Proceedings
of the 15th Annual

Integrated Crop Management Conference

December 3 and 4, 2003
Iowa State University
Ames, Iowa

IOWA STATE UNIVERSITY
University Extension

CORN ROOTWORM MANAGEMENT WITH YIELDGARD® ROOTWORM CORN: THIS CHANGES EVERYTHING

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Northern corn rootworms (Diabrotica barberi) and western corn rootworms (Diabrotica virgifera virgifera) are perennial pests of corn (Zea mays) across the Corn Belt. Larval feeding on corn roots interferes with water and nutrient uptake, increases stalk lodging, allows entry of stalk rot pathogens, and decreases yields. Traditional methods of rootworm control include the use of insecticides (soil insecticides or seed treatments for larvae, and foliar sprays for adults) and crop rotation. The recent commercialization of transgenic Bt corn for control of corn rootworm larvae has the potential to dramatically change the way this pest complex is managed by farmers in the Corn Belt.

YieldGard® Rootworm Approved by EPA

On February 25, 2003, the Environmental Protection Agency (EPA) announced approval for commercial use of transgenic corn that prevents root injury by corn rootworm larvae. This transgenic corn, developed by Monsanto Company and referred to as MON 863, will be commercially marketed as YieldGard® Rootworm. This corn produces its own insecticide within the plant that is derived from the naturally occurring soil bacterium Bacillus thuringiensis kumamotoensis (Bt). The Bt protein, called Cry3Bb1, controls corn rootworm larvae but not the adult beetles. This control prevents larvae from causing significant injury to corn roots.

On October 31, 2003 the EPA completed its review and granted registration for YieldGard® Plus corn. This is the first transgenic corn product designed to control both European corn borer and corn rootworms.

Either of these two new products, YieldGard Rootworm or YieldGard Plus, will provide corn growers with a safe pest control alternative that can reduce reliance on traditional insecticides. The reduced insecticide use will directly benefit the environment and can mean less chemical exposure to people who apply pesticides to corn.

YieldGard Rootworm Corn Evaluated

In 2002 (Table 1) we evaluated the performance of a variety of control measures for corn rootworm larvae including YieldGard Rootworm. YieldGard Rootworm corn provided excellent root protection and 100 percent consistency under moderately heavy populations of corn rootworm larvae (1.90 nodes eaten in the untreated check).

With the registration of YieldGard Rootworm in 2003 it was possible to plant larger replicated plots and harvest the treatments. Plots were replicated four times at each location: Crawfordsville (1-row plots, 17.5 ft long), Nashua (2-row plots, 87 ft. long) and Sutherland (2-row plots, 87 ft. long). Tables 2-4 report the 2003 YieldGard and insecticide replicated corn rootworm efficacy trials. Again this year the YieldGard Rootworm provided superb protection from larval feeding. There was a small difference, however, during 2003. In the past the YieldGard root-protection consistency had been 100%, but at Crawfordsville there was some larval feeding. The feeding occurred on the first node of brace roots (7^{th} node). There was volunteer corn in the test plot and the feeding could have resulted from larvae beginning development on the volunteer corn and moving to the YieldGard Rootworm later in the season as the brace roots entered the soil. The concentration of the protein toxin in the later emerging roots may not have been high enough to control the large larvae.

The 2003 results are presented as separate tables rather than a single summary table because there were differences in yield protection between locations. At Crawfordsville (Table 2) and Nashua (Table 3) the YieldGard produced 44 and 27 bushels more corn then the untreated, respectively, while at Sutherland the difference was only 6 bushels (Table 4). It is likely that the differences were caused by differences in the density of corn rootworms and the soil moisture during the time that larvae were feeding. At Sutherland there was only a moderate corn rootworm infestation, 1.24 nodes of roots destroyed in the untreated, and at Crawfordsville and Nashua the plots were heavily infested, 2.14 and 2.46 nodes destroyed in the untreated, respectively. Also the summer rainfall at Sutherland was near normal with a surplus during June, the peak period of larval feeding, so plant stress was less (Table 5).

