

Corn Rootworm Biology and Management

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Corn Rootworm

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- History and Pest Status
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Introduction

Corn rootworms (CRW) are a major pest of corn (*Zea mays* L.) in the United States, Eastern Canada, and Europe. Current estimates for the United States alone, indicate that rootworms cause well over \$1 billion in damage and control costs annually.

Corn damage consists of larvae root feeding which reduces the quantity of corn roots available for water and nutrient uptake resulting in reduced grain and silage yields. The reduced root mass also results in “goose-necking” during the growing season and lodging at harvest.

Adult CRW beetles can feed on corn silks resulting in reduced pollination and kernel set on the ear resulting in reduced grain and silage yield.



Root feeding of corn due to corn rootworm resulting in reduced quantity of corn roots. Courtesy of Marlin Rice.



“Goose-necking” of corn due to corn rootworm. Courtesy of Marlin Rice.

Introduction

The corn rootworm complex in the United States consists of four insects in the genus *Diabrotica*:

- western corn rootworm (*Diabrotica virgifera virgifera* LeConte)
- northern corn rootworm (*Diabrotica barberi* Smith and Lawrence)
- southern corn rootworm (*Diabrotica undecimpunctata howardi* Barber)
- Mexican corn rootworm (*Diabrotica virgifera zea* Krysan & Smith).

Although some corn production regions can have three species at once, most of the damage in the Midwest is caused by western CRW and northern CRW. The maps below show the distribution of the western CRW, northern CRW, southern CRW, and Mexican CRW.

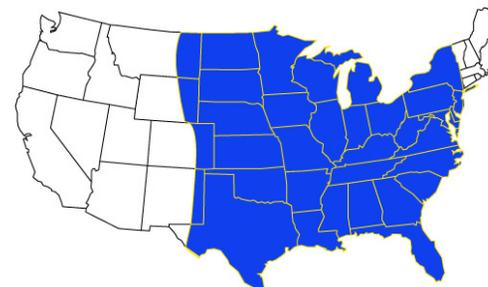
Distribution of western corn rootworm



Distribution of northern corn rootworm



Distribution of southern corn rootworm



Distribution of Mexican corn rootworm



Introduction

The genus *Diabrotica* contains over 350 described species and is commonly divide into three groups: *fucata*, *signifera*, and *virgifera*. The *signifera* group contains only a few species that are found in Central and South America. The *fucata* group contains more than 300 species, most of which are in Central and South America. However, there are a few species in the *fucata* group, including southern corn rootworm, in the temperate regions of North America. Species within this group found in the temperate regions of North America are **multivoltine**, have a reproductive adult **diapause**, and are **polyphagous** in both the larva and adult stages.

Scientific classification of the <i>Diabrotica</i> species discussed in this module							
Kingdom:	Animalia						
Phylum:	Arthropoda						
Class:	Insecta						
Order:	Coleoptera						
Suborder:	Polyphaga						
Superfamily:	Chrysomeloidea						
Family:	Chrysomelidae						
Subfamily:	Galerucinae						
Tribe:	Luperini						
Genus:	<i>Diabrotica</i>						
Species:	<i>virgifera</i>	<i>virgifera</i>	<i>barberi</i>	<i>longicornis</i>	<i>undecimpunctata</i>	<i>undecimpunctata</i>	<i>balteata</i>
Subspecies:	<i>virgifera</i>	<i>zea</i>			<i>howardi</i>	<i>undecimpunctata</i>	
Author:	LeConte	Krysan & Smith	Smith & Lawrence	Say	Barber	Mannerheim	LeConte
Common Name	Western Corn Rootworm	Mexican Corn Rootworm	Northern Corn Rootworm	(formerly Northern Corn Rootworm)	Spotted Cucumber Beetle or Southern Corn Rootworm	Western Spotted Cucumber Beetle	Banded Cucumber Beetle
Diabrotica Group:	<i>virgifera</i>				<i>fucata</i>		

Introduction

The *virgifera* group contains 35 species found mostly in North and Central America. In the temperate areas of North America, the species are **univoltine** and **diapause** in the egg stage. Larvae of the species within this group feed on various grass roots with western corn rootworm and northern corn rootworm feeding specifically on corn roots, and Mexican corn rootworm feeding on the roots of several grasses, including corn.

Even though four insects make up the corn rootworm complex, this learning module will focus primarily on the western and northern corn rootworms because they are the primary rootworm pests of corn in the Midwest. When possible, the similarities and differences between all four members of the complex are included.

In the last 20 years, considerably more research has been published on the western corn rootworm than any other members of the complex. As such, there are more information gaps regarding the northern, Mexican, and southern corn rootworms than the western corn rootworm.

Objectives

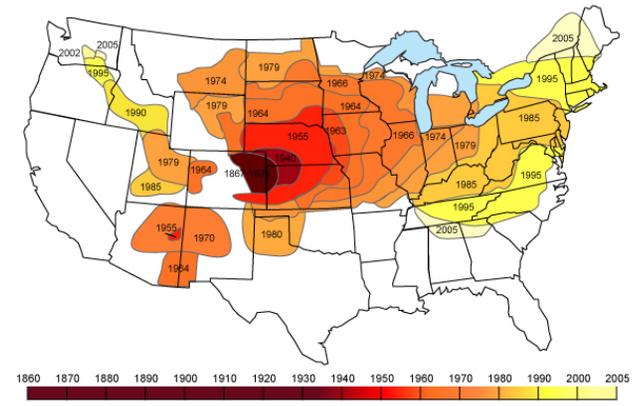
- ✓ To review the history and origin of corn rootworms in the United States
- ✓ To describe the identification of the four species of rootworms found in the United States
- ✓ To describe the life cycle of the corn rootworms found in the United States
- ✓ To describe the management of corn rootworms and their effects on yield
- ✓ To describe cultural, biological, insecticide, and transgenic control methods

History and Pest Status

Western Corn Rootworm

The origins of the western corn rootworm (WCR) have been traced back to Central America, specifically Guatemala, where they have been pests of maize for several thousand years. Some have suggested that the western corn rootworm became a more challenging pest after the Spanish introduced the European production system of large tracts of **monocultural** corn. This was a significant departure from the more diverse agricultural landscape of Mesoamerica, where scattered patches of corn grew amid other grasses.

Western corn rootworm has been a resident in the western half of the Great Plains since at least 1867. For many years it was simply an obscure species until it started damaging corn in north central Colorado in 1909. Prior to its expansion across the modern corn belt, it was originally referred to as the Colorado corn rootworm. By 1940 it was regularly damaging corn in Nebraska. A dramatic eastward range expansion began in 1945 and reached the states on the Atlantic Coast by the mid 1980's. The WCR also expanded west into all the major corn growing areas west of the Rocky Mountains, except California. It is considered a major pest in continuous corn throughout its range.



[Click to enlarge](#)

History and Pest Status

Western Corn Rootworm

The western corn rootworm has become well known for its ability to adapt to selective pressures imposed by pest management strategies. It has evolved resistance to some insecticides in parts of Nebraska and resistance to crop rotation in parts of Illinois, Indiana, Ohio, Michigan, Wisconsin, and Iowa. Western corn rootworm has also successfully invaded the continent of Europe, an ocean away.

Because of these economically significant evolutions, the cost of managing western corn rootworm is one of the largest annual expenditures for insect management in the U.S. Corn Belt.



History and Pest Status

Western Corn Rootworm Insecticide Resistance

Cyclodiene insecticides with active ingredients such as benzene hexachloride, aldrin, chlordane, and heptachlor were commonly used as soil treatments for the control of western and northern corn rootworms from the late 1940's to the early 1960's. Resistance to this class of insecticides was first noted in Nebraska in 1959 and further validated in 1960 and 1961.

The development of cyclodiene resistance coincided with WCR's eastward expansion so that by 1980, cyclodiene resistant WCR covered most of the Corn Belt, including areas that rarely used cyclodiene soil insecticides.

The vast majority of WCR in the Corn Belt today are still resistant to this class of insecticides decades after use was discontinued.



Resistance to cyclodiene insecticides such as Chlordane is still found in most WCR in the corn belt. Courtesy of © 2010 Theodore Gray periodictable.com.

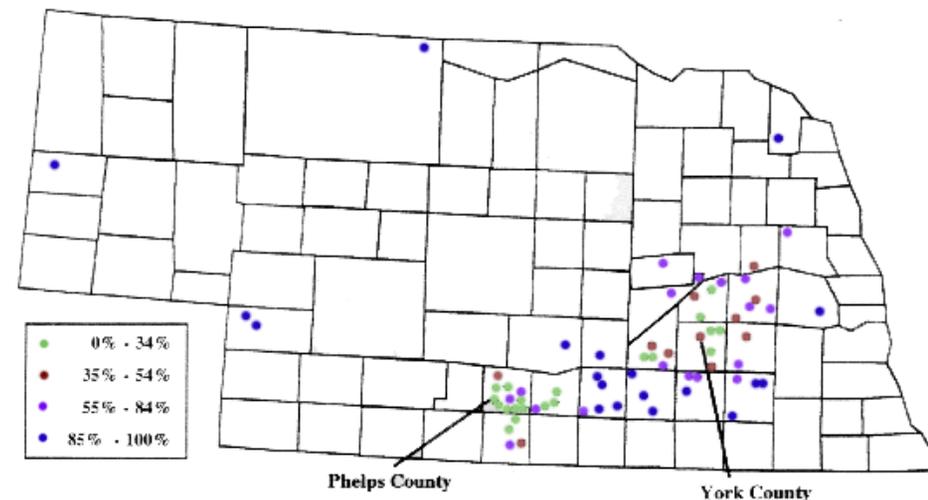
History and Pest Status

Western Corn Rootworm Insecticide Resistance

After the failure of cyclodienes, organophosphate and carbamate insecticides became the predominant rootworm insecticides throughout the U.S. Corn Belt. Both classes are still used as soil and foliar insecticides against CRW larvae and adults. Use of both soil and foliar insecticides was adopted as management tools where irrigated continuous corn is planted over large areas throughout the Platte River valley of Central Nebraska. In some areas microencapsulated methyl parathion was used almost exclusively in consecutive years for adult control.

Reports of aerially applied methyl parathion failures first occurred in the early 1990's. Resistance to organophosphate and carbamate active ingredients has been documented in both adults and larvae indicating that the metabolic mechanisms conferring resistance are present in all stages of life.

Despite the concern that resistance is spreading, there are still populations of rootworm that are susceptible to methyl parathion in close proximity to resistant populations.

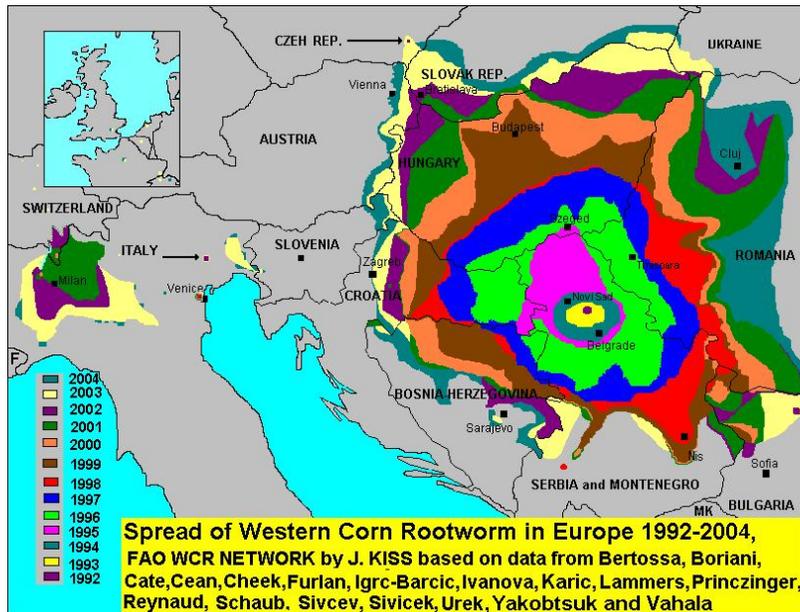


The 1998 distribution of methyl parathion resistant WCR in Nebraska, based on the percentage of individuals killed by a diagnostic concentration after 4 hours. Courtesy of Wright, R. et al., 1999.

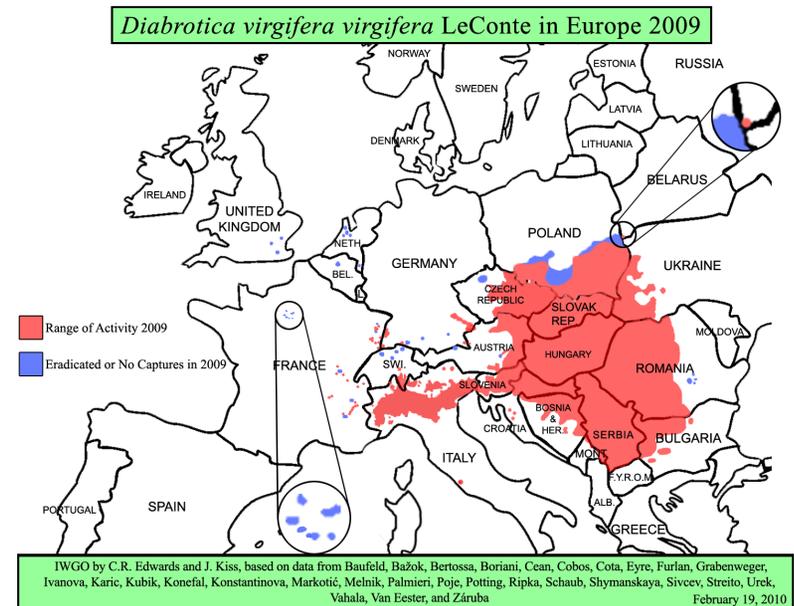
History and Pest Status

Western Corn Rootworm in Europe

In 1992, a western corn rootworm infestation was found in a small maize field near the Belgrade Airport in present day Serbia. The pest has spread rapidly and has been confirmed in 20 European countries in 2008. Molecular studies have confirmed that the introduction and spread of WCR in Europe is the result of at least three separate invasions.



Western CRW has spread rapidly in Europe since it was first found in Serbia in 1992. Courtesy of Joseph Kiss.



Recent western CRW spread in Europe. Courtesy of C. Richard Edwards.

History and Pest Status

Rotation Resistant Western Corn Rootworm

In June 1987, severe rootworm larval damage was reported in seed corn fields that had been rotated with soybeans in a small area near Piper City, Ford County, Illinois. In subsequent years the same type of damage occurred again. In 1993, rootworm larval injury in first-year commercial corn was observed in other areas of eastern Illinois. In all cases, WCR was the predominant species and studies showed that they were not exhibiting extended diapause as had recently been observed in populations of northern corn rootworm (NCR).

Initial investigations focused on the possibility that pyrethroid insecticide use had encourage WCR adults to leave corn fields and lay their eggs in neighboring soybean fields. However, this was disproven as pyrethroids were not used in many cases.

Regardless of the cause, this new subspecies, sometimes called the “soybean variant”, “Eastern variant”, “first-year rootworm”, or “rotation resistant” WCR had learned to migrate to neighboring crops, such as soybeans, to lay its eggs. These eggs hatch the following year when the field is rotated back to corn.



Crop-rotation resistant western corn rootworm beetles lay their eggs in soybean fields. Courtesy of © 2010 Joseph L. Spencer.

History and Pest Status

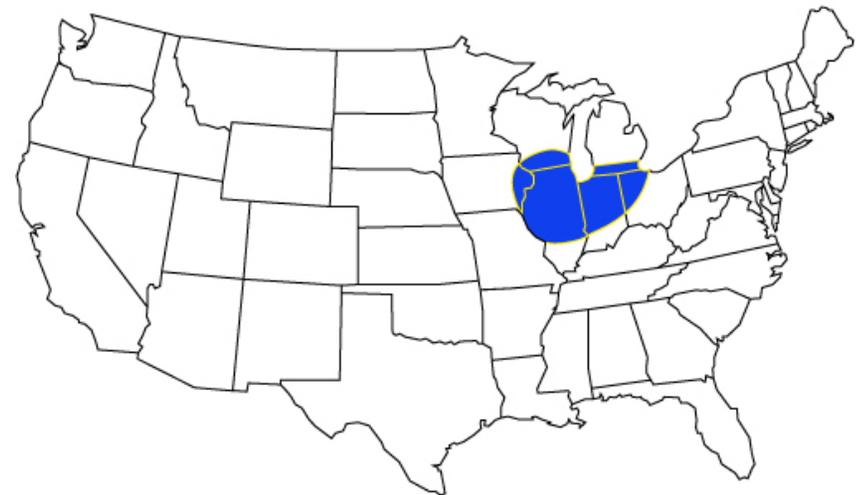
Rotation Resistant Western Corn Rootworm

By 2009, the rotation-resistant subspecies had spread from Piper City, Illinois to cover the northern 2/3rds of Illinois and Indiana, and parts of southern Wisconsin, eastern Iowa, western Ohio, and southern Michigan.

Since this subspecies can no longer be controlled by crop rotation, it is forcing producers to utilize less economical control options such as insecticides and transgenic corn rootworm hybrids in both first-year corn and rotated corn.

Because of the economic damage inflicted by the rotation-resistant subspecies, considerable efforts have been expended to determine how it lost its **fidelity** for **ovipositing** in corn, how it disperses, and what the next mutation might be.

Distribution of variant western corn rootworm



History and Pest Status

Northern Corn Rootworm

Prior to 1967, the northern corn rootworm (NCR) was grouped with a sister species, *Diabrotica longicornis*, and literature prior to that time did not distinguish between the two species. However, geographical and habitat differences determine which of the two species early literature referred to. While *Diabrotica longicornis* was first recorded in Colorado in 1824, what we now call northern corn rootworms were first found feeding on corn in Illinois and Missouri in the 1870's and 1880's.

Both species most likely originated in the grass prairies of the Great Plains, although some have suggested NCR may have originated in the north central United States. By 1955, NCR was found throughout the Corn Belt. In the 1960s and 1970s, NCR's range expanded eastward into New York, Pennsylvania, and eastern Canada. Its current range extends north and eastward from Kansas and Nebraska.

Family CHRYSOMELIDÆ.

54. THE CORN ROOT WORM.

(*Diabrotica longicornis*, Say.)

1823. SAY, THOMAS.—*Galleruca longicornis*. Journ. Acad. Nat. Sci. Phila. III., 460. Complete writings II., 223. Original description. Obtained specimens near Rocky Mountains.
1879. RILEY, C. V.—*Diabrotica longicornis*. Rep. Com. Agr., 1878, p. 208. Correspondent from Missouri reports that his INDIAN CORN was seriously damaged by larvæ of this insect.
1880. FRENCH, G. H.—A Corn Insect. Prairie Farmer, Aug. 9. Publishes a letter from Dr. E. R. Boardman, Stark county, Ill., [see following entry] accompanying corn root worms. Describes these briefly, notes their resemblance to larvæ of *Diabrotica vittata* and determines them doubtfully as larvæ of Chrysomelidæ.
- BOARDMAN, E. R.—Idem. Prairie Farmer, Aug. 9. In a letter to Prof. French reports serious injury to roots of INDIAN CORN, and sends larvæ evidently responsible for it.
- FRENCH, G. H.—The New Corn Insect. Prairie Farmer, Sept. 4. Reports additional letters from Dr. Boardman (see following entry); identifies larva as that of *Diabrotica longicornis* by breeding; and infers from the life history of *D. vittata* that *D. longicornis* will prove to be two- or three-brooded, and that it deposits its eggs at the roots of INDIAN CORN. Discusses clean culture, rotation of crops, and alkaline applications as remedies.
- BOARDMAN, E. R.—Idem. Prairie Farmer, Sept. 4. Letters to Prof. French reporting great abundance of *Diabrotica longicornis* in localities infested by the corn root worm, and expressing the belief that the latter is the larva of that species. Gives additional details on life history and extent of injury to INDIAN CORN, and notes abundance of imago on rag weed. Approves rotation of crops and suggests destruction of rag weed as a remedy.

Click to enlarge. Copy of an 1885 report by the Illinois State Entomologist. Note that northern corn rootworm was originally listed as *Diabrotica longicornis*, Say.

History and Pest Status

Northern Corn Rootworm

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- saying that it occurs in the roots of INDIAN CORN stalks. Treats as a grape insect. Describes the larva.
1870. RILEY, C. V.—*Prionus imbricaria*. 2d Rep. St. Ent. Mo., pp. 89-91, fig. 63. States that the larva he described as *Orthosoma cylindricum* is probably that of above species. Gives food habits of two other closely allied species.
1871. GLOVER, TOWNSEND.—Idem. Rep. Com. Agr., 1870, p. 72. Gives food plants according to Riley.
1876. THOMAS, CYRUS.—Idem. 6th Rep. St. Ent. Ill., p. 148. Distinguishing characters. Remedies.

Family CHRYSOMELIDÆ.

54. THE CORN ROOT WORM.

(*Diabrotica longicornis*, Say.)

