary in 4-generation area	No concern
2nd crop corn—short-season hybrid resistant to leaf feeding	Mid-late season	No concern	No concern	Scout, should not have to treat for borer; will have to treat for fall armyworm	Scout, treat for borer if necessary; will have to treat for fall armyworm
2nd crop corn—short-season hybrid susceptible to leaf feeding	Mid-late season	No concern	No concern	Scout, treat for borer and fall armyworm at 7-10 day intervals	Scout, treat for borer and fall armyworm at 7-10 day intervals

Second generation. Oviposition by female moths usually occurs at the time of pollen-shed in late-planted corn. Most eggs will be laid in the ear zone and on the three leaves above or below the ear zone. Early stage larvae will feed on pollen at leaf axils, in the sheath, and around the sheath collar before entering the stalk, ear shank, and ear. Tunneling will result in broken stalks and dropped ears. Timing of insecticidal control for second generation is critical, and applications must be made soon after hatch and before the larvae migrate to the ear tip, or deep into the leaf axils, the sheath, and collar, and before they enter the stalk or ear shank. A second application may be needed in 7 to 10 days. Determine treatment window and develop potential population densities (PPD) and economic injury levels (EIL) after the first egg mass or early stage larvae in the leaf axils have been found on plants in pre- to post-tasseling stage of development. Extremely late-planted corn will be attacked during the whorl stage by second-generation borers. Also, there is a correlation between large numbers of European corn borer, stalk rot, and aflatoxins.

Three- or More-generation Regions (table 12)

First generation. Normally in four-generation areas, the first generation will develop on early hosts, both economic and noneconomic, before corn is available. In three-generation areas, management practices should be similar to two-generation regions (table 11).

Second and third (or subsequent) generations. During the whorl stage of corn development, early-planted short- or medium-season varieties will normally receive infestations from the first (only in three-generation areas) and second-generation borer populations. Long-season varieties may be severely damaged by second and third generations. Late-planted corn planted as a second crop may be severely damaged during the whorl stage from leaf feeding by the third and fourth generations of corn borer and a summer generation of fall armyworm, *Spodoptera frugiperda*. The later the corn remains succulent, the greater the potential for corn borer damage (table 4). Most eggs are laid on the ear, on the ear leaf, and on the three leaves above and the three leaves below the ear zone. Larval feeding in the ear shank and ear of early-planted corn is greater in the third- and fourth-generation regions. Insecticidal control for European corn borer on second crop corn should be timed the same as for first generation in the two-generation areas. Insecticidal control for corn borer on the first crop corn should be timed the same as for the first and second generations in the two-generation regions. A second application usually will be necessary 7 to 10 days after the first application. Early harvest is important. High corn borer populations may increase incidence of stalk rot and aflatoxins.

European Corn Borer on Commodities Other than Field Corn

Sweet Corn

Life History and Damage

The life cycle of the European corn borer on sweet corn is very similar to that on field corn. Large populations of larvae on plants usually result when oviposition has taken place between early whorl and fresh silk stages of sweet corn development. The most vulnerable time for ear infestations is when oviposition occurs during silking. Late-planted sweet corn and long-season varieties usually have heavier infestations of larvae than do early-planted short-season varieties. The late summer populations of larvae are generally higher in sweet corn than in field corn under similar conditions.

The major damage by borers in sweet corn is from direct feeding on the ears. This affects acceptability of the corn for fresh market or for processing. Most ear damage occurs from larval feeding on the kernels along the side of the ear (figure 15). Many processors feel the European corn borer is a more serious problem than the corn earworm because of the difficulty in detecting the infested kernels on the side of the ear and consequently the increased likelihood of insect contamination of the food product. Additional damage occurs from feeding on the leaves and boring in the ear tip, shank, and stalk that may reduce yield through the physiological effect on the sweet corn plant.

Figure 15. European corn borer larvae feeding on ear kernels.

The damage allowed in ears of sweet corn varies depending on the processor or fresh market outlet. Some processors can tolerate up to 20 percent ears with tip damage and up to 5 percent with side-kernel damage before the quality of the final food product is affected. Most processors prefer little or no damage and in some cases provide a bonus for insect-free corn. Fresh market outlets generally tolerate less ear damage than processors.

