1999

EC99-1563 Corn Rootworm Management

Robert J. Wright
University of Nebraska, rwright2@unl.edu

Lance J. Meinke
University of Nebraska - Lincoln, lmeinke1@unl.edu

Keith J. Jarvi
University of Nebraska - Lincoln, kjarvi1@unl.edu

Nebraska Cooperative Extension EC99-1563

Corn Rootworm Management

Robert Wright, Extension Entomologist
Lance Meinke, Professor, Department of Entomology
Keith Jarvi, Extension Assistant, Integrated Pest Management

- Introduction
- Life Cycle and Damage
- Scouting and Economic Thresholds
- Management Options
- Insecticide Resistance Management

Introduction

Corn rootworms (*Diabrotica* spp.) are one of the most economically important corn insects in Nebraska. The western corn rootworm, *D. virgifera virgifera* LeConte, and the northern corn rootworm, *D. barberi* Smith and Lawrence, are the most economically important rootworm species in Nebraska. A third species, the southern corn rootworm, *D. undecimpunctata howardi* Barber, causes little economic damage to corn and has not been shown to overwinter in Nebraska. This publication will focus on the biology and management of the western and northern corn rootworms.

Life Cycle and Damage

The western corn rootworm is the most common species in Nebraska corn fields. The northern corn rootworm is more frequently found in northeastern Nebraska, sometimes making up more than 25 percent of the total rootworm population. There are many similarities in the life cycle of these species. Both overwinter in the egg stage in the soil. Larvae hatch in late May or early June, feed on corn roots, go through three larval stages (instars), pupate in the soil and emerge as adults in July and August. There is one generation a year. These rootworms do differ in other characteristics which are discussed below.

Figure 1. Adult western (left) and northern (right) corn rootworms (Jim Kalisch, UNL Department of Entomology)

Adult rootworms are about 1/4 inch long *(Figure 1)*. Western corn rootworms are yellowish with a black stripe on each wing cover. Males often have a more solid black marking on the wings, and females have a more distinct stripe, but this is not a reliable characteristic to determine sex. Male *Diabrotica* beetles have an extra segment at the end of the abdomen *(Figure 2)*. Northern corn rootworm beetles are solid in color, and vary from light tan to pale green. There are few visible differences among *Diabrotica* species in the egg, larval and pupal stages. Eggs, which are deposited in the soil during the summer, are football-shaped, white and less than 0.004 inches long. Eggs overwinter in the soil and hatch in late May to early June.

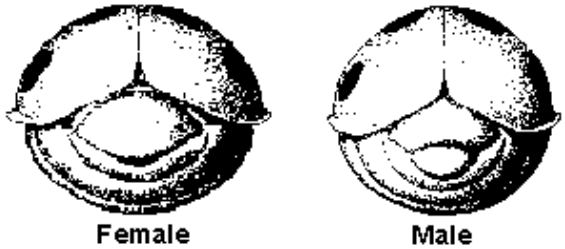

Figure 2. Characteristics to sex Diabrotica beetles

Newly hatched larvae are small (less than 1/8 inch long) white worms. Larvae have brown heads and a brown marking on the top of the last abdominal segment, giving them a double-headed appearance *(Figure 3)*. Larvae have three pairs of legs, but these usually are not visible without magnification. After feeding for several weeks, the larvae dig a cell in the soil and molt into the nonfeeding pupal stage. The pupal stage is white, and has the basic shape of the adult *(Figure 4)*.

Figure 3. Larval corn rootworms (Jim Kalisch, UNL Department of Entomology)

Timing of egg hatch varies from year to year, due to temperature differences. For any given year, hatch also varies with location: hatch occurs later in northern and western Nebraska than in southeastern Nebraska. The length of western corn rootworm larval and pupal stages is related to temperature *(Table I)*. Western corn rootworm adult emergence usually begins in southeastern Nebraska by July 4, but may start earlier. In some years, northern corn rootworm adults may begin to emerge later than western corn rootworm. Corn rootworm males begin to emerge before females. Emergence often continues for a month or more *(Table II)*. In years with hot, dry summers, numbers of western corn rootworm beetles may decline rapidly after mid-August, although in summers with less extreme conditions, they may be found up until the first frost.