1823. SAY, THOMAS.—*Galleruca longicornis*. Journ. Acad. Nat. Sci. Phila. III., 490. Complete writings II., 223. Original description. Obtained specimens near Rocky Mountains.
1879. RILEY, C. V.—*Diabrotica longicornis*. Rep. Com. Agr., 1878, p. 308. Correspondent from Missouri reports that his INDIAN CORN was seriously damaged by larvae of this insect.
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- FRENCH, G. H.—The Corn Root Worm. Prairie Farmer, Sept. 18. Reports letters of S. A. Forbes and E. R. Boardman; repeats suggestion of clean culture and rotation of crops; and expresses belief that larvae will be found feeding upon the roots of Composites.
- FORBES, S. A.—Idem. Prairie Farmer, Sept. 18. Reports to Prof. French absence of imagos in food of birds, and determines, by dissection, that adults feed upon pollen of thistles.
- BOARDMAN, E. R.—Idem. Prairie Farmer, Sept. 18. Gives additional data on life history and injuries to INDIAN CORN; notes damage done by imagos by eating silk and preventing fertilization. Reports that he has found larvae in roots of rag weed, and thinks proof conclusive that the insect is more than one-brooded.
- RILEY, C. V.—*Diabrotica longicornis*. Amer. Ent. Ill., October, p. 247. Date of first receipt of larva and pupæ, August, 1874. Invariably found in conjunction with real wireworm, *Drusisteria amabilis*, which he believes feeds upon corn root worm. Suggests rotation of crops, destruction of ragweed, and the application of lime and ashes.
- WEBSTER, F. M.—More about the New Corn Insect. Prairie Farmer, October 2, 1880. Notes no damage at time of writing, although in cornfields in numbers double that of year preceding. *Leptotrachelus dorsalis* more abundant than formerly.
1881. THOMAS, CYRUS.—*Diabrotica longicornis*. 10th Rep. St. Ent. Ill., pp. 44-46. Contains a letter from Dr. E. R. Boardman, of Stark county, Ill. (See under 1880, French, G. H.) Describes larva and imago; gives distribution; and expresses the opinion that the insect is not likely to prove troublesome.
1882. FRENCH, G. H.—Idem. 11th Rep. St. Ent. Ill., pp. 65-73. Character and amount of injury done as reported by several correspondents. Said to live in roots of ragweed as well as in INDIAN CORN, and thought to be two- or more brooded. Food of imagos. Rotation of crops and clean culture recommended. Description of larva and imago.
- SAUNDERS, W.—Idem. Rep. Ent. Soc. Ont., 1881, p. 7. Brief synopsis of the account of this insect in 10th Rep. St. Ent. Ill.
- FORBES, S. A.—The Corn Root Worm in McLean County. Bloomington "Leader," September, 1882. Means of identifying the injuries of this insect. Finds it in nearly all the fields of INDIAN CORN visited, retarding growth of plant. Rotation of crops a complete remedy.
- FORBES, S. A.—The Corn Root Worm, *Diabrotica longicornis*, Say. Illinois Department of Agriculture, Circular No. 94, Illinois Crops for 1882, p. 122. Reports the recent discovery of the eggs of the imago, and gives first correct statement

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- of life history. Describes character and amount of injury to INDIAN CORN, and demonstrates sufficiency of rotation of crops as a remedy.
- BOARDMAN, E. R.—Economic Entomology. Stark County News, December 21. General article reporting the discovery that heavy manuring is protection against the injuries of the root worm.
- FORBES, S. A.—Idem. Prairie Farmer, December 30. Reports this insect as one of the most destructive enemies of INDIAN CORN in central Illinois. Gives description and life history of insect, and first figures of egg, imago, and larva; details method, amount, and distribution of injury to corn by larva and imagos, and again recommends rotation of crops as a preventive.
1883. FORBES, S. A.—Notes of the Season. Prairie Farmer, Dec. 8. Reports occurrence of larva in roots of sorghum, its absence in broom corn, and continued injury to MAIZE.
- POTKOR, E. A.—*Diabrotica longicornis*. Third Biennial Rep. Kan. St. Bd. Agr., VIII., 616. Probable occurrence in Kansas. Brief account of its habits, characters, and of preventive measures.
- FORBES, S. A.—Idem. A Lecture on Insects Affecting Corn, pp. 6-12. One-brooded; eggs laid in autumn, hatching June or July following. Larva resulting, immediately attack roots of INDIAN CORN. Rotation of crops a thorough safeguard.
- FORBES, S. A.—Idem. 12th Rep. St. Ent. Ill., pp. 10-31, figs. 1, 2, 3, 4, 5. "A minute, slender, white grub, about two-fifths of an inch long, boring the roots of INDIAN CORN in the ground from June to August, transforming into a grass-green beetle which feeds upon the pollen and silk of the corn, and upon the pollen of other plants." A recent addition to the list of insect pests. Extent and amount of injuries. Imago, pupa, larva, and egg fully described, and life history of each given in detail. Injuries to corn; natural and artificial enemies.
1885. FORBES, S. A.—Idem. 14th Rep. St. Ent. Ill., p. 5. Under head of "Entomological Calendar," states that the corn root worm has continued its injuries, interrupted only by the growing disposition to practice rotation of crops.

55. BROAD-STRIPED FLEA BEETLE.

(*Systema blanda*, Melsh.)

1848. MELSHIMER, F. E.—*Systema blanda*. Proc. Acad. Nat. Sci. Phila., III., 164. Original description.
1874. GLOVER, TOWNSEND. Idem. Rep. Com. Agr. 1873, p. 152, fig. 1. Correspondent writes from Pennsylvania that these beetles

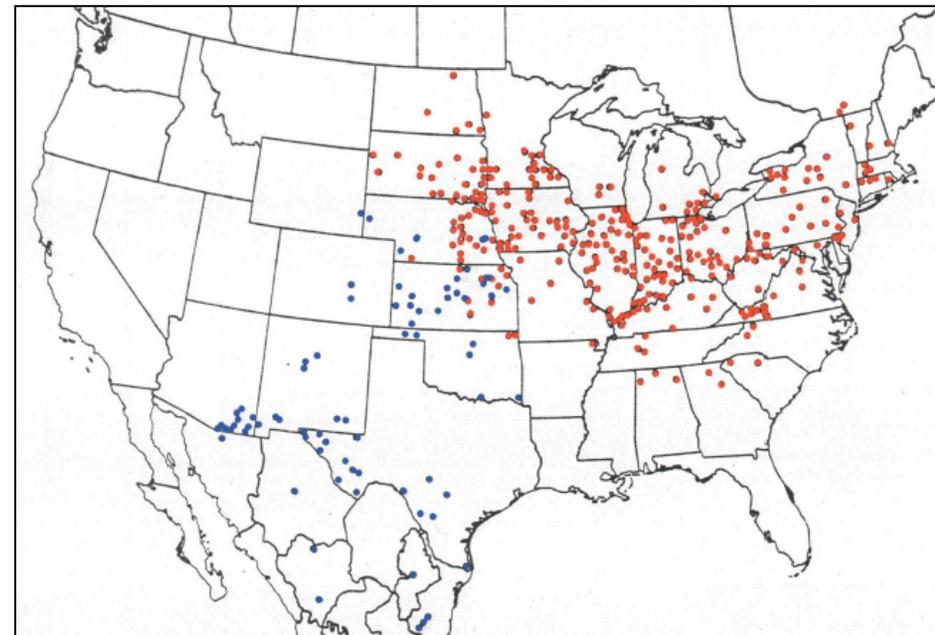
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History and Pest Status

Northern Corn Rootworm

In 1967, two subspecies (*Diabrotica longicornis* and *Diabrotica longicornis barberi*) were formally recognized based on differences in geographic range, economic impact, and different colors for certain morphological features. In 1983, northern corn rootworm was elevated to a species (*Diabrotica barberi*) based on sexual isolation and different habitat preferences.

Although it is considered to be an annual pest of continuous corn throughout its range and in the same fields as western corn rootworms, it is less of a threat than western corn rootworm due to its smaller size, feeding habits, and reproductive potential. It is considered a major pest in parts of South Dakota, Minnesota, and Iowa due to extended diapause.



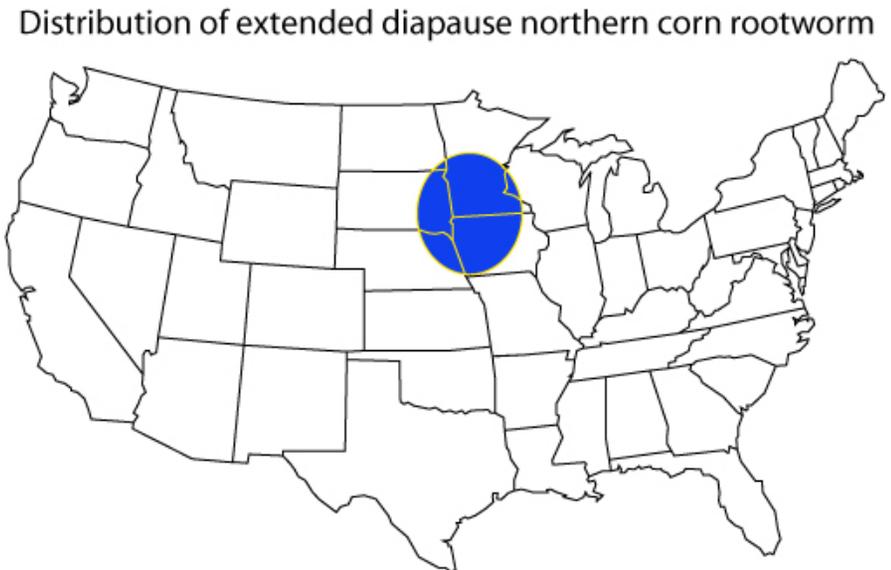
Differences in geographic range of northern corn rootworms (red circles) and *Diabrotica longicornis* (blue circles). Modified from Krysan et al. (1983). Courtesy of Laura Campbell.

History and Pest Status

Extended Diapause Northern Corn Rootworm

In the early 1980s, eggs from a population of northern corn rootworm collected in South Dakota were documented to diapause through more than one winter. Around this same time rootworm damage was reported in first-year corn in southwest Minnesota, eastern South Dakota, and northern Iowa.

In fields where corn is planted every other year, northern corn rootworm eggs are laid in corn and then hatch in corn two years later resulting in damage to first-year corn. Up to 40 percent of the eggs diapause through two or more winters causing a three-year rotation to be ineffective. Damage from extended diapause NCR varies from year to year and field to field, even in fields with a history of the problem, but can be extensive when it does occur.



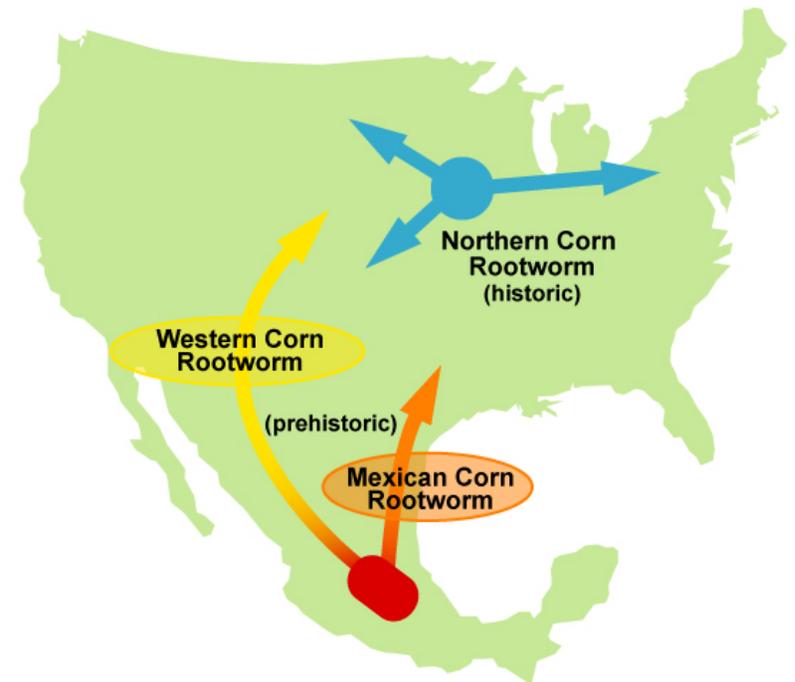
History and Pest Status

Mexican Corn Rootworm

Similar to the western corn rootworm, the Mexican corn rootworm (MCR) is indigenous to Central America. It now ranges from Costa Rica northward to central Texas and Oklahoma. In the United States, its westward distribution is limited by low rainfall, although irrigation has artificially extended its westward occurrence into New Mexico. The Mexican corn rootworm life cycle coincides with the rainy season in Mexico.

Mexican corn rootworm is a serious pest of corn in several areas of central and southern Texas as well as Mexico.

Mexican corn rootworm was not differentiated from the western corn rootworm until 1980 when it was described as a subspecies.



Presumed origins and paths of diffusion of the MCR, WCR, and NCR. Shaded areas represent the centers of origin and the arrows represent the paths of diffusion. Note that the MCR and WCR subspecies have the same center of origin, but diffused through different paths. Modified from Branson and Krysan (1981).

History and Pest Status

Southern Corn Rootworm

The southern corn rootworm (SCR) is native to North America and was first described in 1775 with larval injury to corn first described in 1828. Southern corn rootworms (also called the spotted cucumber beetle in the adult stage) can be found in most areas east of the Rocky Mountains, in southern Canada, and in Mexico. It is most abundant and destructive in the southern United States, with the coastal areas of Texas and Louisiana frequently receiving enough damage to require treatment.

The western spotted cucumber beetle (*Diabrotica undecimpunctata undecimpunctata*), found only in Arizona, California, Utah, Colorado, Oregon, and Washington, is a subspecies of the southern corn rootworm. The western spotted cucumber beetle has a more restricted host range than the spotted cucumber beetle. While the southern corn rootworm larvae prefer to feed on corn roots, they also feed on the roots of several other plants, such as **cucurbits**, **legumes**, sweet potato, and weeds. The western spotted cucumber beetle larvae mainly feeds on corn roots.

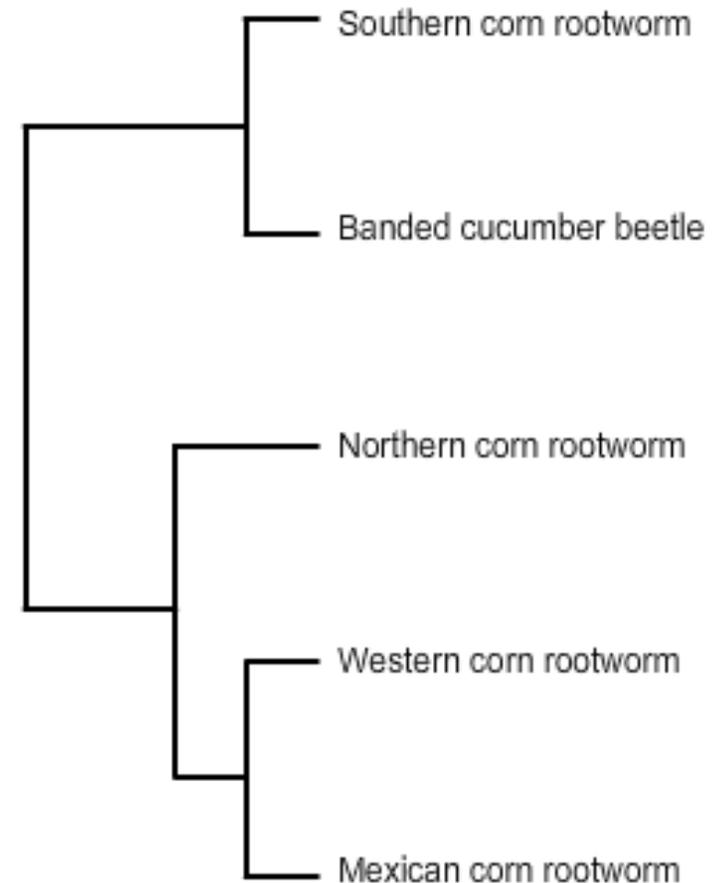
History and Pest Status

Southern Corn Rootworm

The southern corn rootworm is the only member of the rootworm complex in the *fucata* group and as such, is more closely related to other *Diabrotica* species, such as the banded cucumber beetle (*Diabrotica balteata* LeConte), than to the other three corn rootworms found in North America. Similar to southern corn rootworm adults, banded cucumber beetles do not have a strong preference for corn.



Banded cucumber beetle. Courtesy of Russ Ottens, University of Georgia, Bugwood.org



A phylogenetic tree of the rootworm complex based on DNA sequence analysis. (Modified from Szalanski, et al., 2000)

Identification

Western Corn Rootworm

Western corn rootworm adults are about $\frac{1}{4}$ " long, and have yellow bodies with three black stripes on their **elytra**. Females are slightly larger than males and have stripes that are generally more pronounced than the male's stripes. Sometimes the black stripes on males "bleed" together or overlap, making the wings appear solid black.



Western corn rootworm adult. Courtesy of Tom Hall, Pioneer Hi-Bred.



Adult western corn rootworm male (left) and female (right). Courtesy of B. Christine.

Identification

Northern Corn Rootworm

Adult northern corn rootworm beetles are about $\frac{1}{4}$ " long and have no distinctive markings. Newly emerged adults are tan or cream colored when they first emerge, but turn a solid yellowish green as they age. In much of the Corn Belt all body parts are uniformly the same color, but in the north, east, and northeast parts of its range the **antennae**, **tibiae**, **tarsi**, and **clypeus** may be darker.

There are no distinctive markings to differentiate male and female NCR, so the most reliable method is to compare the apex of the abdomen. Females have a somewhat pointed apex, while the males have a rather blunt apex. Males also have an additional **sclerite** on the apex of the abdomen. Males are typically a little smaller than females, and their antennae are longer.



Northern corn rootworm adult. Courtesy of Marlin Rice.



Pointed apex of a northern corn rootworm female. Courtesy of Jim McClarin, Bugguide.net/node/view/144084/bgimage.

Identification

Mexican Corn Rootworm

Mexican corn rootworm adults are similar in appearance and size to northern corn rootworm adults, but can be distinguished by a black stripe on the **femur**, which is absent in the other corn rootworm species. The body of the MCR varies in color from pale green to bright green. Their wing covers may match the body color or may have slightly contrasting yellowish- to orangish-green stripes. Regions inhabited by the Mexican and northern corn rootworm do not overlap.

Similar to the NCR, there are no distinctive markings to differentiate male and female MCR. As is the case with all adult rootworm beetles, the females' abdomens have a somewhat pointed apex, while the males' abdomens have a rather blunt apex. Males are also typically a little smaller than females, and their antennae are longer.



Mexican corn rootworm beetles are similar in appearance to northern corn rootworm beetles. Courtesy of Robert Glodt.

Identification

Southern Corn Rootworm

The southern corn rootworm adult is about 3/8 inch long with a bright yellowish-green body. The head, legs, and antennae are black. Twelve black spots in three rows are present on the wings. The western spotted cucumber beetle (WSCB) subspecies is nearly identical except the center two spots closest to the head are not distinctly separate so the front row only has 3 spots for a total of 11 spots. Southern corn rootworms do not overwinter successfully in the Midwest. Populations migrate from the southern states beginning in April.



Southern corn rootworm (or spotted cucumber beetle) has 12 black spots in three rows. Courtesy of J. Whitney Cranshaw, Colorado State University, Bugwood.org.



The western spotted cucumber beetle only has 11 black spots in three rows. Courtesy of Jim Conrad.

Identification

Similar Looking Beetles

Western corn rootworms, southern corn rootworms (spotted cucumber beetle), and striped cucumber beetle (*Acalymma vittata* (Fabricius)) are commonly found together in pumpkin (*Cucubita mixta* Pang.) patches. Although the striped cucumber beetle and female western corn rootworm are similar in appearance, striped cucumber beetles do not cause damage to corn or soybeans.

The stripes on striped cucumber beetle are straighter than those on western corn rootworm. The WCR strips also do not extend the full length of the elytra. The underside of the striped cucumber beetle is nearly black while it is yellow on the WCR. Additionally, the tibia of the hind leg on the striped cucumber beetle is yellow, while it is black on the western corn rootworm.

FYI: When set on their backs, striped cucumber beetles and WCR beetles immediately right themselves. An easy method to look at their underside is to place them in a plastic bag and then simply turn the bag over.



Comparison of the western corn rootworm male (left), female (center), and the striped cucumber beetle (right). Courtesy of J. Whitney Cranshaw, Colorado State University.



Cucumber beetle is on the left (dark belly), and western corn rootworm is on the right (yellow belly). Courtesy of The Morton Arboretum.

Identification

Similar Looking Beetles

Grape colaspis (*Colaspis brunnea* Fabricius) beetles are sometimes confused with newly emerged northern corn rootworm beetles. The creamy or tan colors may be similar, but grape colaspis beetles are only about 1/6 of an inch long. Grape colaspis also appear striped due to rows of shallow pits that run the full length of their elytra.

Grape colaspis larvae and adults both feed on corn, although the damage is rarely economically significant. They are most frequently found in corn that follows red clover (*Trifolium pratense* L.).



Grape colaspis adult feeding on a soybean leaf. Courtesy of Duane Frederking, Pioneer Hi-Bred.



Pale colored northern corn rootworm beetle. Courtesy of Bill Johnson.