Detection and Assessment

The presence of egg masses on the underside of leaves (figure 4) and young larvae feeding on the whorl leaves, tassels, and silks are the best indications of infestation. A blacklight trap (figure 16) is a useful tool for determining the presence of potential egg-laying females in the vicinity of sweet corn. Pheromone traps also may be considered, although they generally have not been as reliable as light traps or direct sampling. Sampling in grasses along field edges and waterways for adults (figure 11) may prove beneficial in assessing populations.

The time to sample for borer feeding activity in early plantings of sweet corn can be determined by the capture of moths in blacklight traps. Sampling usually begins when the earliest fields reach the early whorl stage of plant development. During the whorl stages, inspect the whorl leaves of 20 plants in each of five locations and record the number of egg masses and plants showing light, moderate, and heavy feeding. During the period when the tassels are emerging from the whorl, inspect only the tassels and record the number of plants that have live larvae feeding on the tassels. It is important to determine if live borers are present and actively feeding. Pull out and carefully unroll the whorl leaves and tassels of the first two plants showing damage at each location and note the number and location of live larvae found. If fall armyworm is present, add the number of plants infested with this insect to the corn borer assessment because a management decision is based on the combined infestation of both insects.

Light whorl feeding is defined as superficial "window pane" damage with a few scattered shot holes on less than half of the leaves. Injury of this type is generally associated with average infestations of less than two young larvae per infested plant. Moderate damage is indicated by notable feeding holes and some midrib injury on more than two-thirds of the leaves with 10 to 50 percent of the leaf area affected. Moderate whorl injury produces many patterns of feeding holes and midrib tunneling that are associated with average infestations of two to five young larvae per infested plant. Heavy whorl injury involves extensive feeding on all leaves with greater than 50 percent of the leaf area affected.

The timing for spraying silking sweet corn is best determined by the number of moths captured in blacklight traps and by the extent of egg laying and larval feeding during the presilking stages of later plantings

Figure 16. Blacklight trap equipped with 15-watt bulb, photocell, and 12-volt battery.

on the same farm. Direct sampling for the corn borer and other ear-damaging insects during the silking period of fresh market sweet corn is marginally effective because of the low economic injury levels. However, assessments of egg and larval stages during silking of sweet corn that will be processed can be made by inspecting 20 plants while the primary ear is in silk. Samples should be taken at each of five locations throughout a field. Records are taken on the percentage of plants carrying egg masses and the percentage of primary ears infested with eggs or young larvae of an ear-damaging insect.

Management Decisions

Management of European corn borer and other sweet corn insects consists of careful assessment of population levels and timely application of insecticides. Decisions for treatment of sweet corn must include considerations for other pest insects; i.e., corn earworm, armyworms, and sap beetles. When selecting the insecticides, consideration also should be given to beneficial insects such as bees and natural enemies. The decision process is further complicated by the fact that low levels of damage are allowed for the ears, and insecticide treatment is the only reliable means of keeping injury levels low. Therefore the present decision-making procedures developed for seed and field corn do not fit the circumstances for sweet corn.