Figure 4. Corn rootworm pupa

Females mate soon after emergence. Western corn rootworm females need to feed for about two weeks before they can lay eggs. Temperature and food quality influence the pre-oviposition period. Females lay eggs in the soil, typically in the top 8 inches of soil, although they may be laid more than 12 inches deep, particularly if the soil surface is dry. Western corn rootworm females are more likely to lay some of their eggs below the 8-inch depth than northern corn rootworm females.

Figure 5. Leaf feeding by western corn rootworm adults

Rootworm larvae can complete development only on corn and a few other species of grasses. Western corn rootworm adults feed primarily on corn silk and pollen, and kernels of exposed ear tips, although they also will feed on corn leaves and pollen of other plants. If western corn rootworm adults begin emerging before corn reproductive tissues are present, adults may begin feeding on leaf tissue, scraping away the green surface tissue, leaving a window-pane appearance *(Figure 5)*. However, adults quickly shift to preferred green silks and pollen when they become available. Northern corn rootworm adults also feed on reproductive tissues of the corn plant but rarely feed on corn leaves. Northern corn rootworm adults are more likely than western corn rootworm adults to abandon corn and seek pollen or flowers of other plants as corn matures.

Most of the damage in corn is caused by larval feeding. Newly hatched rootworms locate corn roots in the soil and initially begin feeding on the fine root hairs and burrow into root tips of the corn plant. As larvae grow larger, they feed on and tunnel into primary roots. When rootworms are abundant, larval feeding and deterioration of injured roots by root rot pathogens can result in roots being pruned to the base of the stalk. Severe root injury interferes with the roots' ability to transport water and nutrients into the plant, reduces plant

growth, and results in reduced grain production. Severe root injury also may result in lodging of corn plants, making harvest more difficult.

Silk feeding by adults can result in pruning of silks at the ear tip, commonly called silk clipping. In field corn, beetle populations are occasionally high enough to cause severe silk clipping during pollen shed which may interfere with pollination.

Table I. Duration of immature stages of western corn rootworm at constant temperatures.

	Days to complete stage (male/female) at different constant temperatures (F)			*Degree days to complete stage (48.2 F base)*	
Stage	*64.4*	*69.8*	*75.2*	*Males*	*Females*
1st instar larva	8.1/8.6	5.6/6.2	4.8/5.3	70.4	77.7
2nd instar larva	6.8/7.1	4.9/5.4	4.3/4.9	61.7	70.6
3rd instar larva	15.0/15.5	11.2/11.9	9.4/10.4	140.5	149.2
Pupa	13.5/13.8	10.1/10.1	7.8/8.4	122.2	125.1
Hatch to adult emergence	43.4/45.0	31.8/33.6	26.3/28.9	394.8	422.6

Source: Jackson and Elliot, 1988, Environmental Entomology 17:166-171.

Table II. Corn rootworm adult emergence, 1994, Saunders County, Nebraska.

	Cumulative percent emergence			
	Western corn rootworms		*Northern corn rootworms*	
Date	*Males*	*Females*	*Males*	*Females*
July 5	17.9	6.3	0	0
July 8	39.3	12.5	30.8	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 adult emergence was detected on June 27. Initial egg laying female western corn rootworm observed July 20.

Data from Meinke, 1995. *Adult Corn Rootworm Management*, University of Nebraska Cooperative Extension publication, MP 63.

Scouting and Economic Thresholds

Damage by corn rootworm larvae is most likely to occur in continuous corn fields; however, it has been estimated that more than 60 percent of Nebraska's continuous corn fields do not have economic corn rootworm infestations in a given year. The only way to determine whether a field is likely to have an economic rootworm infestation is to scout for adults or larvae.

Adult Scouting

There are two methods of sampling rootworms on plants: whole plant and ear zone. The whole plant is examined for rootworm beetles in the first method, taking care to examine all locations including the leaf surface, behind the leaf sheaf, and in the ear tip. The ear zone method samples only the middle of the plant centered on the ear (the under surface of the leaf above the ear, the ear and ear leaf, and the upper surface of the leaf below the ear) *(Figure 6)*. Scout corn for rootworms weekly from mid-July through early September or until the threshold is exceeded.