Identification

Similar Looking Beetles

Diabrotica longicornis is a sister species to the northern corn rootworm and also a member of the *virgifera* group. The two species are separated by habitat preference, color differences, and differences in mating behavior and responses to pheromones. While NCR prefers corn and is found throughout the Corn Belt, *D. longicornis* is found in the grasslands of the southwestern U.S. and Mexico, generally preferring grasslands and buffalo gourd (*Cucurbita foetidissima* HBK) and other cucurbits when found close to wet areas. Their ranges overlap in Kansas and Nebraska, where they are difficult to differentiate.

Similar to NCR, *D. longicornis* is pale green to yellow green throughout most of its range with darker structures further west and south. One differentiator is that *D. longicornis* has black tibiae, tarsi, clypeus, and antennae through most of its range, although both species have darker tibiae, tarsi, clypeus, and antennae in the **distal** parts of their ranges.

Both species are known to undergo extended diapause in a portion of the population.



Diabrotica longicornis. Courtesy of Mike Quinn, Bugguide.net.

Identification

Rootworm Identification Matching Game

Drag the name to the correct insect.

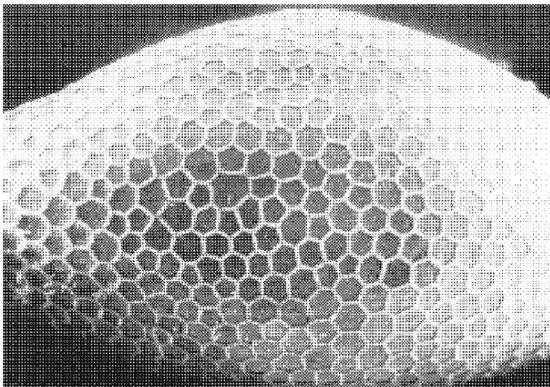
1. Northern corn rootworm
2. Southern corn rootworm
3. Western spotted cucumber beetle
4. Western corn rootworm female
5. Western corn rootworm male
6. *Diabrotica longicornis*
7. Striped cucumber beetle
8. Banded cucumber beetle
9. Mexican corn rootworm



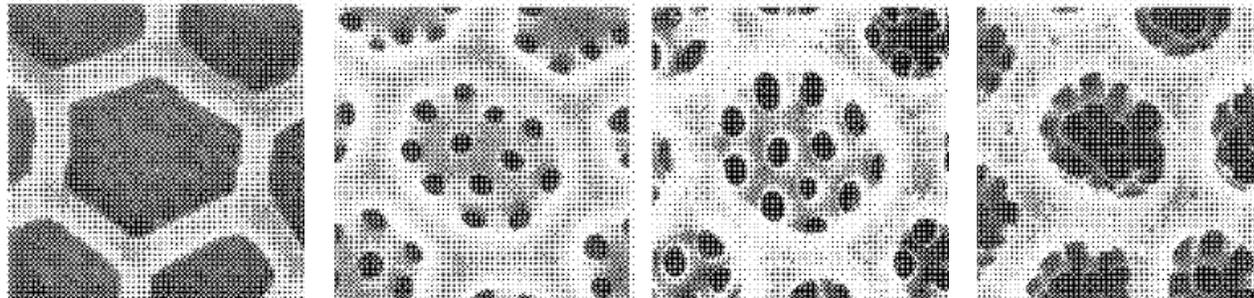
Identification

Eggs

Adult beetles are the only life stage of rootworms that can be distinguished visually without the assistance of a microscope. With the aid of a microscope at a magnification of 200 times the primary sculpturing of *Diabrotica* species' egg's **chorion** can be seen with bold ridges which form polygons, which are usually hexagonal. At 1200 times or greater magnification, secondary sculpturing which lies within the area surrounded by polygonal ridges can be seen. This secondary sculpturing differs between most of the *Diabrotica* species. However, the secondary sculpturing can not be differentiated between WCR and MCR subspecies, the SCR and WSCB subspecies, or the NCR and *Diabrotica longicornis* sister species.



Diabrotica lemniscata egg chorion at 200 magnification.

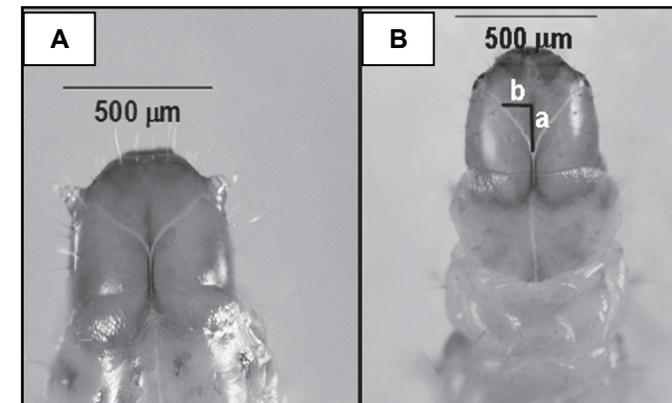


Sculpturing of egg chorion at 2,000 magnification. Starting from the left: WCR, NCR, *Diabrotica longicornis*, and SCR.

Identification

Larvae

The larvae of most *Diabrotica* species are morphologically indistinguishable without the aid of a microscope. With a microscope, WCR and NCR larvae can be differentiated by measuring “the distance between the head capsule frontal **suture** and the **median endocarina** at the appropriate distance **anterad** of the **epicranial stem**” (Becker and Meinke, 2008). In addition to these morphological differences, biochemical and genetic techniques can be used to correctly identify the different species.



Dorsal view of the larval head capsules of 3rd instar WCR larva (A) and NCR larva (B). To distinguish between the species, measure the distance from the left frontal arm of the Y-shaped epicranial suture to the median endocarina (b) at a specific distance anterad of the epicranial stem (a). Courtesy of Becker, S.C. and L.J. Meinke. (2008).

Head capsule measurements that separate western and northern corn rootworm larvae									
Species	1st instar at 12X magnification			2nd instar at 12X magnification			3rd instar at 6x magnification		
	a	Range	Mean ± SD*	a	Range	Mean ± SD*	a	Range	Mean ± SD*
WCR	40	30-40	37 ± 4	80	70-80	77 ± 5	120	120-140	121 ± 3
NCR	40	20-25	21 ± 2	80	50-60	59 ± 3	120	70-90	80 ± 4

a = distance in µm anterad of epicranial stem on the median endocarina.
b = distance in µm recorded from left frontal arm to median endocarina.
* Standard deviation
Adapted from: Becker, S.C. and L.J. Meinke. (2008).

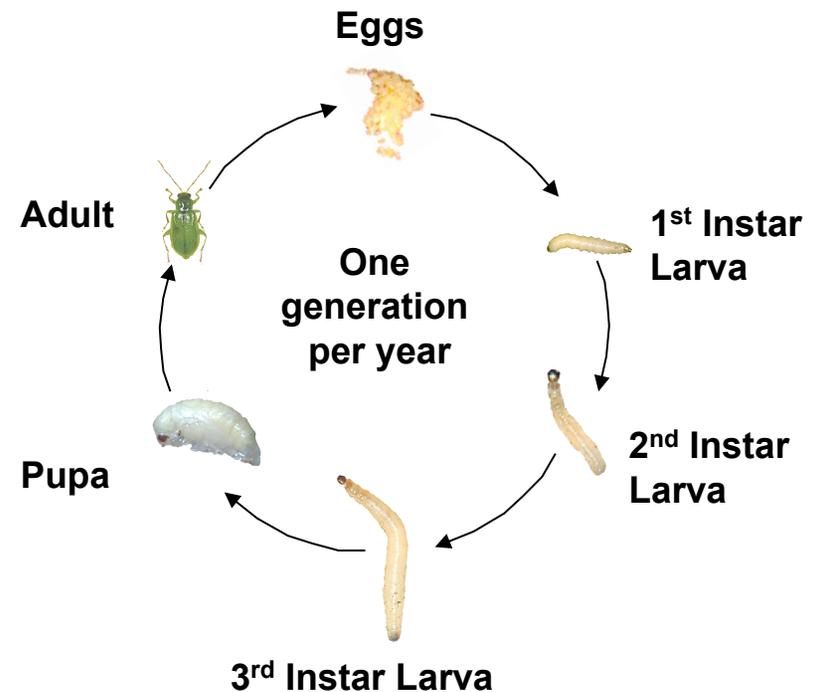
Life Cycle

Western, Northern, and Mexican Corn Rootworm Overview

Western, northern, and Mexican CRW overwinter as eggs, usually near the base of corn stalks. In the spring, newly hatched larvae are attracted to the CO₂ respired from growing plant roots and move down into the soil and begin feeding on corn roots. The larvae go through three instars or worm stages before they pupate in the soil.

About 5 to 10 days after they pupate, adults emerge from the soil and begin feeding, preferably on corn pollen or corn silks.

In late summer, mated females deposit small egg clutches near the base of corn stalks where they remain throughout the winter. After laying eggs female adults reemerge and continue feeding. The adults die after several hard frosts in the early autumn.



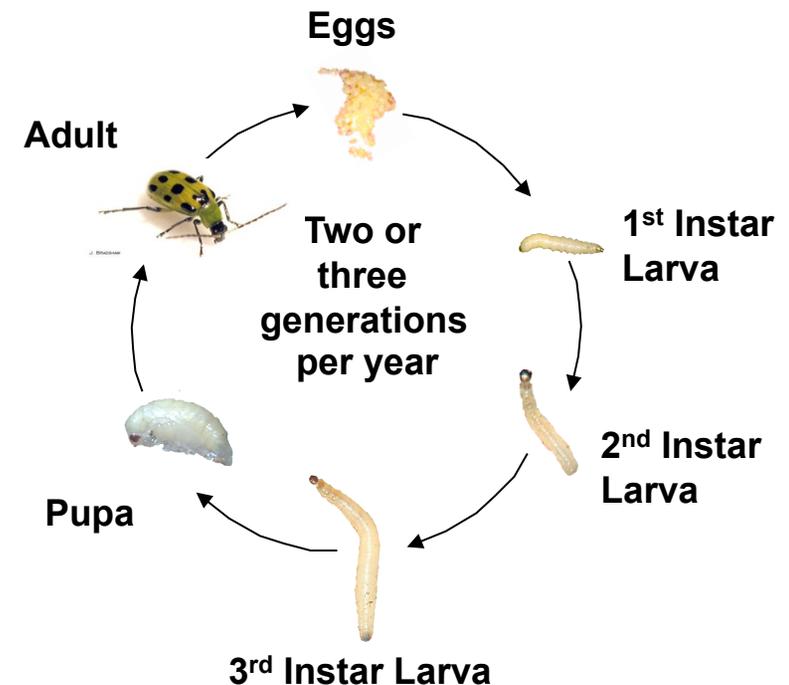
Life Cycle

Southern Corn Rootworm Overview

Southern CRW overwinter as adults in and around the base of plants or other protected places. In Southern states, adult beetles become active in the spring, feeding on a variety of host plants including weeds and grasses.

Soon after corn and sorghum (*Sorghum bicolor* L.) emerge, the adults lay 200-1200 eggs singly in the soil close to the base of larval host plants. Eggs hatch 5 to 11 days later. Young larvae feed on the roots of corn, sorghum, or other hosts for 2 to 4 weeks, and pupate. First generation adults emerge 1 to 2 weeks after pupation. The whole life cycle takes only 6 to 9 weeks to complete.

SCR are multivoltine. In areas where multiple generations occur, first generation larvae are found on the roots of corn from late spring until mid-summer. Second generation adults are found from September to November on clover (*Trifolium* L.), alfalfa (*Medicago sativa* L.), and other plants. Adults may come out to feed during warm periods of the winter months.



Life Cycle

Egg

Corn rootworm eggs are creamy white, football shaped, and less than 1/32" long. Once the eggs of WCR, NCR, and MCR are laid in the late summer to early fall, they remain unhatched until spring.

Eggs of all three species must go through a period in which development is suspended, known as "diapause", to prevent larvae from hatching in the fall and dying in the cold winter temperatures or when the weather is unsuitable for a host.

First generation SCR eggs are laid in the spring and hatch in 7 to 10 days.



Western corn rootworm eggs. Ken Gray Image, Courtesy of Oregon State University.

Life Cycle

Diapause

Winter dormancy consists of two stages, a period of **obligate** diapause which is followed by a period of **facultative quiescence**. Soon after oviposition the embryo begins to develop, but development stops within 11 to 13 days at 68 degrees Fahrenheit as the egg enters diapause. As diapause starts, the embryo is immersed in the yolk and remains there until diapause ends.

There is a geographic **cline** in **diapause intensity** with the length of diapause increasing from north to south. While diapause intensity is under genetic control, artificial selection selects individuals that can hatch when there will be a host present for the larvae to feed on. In one study, diapause duration lasted an average of 253 days for MCR and only 73 days for WCR under the same laboratory conditions. Depending on location, diapause intensity reportedly varies from less than 80 days to more than 160 days for WCR.

The end of diapause is determined by time, and is not triggered by any known environmental signals. In the temperate regions of the U.S. Corn Belt, the end of diapause occurs during the winter when soil temperatures are still below 52 degrees Fahrenheit, the thermal threshold for development.

Life Cycle

Quiescence

After the end of diapause, eggs remain dormant in a state of **chill-quiescence** until the soil temperature warms to at least 52 degrees Fahrenheit.

In addition to the temperature requirement, post-diapause eggs also have to absorb water to complete development. In the absence of water post-diapause eggs will go into a state of **dry-quiescence** until water is absorbed.

After the soil warms to at least 52 degrees Fahrenheit and sufficient water is absorbed, post-diapause development begins again and continues until hatching.

FYI: It is thought that a long duration diapause is necessary for the MCR to prevent post-diapausal development from occurring during winter showers instead of waiting for the true rainy season to break dry-quiescence. In Mexico, WCR and MCR eggs diapause during the dry season when host plants are not available. Following diapause, the eggs go into a dry-quiescence until the rainy season allows corn planting, and post-diapause development to occur synchronously.

Life Cycle

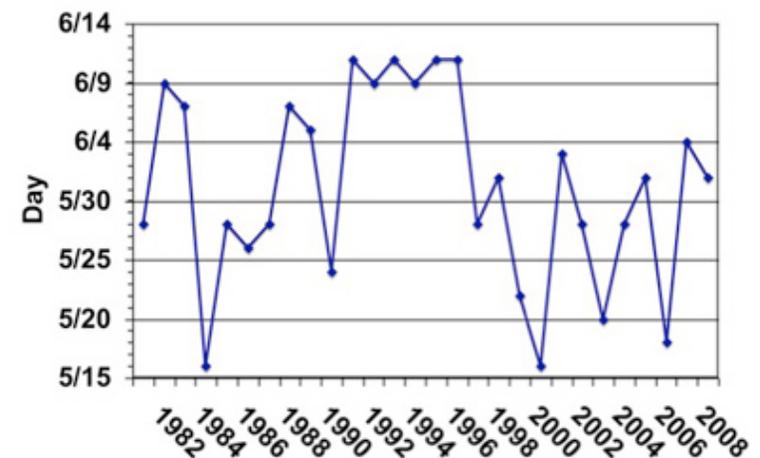
Egg Hatch

Depending on location and weather conditions, larvae in the Corn Belt begin to **eclose** from overwintering eggs in the middle of May or early June. The chart on the right shows the yearly variation in first observation of rootworm larvae in corn roots in west central Indiana. The average length of egg hatch has been reported as 29 days for males and 32 days for females.



The firefly, or lightning bug, is a beetle that creates light. Courtesy of Gail Shumway/Getty Images.

First Observation of Rootworm Larvae in Corn Roots, Tippecanoe County, Indiana, 1982-2009



FYI: One often cited indicator of rootworm eclosion from the egg stage is the emergence of fireflies in the spring and early summer. While this is not 100% reliable due to the large number of species of firefly, it is an indicator that it is a good time to look for rootworms.

Life Cycle

Larvae

Newly hatched larvae are nearly colorless, but turn white as they get older. Mature larvae are a creamy white color with a brown head capsule and brown plate on top of the last abdominal segment, which gives them a double-headed appearance. Larvae of all CRW species have three pairs of short legs behind the head capsule.

All species of CRW larvae develop through three instars. The larval stage for WCR and NCR lasts from 4 to 6 weeks, while SCR larvae develop through three instars in 10 to 16 days.

The first instar larva of all four rootworms is less than 1/8 inch in length. Third instar WCR and MCR larvae grow to about 1/2 inch long, while NCR larvae grow to about 5/8 inch. Third instar SCR larvae can grow to about 3/4 inch long when fully developed.



Western corn rootworm larvae that are about 1/4" long. Courtesy of Scott Bauer, USDA Agricultural Research Service, Bugwood.org.



Different sizes of rootworm larvae. Courtesy of Purdue University.

Life Cycle

Larvae

An instar is the growth stage between two molts. When a corn rootworm larva first ecloses from an egg it is in its first instar. This freshly eclosed larva has a rigid head so in order to grow it has to shed its skin by molting. The second instar occurs after the first molt; the third instar is after the second molt. Although not easy to perform with live larvae, one method of differentiating each of the three larval instars is to measure the head capsule width with a micrometer.

Corn rootworm species instar differentiation			
	<i>Head Capsule Width in Micrometers (μm)</i>		
<i>Species</i>	<i>1st Instar</i>	<i>2nd Instar</i>	<i>3rd Instar</i>
Western Corn Rootworm	200-260	300-400	440-560
Northern Corn Rootworm	200-270	270-410	410-560
Southern Corn Rootworm	250-300	390-415	580-640

WCR and NCR source: Hammack, L., et al. (2003). SCR source: Arant, F.S. (1929).

Life Cycle

Larvae Survival

Larvae that eclose in very dry or sandy soils may become scratched and lacerated as they search for food causing them to lose moisture and die. Larvae that eclose in silty or loam soils are able to move further to find food and have a higher survival rate.

Many larvae that eclose into soil that is flooded or saturated with water will either drown or be unable to locate a suitable host. Additionally, if a host is not present, such as when corn has not been planted, the larvae will starve to death.



Rootworm larvae cannot survive flooding; however, rootworm eggs can. Courtesy of Dennis Nowaskie, Southwest Purdue Agricultural Center.

Life Cycle

Larvae Movement

First-stage larvae are attracted to the CO₂ released by corn roots. Since young larvae are small and soft bodied, movement in the soil is likely accomplished by crawling through interconnected air-filled pores.

Young larvae typically crawl through about 6 inches of soil to reach their food source, but they may crawl through up to 18 inches of soil for food when necessary. However, if soil pore size is smaller than head capsule width, such as in compacted soils, movement is limited and the larvae may starve to death.

Until a host is found, young larvae exhibit a ranging behavior with a relatively fast rate of travel and few turns.



Young rootworm larvae can move several inches in search of food, but they cannot move through compacted soil such as this tractor tire rut. Courtesy of David Goad.

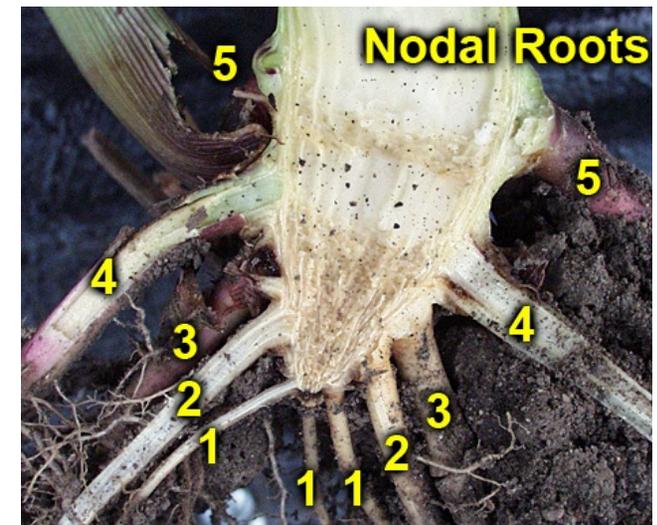
Life Cycle

Larvae Feeding

While CO₂ stimulates larvae movement towards host plants, exposure to a host root slows down their movement. Larvae will turn and cross over its previous path until it makes contact with an actual root. Feeding is stimulated by a compound found in germinating corn roots.

First instar larvae initially feed on root hairs and burrow into the roots of the lower nodes. As the corn plant continues to grow and larvae reach the 2nd and 3rd instars, they tend to leave the initial roots they were feeding on and move toward the base of the stalk where newer nodes (4-8) are developing. Root feeding continues until the larvae reach the pupation stage prior to becoming an adult.

If CRW feeding pressure is high enough, larvae can leave the plant they were established on and move up to three plants away in the same row and across an 18-inch row in search for food. Movement of 24 inches from egg hatch to adult emergence is conceivable.



A corn plant's nodal root system. Courtesy of R.L. Nielsen, Purdue University.



Rootworm larvae inside corn root. Courtesy of Purdue University.

Life Cycle

Larvae Feeding

It is currently unknown if WCR or NCR larvae regularly feed on the roots of weeds, but studies suggest that WCR larval development could occur on several non-corn grass species. In experiments, two weed species commonly found in corn fields, fall panicum (*Panicum dichotomiflorum* Michx.) and large crabgrass (*Digitaria sanguinalis* (L.) Scop.), appear to be able to support WCR larvae nearly as well as corn. Studies have also shown that WCR can survive to adulthood on the perennial grass giant miscanthus (*Miscanthus x giganteus*), a potential biofuels crop that could grow next to corn.