Under heavy rootworm pressure (Crawfordsville and Nashua, Tables 2 & 3), the yield difference between the YieldGard and the untreated was greater at Crawfordsville than Nashua (44 and 27 bushels, respectively). While the rootworm pressure was similar and moisture was deficient at both locations, the moisture deficiencies occurred at different times with respect to larval feeding. The greatest yield impact due to rootworm feeding occurred at Crawfordsville where the rainfall was only normal during June, the month of peak larval feeding, followed by a 2.43 inch shortfall during pollination. Nashua had a larger moisture deficit (4.91 inches), but at Nashua the June rainfall during larval feeding was 1.18 inches above normal which compensated for a 1.68 inch shortfall during pollination. Nashua's greatest moisture deficit didn't occur until grain fill.

With greater yield differences between YieldGard Rootworm and untreated plots, there were also differences between the YieldGard and soil-applied granular insecticides. At Crawfordsville (Table 2), were YieldGard yielded 44 bushels more than the untreated, it also produced 24 more bushels than the best soil-applied granular insecticide and 34 more bushels than the average of the granular insecticide. At Nashua where the YieldGard and untreated were 27 bushels different (Table 3), the YieldGard was only 5 bushels better than the highest-yielding granular material and 16 bushels higher than the average of the granular materials. At Sutherland (Table 4), where moisture was not deficient, yields were very high and the difference between the YieldGard and untreated was small (6 bushels) and some of the insecticide treatments had higher yields than the YieldGard.

There was an additional interesting trend in yields during 2003. As has been true in the past, seed treatments failed to keep root pruning below a node of roots under moderate to high rootworm infestations. During 2003, however, the seed treatments did not suffer much yield loss despite the damage. The Cruiser® yields were not statistically different from the YieldGard at any location with replicated trials and at Crawfordsville (Table 2) it had the highest yield of any of the insecticide treatments. In general at the heavy rootworm infestations (Crawfordsville and Nashua), both Cruiser and Poncho® yielded as well as the granular insecticides despite loosing nearly a node more of roots.

Also in 2003, YieldGard Rootworm was evaluated in two plots in Boone County on three different planting dates. YieldGard was evaluated against its nonBt, near-isogenic hybrid. Plots were unreplicated, four rows wide and 100 feet long. Roots were dug on July 25 and evaluated on the Iowa State 0-3 scale (0=no injury, 3=three nodes completely removed). Grain yields were machine harvested October 22 from the two center rows and adjusted to 15.5 percent moisture. Plots had been continuous corn for 4 years with no soil insecticide used during this time period.

The field trial was subjected to very heavy pressure from the corn rootworm larvae. Most nonBt corn roots scored significant amounts of root injury from the larvae, often scoring the maximum rating of 3 (Table 6). This injury translated into substantial yield differences with the advantage going to the genetically-engineered corn (Table 7). The paired comparisons showed yields ranging from 28.8 bushels more on the April 24 planting date to 4.8 bushels more on the May 20 planting date. These data suggest that fields planted earlier may receive a greater benefit from the YieldGard technology as opposed to fields planted later.

Scouting YieldGard Rootworm Corn for Adult Beetles

Economically damaging densities of corn rootworm larvae do not occur in all cornfields, thus rootworm control is not necessary in every field. Nowatzki et al. (2002) showed that peak adult emergence can be predicted using a biofix model based on capture of the first emerging rootworm adults in a field. Using the principles of integrated pest management, initiation of field scouting to estimate adult beetle densities can be targeted based on this biofix model. The information could be used to determine the need for control measures in the subsequent year – whether crop rotation, insecticides, or YieldGard Rootworm.

Extension and research entomologists from six Midwestern states met in 2003 to discuss the development of a uniform scouting plan. Research papers and extension bulletins were distributed and read before the meeting was held. Based upon our discussion, we developed a flowchart that summarizes the steps for scouting corn rootworm adults in a cornfield. This scouting procedure is preliminary and may change as it is field tested over the next couple of years.

Cornfields should be monitored with the kairomone-baited Pherocon® CRW Trap (Trecé, Salinas, CA, www.trece.com/product.html). One trap is to be placed in each field preceding the first emergence of corn rootworm adults (mid June in Iowa) and checked twice weekly. As soon as the first adult corn rootworm is detected in the trap, the biofix for that field is determined as the date midway between the last date when no beetles were captured and the date when the first beetle of either sex or species was observed. Degree-days are accumulated from the biofix, and field scouting is initiated when 772 FDD (Fahrenheit degree-days) have accumulated (90% beetle emergence, Nowatzki et al. 2002). Counts of adult corn rootworms determine whether the field has a high or low probability of economic damage from corn rootworm larvae in the following season. Recommendations for rootworm control next year are determined from the density of corn rootworm adults within each field. The flowchart shows the procedure for scouting a field.