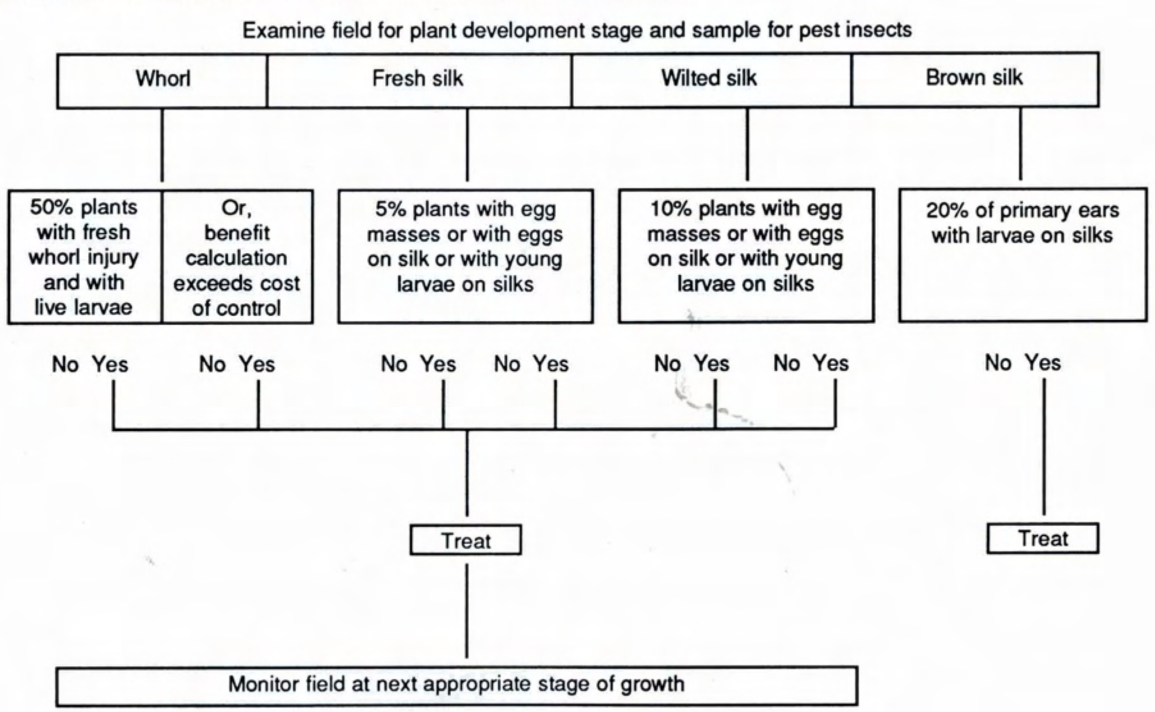
The criteria for treating processing sweet corn for borer control (figure 17) are different than for fresh market because economic injury levels are much higher and the raw product is marketed on a weight basis rather than by the dozen. As a general guideline before silking, whorl treatment of sweet corn grown for processing under average management practices is suggested if 50 percent or more of the plants show fresh whorl injury and have live borers in the whorl. For more precise decisions, the following equation can be used to calculate the anticipated benefit to be gained by a whorl application of insecticide based on economic factors and the extent of whorl feeding. The benefit should be compared with the control cost to arrive at a management decision. If the benefit exceeds the cost of control, then the cost of treatment is economically feasible.

$$\text{Benefit} = ((0.0008 \times \text{PLD}) + (0.0024 \times \text{PMD}) + (0.0044 \times \text{PHD})) \times \text{PC} \times \text{MV} \times \text{EY}$$

where:

PLD, PMD, and PHD = Percentage of plants infested with live larvae and showing light, moderate, or heavy whorl feeding, respectively

Figure 17. Management decisions for European corn borer on processing sweet corn.



PC = Proportion of the European corn borers controlled (expected to be killed by the insecticide)
MV = Sweet corn market value in dollars per ton
EY = Expected yield in tons per acre

In the example that follows, assume that PLD = 15 percent, PMD = 30 percent, and PHD = 10 percent. Also, the proportion of borers expected to be controlled (PC) by insecticide application is 0.67, the market value (MV) is $60 per ton, and the expected yield (EY) is 3.5 tons per acre. The total cost of control for one application is $15 per acre. The economic benefit would be:

$$\text{Benefit} = ((0.008 \times 15) + (0.0024 \times 30) + (0.0044 \times 10)) \times 0.67 \times 60 \times 3.5$$

Benefit = $18 per acre

In this example, the benefit exceeds the cost of control by $3 per acre. This indicates the need for control. There may not be a sufficient benefit margin, however, to justify control, especially when considering other factors. These factors include the time involved in lining up the applicator, impact on other farm operations, environmental concerns, and the amount of risk the grower is willing to take.

Decisions to treat processing sweet corn during silking are based on the percentage of ears that are potentially damaged by the presence of eggs and/or young larvae of ear-damaging insects (figure 17). A primary ear is potentially damaged if it meets one of the following criteria:

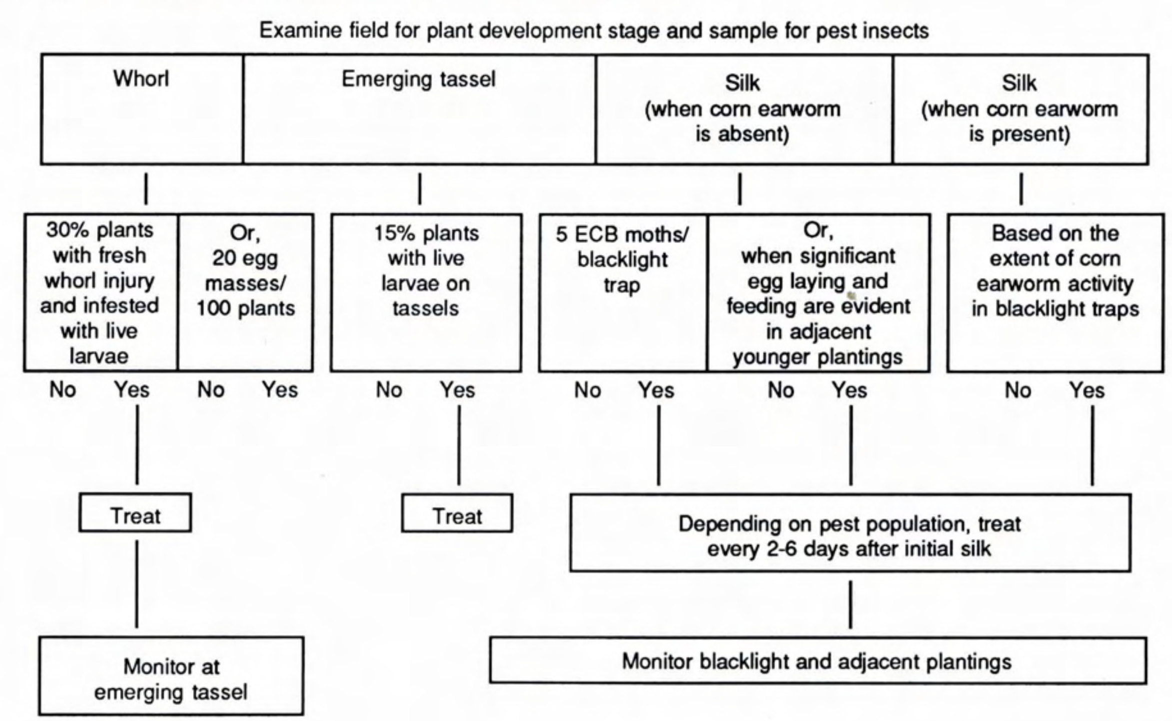
1. The plant carries one or more unhatched egg masses of the borer (or any other ear-damaging insect);

2. There is one or more eggs of an ear-damaging insect in the silk of the primary ear; or

3. A young larva of the borer (or any other ear-damaging insect) is feeding in the silk.

If less than 100 percent of the sweet corn plants are silking, the number of ears vulnerable for damage on plants in criteria two and three must be adjusted to the percentage of plants with silking ears. During fresh silk (18 to 20 days before harvest), treat if 5 percent or more of the plants in silk meet one or more of the above criteria. During wilted silk (about 16 to 18 days before harvest), treat if 10 percent of the plants fall into one or more of the above criteria. At the onset of 100 percent brown silk on primary ears (10 to 12 days before harvest), treat if 20 percent of the ears have larvae

Figure 18. Management decisions for European corn borer on fresh market sweet corn.



feeding on the silks and the larvae are exposed enough to be killed by insecticides.

The criteria for treating fresh market sweet corn for European corn borer or fall armyworm control (figure 18) before tasseling are for 30 percent or more of the plants to show leaf feeding in the whorl and have live larvae or when 20 or more unhatched egg masses are found per 100 plants. Usually one whorl application of insecticide is sufficient to prevent economic loss in the number of marketable ears. Foliar treatments of granules or high volume sprays directed in the whorl by ground applicators are the most effective. For early tassel infestations, treat if 15 percent or more of the plants have live borers or fall armyworms feeding in the emerging tassels. As the tassels emerge, larvae disperse to other plant parts and thus are more exposed to insecticide at this time. Larvae present during tasseling also have a greater chance to invade the developing ear, causing a quality problem.