Large crabgrass plants could support WCR larvae. Courtesy of Mark and Barbara Shepard.



Fall panicum plants could also support WCR larvae. Courtesy of the University of Missouri.



WCR will survive to adulthood on giant miscanthus plants. Courtesy of Mary M. Meyer, University of Minnesota.

Life Cycle

Larvae Feeding

Studies to determine if non-corn species could support NCR larval development have been inconclusive. While corn is the preferred food of SCR larvae, they are known to feed on several other grasses and even a few non-grass hosts.

Mexican CRW has been documented to feed on the roots of several grass species. Adult MCR beetles have been recovered from emergence traps placed over creeping signal grass (*Brachiaria plantaginea* (Link) Hitchc.), Indian goosegrass (*Eleusine indica* L.), Indian lovegrass (*Eragrostis indica* (Hornem.)), and southern crabgrass (*Digitaria ciliaris* (Retz.)).

Mexican CRW larva and pupa have also been collected from Hall's panicgrass (*Panicum hallii* Vasey), Alexandergrass (*Brachiaria plantaginea* (Link) Hitchc.), and fragrant flatsedge (*Cyperus odoratus* L.) in Mexico.



Indian goosegrass can be found throughout most of the southern U.S., including Iowa. Courtesy of Vic Ramey, University of Florida/IFAS Center for Aquatic and Invasive Plants.

Life Cycle

Pupae

After the larvae have completed the three instars, they will pupate in discrete earthen cells. The pupa stage is the dormant stage when no feeding takes place. During this stage the larva is developing into an adult. The CRW pupa is white and somewhat translucent. Pupation lasts five to ten days.



A CRW pupa in a discrete earthen cell. Ken Gray image, Courtesy of Oregon State University.



The CRW pupa is white and somewhat translucent. Courtesy of Jim Kalisch, Department of Entomology, University of Nebraska-Lincoln.

Life Cycle

Adult Emergence

Adult corn rootworms typically emerge between mid-July and mid-August, depending on weather conditions during their developmental period. The duration of adult emergence varies among fields and years, but generally continues for four to six weeks. In a 6-year study in Iowa, WCR average emergence duration was 33.4 days for males and 51.3 days for females. Peak emergence often occurs in July.

Within a given day, peak emergence for both males and females occurs at approximately 8 a.m. with a secondary peak near 8 p.m.



Western corn rootworm beetle emerging from the soil. Courtesy of the Agricultural Institute of Slovenia.

Life Cycle

Adult Emergence

Male western corn rootworms emerge first, followed by WCR females. Northern corn rootworm beetles emerge five to seven days after the emergence of WCR begins with NCR males emerging 2-10 days before the NCR females. Peak cumulative male emergence also occurs earlier than peak female cumulative emergence for both WCR and NCR.

These differences in emergence dates between the sexes are a function of the post-diapause developmental rates of the embryo and larvae.

Corn rootworm adult emergence, 1994, Sanders County, Nebraska				
Date	Cumulative percent emergence			
	Western corn rootworms		Northern corn rootworms	
	Males	Females	Males	Females
July 5	17.9	6.3	0.0	0.0
July 8	39.3	12.5	30.8	0.0
July 12	71.4	31.3	46.2	12.5
July 18	85.7	59.4	61.5	37.5
July 26	89.3	75.0	100.0	100.0
August 2	100.0	84.4		
August 11	100.0	96.9		
August 18	100.0	100.0		

Initial corn rootworm egg hatch was detected on June 2. Initial western corn rootworm emergence was detected on June 17. Initial egg laying female western corn rootworm observed July 20.

Source: Meinke, L.J. (1995).

Life Cycle

Adult Emergence

Many factors affect the number, timing, and size of the emerged adults.

Delayed planting of the corn field where the eggs are laid can delay initial adult emergence and reduce the total number that emerge. This is due to the reduced availability of corn roots and larval colonization sites which result in the death of the earliest hatching larvae.

Adult emergence in conservation tilled fields is often delayed as cooler soil temperatures during egg and larval periods slow development. However, total cumulative emergence is comparable across tillage systems.

The presence of suboptimal alternative hosts, such as grassy weeds in corn, can delay adult emergence and also result in smaller adults compared to a weed-free corn field.



Top: No-till fields are cooler, which delays larval development and adult emergence. Bottom: Grassy weeds in a corn field can lead to higher total adult emergence. Both photos courtesy of Pioneer Hi-Bred.

Life Cycle

Adult Emergence

Reduced row spacing in corn can lead to higher total adult emergence per area. However, on individual plants, increased density of larvae on roots results in delayed emergence, smaller adults, and lower cumulative adult emergence.

Exposure to soil insecticides can impact total adult emergence (see “Total” row in the table to the right), can delay emergence (compare the “Control” to the insecticide-treated emergence on July 27), and in some cases emergence patterns and sex ratios of emerged adults.

Similarly, larvae reared on plants expressing the Cry3Bb1 rootworm *Bacillus thuringiensis* (*Bt*) protein have been shown to develop slower, have delayed adult emergence, and a sex ratio of emerged adults that is skewed more towards females.

Date	Cumulative percent emergence			
	Carbofuran	Chlorpyrifos	Terbufos	Control
June 29	0.0	0.0	0.0	0.0
July 2	0.0	0.0	0.1	0.0
July 6	0.4	0.4	0.7	0.3
July 9	1.4	1.9	2.5	1.6
July 13	5.6	4.9	6.1	6.0
July 16	11.5	9.2	10.6	13.2
July 20	19.1	15.5	16.3	21.7
July 23	31.1	26.5	26.3	36.7
July 27	41.2	40.7	40.9	51.0
July 30	50.1	50.5	48.8	58.7
August 6	60.8	58.8	59.1	67.7
August 13	76.9	74.7	77.2	79.4
August 20	90.7	90.4	91.6	91.3
August 26	97.9	97.8	97.6	98.1
September 3	100.0	100.0	100.0	100.0
	Cumulative average beetle count			
Total	108.6	102.6	81.5	136.0

Source: Adapted from Gray, M.E, et al. (1992).

Life Cycle

Adult Mating

Soon after females emergence, they mate, feed and then disperse, sometimes over long distances. Research on mating behavior of rootworms has focused on WCR and SCR. Very little is known about mating behavior of NCR or MCR.

It takes approximately 5-7 days after male WCR emerge for them to reach sexual maturity. WCR females are sexually mature when they emerge. Soon after emergence, young females crawl up nearby corn plants or fly a short distance to a nearby plant where they feed, groom, rest, or begin **calling** for a male.

Female WCR produce a pheromone by remaining stationary and exerting the terminal abdominal segments. This calling behavior can last for several hours, and most frequently occurs in the morning hours before noon.

In-field dispersal of male WCR in response to pheromone release may be fairly extensive.



Western corn rootworm adults mating.
Courtesy of David Kleiman.

Life Cycle

Adult Mating

Many WCR females mate within hours of emergence. Almost all WCR females mate within two days of emergence. Females rarely mate more than once as one mating usually provides enough sperm to adequately maintain an elevated rate of egg development to support oviposition for 4-5 weeks. Females will not remate when they are ovipositing.

Male WCR sometimes mate more than one female in a day and may mate many times over the several week emergence window. However, it is rare for males to mate more than two or three times. Males typically mate while they are young with the majority of males not mating more than ten days after their initial mating.

Female SCR start mating when they are 5 to 18 days old and begin ovipositing about six days later.

FYI: Hybridization between different species within the *virgifera* group or within the *fucata* group, can occur in lab conditions, but is probably limited in the field.

Life Cycle

Adult Feeding

Adult WCR and NCR beetles are strongly attracted to corn pollen and silks. Since the distribution of silking plants in a corn field is not uniform on any given date, adults are known to concentrate in clusters of silking plants. Population densities within a field and among early to late planted corn fields can occur rapidly in response to which fields or parts of fields are silking.

Both WCR and NCR adults will move away from their preferred habitat (corn) to secondary habitats if the relative attractiveness of the secondary is greater. Adult WCR beetles have been found feeding on other crops such as soybean (*Glycine max* (L.) Merr.), alfalfa, cucurbits, and sunflowers (*Helianthus annuus* L.) as well as non-crop flowers such as giant ragweed (*Ambrosia trifida* L.). Adult NCR beetles, especially females, can be found feeding on other crop and non-crop flowers after corn pollination has ended. When found in prairie systems neighboring corn fields, WCR and NCR prefer pollen from the **Poaceae** and **Asteraceae** families.

As long as other high quality pollen is available, SCR beetles do not have a strong preference for corn. Adult MCR feed primarily on non-corn grasses, but will also feed on corn pollen, and other non-grass pollen.



Life Cycle

Adult Dispersal

Male rootworm beetles are not generally believed to disperse as much as females. One study has shown that the number of variant WCR males caught 200 meters from a refuge is no different than the number of males caught at <22 meters from the refuge, implying that variant WCR males may fly several hundred meters in a short period of time when searching for a female. However, no studies have shown that rootworm males, other than variant WCR typically fly that far from the refuge.

After mating, WCR females remain in the field they were born to feed for up to a week. During this time both males and females move within the field an average of 6-17 meters per day.

After mating and feeding for a few days many ascend and disperse to a different corn field. The majority of dispersing WCR are **gravid** females (after mating, males seem less likely to initiate sustained flight). This bias in dispersal results in populations that move into new fields being heavily dominated by females, most of which are gravid. Once females have dispersed into a new corn field, they resume feeding as their eggs continue to develop.



Extended abdomen of a gravid female western corn rootworm. Courtesy of Paula Davis, Pioneer Hi-Bred.

Life Cycle

Adult Dispersal

In addition to the intrafield and interfield movement, adults may make some long distant journeys during the post-mating, pre-ovipositional dispersal period. Favorable conditions promote WCR ascent and flight from corn fields. Occasionally, airborne adults may be drawn into summertime storms and carried for many miles.

In addition to dispersal through storms some pre-ovipositional WCR may fly up to 24 miles in a given day. Although long distance dispersals are not common, western corn rootworm adults have the capacity to spread rapidly.

Little is known about NCR dispersal, but they are generally considered less mobile than WCR. Adult SCR beetles are strong fliers and are known to migrate as far north as southern Canada most years.



Northern corn rootworm about to take flight.
Courtesy of Tom Murray.

Life Cycle

Adult Egg Laying

About 14 days after emergence the eggs of an adult female matures and she returns to the soil to oviposit her eggs. Historically, WCR oviposited in corn. However, the rotation-resistant WCR populations are now found to oviposit in many crops, including corn, soybean, wheat (*Triticum aestivum* L.), and wheat doubled cropped with soybeans. In general, CRW oviposit in whatever crop they are feeding.

Adult WCR beetles often seek oviposition sites with optimal moisture conditions, which are influenced by soil texture and residue cover. Since WCR do not burrow, they typically utilize drought cracks, earthworm burrows, or root channels to find soil with optimal moisture levels.



Female CRW typically utilize drought cracks to reach oviposition sites with optimal moisture levels. Courtesy of Aninka, Dreamstime.com.

Life Cycle

Adult Egg Laying

Most females oviposit their eggs in the top 4 to 6 inches of soil, but during dry years, WCR females may go as deep as 10 to 12 inches and NCR females may go as deep as 8 inches to lay eggs. Adult MCR typically lay their eggs in the top 2 to 8 inches of soil.

Adult SCR oviposit their eggs at the soil surface. A female protrudes her ovipositor, feels around over the soil surface until a crevice or soft spot is found, forces the ovipositor into the soil at that point, and deposits eggs there. After depositing a few eggs, she moves a short distance and repeats the same process.



Ovipositor expressed from western corn rootworm adult. Courtesy of Marlin Rice.



Female western corn rootworm beetle with eggs expressed. Courtesy of Marlin Rice.

Life Cycle

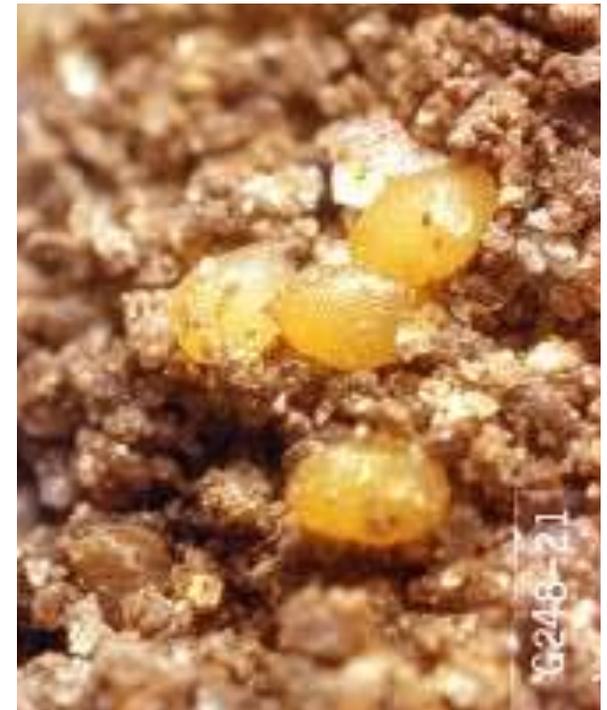
Adult Egg Laying

Adult WCR and NCR usually start laying eggs in August. Once a female begins, she will deposit 75 percent of her eggs over a period of 30 to 35 days in clutches of 50 to 80 eggs. During this time she will alternate between ovipositing and returning to the surface to feed.

A female WCR lays an average of 400 eggs, but may deposit more than 1,000 eggs during her life. A female NCR will lay approximately 300 eggs during her life.

First generation SCR adults lay an average of 400 eggs, but may lay up to 1,200 eggs singly or in groups soon after corn and sorghum emerge in the spring.

After females have oviposited all their eggs, they continue feeding until killed by a frost or eaten by a predator.



Western corn rootworm eggs. Ken Gray Image, Courtesy of Oregon State University.

Life Cycle

Egg Mortality

Western, northern, and Mexican CRW overwinter as eggs in the soil. Egg mortality can be caused by extremely cold temperatures. However, the actual temperature the egg experiences depends on several factors which vary spatially. The deeper the eggs are laid, the more they are buffered from extreme and varying air temperatures. Hence, the soil moisture levels during oviposition have an influence on where the eggs are oviposited and their survival through winter. The depth of eggs can be changed when disturbed during fall tillage. Egg mortality is also higher when subjected to intermittent freezing and thawing temperatures.

Summary of percent CRW egg hatch based on duration of different overwintering temperatures based on 3 studies

		Weeks							
		1	2	4	6	8	10	12	14
Temperature (degrees Fahrenheit)	32			77%		83%			
	28.4		90%				16%		
	23			57%					0%
	18.5			54%		0%			
	14	43%	23%	0%					
	5	0%	0%	0%					

Sources: Woodson W.D. and R.D. Gustin. (1993), Chiang, H.C. (1973), Patel, K.K. and J.W. Apple. (1967).

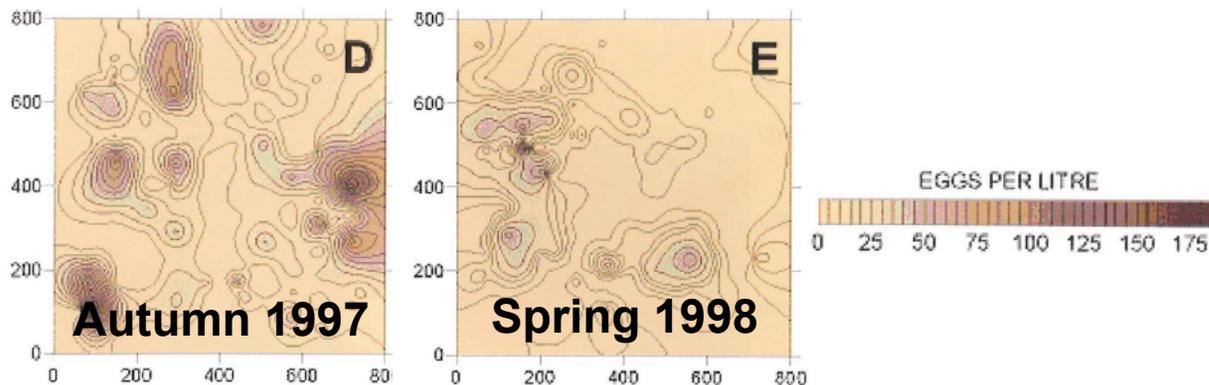
FYI: Western corn rootworms are less cold tolerant than northern corn rootworms. Models projecting rootworm expansion under a global warming scenario show that WCR could become dominant in new areas such as northern Minnesota and the Dakotas because of reduced overwintering mortality.

Life Cycle

Egg Mortality

Soil moisture and texture at a given depth, which influences temperature, varies throughout a field, which can differentially effect the eggs at a given depth in the field.

Snow and residue from reduced or no-till can insulate the soil from extreme temperatures resulting in higher spring egg densities and subsequent root damage in no-till fields than conventional tilled fields. Topography can also cause differences in exposure to wind.



Contour maps of kriged data for NCR eggs in the same field in the autumn and following spring. Note that the areas of the field with the most eggs in the autumn differs from the areas of the field with the most eggs in the spring. Courtesy of Western Corn Rootworm Ecology and Management, CABI Publishing.



Cold temperatures do not have much impact on CRW eggs when the soil is well protected. Courtesy of <http://eastwillimburywow.blogspot.com>



Extremely cold temperatures can reduce egg survivorship if the soil is exposed to the cold or experiences intermittent freezing and thawing. Courtesy of <http://tinyfarmblog.com>

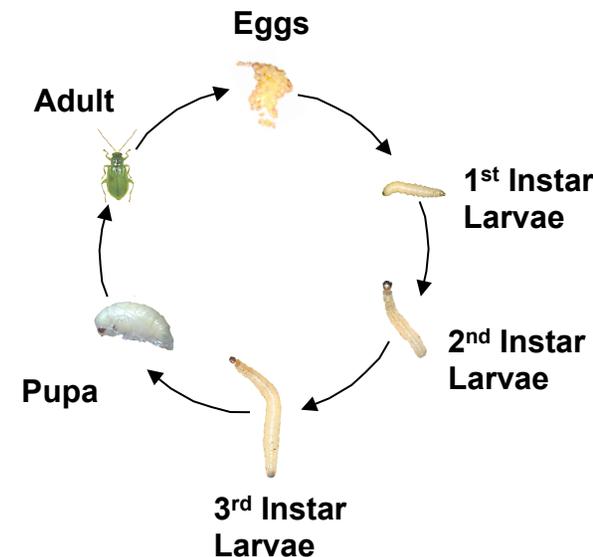
Life Cycle

Models

Several models have been developed to predict key points in a rootworm's life cycle. Since many of the life cycle stages begin or peak over a period of several days or weeks, models that reliably predict the different stages allow scouting to be focused on key periods, such as peak emergence, instead of scouting over the entire season.

Linear and non-linear models utilize accumulated heat units to forecast post-diapause development time to egg hatch. Several factors, including microclimate, egg depth, tillage practices, and soil characteristics affect soil temperature and moisture at the egg's exact location. As such, each of these influences the predictability of egg hatch and may be included in models.

Other models utilize calendar date, air degree-day accumulations, soil degree-day accumulations, and specific development thresholds to predict adult emergence patterns. Degree-day models have proven to be better predictors than calendar date, but strong regional differences exist between models making them less reliable when used in geographies and environments different from those where the model was developed.



Signs and Symptoms

Larvae

Signs and symptoms of rootworm larvae injury include poor plant health, signs of reduced water intake, reduced yield, root lodging, and root feeding.

Plant Health. Symptoms of larval rootworm feeding may range from no visible effect to plants that are severely stunted and chlorotic.

Plants may grow more slowly under cool growing conditions and exhibit a purple coloration in the leaves caused by lowered phosphorus uptake in the plants, or they may show nitrogen deficiency symptoms. Rootworm injury may be mistaken for growth regulator herbicide injury or shallow rooting in wet or loose soil.

Damaged roots are also more likely to become infected with diseases.



Rootworm damage can seriously impact plant health. Courtesy of Clemson University - USDA Cooperative Extension, Bugwood.org.

Signs and Symptoms

Larvae

Reduced Water Intake. Root feeding disrupts the plants' ability to take in water so rootworm-damaged plants also wilt more quickly than do undamaged plants. Under moist soil conditions, most corn plants can compensate for rootworm damage by rapidly growing new root tissue. As long as lodging does not occur, they will typically not experience significant yield reductions.

Fields with soil compaction problems may be stressed even more severely by rootworm damage because the root system is restricted to the upper six inches of soil. This is where rootworm numbers are highest and the soil is more likely to dry out.

Dry conditions restrict the plant's ability to compensate for root pruning. When soil moisture is lacking, high larval populations and heavy feeding can kill a small plant (four to six leaves).



Leaf rolling is a response to dry conditions. Courtesy of Jean-Marc Montpetit, Pioneer Hi-Bred.

Signs and Symptoms

Larvae

Yield Reduction. The relationship between corn rootworm damage and corn growth characteristics such as leaf area index or crop growth rate is subtle. However, yield losses of 7 to 9 percent are not uncommon in years of moderate stress, and yield losses of over 25 percent are possible in high pressure fields such as corn on corn or areas where rotation resistant CRW is prevalent.