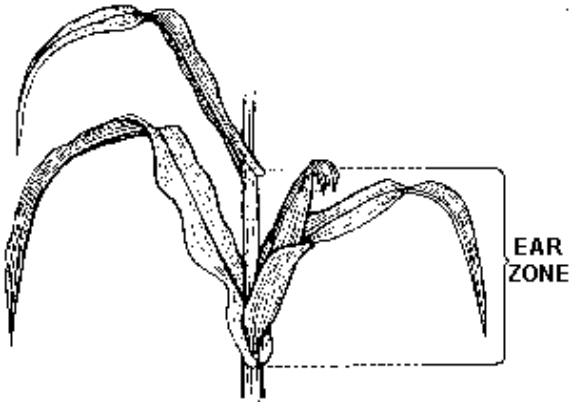

Figure 6. Ear zone

Research has shown that the most efficient way to reliably scout for corn rootworm beetles using whole plant counts is to examine two plants per site and to sample at least 54 plants per field (27 sites). Samples should be taken in a pattern (e.g., U-, V-shaped) so that some samples are taken from each quarter of the field. The two plants per site should be several paces apart so that you do not disturb beetles on the second plant when examining the first plant. The most efficient way to reliably scout for corn rootworm beetles using the ear zone method is to examine five ears per site and 32 sites per field (160 plants total), examining plants from all four quarters of the field. Although the ear zone method takes less time per plant, it may take more time overall because more plants need to be sampled to obtain a reliable estimate. Also, the ear zone method samples a variable percentage of the population that may change during the season. Averaged over the whole season, ear zone counts represent about 50 percent of the total beetle population.

Economic thresholds for western corn rootworms have been developed based on whole plant and ear zone sampling methods *(Table III)*.

Table III. Average number of western corn rootworm beetles present in cornfields that may produce an economically damaging rootworm population in corn the following year.

	Average number of rootworm beetles			
	Continuous corn[1]		*First year corn*[2], [3]	
Plants per acre	*Per plant*	*Per ear zone*	*Per plant*	*Per ear zone*
14,000	1.28	0.64	0.96	0.48
16,000	1.12	0.60	0.84	0.42
18,000	1.00	0.50	0.75	0.37
20,000	0.90	0.45	0.68	0.34
22,000	0.81	0.40	0.61	0.30
24,000	0.75	0.37	0.56	0.28
26,000	0.69	0.34	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

[1]Based on a 50:50 ratio of females to males.

[2]Based on a 70:30 ratio of females to males.

[3]Use 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).

Although no studies have developed thresholds specifically for northern corn rootworms, these thresholds should be acceptable. Thresholds for whole plant counts are equal to 0.75 beetles per plant with 24,000 plant per acre (=18,000 rootworm beetles per acre) and assume a 50:50 ratio of males to females. Thresholds expressed as number of rootworms per plant are shown in the table for various plant populations. Different thresholds have been developed for corn after corn, and corn after another crop (first year corn) because research has shown that females have a greater tendency to migrate and make up a greater proportion of the population in first year corn. Since these thresholds predict the potential for a problem to occur next year based on the potential level of eggs laid by females, threshold levels are lower in first year corn. If beetle numbers in a field exceed the threshold, there is a potential for economic damage if corn is planted back into the field the next year.

These thresholds also can be used to determine the need for foliar sprays during the current year, if adult control programs are used. An additional factor to consider is the reproductive status of the females. Thresholds should be based on the number of beetles and the presence of females ready to lay eggs (gravid). Females may be checked by gently squeezing the abdomen between the thumb and forefinger, and examining the contents. If females are gravid, tiny cream colored eggs should be visible. A 10X hand lens may be useful to clearly see the eggs.

An alternative to using a constant sample size would be to use a sequential sampling plan. Sequential sampling plans often save time because they are based on smaller sample sizes when beetle numbers are much above or below the threshold level. In this way sampling effort is concentrated on fields which are nearing the threshold. A sequential sampling plan based on whole plant counts was developed at Iowa State University, and assumes a threshold level of 0.7 beetle per plant *(Table IV)*. To use the sequential sampling plan, first count the number of beetles on 10 plants (two each at five sites). Compare the total number of beetles found with the values in the table. If two or fewer beetles have been found, you should stop sampling and resample next week. If 12 or more beetles are found, stop sampling because the threshold has been exceeded. If the total is 3-11, you should sample two plants at another site. Compare totals to the table again. This process is continued until a decision is reached, or the maximum sample size has been attained.