The criteria for treating (figure 18) fresh market sweet corn during silking are generally based on the extent of corn earworm (one moth per night) activity in blacklight traps. However, for plantings that are silking when the earworm is absent, begin treatments at the first sign of silking if corn borer catches in blacklight traps exceed five moths per night, or if egg laying and leaf feeding are evident on the presilk stages of younger plantings on the same farm. Levels of 10 or more egg masses per 100 plants or more than 15 percent of the plants showing fresh feeding indicate that corn borer and/or fall armyworm moths are laying eggs in nearby plantings-in-silk. Repeat sprays every 4 to 6 days depending upon the overall activity of both insects.

Maximum control during silking is achieved with high volume sprays of insecticides using a high clearance boom applicator with solid cone nozzles dropped between rows and directed at the ear zone. Aerial application and air-blast sprayers also provide adequate coverage if used at maximum spray volume. The number of rows to be sprayed by air-blast application should be adjusted to the canopy structure of the variety. Extensions also can be added to certain applicators to direct the air blast down through the canopy, thus improving the spray distribution across the rows. For ground application, high volume sprays of 50 to 75 gallons per acre should be used whenever possible.

When treating with insecticides, be sure to observe the label restrictions for the minimum number of days before harvest. **Note:** application of insecticide during pollen shedding can seriously reduce bee populations. If an insecticide must be applied, select a material with low toxicity to bees. Apply it during late evening since bees usually forage corn for pollen only in the morning and not in the afternoon.

Popcorn

Life History and Damage

The life cycle of the European corn borer on popcorn is very similar to field or sweet corn. Popcorn is susceptible to ECB damage and will have considerable yield losses when infested during plant growth stages, mid-whorl to 4 weeks postpollen shed.

The major damage to popcorn by ECB is similar to damage in field corn. Yield losses from stalk breakage are particularly large when popcorn is infested during pollen shed or postpollen shed and can average as much as 25 percent of the total yield. The borer causes very little direct damage to popcorn kernels, probably because of the hard, starchy nature of the kernels.

Table 13 shows yields of IOPOP 12 popcorn hybrid (the most widely grown popcorn hybrid in the Midwest) in pounds per acre when infested by 0, 0.5, 1.0, 2.0, and 4.0 European corn borer egg masses per plant. Yield losses were large with just 0.5 egg masses per plant. Table 13 shows that losses in excess of 1,000 pounds per acre can occur.

Detection

Scout for damage and live larvae on whorl stage popcorn. During pollen shed and postpollen shed, scout for egg masses on leaves or young larvae in leaf axils of popcorn.

Management Decisions

Develop PPD and EIL similar to those calculated for whorl stage field corn. One treatment should be sufficient. During pollen shed and postpollen shed, develop PPD and EIL similar to those calculated for field corn at pollen shedding. Popcorn value is approximately $0.10 per pound and yield is usually expressed as pounds per acre.

Table 13. Pounds per acre of IOPOP 12 popcorn after infestation with several levels of European corn borer (Polk County, Iowa, J. L. Jarvis).[1]

Mean number of egg masses/plant	Yields, lb./A
Infestation during whorl stage	
0	4160
0.5	3575
1.0	3510
2.0	2990
4.0	2730
Infestation during pollen shedding stage	
0	4290
0.5	3445
1.0	3250
2.0	3120
4.0	2730

[1]1983-1984.

Peppers

Life History and Damage

The life history of the European corn borer on peppers usually involves the midsummer and late generations. Occasionally, early summer larvae are found on transplants that were infested in the seed beds. Egg masses are usually deposited on leaves. The eggs hatch in 3 to 7 days and the larvae disperse over the plant. First-stage larvae enter the upper part of the fruit by crawling under the calyx and boring into it or into the fruit wall. First- and second-instar larvae feed on the calyx, flesh around the calyx, or in the placenta. Third-stage larvae may continue feeding on the pepper fruit, or may leave the fruit. Those leaving the fruit commonly bore into uninfested fruit or into stems. Larvae continue to develop and may pupate in fruit or stems. Or, if late enough in the season, larvae may go into diapause and overwinter in stems and fruit peduncles.

Early-infested fruit usually rot and drop off the plant. Fruit infested late in development may appear healthy, but are rejected upon marketing or processing because of contamination. Damage due to feeding around the calyx may also reduce the quality of fruit that escape internal infestation.