In stressful years when root regeneration is suppressed after larvae feeding, CRW damage can reduce grain yields by 10 percent or more.



Reduced water and nutrient uptake can result in reduced yield. The moderately damaged root on the right has a shorter ear with fewer kernels than the ear from the undamaged root on the left. Courtesy of Jim Boersma, Pioneer Hi-Bred.

Signs and Symptoms

Larvae

Lodging. Severe root pruning and damaged brace roots make plants more susceptible to strong winds. “Goose-necking” occurs when plants with heavily damaged root systems lean over after heavy rains and high winds and then try to right themselves resulting in a curved stalk. By the time “goose-necking” is evident, root pruning is nearly complete. In some cases, plants may fall over onto the ground resulting in poorly pollinated ears. If lodging occurs long after tasseling, the stalk may remain straight, but simply lean or fall over at the base of the plant.



Corn stalk “goose-necking” resulting from root damage caused by corn rootworm . Courtesy of Lou Chapko, Pioneer Hi-Bred.



Corn stalks that have lodged after tasseling are straight, but nearly flat. Courtesy of Jim Boersma, Pioneer Hi-Bred.

Signs and Symptoms

Larvae

Lodging may occur in streaks, on hill sides, in pockets, or may be sporadic throughout the field. Only rarely is lodging from CRW damage uniform throughout the field.

Lodged corn can cause problems at harvest time. Lodged corn is often wetter, which may delay the start of harvest. Combine harvest speeds are slower. Combines are frequently damaged as rocks or corn roots with a lot of soil on them are pulled in when the combine header is close to the soil surface.



Lodging usually occurs in pockets or is scattered throughout a field. Courtesy of Jim Boersma, Pioneer Hi-Bred.



Farmer using a reel on a combine to pick up corn that was severely lodged as a result of extreme corn rootworm feeding pressure. Courtesy of David Johnson, Pioneer Hi-Bred.

Signs and Symptoms

Larvae

Root Feeding. Larval injury is usually limited to the 3rd through 6th nodes of the corn roots because the development of these roots coincides with egg hatch and larval development.

Initially, injured root tips will be discolored or have brown lesions. Over time, primary and secondary roots can be completely pruned. Larvae often injure the succulent meristematic tissue near the root tip as the roots enter the soil. This stops root elongation giving these roots the appearance of being pruned. Larvae may tunnel into larger roots and occasionally into the plant crown.

Damaged corn roots are more likely to be infected with root and stalk fungal diseases.

Since WCR larvae tend to hatch earlier in the season and feed more vigorously than NCR larvae, they are more likely to cause severe damage to corn roots.



Heavy root feeding injury. Notice that the primary and secondary roots are missing or turning brown from larvae tunneling inside while feeding, and that the 1st and 2nd nodes appear untouched. Courtesy of Marlin Rice.

Signs and Symptoms

Assessing Root Damage

Many techniques have been used to measure rootworm damage and the effectiveness of larval control tactics. Various techniques have included taking larval counts, collecting adults in emergence cages, root-damage ratings, root-size ratings, root-regrowth ratings, measuring root-pull resistance, measuring the percentage of lodged plants, and measuring grain yield.



Measuring the percent of lodged corn plants is one method to measure the efficacy of larval control tactics. Courtesy of Marlin Rice.



Collecting adults in emergence cages is a method of measuring the efficacy of larval control methods typically reserved for scientists due to their high cost. Courtesy of Paula Davis, Pioneer Hi-Bred.

Signs and Symptoms

Assessing Root Damage

Root-Damage Ratings. The root-damage ratings method has generally been adopted as the standard method for measuring the effectiveness of larval control techniques. Root sampling is relatively efficient and much cheaper than more expensive methods such as using emergence cages.

Environmental conditions and genetics also cause more variability when measuring the relationship between larval injury and plant growth characteristics (such as root size, root regrowth, root-pull resistance, lodging, and grain yield) than root-damage ratings.



Range of damage due to corn rootworm feeding, from severe (left) to no damage (right).
Source: USDA.

Signs and Symptoms

Assessing Root Damage

The primary root injury rating scale used for many years was the Iowa 1-6 scale first described in 1971. The Iowa 1-6 scale classifies injury level into one of six categories ranging from little or no damage (rating of 1) to three or more nodes of roots pruned to within 1.5 inches of the stalk (rating of 6). The downside of the Iowa 1-6 scale is that each increase in root rating score does not reflect a linear increase in the amount of injury to the root, resulting in a more subjective score rather than a quantitative score.

In 2005, the node-injury scale (NIS) was introduced to overcome the deficiencies of the Iowa 1-6 scale. Similar to the Iowa 1-6 scale, a root is considered pruned on the node-injury scale if it is pruned to within 1.5 inches of the stalk or 1.5 inches from the soil for the brace roots initiated from the stalk above the soil. The node-injury scale has been rapidly adopted as the standard scale to measure root injury.

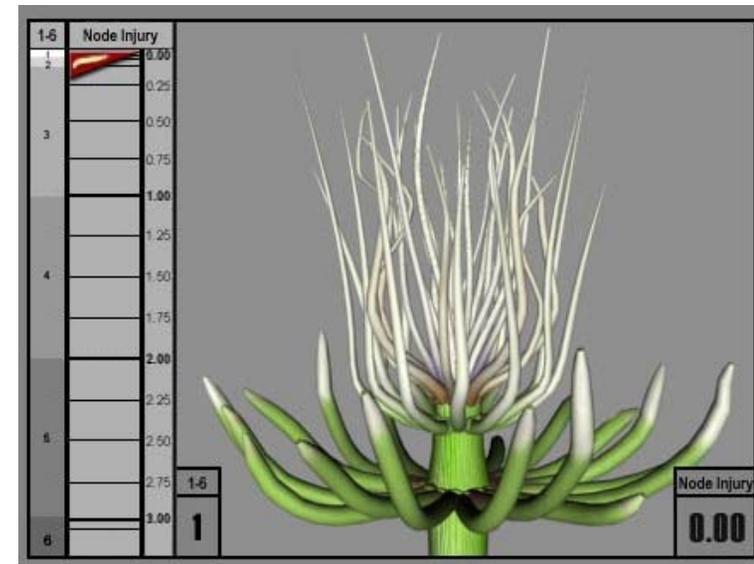
Description of root-damage rating systems	
<i>Iowa 1-6 root damage rating system</i>	<i>Node-injury scale</i>
1. No damage or only a few minor feeding scars	0.00 No feeding damage
2. Feeding scars evident, but no roots eaten off to within 3.8 cm (1.5 in.) of the plant	1.00 One node (circle of roots), or the equivalent of an entire node, pruned back to within approximately 3.8 cm (1.5 in.) of the stalk (or soil line if roots originate from above ground nodes)
3. Several root eaten off to within 3.8 cm (1.5 in.) of the plant, but never to the equivalent of an entire node of roots destroyed	
4. One node of roots completely destroyed	
5. Two nodes of roots completely destroyed	2.00 Two complete nodes pruned
6. Three or more nodes of roots destroyed	3.00 Three or more complete nodes pruned (highest rating that can be given)
Iowa 1-6 rating source: Hills, T.M. and D.C. Peters. (1971). Node-injury scale source: Oleson, J.D., et al. (2005).	

Signs and Symptoms

Assessing Root Damage

The process of assigning a node-injury score to a root is:

1. Randomly select several roots from the sample area and calculate the average number of roots per node for those nodes where injury occurs. The number of roots on the same nodes can differ by hybrid and environmental conditions.
2. Examine the root system of each plant and determine whether one node of has been pruned to within 1.5 inches of the stalk. For example, if 12 roots have been eaten to within 1.5 inches of the stalk on a node that contained an average of 12 roots and there was no injury on any other nodes, a score of 1.00 would be recorded.
3. If additional injury is found on another node, that score would be added to the 1.00. For example, if the next node had 3 roots eaten to within 1.5 inches of the stalk from an average of 12 roots, that node would equal 0.25 and the final node-injury score for the plant would be 1.25 (1.00 plus 0.25).



Click on the image above to use the interactive node-injury scale. Courtesy of David C. Killpack © 2000 – IlluminationStudios.com.

Signs and Symptoms

Assessing Root Damage

Depending on the level of precision needed, the node-injury scale provides flexibility in how injury scores are assigned. The most precise method is to count the number of pruned roots on each node and divide by the total number of roots on that node. When scoring experiments that require hundreds of roots, the time required to count the roots on each node should be compared to the level of precision that is needed.

The table to the right assigns root scores at quarter-node injury increments, except for minor feeding. Using this quarter-node injury method may be more practical when counting high numbers of roots, but is still more precise than previous ratings scales.

Node-injury scale scores for pruned roots										
Node-injury score	Total number of roots per node									
	15	14	13	12	11	10	9	8	7	6
	Number of roots pruned ^a									
0.00	0	0	0	0	0	0	0	0	0	0
0.02	Root system not perfect; scarring and/or channeling									
0.05	Severe scarring or only the tips of several roots injured									
0.10	1-2	1-2	1-2	1-2	1	1	1	1	1	1
0.25	3-5	3-5	3-4	3-4	2-3	2-3	2-3	2-3	2	2
0.50	6-9	6-8	5-8	5-7	4-6	4-6	4-5	4	3-4	3
0.75	10-13	9-12	9-11	8-10	7-9	7-8	6-7	5-6	5-6	4-5
1.00	14-15	13-14	12-13	11-12	10-11	9-10	8-9	7-8	7	6
1.25	One full node pruned + additional injury to a second node (calculated from shaded area above)									
1.50										
1.75										
2.00	Two full nodes pruned + additional injury to a third node (calculated from shaded area above)									
2.25										
2.50										
2.75										
3.00										

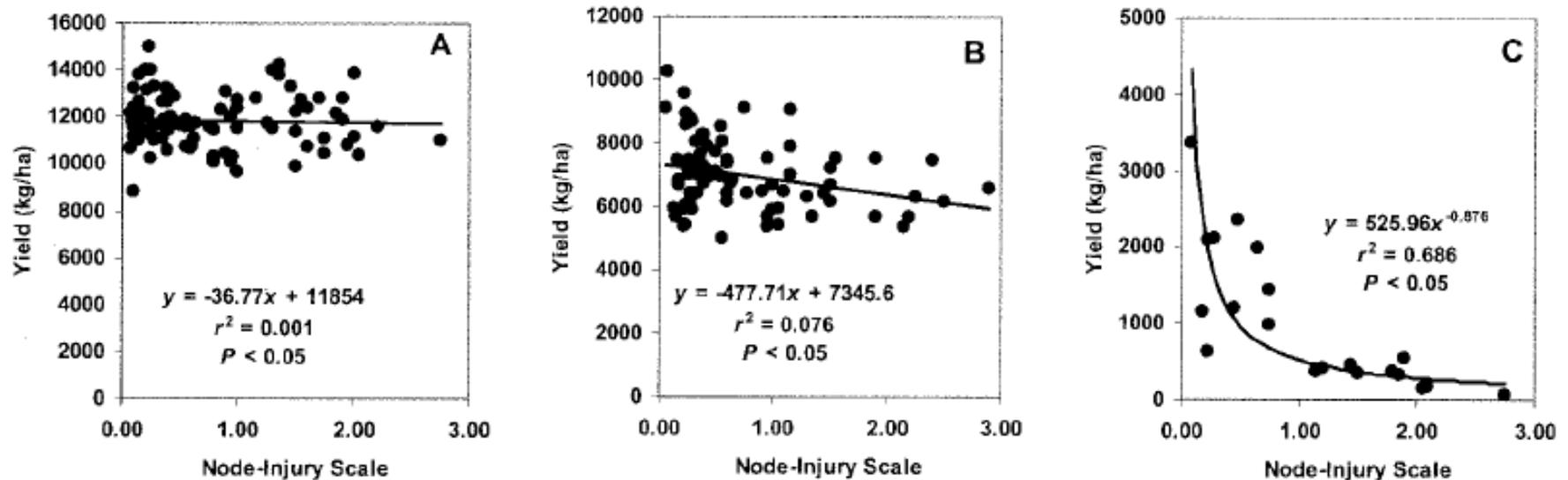
^a Root(s) pruned to within 1.5 inches of the stalk (or soil line on roots coming from above ground nodes).

Source: Oleson, J.D., et al. (2005).

Signs and Symptoms

Assessing Root Damage

Despite the precision in measuring efficacy of various products using the NIS method, there is generally a poor relationship between the NIS and the resulting yield from the field when growing conditions are favorable. Favorable environmental conditions allow plants to compensate for root pruning which prevents injury from having a major influence on grain yield. However, there is a much stronger relationship between node-injury score when conditions are highly stressful.



Relationship between yield and root injury-score under three environmental stress levels: A, low stress; B, medium stress; and C, high stress. Source: Oleson, J.D., Y.L.Park, T.M. Nowatzki, and J.J. Tollefson (2005).

Signs and Symptoms

Assessing Root Damage

Larvae Sampling. Scouting for larvae immediately after they hatch is difficult, as the larvae are very small and hidden within the roots. One to two weeks after they hatch, the larvae will have grown large enough that sampling can be done to get an indication of the performance of the soil/seed insecticide or trait deployed.

To scout for rootworms, use a shovel to cut out a 7-inch cube of soil around corn plant's root mass. Lift out the root mass and surrounding soil and place it on a dark surface such as a black plastic garbage bag. Carefully remove the soil from the root mass and break up the clods. Sort through the soil looking for 1/4 to 1/2 inch larvae and inspect the root for scarring and pruning. Tear away the leaves that are close to the nodal roots and check for larvae under the leaf collars. Look for larvae sticking out of the roots. Complete this process with several plants in different areas of the field.



[Click here to watch a movie of CRW sampling.](#)
Courtesy of Purdue University.

Signs and Symptoms

Assessing Root Damage

Another sampling method is to submerge the entire root ball into a 5-gallon bucket of clean water. Swish the root ball around until the soil falls off the roots. Larvae will float to the water surface after a few minutes. The worms will float to the surface more easily if the water is saturated with salt.

The cleaned roots can easily be inspected for damage. Again, repeat this process with several plants in different areas of the field.

If the average number of worms per washing is eight or more, a post-emergence soil insecticide may be needed.



White northern corn rootworm larvae floating on top of the water after soaking and swishing the root. The bucket is red. Courtesy of John Eidenshink, Pioneer Hi-Bred.

Signs and Symptoms

Adults

Leaf Feeding. Both WCR and NCR beetles prefer to feed on corn pollen and silks. However WCR will feed on corn leaves before pollination begins. When WCR adults feed on the leaves, they remove the upper layer of the leaf tissue resulting in areas on the leaf that appear gray or silver. Leaf feeding rarely results in significant yield loss.



Corn leaf damage caused by adult western corn rootworm beetles feeding before pollination. Courtesy of Duane Frederking, Pioneer Hi-Bred.

Signs and Symptoms

Adults

Silk Feeding. Adults may clip corn silks before pollination which can result in poorly filled ears. The earliest silking fields in an area often are most heavily damaged because beetles will move to these fields in search of green silks. However, since adult beetles are consistently attracted to pollen sources throughout their lifespan, late-planted fields are also susceptible to silk-clipping.



Severely-clipped silks by adult corn rootworm.
Courtesy of Brad Van Kooten, Pioneer Hi-Bred.



Unpollinated kernels are the result of clipped silks.
Courtesy of Jim Boersma, Pioneer Hi-Bred.

Signs and Symptoms

Assessing Adult Damage

Although rare, damage from silk clipping can be economical if damage is severe and occurs before pollination. Begin scouting corn fields shortly before silk protrudes from the tip of the developing ears. Check 5 plants in each of 5 random areas in the field. If no beetles are found, check the field again in three days. If no beetles are found, check the field twice a week until the beetles are found or the silk turns brown.

If tassels are shedding pollen and green silk is continuously clipped back to within $\frac{1}{2}$ inch or less before 50 percent pollination occurs and beetles are still in the field, an insecticide treatment may be warranted to prevent yield loss.

To determine if the ears are pollinated, remove an ear from a plant and carefully roll back the shucks. While holding the ear horizontally, shake it gently. If most of the silks stay attached, the ear is not yet pollinated. If most of the silks fall off, then pollination has occurred and adult control is not warranted.



If most of the silks remain attached after shaking then the kernels are not pollinated. Courtesy of Mark Apelt, Pioneer Hi-Bred.

Signs and Symptoms

Predicting Potential Injury

The potential for rootworm larvae injury in corn following corn can be predicted by monitoring adult activity during the summer of the previous season.

Fields must be scouted weekly during the period of peak adult activity, which coincides with silk emergence and pollination. Scouting on a weekly basis continues until either a threshold is reached or until adult numbers decline to low levels. Adult numbers usually decline when all the silks in the field turn brown and dry up. This is typically the middle of July through the beginning of September for most of the Corn Belt.



Corn tassel at beginning of pollen shed showing a few anthers extruded (left), and corn silks emerging (right). Both photos courtesy of Pioneer Hi-Bred.

Signs and Symptoms

Predicting Potential Injury

The whole plant count method is an accurate way to predict larval injury the following year.

Sample two plants that are about 10 feet apart from each other in at least 20 different locations in a field for a total of 40 plants. Several states recommend sampling at least 27 areas for a total of at least 54 plants. Each location should be at least 25 rows from the edge of the field.

Approach each plant carefully as adults will fly away or drop to the ground when disturbed. Start by holding the ear tip closed to prevent adults from dropping out. With your free hand, examine the whole plant starting at the tassel and work down the plant, looking on both sides of the leaves. Pay particular attention to the leaves closest to the ear and look carefully in leaf collars where pollen collects. Then slowly open your hand and watch for adults to drop as you strip the husk away from the ear tip. Also try to note any beetles that fly away and remember to check the secondary ears.



Whole plant counts is the most accurate way to determine if adult treatment thresholds have been reached. Courtesy of Marlin Rice.

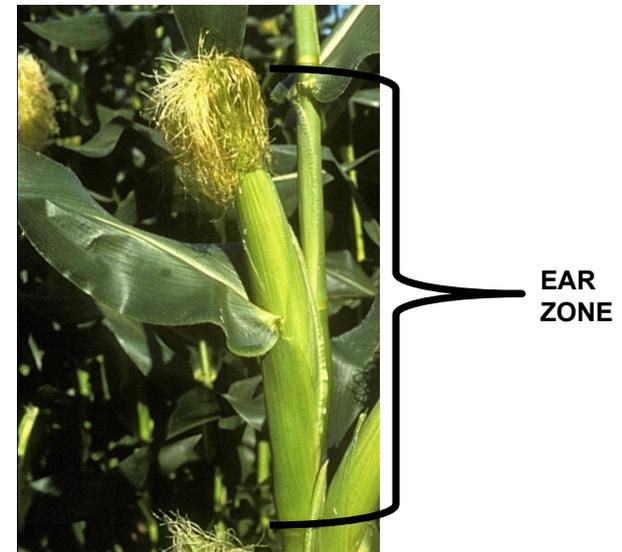
Signs and Symptoms

Predicting Potential Injury

Another method to predict larval injury the following year is to use the ear zone method to sample adults. The ear zone method requires that five plants be sampled in at least 32 locations, for a total of 160 plants. The ear zone method takes less time per plant, but it may not be any quicker overall since it takes so many more plants to obtain a reliable estimate.

Averaged over the whole season, ear zone counts represent approximately 50 percent of the total adult beetle population.

Similar to the whole plants method, the five plants at each location should be approximately ten feet from each other in order to not disturb the beetles on the next plant to be examined while examining the current plant. Each location should be at least 25 rows from the edge of the field.



Sampling the ear zone can be quicker per plant, but it requires more plants to obtain a reliable estimate. Photo courtesy of Doug Wilson, USDA, Agricultural Research Service.

Signs and Symptoms

Predicting Potential Injury

Regardless of the sampling method used, sampling should be done weekly starting at pollination to determine the average number of beetles per plant.

Thresholds vary by state and may change over time so check with your local extension office for the recommended thresholds for your state. If economic levels of rootworm beetles are observed in fields that will be planted to corn the following year, a management tactic should be utilized to prevent significant yield loss.

Some state's thresholds for first-year corn indicate they are based on a ratio of seven females for every three males, while thresholds for corn after corn are a 50:50 ratio. The reason for the different ratios is that females have a greater tendency to migrate and thus make up a greater proportion of the population in first-year corn. Since these thresholds predict the potential for a problem to occur the next year, based on the potential level of eggs laid, thresholds are lower in first-year corn.

Average number of beetles per corn plant which is likely to produce an economic larval population the following year

Avg. no. of corn plants/acre	Avg. no. of beetles per corn plant	
	Continuous corn ¹	First-year corn ²
14,000	1.4	1.0
16,000	1.3	0.9
18,000	1.2	0.8
20,000	1.1	0.7
22,000	1.0	0.6
24,000	0.9	0.6
26,000	0.8	0.5
28,000	0.7	0.5

¹Based on a 1:1 ratio of females to males. Corn following corn.
²Based on a 7:3 ratio of females to males. Corn following soybean or alfalfa.
 Source: Bledsoe, L.W., and J.L. Obermeyer. (2008).