Table IV. Corn rootworm sequential sampling plan for use in continuous corn fields.

	Number of beetles found		
Number of plants sampled	*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: G. L. Hein and D. E. Foster, 1988. *Corn rootworm management*, Iowa State University Pm-670.			

Another method to scout for rootworm beetles is to use yellow sticky traps *(Figure 7)*. These traps are placed at ear level on corn plants. The yellow color attracts beetles and a sticky adhesive coating on the trap captures beetles when they land. The traps are checked weekly and the number of beetles trapped counted. Traps normally are changed after seven days to ensure maximum trapping efficiency. Research in Iowa has shown that using 12 unbaited Pherocon AM traps spaced out over a field adequately samples rootworm beetle numbers. An economic threshold for using these traps is six beetles per trap per day. Some advantages of using sticky traps are that they sample over several days and average out effects of time of day or short-term weather changes that may influence visual counts. They also provide a good solution for people who question their ability to adequately count beetles visually. Disadvantages include the added cost (ca. $1 per trap) and the possibility of getting the sticky adhesive from the trap on your hands and clothes.

Silk clipping

Corn rootworm beetles occasionally interfere with pollination if there are sufficient numbers to keep silks severely clipped *(Figure 8)* during the pollen-shedding period. Control is indicated in field corn only when severe silk clipping (silks chewed to within 1/2 inch of husks) is occurring at 25-50 percent pollen-shed. In most years few fields will need to be sprayed to prevent silk clipping. Beetles are most likely to cause a problem in late-planted or late-silking fields or where water stress delays or reduces silking. Silk clipping after pollination causes no problems.

Larval Sampling

Sampling of rootworm larvae may be done to detect initial egg hatch, determine the need for a cultivation time treatment, or to evaluate the efficacy of a planting time treatment and the need for a rescue treatment. Because of the labor required to sample soil insects, it is not practical to sample as intensively as for adults, thus larval samples may not be as accurate.

Figure 7. Yellow sticky trap

Because first instar larvae are very small and tend to burrow inside small corn roots, they are rarely detected in the soil. A simple way to detect when rootworm egg hatch begins is to dig up 5-10 plants from different locations in a field and suspend the roots over a pan of water for 24-48 hours. A frame of coarse wire mesh screen can be used to hold the roots over water. As the roots dry, larvae will drop out of the roots and be visible in the water. This procedure can be repeated over time during late May and early June until the first larvae are found, indicating the beginning of egg hatch at that location. When larvae become larger (second instars), the following techniques can be used.

Figure 8. SIlk clipping by western corn

Randomly select one plant in each of ten locations in a field. Using a spade or shovel, dig up a 7-inch cube of soil centered on the plant.

Lift the plant and associated soil out of the ground and slowly search through the soil and roots for rootworm larvae. Rootworms are small, slender worms, with a brown head and tail. It may be easier to see the white rootworms if the soil is searched over a black piece of plastic to provide greater contrast to see the white worms. An alternate method is to place the soil and roots into a bucket of water. Water pressure and stirring can be used to break up the soil and free rootworm larvae. Larvae will float to the top and can be counted. Adding salt to the water (1 lb salt per gallon of water) will increase the tendency of the larvae to float to the top.

rootworm adults

Regardless of the amount of care used with either method, often only a small percentage of larvae present may be found, especially if sampling is done soon after egg hatch. Some rough guidelines are that treatment may be needed if an average of two or more rootworms per plant are found by visual searching, or eight or more are found by soil washing. Individual situations then need to be considered. The larval stage needs to be taken into account; if most rootworms are 1/2 inch long or if pupae are found, most of the damage may already have occurred, and it may be too late to treat. If most larvae are very small, you may be seeing a small percentage of what is present. Also, additional egg hatch may occur after sampling.