Detection

A blacklight trap to detect adult females in or near the pepper field should be operating before the second generation of corn borer is anticipated. Insects collected in the trap should be removed and female borers counted daily. Thresholds for treatment consist of four or more female moths per blacklight trap per night for three consecutive nights. Local phenology models for the European corn borer are useful in predicting the second generation. It is useful also to inspect nearby corn for egg masses or whorl feeding. The results of recent research in Iowa suggest that nearby late-planted sweet corn can serve as a trap crop with fewer egg masses being deposited on peppers. Because of the low threshold of infestation tolerated for peppers for processing, it is impractical to sample for egg masses or larval stages.

Management Decisions

When pepper fruits are forming on plants, insecticide treatment should begin when an average of four or more female moths per light trap are collected per night for three consecutive nights. Once insecticide applications have begun, they should continue on a 7-day schedule until harvest. It is important to maintain this schedule because of the low infestation level for rejection of the crop. When 10 percent or more of the peppers are infested with corn borer at delivery for processing, the entire crop is rejected. For peppers to be processed whole, such as for pickling, the threshold for rejection may be as low as 1 to 5 percent.

Insecticides can be applied with either conventional ground or aerial spray equipment. If adequate control is to be obtained, generally the insecticide used must have residual activity for about 7 to 10 days. Consult your Cooperative Extension Service for recommendations on insecticides and rates of application. Also, note preharvest time and restrictions stated for treatment.

Snap Beans

Life History

Snap beans are incidental hosts of the European corn borer. Economic problems can occur before preferred hosts are available, after preferred hosts dry up and become unattractive, or when corn borer populations are extremely high. Corn borer infestation of snap beans occurs primarily in late spring (before corn is available) or in midsummer. Egg masses are deposited on leaves about the time of blooming. The larvae hatch in about 4 days and disperse over the plant. First- and second-stage larvae usually feed on leaf tissue, particularly new tissue. Second- and third-stage larvae will feed on leaf petioles and in axils. Larvae may bore in stems and petioles before pods are present and then enter pods after they form.

The impact of infestation on growth and development of the plant is minimal. The major problem is borer contamination of pods in snap beans used for processing. Tolerance of infested pods is quite low. It varies among processors, ranging from 0.2 to 1 infested pod per 1,000 pods. A single sample with an infestation at or above the tolerance level usually results in the harvest of an entire field or farm being rejected for processing.

Detection

Moth catch in blacklight traps placed near the bean field is the best indicator of potential corn borer infestations. The presence of egg masses on nearby corn, if available, is also a good indicator. Since there is such a low tolerance level of corn borer on snap beans, it is impractical to survey for egg masses or larvae on the beans.

Management Decisions
Insecticide treatment should begin at 8 to 10 days before bloom when an average of five or more moths per night are captured in local light traps or when egg masses found on nearby corn exceed 10 per 100 plants. Repeat treatments at 7-day intervals if moth captures in light traps average 5 to 10. Treat at 5-day intervals if moth captures average 10 to 20, treat every 4 days if captures average 20 to 50, and treat every 3 days if captures exceed 50 moths per night.

Potato
European corn borer is known to infest potatoes in several areas of the United States. Eggs are deposited by early season adults on the underside of leaves of young plants. Larvae enter potato vines by tunneling through the stems, usually in the leaf axil at the node. The fecal material, or frass, at these axils is a good indicator of the presence of ECB larvae. A later generation of moths may lay eggs before harvest.

The economic impact of corn borer on potato has not been determined. Studies on the direct effect of corn borer on yield reduction have not shown losses to the extent that warrant treatment. There has been some concern about corn borer damage predisposing the potato plant to the bacterial soft rot organism *Erwinia carotovora*. Indoor studies show that plants can be infected by artificially inoculating the bacterium at borer entrance holes. However, natural inoculation in the field is probably minimal because the bacteria are generally found on the plant near the soil and the larvae usually enter the stem fairly high up on the plant.

Other Crops
Since the European corn borer is a polyphagous insect, it has been reported on a number of other crops. Some of these include apple, cotton, lima bean, soybean, small grains, sorghum, tomato, and onion. When ECB is found on these crops, it is generally from incidental infestations resulting from high populations in corn. Occasionally, isolated cases can be found where rather heavy infestations occur. These may result in economic losses depending on the value of the crop. Crops with a high value and low consumer tolerance for damage, such as apples, can have a significant economic loss due to borer feeding.

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