[Click to enlarge](#)

Average number of western corn rootworm beetles present in corn fields that may produce an economically damaging rootworm population in corn the following year

Avg. no. of corn plants/acre	Avg. no. of beetles per corn plant			
	Continuous corn ¹		First-year corn ^{2,3}	
	Per plant	Per ear zone	Per plant	Per ear zone
14,000	1.28	0.64	0.96	0.48
16,000	1.12	0.56	0.84	0.42
18,000	1.00	0.50	0.75	0.38
20,000	0.90	0.45	0.68	0.34
22,000	0.81	0.41	0.61	0.31
24,000	0.75	0.38	0.56	0.28
26,000	0.69	0.35	0.52	0.26
28,000	0.64	0.32	0.48	0.24
30,000	0.60	0.30	0.45	0.23
32,000	0.56	0.28	0.42	0.21

¹Based on a 1:1 ratio of females to males. Corn following corn.
²Based on a 7:3 ratio of females to males. Corn following soybean or alfalfa.
³Use this threshold for continuous corn fields that did not have larval populations earlier in the season (adult beetles are immigrants, similar to first year corn).
 Source: Meinke, L.J. (1995).

[Click to enlarge](#)

Signs and Symptoms

Predicting Potential Injury

An alternative method to sampling a constant number of plants throughout the whole field would be to use a sequential sampling plan developed at Iowa State University. Sequential sampling plans may save time because they are based on a smaller sample size when beetles are above or below the threshold level.

The sequential sampling plan shown at the right is based on whole plant counts and assumes a threshold of 0.7 beetles per plant. To use this method, inspect five plants at each of two locations. If the total number of beetles is less than two, then sampling should be suspended in that field for a week. If the number of beetles is 12 or greater, then the threshold has been met. If the number of beetles is between 3 and 11, then two more plants are sampled. This continues until a decision is reached or the maximum sample size is attained. Check with your state extension office to see if they have a plan for your state.

Corn rootworm sequential sampling plan for use in continuous corn fields			
Number of plants sampled	Number of beetles found		
	Stop sampling; Resample in 7 days	Continue sampling	Stop sampling; Threshold exceeded
10	<2	3-11	>12
12	<3	4-12	>13
14	<4	5-14	>15
16	<6	7-15	>16
18	<7	8-17	>18
20	<8	9-18	>19
24	<11	12-21	>22
28	<14	15-23	>24
32	<16	17-26	>27
36	<19	20-29	>30
40	<22	23-31	>32
44	<24	25-34	>35
48	<27	28-37	>38
52	<30	32-41	>41
54	<31	32-41	>42

Source: Hein, G.L. and D.E. Foster, (1988).

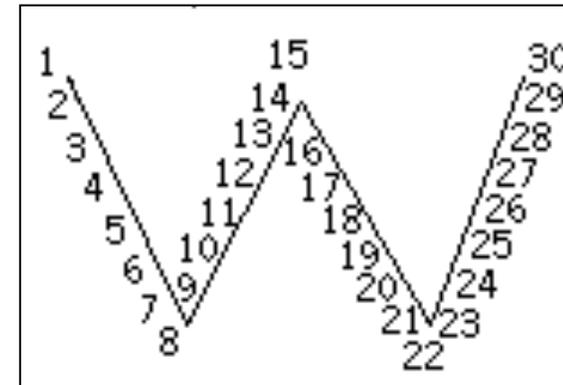
Signs and Symptoms

Predicting Potential Injury

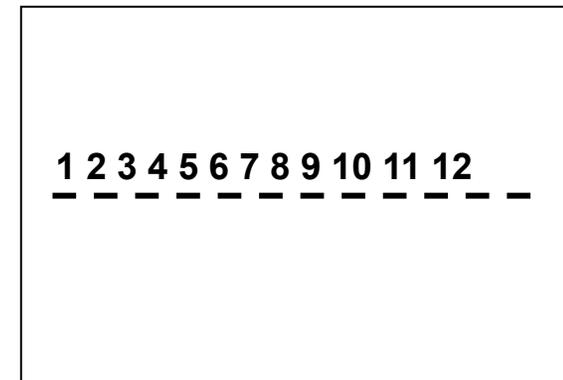
The commonly recommended way to sample the whole plant count or ear zone count methods is to walk the field in a “W” or “V” pattern to ensure that all parts of the field have been covered.

Another relatively new method is called transect sampling. When using the transect method, samples are taken in a straight line down the middle of a field. Computer models show that transect sampling for CRW with a sequential sampling plan significantly reduces the time required to make an “above” or “below” threshold decision while only minimally reducing accuracy.

Some question the performance of transect sampling in large fields where CRW beetles are highly aggregated or clumped in certain areas of a field. However, computer simulation models suggest that transect sampling performs well even in instances of extreme aggregation.



Scouting path of the traditional “W” shaped pattern.



Straight line path of the transect method.

Signs and Symptoms

Predicting Potential Injury

Another method to scout for CRW beetles is to use traps. Two types of traps typically used are non-baited sticky traps, and baited **kairomone** traps. One advantage of using traps is that they sample over several days, which removes the effects of time of day or short term weather changes that impact visual counts. The main disadvantage is the cost associated with purchasing the traps.



Kairomone lure trap tied to a corn stalk at ear level.



Yellow sticky trap tied to a corn stalk at ear level. Courtesy of the Agricultural Institute of Slovenia.

Signs and Symptoms

Predicting Potential Injury

There are several brands of sticky traps available, but the Pherocon® Adult Monitoring (AM) yellow sticky traps seem to be the most widely used in University studies. Sticky traps use a yellow color to attract CRW beetles and the sticky substance captures them when they land.

Sticky traps should be placed at ear level on 12 corn plants spaced at least 100 feet apart over a field. The number of CRW beetles on traps is recorded each time the traps are changed. The traps are typically changed every seven days, but can last 10 to 12 days without significant reduction in catching ability. Since adult emergence can stretch over a period of six weeks, the traps should remain in the field for six weeks.

The economic thresholds for sticky traps varies by trap brand, with most states publishing thresholds for the Pherocon® AM yellow sticky traps. If the economic threshold for Pherocon® AM yellow sticky traps of 6 beetles per day is reached (Nebraska and Iowa threshold; check with your state for local thresholds), there is a high potential for problems the following spring if corn is planted.

FYI: Several different yellow sticky traps are available in the marketplace. Each one has varying levels of stickiness, resulting in different thresholds. When using yellow sticky traps, make sure you are using the economic threshold for that specific trap.

Signs and Symptoms

Predicting Potential Injury

Kairomone lure traps are comprised of a capture top dome, a capture reservoir, and a container containing a kairomone lure or bait. One type of lure trap, the Pherocon® CRW Kairomone trap uses a kairomone derived from squash blossoms to lure beetles. Lure traps typically collect more beetles than yellow sticky traps do in the same location resulting in higher thresholds. Lure traps are best suited to detecting rootworm beetles that are present in very low densities.

Comparison of sticky traps and kairomone traps		
	<i>Pherocon® AM/NB yellow sticky traps</i>	<i>Pherocon® CRW kairomone traps</i>
Number of Traps used per 80+ Acres	12	8
Trap replacement	Every 2 weeks or less	Trap may be used multiple seasons
Replace lure/bait	Never	Lure lasts season long; bait is replaced as necessary
Manufacturer recommended thresholds*	35 beetles per trap per week	200 beetles per trap per week
*Consult your local University for local recommendations. Source: www.greatlakesipm.com		

Signs and Symptoms

Predicting Potential Injury

In areas where the WCR variant is prevalent, assessing the population in soybeans is the best way to determine the potential for problems in corn the following year. Adult WCR monitoring is done by placing at least six Pherocon® AM yellow sticky traps at least 100 feet into a soybean field and 100 feet apart from one another.

The traps should be monitored every seven days by counting the number of adult WCR on them. The sticky traps should be changed every week when adults are counted. Since adult emergence can stretch over a period of six weeks, the traps should remain in the field for six weeks. The average number of adult WCR beetles collected per day on each trap is an index of the adult rootworm activity in the field. If the number of beetles ever reaches the threshold of 5 beetles per day, it suggests a high potential for problems the following spring if corn is planted.

Daily weather conditions and adult flight patterns are too variable for sweep net sampling in soybeans to give accurate estimates of beetle abundance so this method is not generally recommended.



Yellow sticky trap in soybeans to capture corn rootworms moving into a soybean field from a corn field.
Courtesy of Jon J. Tollefson.

Management

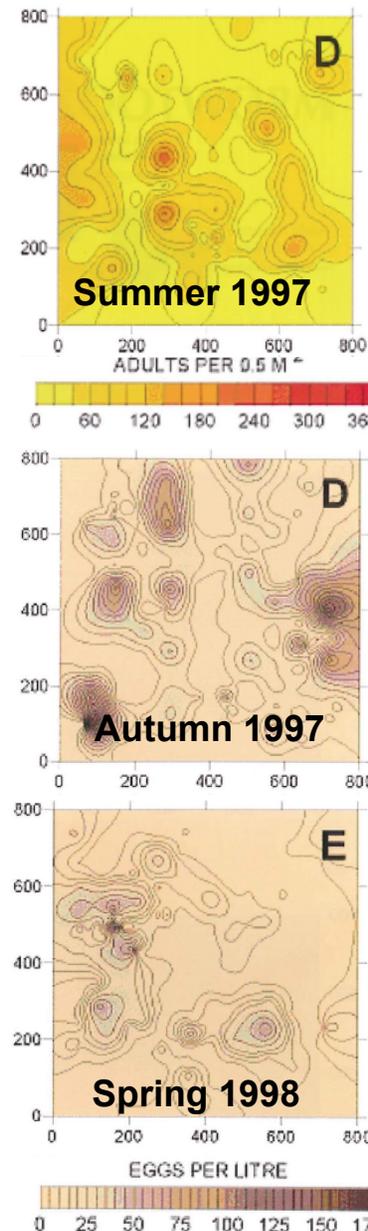
Adult Density Estimates

Using summer adult densities to predict larval damage potential the following year is not foolproof. The reliability of this prediction depends on three aspects of corn rootworm biology: oviposition magnitude, egg overwintering survival, and larval survival and establishment.

Female rootworm adults vary spatially in a field based on the location of food. They typically oviposit in the same place they are feeding. If adult density estimates are taken too early in the year, the adults may move and oviposit at other locations. Notice the difference between the adult densities in the summer of 1997, and the egg densities in the autumn of 1997.

Egg overwintering survival varies spatially within a field based on soil moisture, and the duration and intensity of cold temperatures, which are partially dependent on soil texture, topography, and tillage practices. Notice the differences in egg densities between the autumn 1997 and spring 1998.

Larval establishment and survival are impacted by food availability upon eclosion, flooding after eclosion, and soil properties such as extremely sandy texture or high soil density caused by compaction.



Management

Cultural Controls

Hybrid Selection. Hybrids with good root regeneration capability or large root systems seem to be more tolerant to rootworm damage. Also, hybrids with massive fibrous root systems or long roots are less prone to lodge as a result of rootworm damage and may be able to outgrow the rootworm damage.

Weed Management. A good weed management program reduces competition with the young corn plants, thereby aiding crop growth by reducing competition for light, nutrients, and water. A good weed management program also reduces other potential hosts for young CRW larvae to start feeding on as well as eliminates other sources of pollen for adults to feed on.



Most hybrid seed corn catalogs contain root strength scores to assist in hybrid selection. Courtesy of Steven Mitchell, Pioneer Hi-Bred.

Management

Cultural Controls

Early Planting. Early planting may allow the majority of the plants within a field to silk before peak adult emergence resulting in less feeding as adults move to different fields in search of fresh pollen. Since rootworm typically oviposit where they are feeding, early planted corn will also result in fewer eggs oviposited. Early-planted corn will also have a larger root system by the time eggs hatch and larvae start to feed.

Root Growth. Practices that encourage plant vigor, root development, and root regeneration will help the plant overcome rootworm damage. Practices include good soil fertility and nitrogen management, tillage to reduce compaction, and planting with reasonable plant populations.



© William J. Cox
Early-planted corn may avoid some of the damage that late planted corn receives. Courtesy of William J. Cox.

Management

Cultural Controls

Crop Rotation. Historically, WCR and NCR adults have had a strong fidelity towards laying their eggs in corn fields. Additionally, rootworm larvae can only move a few feet to feed on corn roots and are generally unable to complete development on most other plants. The result is that crop rotation with a non-host crop has been the primary cultural control for CRW for over 100 years.

Rotation also reduces the possibility of rootworms developing resistance to a particular insecticide, which can occur when insects are continuously subjected to selection pressure from insecticide use.

Over the last two decades rotation has become ineffective in large parts of the Corn Belt because of the spread of extended diapause NCR and rotation-resistant WCR.



Crop rotation has historically been the most effective cultural control of CRW. Courtesy of Reuters.

Management

Cultural Controls

While rotation with non-host crops is usually a good management strategy, rotating to crops that CRW adults feed on can lead to extremely high rootworm pressure if corn is planted the following year.

After corn silking is complete CRW adults search for other sources of food. Rootworm beetles are attracted to cucurbits such as cucumbers, squashes, and pumpkins. Adult beetles prefer to feed on cucurbit pollen, but will also feed on the fruits. Adult WCR and NCR are frequently the dominant insect found in cucurbits in Illinois and Wisconsin.

Since rootworms typically lay their eggs in the crop they are feeding on, corn planted after pumpkins or other cucurbits can result in extremely high rootworm feeding pressure.



Adult WCR on a cucurbit flower. Courtesy of the Agricultural Institute of Slovenia.



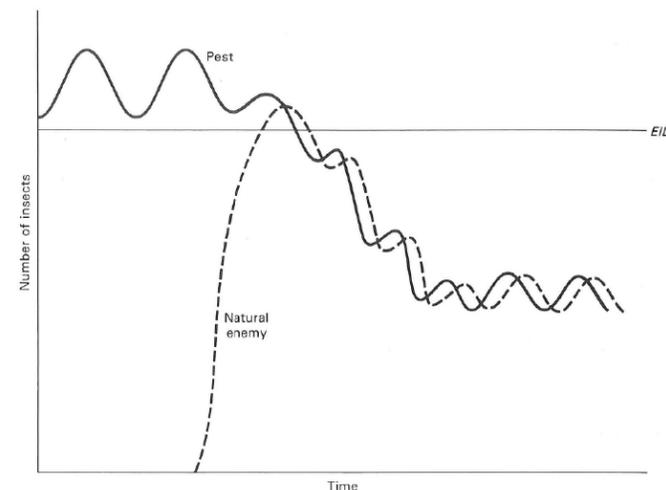
Western corn rootworm (left) and striped cucumber beetle (right) damaging a pumpkin. Courtesy of Ontario Ministry of Agriculture, Food and Rural Affairs.

Management

Biological Control

The aim of classical biological control is to reduce a pest's ecological status by manipulating part of the pest's natural enemy complex. This can be done by introducing the pest's natural enemy in the hope that it becomes established and keeps the pest below the economic-injury level (EIL) indefinitely. Additional methods include augmenting the existing population through either a one-time **inundative** release or through multiple **inoculative** releases, and conserving and enhancing the natural population of the pest's enemies.

While not used extensively in North America, biological control is being extensively studied for control of WCR in Europe. Corn rootworms are attacked by a range of natural enemies including fungi, nematodes, insects, and parasitoids. Corn rootworms can also be killed by bacteria. Each of these natural enemies has biocontrol potential.



Click to enlarge. Classic biological control representation of the relationship between a pest and the introduction of an effective natural enemy. Source: Pedigo, L.P. (2002).

Management

Biological Control

Fungi. In North America, natural fungi that have been found infecting rootworms include species of *Beauveria*, *Metarhizium*, *Paecilomyces*, and *Laboulbenia*. Field studies with *Beauveria* and *Metarhizium* species have shown efficacies high enough against rootworm larvae to consider using them as biological control.

Beauveria bassiana are naturally occurring fungi found in soils throughout the world. Many soil dwelling insects exhibit natural tolerance to *B. bassiana*, so commercial development has focused on foliar feeding insects. *B. bassiana* is commercially sold under brand names such as Mycotrol[®], Botanigard[®], and Naturalis[®]. Adult rootworm populations have been reportedly reduced up to 50 percent following a single application of *B. bassiana* conidia. *B. bassiana* is known as the white muscardine fungus because infected insects turn white or gray.

MYCOTROL O[®]

Emulsifiable Suspension Mycoinsecticide

OMRI
Listed

◆ Listed by the Organic Materials Review Institute (OMRI) for use in organic production

For use in controlling Whitefly, Aphids, Thrips, Psyllids, Mealybugs, Leafhoppers, Weevils, Plant Bugs, Borers and Leaf-feeding Insects in Field, Agronomic, Vegetable and Orchard Crops; Grasshoppers Mormon Crickets, Locusts and Beetles in Rangeland, Improved Pastures and Agronomic Crops; Whitefly, Aphids, Thrips, Psyllids and Mealybugs in Vegetables and Ornamentals grown in Indoor/Outdoor Nursery, Greenhouse, and Shadehouse.

Active Ingredient:

Beauveria bassiana Strain GHA.....10.9%*

Inert Ingredients.....89.1%

Click to enlarge the label for Mycotrol O[®] to see a listing of some of the insects controlled by *B. bassiana*.



The white fungus on this striped cucumber beetle is a tell-tale sign of *Beauveria bassiana*. Courtesy of North Dakota State University.

Management

Biological Control

Metarhizium anisopliae is commercially available in the U.S. for household cockroaches. Mortality of up to 50 percent in WCR larvae and 90 percent in WCR adults has been reported in bioassays. In addition to corn rootworms, *Metarhizium* species are being tested on some white grub and root weevil species. The mycelium on infected insects can be white or green, but the spores are green.



Mealworm (*Tenebrio molitor*) pupa killed with *Metarhizium anisopliae*. Note the white mycelium and green color of the spores. Courtesy of Dan Johnson.

Management

Biological Control

Nematodes. Entomopathogenic nematodes are used against several insect pests and some show potential against rootworm larvae. Species within the genera *Steinernematidae* and *Heterorhabditidae* have been the most widely researched as possibilities for biological control of rootworms. However, they are not currently being used as biological control for corn rootworms.

The most commercially available species of entomopathogenic nematodes is *Steinernema carpocapsae*. Formulations of this nematode have been mass produced for biological control since the 1980's and are most effective against surface dwelling insects.

Although an important entomopathogenic nematode, the relatively short shelf-life of *Heterorhabditis bacteriophora* limits its commercial use. While it can attack caterpillars and beetle larvae, it is most useful against root weevils.

Entomophagous nematodes that attack corn rootworms		
Host	Nematode genera	Stage attacked
Western corn rootworm	<i>Heterorhabditis</i>	larva, pupa, adult
	<i>Steinernema</i>	larva, pupa, adult
	<i>Micoletzkyia</i>	larvae
	<i>Panagrolaimus</i> ¹	larvae
Northern corn rootworm	<i>Heterorhabditis</i>	larvae
Southern corn rootworm	<i>Steinernema</i>	larvae, adult
	<i>Howardula</i>	larvae
	<i>Diplogaster</i>	larvae
	<i>Oesophagomermis</i>	larvae
	<i>Hexameris</i>	adult

¹Insect associated but not entomopathogenic nematodes. Adapted from: Toepfer, S. et al., (2009).

Management

Biological Control

The control of rootworm larvae with different species and strains of *Steinernematidae* and *Heterorhabditidae* is highly variable. Laboratory tests show that nematodes can control 70 to 90 percent of CRW larvae and pupae. Some field results show similar control as the lab experiments. However, some field trials show no control. Field results are very dependent on environmental conditions, such as soil moisture, application techniques, and size of the larvae (3rd instar larvae are more susceptible than 1st or 2nd instar larvae).

Combining two nematode species in a suppression program against western spotted cucumber beetle is no more effective than using one species alone.



Entomopathogenic nematodes attacking a larva.
Courtesy of North Dakota State University.

FYI: The roots of some corn plants emit a volatile compound called beta-caryophyllene when attacked by corn rootworm larvae. The compound attracts insect-parasitic nematodes, such as *Heterorhabditis megidis*, that can kill the rootworm larvae. While this compound is emitted by ancestral maize and European lines, many American hybrids have lost this ability to attract parasitic nematodes.

Management

Biological Control

Bacteria. The soil bacteria *Bacillus thuringiensis* Berliner (*Bt*), is the most important biological-based pest management strategy used to date. These spore forming bacteria produce several classes of insecticidal proteins, which are insect-specific gut toxins against **Lepidoptera**, **Coleoptera**, and **Diptera** insects.

The strains of *Bt* that are toxic to WCR, NCR, and MCR usually express Cry3 toxins or the binary Cry34/35 toxins. Many corn hybrids have been altered to express a *Bt* transgene for control of target pests (see transgenics section). Although a strain of *Bt* has been shown to have moderate activity against the larvae of SCR via expression of a Cry 3B2 toxin, it is not commercially available in transgenic corn.

Bt insecticidal proteins that kill lepidopteron worms have been widely sold under names such as Dipel® and Thuricide® for many years. However, no conventionally formulated *Bt* based products are used against rootworms in field crops.



Bt is commonly sold as a biological insecticide for home gardens.

Management

Biological Control

Parasitoids. Parasitoids are arthropods that live in or on the body of another arthropod for part of its life cycle and kills it. Parasitoids are a common type of natural enemy used for biological control of many insects.

While they do not exert a major influence on the rootworm populations in North America, some species of **tachinids** and **braconids** are regularly found parasitizing rootworm beetles in North America. There are no known parasitoids of rootworm larvae.