Management Options

Crop Rotation

Crop rotation away from corn for one year is a highly effective nonchemical control practice for corn rootworms in Nebraska. As a way to reduce rootworm densities, it is more effective than insecticides. First year corn is unlikely to benefit from soil insecticide applications for corn rootworm control in most situations. Consider treating first year corn only if corn follows oat stubble in areas with a history of rootworm damage in first year corn, or soybean fields heavily infested with volunteer corn or weeds. In a very small percentage of fields following soybeans or other rotations, northern corn rootworm larvae may damage first year corn. This is because a certain percentage of the eggs may hatch two years after being laid - a phenomenon referred to as extended diapause. These fields cannot be identified with certainty, but tend to occur in localized areas. Growers in areas where extended diapause has been a problem, must base their treatment decision on the presence of past rootworm problems in theirs and their neighbors' fields. In this case, extended rotations (i.e. more than two years) are encouraged if practical. The damage to first year corn from western corn rootworms reported from parts of Indiana, Illinois, Ohio and Michigan is due to beetles laying large numbers of eggs in soybeans in a corn-soybean rotation system. This problem is not known to occur in Nebraska.

Plant Resistance/Transgenics

Currently (1999) there are no corn hybrids commercially available with sources of resistance effective in controlling corn rootworms; however, several hybrid traits may reduce damage from larval rootworm feeding, including stalk strength and increased root mass size. These characteristics allow a plant to better tolerate rootworm feeding, with reduced likelihood of lodging. In the near future, several seed companies will be releasing transgenic corn hybrids with resistance to larval rootworm feeding.

Biological Controls

There are a variety of natural enemies of egg, larval, and pupal stages of corn rootworms, including other insects, mites, nematodes and fungi. Studies have shown that many of these natural enemies are more common in reduced-tillage systems, and in fields with higher levels of organic matter. Soil insecticide use can reduce the survival of these generalist predatory insects and mites. Insect-attacking nematodes and fungi have been studied as possible microbial control products that could be applied to the soil, but are not currently cost-effective for use in corn production. Currently there are no biological control agents that will consistently reduce medium to high populations of corn rootworms and associated injury below economically damaging levels.

Chemical Controls

Larval control

Traditionally, most insecticide use has been targeted at the larval stage. A variety of insecticide formulations and application methods are available. Liquid or granular insecticides may be applied at planting or at cultivation. Specific insecticide use information is available from the product label. Updated information for Nebraska is also available on the Internet at the UNL Entomology home page at http://www.ianr.unl.edu/ianr/entomol/entdept.htm

Planting time treatments may be applied infurrow or in a band in front of the press wheel (T-band) or behind the press wheel (surface band). Often a T-band is the best approach for controlling corn rootworms since it provides a wider band of insecticide protection of the roots than an infurrow application. However, many years of data from UNL research has shown little difference in root protection when using a T-band or infurrow application. If other early season soil insects, such as wireworms or white grubs are also a concern, an infurrow application is preferable. If surface feeding insects such as cutworms are also a concern, a T-band or surface band may be favored. Regardless of application method, soil insecticides should be lightly incorporated with soil during application. This can be accomplished with tines or a drag chain behind the press wheel. Granules or liquids remaining on the surface may volatilize or break down, resulting in poor performance. Also, leaving insecticide on the soil surface may increase the chances of environmental contamination and the poisoning of nontarget organisms.

Many insecticide performance failures can be traced to poor calibration of application equipment. In many cases, amounts used are below those recommended on the label. Higher than desired rates may cause plant injury and are a needless expense. Application equipment should be calibrated each year and any time a different product is used. Although two granular products may be applied at the same rate, they may have different handling characteristics which influence flow rate. By calibrating applicators to deliver the suggested amount of granules per 1,000 feet of row, the amount will be correct regardless of row spacing. If you are growing corn at a row spacing less than 30 inches, be aware than many products have a maximum rate per acre, regardless of row spacing.

Weather during planting, soil conditions, and type of planting equipment can greatly affect the placement of soil insecticides, which is an important factor in rootworm management. If planting under windy conditions, placing the bander close to the soil surface and using flexible wind shields on either side of the bander can reduce drift. The effectiveness of soil insecticides can be reduced if the soil remains dry after application, if excessive rainfall occurs, if soils are highly alkaline, or if insecticides are applied at planting on early planted corn.