No parasitoids have been found in Europe in association with WCR, but research is being conducted on species in the *Celatoria* and *Centistes* genuses as potential biological control of WCR in Europe.

Host records and laboratory test of tachinid and braconid parasitoid species parasitizing rootworm beetles in North America						
			Host records		Laboratory tests	
Genus	Parasitoid species	Rootworm species	Parasitism	Country	Attack	Develop
Tachinid	<i>Celatoria compressa</i> (Wulp)	WCR	6.6%-16%	Mexico	Yes	Yes
		MCR	rarely	Mexico	-	-
	<i>Celatoria diabroticae</i> (Shimer)	NCR	<1%	USA	Yes	Yes
		WCR	<1%	USA	Yes	Yes
		SCR	2%-35%	USA	-	-
WSCB	1%-35%	USA	Yes	Yes		
Braconid	<i>Centistes diabroticae</i> (Gahan)	MCR	0%-8%	Mexico	-	-
		SCR	-	-	Yes	Yes
	<i>Centistes gasseni</i> Shaw	WCR	-	-	Yes	Yes

Adapted from Toepfer, S. et al., (2009).

Management

Biological Control

Arthropods. There are many generalist predators within agroecosystems that consume a wide variety of insects including rootworms. The three groups of rootworm predators that have been studied the most include: mites (Acari), ants (Formicidae), and carabid beetles (Carabidae).

One comprehensive study examined the gut contents of predators for WCR eggs and larvae based on molecular markers. Of the 17 taxa of predators that fed on WCR eggs and larvae, phalangiids (Phalangida) and staphylinids (<5 mm in length) were the most abundant rootworm predators. However, two carabids and two lycosids (Araneae) relied most frequently on WCR immatures as prey.

Another study looking at the SCR predator community found several insects eating SCR eggs including: mesostigmatid mites (Acaridae), larvae of cantharids, carabids, and staphylinids; carabid adults, centipedes, and ants.



Western corn rootworm adult being eaten by a spined soldier bug nymph. Courtesy of Don Specker, Pioneer Hi-Bred.

Management

Biological Control

Although polyphagous, predaceous mites such as *Tyrophagus putrescentiae*, have been shown to reduce immature rootworm densities under field conditions. In a laboratory setting, these mites can successfully detect CRW eggs up to 8 cm away. Despite all the studies showing that predaceous mites may help control rootworm populations, more work is needed on using them as biological control.

Ants are dominant predators of immature rootworms and may have a significant impact on rootworm egg abundance. However, the application of ants as biological control agents of rootworms in field studies has not been attempted.

Carabids are an abundant generalist predator found in corn fields with more than 24 species known to eat *Diabrotica* species in the laboratory or field. One study showed that carabids and spiders were able to reduce SCR populations in small vegetable plots by more than 50 percent.



Carabid beetles, such as this *Cyclotrachelus alternans*, are an important predator of corn rootworm larvae. Courtesy of Jonathan Lundgren.

Management

Biological Control

One potential form of biological control is to reduce the amount of feeding done by the adult rootworm. For example, the large wolf spiders *Hogna helluo* and *Rabidosa rabida* are very dangerous predators to southern corn rootworm adults. Studies have shown that adult SCR beetles will adjust their antipredator behavior in the presence of these large wolf spiders eating less and moving to other plants which results in less plant damage. Adult SCR beetles do not adjust their antipredator behavior or feeding habits in the presence of other similar-sized, but less dangerous predators. The results of these studies show that the amount of plant damage by rootworm adults could be reduced simply by the presence of major predators, even if predation on the rootworm adult does not occur.



Southern corn rootworm adults reduce their feeding and move to avoid capture in the presence of large wolf spiders, such as this *Rabidosa rabida*. Courtesy of Erik Blosser, Bugguide.net.

FYI: Female SCR are much more responsive to the presence of wolf spiders and are more likely to avoid capture than males. In one experiment, males were 16 times more likely to be eaten, while in another experiment only 5 percent of males survived two days with *Hogna helluo*.

Management

Biological Control

Many farmers are building bat houses as a form of biological control. Bats can eat up to half their body weight in insects every night and studies in Indiana and Illinois show that during the month of July about 1/4th of a big brown bat's (*Eptesicus fuscus*) diet is from *Diabrotica* species insects. Southern corn rootworm beetles are the primary *Diabrotica* species consumed as northern and western corn rootworm adults are presumed to be **diurnal**.



A big brown bat (*Eptesicus fuscus*) approaching a moth. Courtesy of William Conner and Nickolay Hristov, Wake Forest University.

Management

Chemical Control

Chemical control for several decades consisted of soil-applied insecticides aimed at controlling larvae and foliar-applied insecticides aimed at controlling adults. Several insecticides are registered for use in the United States, but the organophosphate, pyrethroid, and a mixture of the two classes dominate the market.

In the last decade insecticide seed treatments and transgenic corn both aimed at controlling larvae moved into the marketplace.

Prior to the growth of the geography covered by the eastern variant of the western corn rootworm, chemical control was targeted towards fields planted in corn after corn. However, most corn after corn fields did not have high enough populations to justify chemical control. With the expansion of the eastern variant of the western corn rootworm, there are now more first-year corn acres chemically treated than corn after corn acres.

Common insecticide active ingredients and brands by chemical class		
Chemical class	Active ingredient	Brands
Pyrethroid	Permethrin	Ambush®
		Pounce®
	Esfenvalerate	Asana®
	Bifenthrin	Capture®
	Cyfluthrin	Baythroid®
	Zeta-Cypermethrin	Fury®
		Mustang Max™
	Tefluthrin	Force®
Cyhalothrin-Lambda	Warrior®	
Organophosphate	Terbufos	Counter®
	Chlorethoxyfos	Fortress®
	Chlorpyrifos	Lorsban®
	Phorate	Thimet®
Organophosphate-Pyrethroid Mix	Cyfluthrin/ Tebupirimphos	Aztec®
Carbamate	Carbofuran	Furadan®
	Methomyl	Lannate®
	Carbaryl	Sevin®

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Management

Chemical Control

Soil Insecticides. Soil applied insecticides have been a primary chemical strategy against corn rootworm larvae since their discovery around 1940.

Soil insecticides are available as both a granule or liquid. Granules generally persist longer in the soil than liquids and the active ingredient is less likely to leach or breakdown. Because of those benefits, granules have dominated the soil insecticide market for many years.

FYI: Some insecticide labels do not include in-furrow recommendations because the insecticide may injure the seed if it comes in contact with the seed.

Common insecticides for corn rootworm larvae

<i>Insecticide^a</i>	<i>Amount of product per 1000 ft. row</i>	<i>Placement</i>	<i>Timing of application, comments</i>
*Aztec [®] 2.1%G	6.7 oz	Band, furrow	At planting. To minimize potential adverse effects to wildlife, incorporate insecticide granules or apply the insecticide in-furrow (if labeled) and shut off insecticide units in turn rows.
*Aztec [®] 4.67G ^b	3 oz	Band, furrow	
*Capture [®] 2EC	0.3 oz	Band	
*Counter [®] 15G ^b	8 oz	Band, furrow	
*Force [®] 3G ^b	4 to 5 oz	Band, furrow	
*Force [®] CS	0.46 to 0.57 oz	Band, furrow	
*Fortress [®] 2.5G	7.5 to 9 oz	Furrow	
*Fortress [®] 5G ^b	3 to 4.5 oz	Furrow	
*Lorsban [®] 4E	2.4 fl oz	Band	
Lorsban [®] 15G ^b	8 oz	Band	

*Use restricted to certified applicators.

^aFormulation most commonly used in Illinois.

^bAztec 4.67G and Fortress 5G are available only in the SmartBox[®] closed handling and application system. Counter 15G, Force 3G, and Lorsban 15G also are available in the SmartBox closed handling and application system. Source: Steffey, K.L., and M.E. Gray. (2008)

Aztec is a registered trademark of Bayer AG. Capture is a registered trademark of FMC Corporation. Force is a registered trademark of a Syngenta Group Company. SmartBox, Counter and Fortress are registered trademarks of AMVAC Chemical Corporation. Lorsban is a registered trademark of Dow Agro Sciences, LLC.

Management

Chemical Control

Insecticides may be applied at planting or post-planting (also called cultivation-time, or rescue treatments). Planting time treatments can be applied in the furrow, in a band in front of the press wheel (T-band) or behind the press wheel (surface band).

Insecticides applied at planting need to remain in the area around the roots for 6 to 10 weeks to be effective from larval hatch through larval feeding. Even though insecticides applied at planting have to remain around the roots for several weeks, applications at planting are generally more effective than post-planting applications. Post-planting applications usually depend on rainfall or irrigation for activation, plus the window of time for the cultivation application can be delayed due to seasonal rains.



John Deere planter equipment with AMVAC smart boxes. Courtesy Jim Boersma, Pioneer Hi-Bred.

Management

Chemical Control

Post-planting treatments may be applied by airplane, by ground, or through **chemigation**. Post-planting application is usually used when **alkaline** soils accelerate decomposition of the insecticide, the soil has high organic matter which can tie up the insecticide and make it unavailable to kill larvae, or if the producer is applying liquid UAN at the base of the young plants. If tank mixing with 28 percent UAN, insecticide labels should be read for restrictions and mixing information.

One disadvantage of post-planting treatments is that wet weather may delay or completely prevent the application. Since cultivation is used to incorporate the insecticide, post-emergence treatment may not be possible in reduced till or no-till fields.



Post-emergence insecticide application can occur when UAN is sidedressed. Courtesy John Lundvall.

Management

Chemical Control

Insecticide performance failures are not uncommon and are frequently traced to poorly calibrated equipment. Equipment should be calibrated every year and every time the product applied is changed. Applying less product than recommended may result in poor performance. Applying more than the correct amount could result in a waste of money, could cause environmental concerns, and is against the application label.

Drop tubes and banders should be kept clear for even delivery of the insecticide. Windshields should be used to dramatically reduce drift, and the closing/press wheel should fully close the furrow to minimize insecticide exposure to the elements.

Regardless of application timing, soil insecticides should be lightly incorporated into the soil during application to prevent volatilization, decrease chances of environmental contamination, and poisoning of non-target organisms.



Equipment calibration is one key of successful insecticide performance. Courtesy Jim Boersma, Pioneer Hi-Bred.



Tines to lightly incorporate insecticide. Courtesy Jim Boersma, Pioneer Hi-Bred.

Management

Chemical Control

In addition to application calibration, the soil environment is an important factor affecting the ultimate level of control with a soil insecticide. If the soil is too dry, the insecticide may not adequately distribute through the soil profile. In extremely wet conditions, the insecticide may leach through the profile or run off with surface water.

Soils that are highly **alkaline** deteriorate insecticides faster than soils that are neutral to slightly acidic.

The soil-applied insecticides used today are biodegraded by microorganisms such as bacteria, fungi, and actinomycetes. In some areas, this biodegradation has accelerated to the point that the insecticide no longer provides protection by the time rootworm eggs hatch. Problems with biodegradation may be avoided or postponed by rotating insecticides with one from another mode of action (MOA) class.



Insecticide may leach outside the root zone in the ponded areas of this corn field. Courtesy Mark Jeschke, Pioneer Hi-Bred.

Management

Chemical Control

Even with well calibrated equipment and good timing, none of the insecticides provide complete control of rootworm larvae (60 to 80 percent is more realistic). The goal is to protect the primary portion of the root system from an economic attack. Even when the primary portion of the root is protected larvae may still attack the portion of the root outside the applied insecticide band. Even if the insecticide is still effective, economic damage may still occur if larval populations are extremely high, or the timing of egg hatch is delayed.

While soil insecticides protect corn roots from feeding damage, they have no effect on adult beetles.



John Deere 1770 planter equipped with an insecticide tank for liquid insecticide application. Courtesy Jim Boersma, Pioneer Hi-Bred.

Management

Chemical Control

Foliar Insecticides. Beginning in the 1960's foliar insecticides were used to suppress adult CRW populations. The costs of scouting for adults and applying foliar insecticides are higher than managing CRW with soil insecticides. Beneficial insects and predatory mites are negatively impacted by foliar insecticides, and rain or irrigation can reduce the residual activity as well.

Adult CRW suppression is typically used in two different strategies. First, it can be used to prevent or minimize silk clipping. This is most frequently used in corn grown for seed production. Second, it can be used to control egg numbers and consequently larvae infestation in corn following corn. However, foliar treatments aimed at minimizing oviposition rarely have better results than soil insecticides.

Common insecticides for corn rootworm adults			
<i>Insecticide^a</i>	<i>Amount of product per acre</i>	<i>Placement</i>	<i>Timing of application, comments</i>
*Ambush [®] 25W	6.4 to 12.8 oz	Overall spray or direct toward ear zone.	To protect pollination treat if there are 5 or more beetles per plant, pollination is not complete, and silk clipping is observed.
*Asana [®] XL	5.8 to 9.6 oz		
*Baythroid [®] XL	1.6 to 2.8 oz		
*Capture [®] 2EC	2.1 to 6.4 oz		
*Cobalt [™]	13 to 26 oz		
*Hero [™]	4 to 10.3 oz		
*Lorsban [®] 4E	1 to 2 pt		
*Mustang Max [™]	2.72 to 4 oz		
*PennCap-M [®]	1 to 2 pt		
*Pounce [®] 3.2EC	4 to 8 oz		
*ProAxis [®]	2.56 to 3.84 oz		
Sevin [®] XLR Plus	1 to 2 qt		
*Warrior [®]	2.56 to 3.84 oz		

*Use restricted to certified applicators.

^aFormulation most commonly used in Illinois.

Source: Steffey, K.L., and M.E. Gray. (2008)

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Management

Chemical Control

Beginning in the 1980's a new foliar management strategy involving area wide pest management (AWPM) programs began to be developed. This new approach uses semio-chemical like attractants, sex pheromones, and feeding stimulants or arrestants to attract adult beetles to eat food laced with small amounts of insecticide. Consequently, three products became commercially available: SLAM™, CIDETRAK® CRW, and INVITE™ EC. The baits are applied using aerial or ground sprayers and adhere to plant surfaces as small droplets. One benefit of this approach is that the amount of active ingredient applied is decreased 95-98 percent compared to traditional beetle management methods.

In mid 1990's the USDA's Agricultural Research Service initiated five corn rootworm AWPM programs in several states. The five programs were in South Dakota, Kansas, Texas, Iowa, and Indiana/Illinois. Adults were intensively sampled and the insecticide-laced bait was applied when thresholds were met. All locations had reduced adult populations, however they did not have consistently reduced root damage, reduced beetle emergence, or increased yield.



Aerial applicators may be used to control adult CRW populations. Courtesy of farmerdoodah, flickr.

Management

Chemical Control

Seed Treatments. Beginning in the 1990's seed treatments from a new class of systemic insecticides, neonicotinoids, began coming into the market. The neonicotinoids have high photostability, good residual activity, high intrinsic insecticidal potency, broad insecticidal spectrum, excellent systemic properties, and a favorable safety profile. Currently, imidacloprid (Gaucho[®]), thiamethoxam (Cruiser[®]), and clothianidin (Poncho[®]) are available for commercial corn production.

Efficacy of all three active ingredients is similar to most of the soil-applied insecticides. However, efficacy is not always consistent and use of seed treatments are recommended only when CRW populations are low to moderate. Rates recommended for CRW are higher than recommended rates for other soil pests such as wireworm. Similar to soil insecticides, weather and soil factors influence efficacy.



The rootworm rate of Poncho, Poncho[®] 1250, is purplish in color. Courtesy of Bayer Crop Science.



Under low to moderate pressure, seed treatments have similar efficacy to soil applied insecticides. Courtesy of Jim Boersma, Pioneer Hi-Bred.

Management

Chemical Control

Late Planted or Replanted Corn. Since egg hatch can occur over an extended period of time, late planted corn or replanted corn will have a reduced risk of rootworm damage. However, there is still a risk if corn is planted at the end of egg hatch or if larvae have found grasses (e.g., foxtails, volunteer corn, etc.) on which to survive. It is generally recommended on corn planted before mid-June to continue a planned rootworm control program. After the middle of June, low rates of seed-applied insecticides (i.e., Cruiser, Poncho) should be sufficient for any remaining larvae that hatch.

For replanting, even if a soil insecticide was used on the original planting, producers should consider reapplying a rootworm insecticide as part of the replanting operation (**see label restrictions on next slide**). Reapplications may be of greatest benefit for planting that originally occurred in April and early May. This is especially true because high amounts of rainfall and ponding have likely moved the insecticide out of the root zone area and/or enhanced the degradation of the product. Even if the insecticide is still present in sufficient quantities to control rootworms, it may be difficult to place the seeds in the previous insecticide band.

Management

Chemical Control

Label Restrictions. Soil insecticide labels restrict the amount of product that can be applied per season. Because the label is the law, this is not to be exceeded. Most soil insecticide rates restrict application to once per season due to potential toxicity issues to non-target organisms, potential toxicity issues with the humans or livestock that consume the crop, or potential toxicity issues with ground or surface water. A couple of exceptions to the one application per season are Lorsban® 15G & 4E if the 16-ounces per 1000 ft. of row (6 pints per acre) limit per season is followed, and the seed-applied insecticides, Cruiser® and Poncho®.

Application equipment should be calibrated per 1,000 feet of row, regardless of row spacing every year and every time a different product is used. If growing corn in narrow rows, be aware that some products have a maximum rate per acre, regardless of row width.

Insecticide replant restrictions	
Product	Can I use the same product at the rootworm rate again?
Aztec® 2.1G & 4.67G	No
Capture® 2EC & LFR	No
Counter® CR & 15G	No
Force® 3G & CS	No
Fortress® 3.5G and 5G	No
Furadan® 4F	No
Regent®	No
Lorsban® 15G & 4E	Yes
Poncho® 1250 (rootworm rate)	Yes
Cruiser® (rootworm rate)	Yes

Source: Obermeyer, J. and L. Bledsoe. (2008(a)).

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Management

Native Resistance

Researchers have been striving to develop novel corn lines that exhibit resistance and/or tolerance to corn rootworm larvae in hopes of lessening soil insecticide use and to provide a sustainable option for farmers in Europe. However, no current commercial hybrids claim to have native resistance to rootworm larvae.

Forms of native resistance can be classified into three mechanisms: **antixenosis**, **antibiosis**, and **tolerance**. For many years breeding efforts have resulted in tolerance to rootworm larvae in the form of well-developed root systems and plants that generate new roots when needed. These improvements have been beneficial, but have not been sufficient to compete with insecticides or genetically modified hybrids. However, recent efforts have resulted in plants that exhibit antibiosis against WCR larvae, although the plant characteristics or chemicals responsible for the antibiosis remain unknown.

FYI: Developing hybrids with native resistance to rootworm larvae is difficult. Conventional methods have used unfinished germplasm such as inbreds, not finished hybrids for screening and the correlation between inbred tolerance and hybrid tolerance is not significant. Additionally, higher yields in native resistance studies may be more due to the larger root systems that result from hybrid vigor than from antibiosis, antixenosis, or tolerance.

Management

Transgenic Control

Transgenic Corn. *Bacillus thuringiensis* Berliner (*Bt*) are soil bacterium that produce crystal proteins (Cry proteins) that selectively kill groups of insects. In February 2003, the Environmental Protection Agency (EPA) approved the first transgenic corn that produces a *Bt* protein within its root cells that kills rootworms, or discourages them from feeding on the corn root. Approvals for other transgenic events that produce *Bt* proteins that kill rootworms soon followed.

All of the transgenic rootworm events approved for sale in the U.S. today effectively control WCR, NCR, and MCR larvae. None of them control southern corn rootworm larvae, and none of them control rootworm adults.

Transgenic rootworm options commonly sold 2003 - 2010					
Developer	Rootworm event(s)	Rootworm gene(s)	Product name	First year of sales	Required rootworm refuge
Monsanto	MON863	Cry3Bb1	YieldGard® Rootworm	2003	20%
	MON863	Cry3Bb1	YieldGard® Plus	2004	20%
	MON863	Cry3Bb1	YieldGard® Plus/RR2	2004	20%
	MON88017*	Cry3Bb1	YieldGard® VT Rootworm/RR2	2007	20%
	MON88017*	Cry3Bb1	YieldGard VT Triple®	2007	20%
	MON88017*	Cry3Bb1	Genuity™ VT Triple PRO™	2009	20%
Monsanto and Dow AgroSciences	MON88017* & DAS-59122-7	Cry3Bb1 & Cry34Ab1/Cry35Ab1	SmartStax™	2010	5%
Syngenta	MIR604	Cry3A	Agrisure® RW	2007	20%
	MIR604	Cry3A	Agrisure® 3000GT	2008	20%
	MIR604	Cry3A	Agrisure® 3000GT w/ Agrisure Viptera™ (Agrisure Viptera™ 3111)	2010	20%
Dow AgroSciences and Pioneer Hi-Bred	DAS-59122-7	Cry34Ab1/Cry35Ab1	Herculex® RW	2006	20%
	DAS-59122-7	Cry34Ab1/Cry35Ab1	Herculex® RW/RR2	2006	20%
	DAS-59122-7	Cry34Ab1/Cry35Ab1	Herculex® XTRA	2006	20%
	DAS-59122-7	Cry34Ab1/Cry35Ab1	Herculex® XTRA/RR2	2006	20%
Pioneer Hi-Bred	DAS-59122-7	Cry34Ab1/Cry35Ab1	Optimum® AcreMax™ 1	2010	10% In-the-bag
	DAS-59122-7	Cry34Ab1/Cry35Ab1	Optimum® AcreMax™ RW	2010	10% In-the-bag

*Molecular stack of MON863 plus RR2.
Adapted from: CERA. (2010) and Gray, M. (2010).