Rootworm density is another factor that may influence soil insecticide performance. Since soil insecticides are applied as a band or infurrow, they only protect the central portion of the roots. When rootworm populations are high, significant feeding may occur by rootworms surviving outside of the zone of insecticide activity, even if the insecticide is working properly. Crop rotation is probably a better option if scouting data from the previous year indicated a high population of rootworm beetles.

Insecticides applied at planting must remain effective 6-10 weeks to be effective when rootworm egg hatch occurs. Insecticide performance is often more reliable if an insecticide is applied at cultivation time in late May or early June, especially if corn was planted in April. Insecticides applied at cultivation allow treatment to occur closer to the time of rootworm egg hatch. Cultivation time treatment is particularly desirable if soil is alkaline (high pH accelerates decomposition of some insecticides) or if the field has a history of poor root protection when insecticides have been applied at planting.

Cultivation time treatments may be applied by ground, by airplane or through chemigation. A disadvantage of cultivation time treatments is that if extended wet weather occurs, application may be delayed or not possible.

If granular products are applied by air without cultivation, control may not be adequate.

After about June 10 (or earlier depending on egg hatch), rescue treatment at lay-by time can be made by applying cultivation-time materials to the soil at the base of the plants. Cover the insecticide with 1-2 inches of soil. This treatment will not guarantee complete root protection because the insecticide will not thoroughly penetrate the soil. It may help reduce further root damage by establishing a barrier between the rootworms and developing roots. If applications are made by aircraft, use granules, cultivate into rows immediately, and irrigate if possible. Considerable variation in insecticide performance has occurred where broadcast applications have not been incorporated into the soil.

Reduced rates. Research at several Midwestern universities, including the University of Nebraska, has shown that use of reduced rates of corn rootworm soil insecticides usually provides acceptable levels of protection from corn rootworm feeding injury. If you are planning to use this approach, consider the following points:

1. Do not reduce the application below 75 percent of the labeled rate.
2. Insecticide application equipment must be well calibrated for this approach to work.
3. If planting early, use a cultivation treatment rather than a planting time treatment.
4. Try reduced rate applications on one or a few fields first, and always include an untreated check strip and a strip treated with the labeled rate for comparison.
5. Although reduced rate applications are legal, the company labeling the insecticide is under no legal obligation to you when products are used below labeled rates.
6. Do not use reduced rates of soil insecticides in areas near Holdrege or York where there is a history of poor control of adults using foliar applied insecticides (e.g. Penncap-M).

Adult control

In Nebraska, adult corn rootworm control programs have been used to manage corn rootworm populations in continuous field corn since the 1960s. The goal of adult spray programs is to suppress corn rootworm beetle populations and reduce egg-laying so that larval populations the following season will not cause economic loss. Occasionally adult control measures are also used to prevent silk-clipping damage that may interfere with pollination, especially in seed production fields. Most insecticides used for beetle control are aerially applied in Nebraska, with some application through sprinkler irrigation systems (chemigation). Most of the insecticide formulations currently used are "contact kill" products. Beetles are killed if directly hit by spray droplets during application or by walking on a sprayed surface.

Adult corn rootworm management is knowledge and labor intensive. A good understanding of beetle biology and factors that affect beetle population dynamics and movement in agroecosystems is needed to effectively use an adult management strategy.

When using an adult corn rootworm management strategy in continuous corn, it is important to scout corn fields starting in late June to early July to identify when initial beetle emergence occurs, to identify which corn rootworm species are present, and subsequently to determine if beetle populations reach the established economic threshold (*Table III*; and 10 percent of the females are gravid).

Several factors related to beetle emergence patterns should be considered to target the optimal time for initial insecticide applications. Female beetles on the average need to feed on high quality food (i.e. pollen, reproductive parts of the plant) for at least 10-14 days before they can lay eggs. Also, during the early beetle emergence period, more males emerge than females. It is advantageous not to spray during the first two to three weeks of the emergence period (little egg laying during this period) even if beetle populations are high. This will allow more females to emerge before application and reduce the pool of emerging beetles that can contribute to population resurgence after the insecticide application.

Many factors can interact to determine beetle population levels in a continuous corn field at different times during the season. The number of beetles emerging from within a field is often a primary contributor to the total population level in a field. Even if an adult management strategy was successfully used the previous year, or a soil insecticide was applied at planting or at cultivation, some larvae will be present (few to many, depending on the situation) and eventually will emerge as adults.

Beetle movement can also contribute to the population level in a field during a specific time. Both western corn rootworm and northern corn rootworm beetles are mobile and short range movement within fields or into neighboring fields occurs during the entire time beetles are present. The amount of isolation (or lack of isolation) of a corn field from other continuous corn fields will influence how large the potential pool of beetle immigrants will be. Western corn rootworm also have been shown to have a true migratory phase in which a certain proportion of a population will move long distances. Migration usually occurs early in the western corn rootworm life cycle; migrating females are usually mated but have not yet developed mature eggs. The mobility of corn rootworm beetles also enables them to colonize first year corn fields. Because a high percentage of migrant western corn rootworm beetles are usually female, more female western corn rootworm are often found in first year corn fields than males. Therefore, economic thresholds in first year corn are lower than in continuous corn *(Table III)*.

Western corn rootworm and northern corn rootworm prefer pollen (especially corn pollen/silks) as a food source, so pollinating fields are always very attractive to beetles. The corn growth stage in an individual field in relation to the surrounding corn fields can greatly influence whether the field will be a "donor field", a "receiver field", or a "neutral field". If a field pollinates later than the surrounding corn fields, the field will be attractive to beetles and some beetles may move into the field (receiver field) from fields that have finished pollination (donor fields). If all fields in a local area pollinate about the same time, each field, in relation to surrounding fields, would be similar in attractiveness to beetles (neutral fields) thereby lessening the chance of mass movement of beetles into one or more fields. Because receiver fields act as trap crops (increase in female beetle population over time results in more eggs being laid in these fields than surrounding fields), it is more difficult to successfully manage corn rootworm populations using an adult-based strategy in receiver fields than in donor or neutral fields (i.e. greater chance for population resurgence in receiver fields after insecticide application).

Weather patterns can greatly influence immature and adult corn rootworm survival, the beetle emergence pattern, and the length of beetle activity and egg-laying periods. Very wet soil conditions during the larval and pupal stages can reduce larval establishment on plants, or kill larvae and pupae, reducing the number of adults emerging in a field. A cool summer can slow larval and plant development times, which will influence initial beetle emergence dates. Cool weather also can lengthen the period for beetle emergence activity (increase survival/longevity) and egg-laying period. Conversely, hot weather can speed up immature rootworm development, greatly compress the emergence period, and reduce beetle activity and egg-laying periods (greater mortality/shorter life span due to heat stress). It is usually easier to use an adult management approach when the beetle emergence and egg-laying periods are shorter because the critical time fields need to be protected by insecticide applications will be shorter and there is less chance of population resurgence.

Rainfall (and to some extent, sprinkler irrigation) also can influence the residual activity of products applied for beetle control. In a cool wet year, with prolonged beetle emergence and egg-laying periods, short product residual due to wash off can create a situation where overall control is poor and population resurgence may be fairly rapid. This would be especially true if the management location is a receiver field. Under these conditions it is extremely important to pick the optimal time to apply the product (as related to rootworm biology and weather) because it will be more difficult to economically use an adult management strategy. If a field is acting as a trap crop in a cool wet year it may be more economical to scout the field and, if warranted, rotate or use a soil insecticide the following year instead of adult control. (Too many aerial applications may be needed to effectively manage the beetle population in this particular field.)

Assessing efficacy of control programs. To assess the success of a control program, it is important to

distinguish between larval control with soil-applied insecticides and adult control with foliar-applied insecticides, because they have different goals and measures of success.

Regardless of the control strategy used, efficacy cannot be reliably determined without having an untreated portion of the field for comparison.