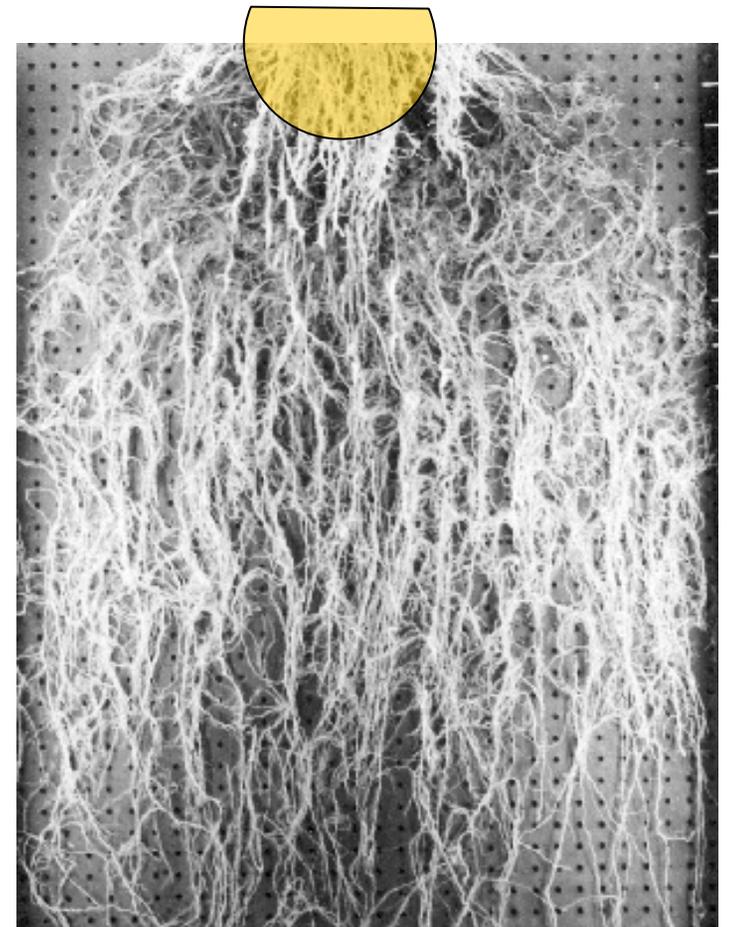
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[Click to enlarge](#)

Management

Transgenic Control

Transgenic rootworm protected hybrids are more efficient than granular insecticides because the whole root is protected, compared to just a small portion of the root protected with insecticides. *Bt* hybrids also increase consistency of rootworm protection compared to insecticides. The increased protection and increased consistency typically results in increased overall yields and increased farm income.



The gold colored area represents the root area protected by T-banded insecticides. Transgenic corn protects the whole root. Note: The root system is mounted on pegboard with 1" x 1" spacing and the soil surface is a few inches above the top of the picture. Courtesy of Ken Ostlie, University of Minnesota.

Management

Transgenic Control

Although the price of transgenic corn is higher than conventional corn, the benefits of using transgenic corn usually outweigh the additional costs.

Planting transgenic corn allows for significant reductions in insecticide use which is a major production cost in some areas of the Corn Belt. Indirect benefits of reduced insecticide use include reduced energy consumption for manufacturing, transporting, and applying insecticides; reduced waste streams from manufacturing processes; reduced insecticide waste container disposal; and reduced residues from insecticide applications.



One of the benefits of transgenic corn is the reduction in the number of insecticide containers that need to be disposed. Courtesy of the Dinwiddie County Virginia Cooperative Extension.

Management

Transgenic Control

Transgenic corn can also conserve biodiversity in a corn field because, unlike soil insecticides, *Bt* hybrids have no adverse effects on non-target above ground or below ground insects, nematodes, or arthropods.

The incidence of stalk rots may also decrease since stalk rots often enter the plant through damaged roots.

Some of the intangible benefits include the safety of not handling an insecticide, time and labor savings, ease of use compared to using insecticides, and better pest control.



Distinctive blackening of the corn stalk rind due to anthracnose stalk rot (*Colletotrichum graminicola*) of corn. Courtesy of Gary Munkvold, Pioneer Hi-Bred.

Management

Transgenic Control

Insect Resistance Management. When farmers realize that one management technique is superior to others there is a tendency to overuse that technique. History shows that when one technique is used a lot, pressure is placed on that pest forcing it to adapt making that technique no longer useable. Rootworms are no exception to this rule with WCR's history of adapting to pesticides and NCR and WCR's adapting to crop rotation.



In order to preserve the technology, the EPA mandates that an Insect Resistance Management (IRM) plan be used when planting corn containing *Bt* genes. Following an IRM plan should prevent or significantly delay rootworm adaptation to *Bt* proteins.

Implementing an IRM plan is accomplished by planting corn that does not contain the transgenic *Bt* gene as a refuge for the insect. The purpose of the refuge is to provide a corn crop habitat that allows rootworms to feed, mate, and reproduce without being exposed to the *Bt* proteins. Rootworms that are exposed to the *Bt* proteins each year for many generations will eventually evolve to become resistant to the *Bt* proteins. By planting a refuge the rare insects that have become resistant will mate with the non-resistant insects from the refuge area. Since resistance would most likely be a recessive trait, the resulting offspring would not be resistant, thus prolonging the use of the technology.

Management

Transgenic Control

The EPA requires planting a refuge as a condition of *Bt* corn hybrid registration and market availability. Farmers enter into a contractual agreement with the seed company when they purchase the seed that obligates the farmer to plant the appropriate refuge.

The EPA's Compliance Assurance Program (CAP) requires seed providers to conduct random on-farm visits to assess whether growers are complying with the IRM requirements. The CAP outlines consistent standards to respond to growers who have not followed the IRM requirements to bring them into full compliance. If found noncompliant, growers will receive a letter notifying them of their compliance deviations, seed companies may conduct a pre-planting compliance visit to assist the grower with planning and implementing an IRM program, and seed companies may conduct a compliance assessment the following season to assess IRM compliance. If a farmer is found noncompliant in two consecutive years he/she will be denied access to the *Bt* corn the third year.

FYI: *Bt* traits are only registered by the EPA for a few years, and have to be re-registered if use is continued. The EPA has the authority to not re-register and even rescind registration of *Bt* traits if they find that farmers in general have become noncompliant of the IRM requirements.

Management

Transgenic Control

What are the refuge requirements for a single rootworm *Bt* trait or stacked with a single corn borer *Bt* trait that are using a common refuge?

- *Bt* protected hybrids may not be planted on more than 80 percent of a farm's total acres.
- At least 20 percent of the total corn acres must be planted with refuge corn that does not contain *Bt* traits for control of corn rootworms.
- The rootworm refuge must be planted in the same field or directly next to the *Bt* corn rootworm field. The refuge field **can not be separated by another field**.
- The refuge can be planted in the same field as a single block, split planter at least four crop rows wide, or as a the field perimeter.
- If the refuge is planted on rotated ground then the *Bt* corn rootworm corn must be planted on rotated ground. If the refuge is planted in continuous corn then the *Bt* corn rootworm corn may be planted in either continuous or rotated ground.
- The refuge acres can be treated with soil-applied or seed-applied insecticides to control rootworm or secondary insect pests.
- The refuge can be treated with a non-*Bt* foliar insecticide if necessary to treat late season pests. However, if rootworm beetles are present then the *Bt* acres must also be treated in a similar manner.

Management

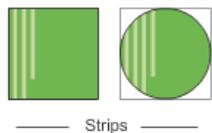
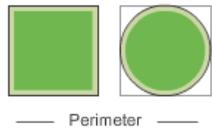
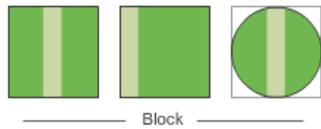
Transgenic Control

Common structured refuge options for genetically modified rootworm hybrids.

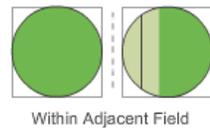
Corn Rootworm Refuge – 20% of Total Corn Acres

Plant an area that serves as a refuge for Western, Northern, and Mexican Corn Rootworm that is within or adjacent to the trait field.

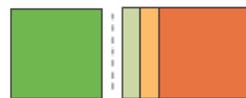
Within



Adjacent



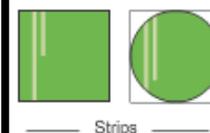
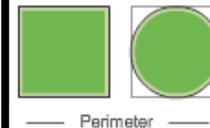
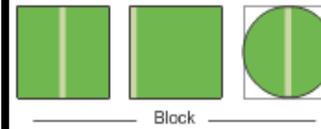
Combined With Another Insect Trait



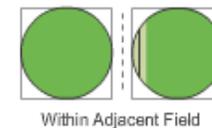
Common refuge – 5% of Total Corn Acres

Plant an area that serves as a refuge for both Corn Borer and Corn Rootworm that is within or adjacent to the trait field.

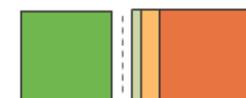
Within



Adjacent



Combined With Another Insect Trait



- Corn Borer Traits
- Other Insect Trait
- Other Trait Refuge Acres

Refuge (a non insect trait like Roundup Ready® Corn 2 or conventional corn and requires a minimum of 4 contiguous rows)

--- Designates ditch, road, path, etc.

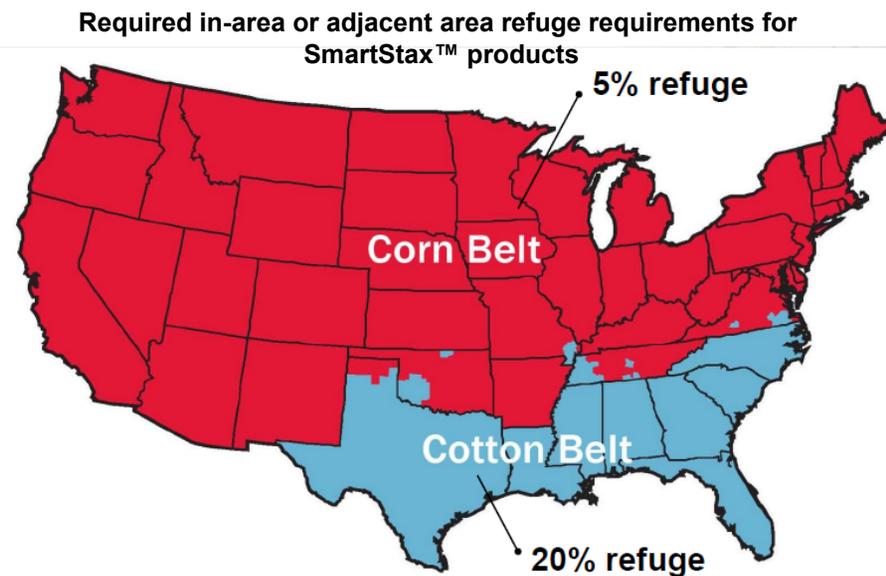
Management

Transgenic Control

Other Refuge Options. In time for 2010 planting, the EPA approved a couple of products that have different refuge requirements than the standard 20 percent in-field/adjacent field requirements.

Smartstax™ products have three modes of action for lepidopterans and two modes of action for corn rootworms. Models show that rootworms are extremely unlikely to become resistant to two modes of action that are **pyramided** in the same product.

Smartstax™ products have a 5 percent structured refuge in the Corn Belt and 20 percent structured refuge in the Cotton Belt, due to cotton bollworm/corn earworm (*Helicoverpa zea*). All other refuge requirements are the same, except that rootworm and corn borer traits must use a common refuge.



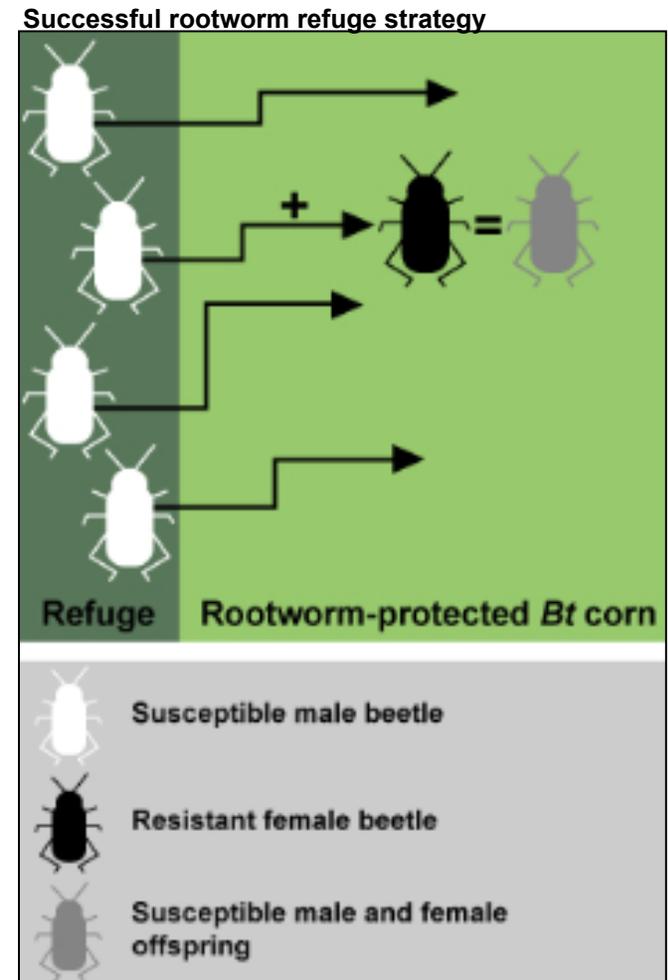
FYI: While a reduced refuge is welcomed by most farmers planting a 5 percent refuge in strips 4 rows wide with a split planter is only possible with a planter that is at least 40 rows wide.

Management

Transgenic Control

In order for a refuge strategy to be successful at managing resistance to *Bt* products, susceptible and resistant adults must disperse and randomly mate in the field. However, females often mate within hours of emerging, before dispersing, and rarely mate more than once, meaning that males are the dispersers in the refuge strategy.

Although males may mate multiple times, they rarely mate more than 2 or 3 times in their lifetime, and rarely later in life. Females rarely mate more than once. Furthermore, adults from refuge areas have been shown to emerge up to a week earlier than adults from the *Bt* corn in the same field, resulting in up to 18 days difference in timing between when males emerge from the refuge and females emerge from the *Bt* portion of the field. The effectiveness of a separate refuge depends on how far susceptible males from the non-*Bt* refuge disperse into the *Bt* portion of the field to mate with resistant females that emerge significantly later.



Management

Transgenic Control

Another option to the standard block or strip refuge is a seed blend or where the refuge plants are mixed and planted at random throughout a field of *Bt* corn. Research on emergence trends in mixes show that the number of males emerging from a standard refuge and the non-*Bt* plants in a seed mix peaked synchronously, which reduces the concern about the emergence timing.

However, late instar larvae may move from highly-damaged refuge plants to *Bt* plants. All of the commercial rootworm *Bt* toxins are considered “non-high dose” toxins so there is a possibility that larvae that move to the *Bt* plants as late instar larvae may survive, which increases the likelihood of passing on resistance to the next generation.

The decision to use a seed mix must be based on the trade off's of grower convenience, forced compliance, and potentially greater number of susceptible males mating with resistant females, and the disadvantages of potential larval movement between refuge and *Bt* plants that could reduce the number of susceptible beetles, and the concern over potentially exposing late instar larvae to sublethal doses of the *Bt* toxin.

FYI: According to annual Compliance Assurance Program reports that seed companies provide to the EPA, by 2008, grower compliance to the refuge size requirement for rootworm – protected *Bt* corn had fallen to 74 percent, while compliance with the distance requirement fell to 63 percent.

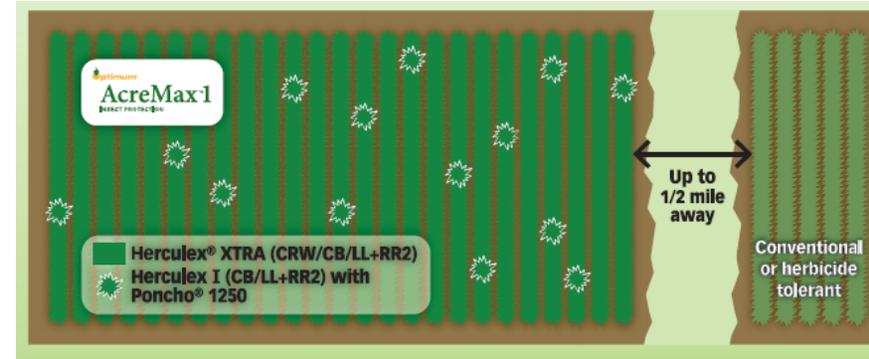
Management

Transgenic Control

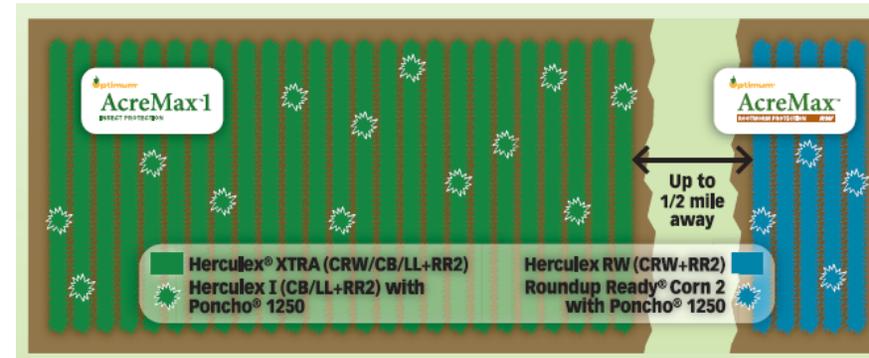
In 2010, the EPA approved the first ever corn products with an integrated in-the-bag refuge for corn rootworms. The EPA's models show that a 10 percent blended refuge has comparable **durability** to a 20 percent block refuge, so the blended refuge also came with an approval to reduce the refuge from 20 percent to a 10 percent blend.

Optimum® AcreMax™ 1 products have a blend of 90 percent **HXX/LL/RR2** and 10 percent **HX1/LL/RR2**, which serves as the CRW refuge. This option allows a field to be fully protected from rootworms, but requires a 20 percent lepidopteran refuge within ½ mile. If the corn borer refuge is planted in the same field, the strips must be at least four rows wide.

Optimum® AcreMax™ RW products have a blend of 90 percent **HXRW/LL/RR2** and 10 percent **RR2**, which serves as the CRW refuge.



By including the CRW refuge in the bag, Optimum® AcreMax™ 1 products allow growers to place the required corn borer refuge in a different field, up to ½ mile away, eliminating the hassles associated with standard in-field refuge configurations.



Growers could plant 80 percent of the farm with A Optimum® AcreMax™ 1 insect protection and 20 percent to an Optimum® AcreMax™ RW product in a separate field up to ½ mile away in order to have CRW technology on 100 percent of their acres.

Management

Transgenic Control

Other Considerations. Blending the refuge in the bag and pyramiding multiple modes of action are the likely future of transgenic control. However, rootworms are notorious for finding a way around management practices.

One transgenic solution, stacking genes in the same corn plant, may actually shorten the durability of *Bt* genes. Most transgenic rootworm *Bt* events are stacked with a glyphosate resistant gene and the prevalence of glyphosate resistant volunteer corn has steadily grown.

Many of the glyphosate resistant volunteer corn plants are being damaged by rootworm larvae and allowing a small fraction of the larvae in the field to survive to adulthood. Any that do survive to adulthood are likely to mate with other adults that emerged from the same volunteer plants, potentially facilitating a more rapid evolution of *Bt* resistance. Some producers are combating this possibility by tank mixing herbicides, such as Assure[®] II with glyphosate, or planting corn hybrids that are not glyphosate resistant.



Volunteer corn is soybeans used to be controlled by an application of glyphosate. Now that most corn hybrids are glyphosate resistant, the plants survive and so can the rootworm larvae that hatch near them. Courtesy of Chris Boerboom, University of Wisconsin.

Summary

The corn rootworm complex has long been a major pest of corn in the United States and Canada causing serious yield losses and harvest woes. Many of the rootworm problems are the result of the pest's history of resistance to management tactics such as insecticides and rotation. While insecticides and rotation have played a major role in reducing the impacts of rootworms in the past, the introduction and growth in the use of hybrids with transgenic CRW control are quickly becoming the mainstay in U.S. farmers' battle against this insect while European efforts are focused on non-transgenic options such as biological and cultural controls.

The benefits of transgenic technology come with a responsibility to follow IRM requirements to ensure that the technology stays ahead of this ever-changing complex of pests. Through the use of pyramiding multiple modes of action and including the refuge-in-the-bag, the future of CRW control will be more simple and more durable than it is today.

Summary

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