Table V. Root injury rating scale	
Rating	*Description of root system*
1	No noticeable feeding damage.
2	Feeding scars present but no root pruning (chewed to within 1 1/2" of stalk).
3	At least one root pruned, but less than an entire node of roots pruned.
4	At least one full node of roots pruned, but less than two full nodes pruned.
5	At least two full nodes of roots pruned, but less than three full nodes pruned.
6	Three or more full nodes of roots pruned.

Larval control programs aim to protect the primary corn root system from economic levels of rootworm injury and to prevent lodging. The goal is not to greatly reduce the rootworm population in the field. After rootworm larval injury is complete (mid to late July, depending on year and location), roots can be dug, washed and examined for root injury. A 1-6 root injury scale *(Table V)* is often used in insecticide efficacy trials. Although there is not a firm relationship between root injury levels and yield loss from rootworms, historically a root rating greater than three has been thought to represent a potential economic loss. **The presence of rootworm larvae or adults is not a good indicator of the efficacy of a larval control program.** Soil insecticides are applied as a seven-inch band or infurrow at planting, or applied to the soil surface at cultivation time. Rootworm larvae can survive in untreated field areas and emerge as adults. If rootworm populations are high, there may be considerable numbers of larvae or adults present, even if the soil insecticide has functioned to protect the corn roots. Studies have shown that at-planting soil insecticides may reduce adult emergence from 20-80 percent, depending on the product and environmental conditions (particularly soil moisture).

Adult control programs aim to kill adults before they can lay enough eggs to cause an economic problem the following year. This goal is different from a larval control strategy because to effectively manage egg populations, the beetle population in the field must be greatly reduced. Beetle counts during the period after adult control sprays are applied are one measure of efficacy, but the reduction in rootworm larval injury and yield loss the next year should be the primary measure of efficacy.

Insecticide Resistance Management

In parts of south central Nebraska, two populations of western corn rootworms have been identified with resistance to methyl parathion and carbaryl insecticides. Methyl parathion is an organophosphate insecticide and carbaryl is a carbamate insecticide. These two populations are centered around Holdrege and York and extend into surrounding counties.

The initial problem was identified following reports of reduced beetle control by foliar insecticides used in adult control programs. Additional research has documented that this resistance is also found in the larval stage and also may effect efficacy of some soil insecticides.

People farming in the areas with documented resistance to insecticides by rootworms should consider the following options for larval control:

- **Crop rotation** is highly effective in controlling rootworms in Nebraska and has the added benefit of not increasing the selection for insecticide resistance.

- **If using adult control**
    - Other foliar insecticides may be used in place of Penncap-M to avoid the adult resistance problem, however most options are more expensive, do not provide the degree of residual activity, or may not control the same spectrum of pests.

    - Increasing gallonage of spray applications may provide better control with existing insecticides by providing better coverage within the canopy. Labels for Penncap-M and Warrior recommend a minimum of one and two gallons spray volume per acre, respectively.

    - Avoid spraying too early for beetle control. Males begin to emerge before females and females require about two weeks after emergence before they lay eggs.

- **Soil insecticides** are another chemical control option. Resistant rootworm larvae do not respond similarly to all organophosphate insecticides. Based on 1997 research at Holdrege, planting time applications of Lorsban, Counter and Aztec provided adequate levels of root protection against a moderate-heavy rootworm population at a location known to have adult resistance to methyl parathion and carbaryl.

- If using soil insecticides, **do not use less than labelled rates** for rootworm control.

- Whether you use adult control or soil insecticides, **do not use the same insecticide** in a field over several successive years.

- **Base the decision to use insecticides** on the level of rootworms present in individual fields, based **on adult scouting and economic thresholds.**

People farming in areas outside of the resistance area should consider the following practices to decrease the potential for insecticide resistance to occur in the future:

- **Rotate** some of your corn acres.

- Whether you use adult control or soil insecticides, **do not repeatedly use the same insecticide** in a field over several years.

- **Base the decision to use insecticides** on the level of rootworms present in individual fields, based **on adult scouting and economic thresholds.**

File EC1563 Under: FIELD CROPS
Issued July 1999

Issued in furtherance of Cooperative Extension work, Acts of May 8 and June 30, 1914, in cooperation with the U.S. Department of Agriculture. Elbert C. Dickey, Director of Cooperative Extension, University of Nebraska, Institute of Agriculture and Natural Resources.