Corn producers and scouts can use these recommendations to determine the need for rootworm control measures in next year's corn. In fields with low rootworm densities, soil insecticide use is expected to decrease (i.e., elimination of the soil insecticide, using a reduced rate, or using a seed treatment), or the more expensive corn hybrids with YieldGard Rootworm technology will not be planted. The potential outcomes are less insecticide in the environment; the replacement of conventional, broad-spectrum insecticides with reduced-risk products; and less expense to the producer. Producers also will be able to determine which fields will benefit most from the use of YieldGard Rootworm corn and its associated nonBt refuge.

By closely following the scouting procedure outlined in this uniform scouting plan, producers and crop scouts can determine with a degree of confidence whether rootworm control measures are necessary to prevent economic damage. Decisions based upon this scouting procedure can result in more economic production of corn. The scouting plan may also help producers and commercial scouts make better use of limited time and money by targeting their scouting activities.

YieldGard Rootworm Corn Requires a Refuge

The EPA requires Monsanto to ensure that 20 percent of the planted acreage of YieldGard Rootworm be set aside where non-Bt corn will be grown to serve as a refuge. These refuge acres will support populations of corn rootworm not exposed to the Bt protein and reduce the possibility of corn rootworm developing resistance to Bt corn. The corn rootworm populations in the refuges will help prevent resistance development when they cross-breed with insects in the Bt cornfields. This resistance management strategy was developed as a condition of the registration, and EPA will require routine monitoring and documentation that these measures are followed.

The following information on refuge requirements was modified from a Monsanto publication, "YieldGard Rootworm Insect Resistance Management–2003 IRM Guide." Anyone planting YieldGard Rootworm corn in 2004 must follow these refuge requirements.

Refuge Requirements for the Corn Belt

In this area, refuges must be established as follows:

- On each farm, up to 80 percent of corn acres may be planted with YieldGard Rootworm corn. Plant at least 20 percent of the corn acres to a corn refuge that does not contain a Bt technology for control of western or northern corn rootworm. The corn refuge can be treated for corn rootworm larvae and other soil pests with soil-applied, seed-applied or foliar-applied insecticides. The corn refuge can be treated with a non-Bt insecticide to control late season pests such as European corn borer, however the YieldGard Rootworm Corn must also be treated. Corn refuge options include YieldGard Corn Borer, RoundupReady corn, and conventional corn, but no other Bt product for corn rootworm management.

- Plant the refuge within or adjacent to YieldGard Rootworm corn fields. The corn refuge can be separated by a ditch or a road but not by another field. Adjacent refuge fields must be owned by or managed by the grower.

Refuge Planting Requirements

Any corn hybrid that does not contain a Bt technology for control of western or northern corn rootworm and is planted within or adjacent to the YieldGard Rootworm field corn can serve as a refuge.

- Plant a refuge on every farm where YieldGard Rootworm corn hybrids are planted.
- Plant the refuge at the same time as YieldGard Rootworm corn.
- The effectiveness of the refuge can be reduced because plant stands and plant vigor may be decreased. With less plants and decreased health you would get fewer susceptible insects in the refuge.
- Mixing non-Bt seed with YieldGard Rootworm seed for use in the refuge is not permitted.
- Plant the refuge and the YieldGard Rootworm corn to fields with similar crop history. For example, if the field planted to YieldGard Rootworm was corn the previous year, then the refuge must also be planted in a field that was planted to corn the previous year.

Refuge Configuration Options

The refuge on each farm may be arranged in a number of configurations. These options offer the flexibility to easily incorporate an effective corn refuge into farm operations. Options include:

- Plant a corn refuge adjacent to each YieldGard Rootworm corn field.
- Plant a corn refuge as large strips or blocks within a YieldGard Rootworm field.
- Split the planter to alternate at least 6 and preferably 12 consecutive rows of corn refuge with YieldGard Rootworm corn.
- Plant field perimeters or end rows to a corn refuge.

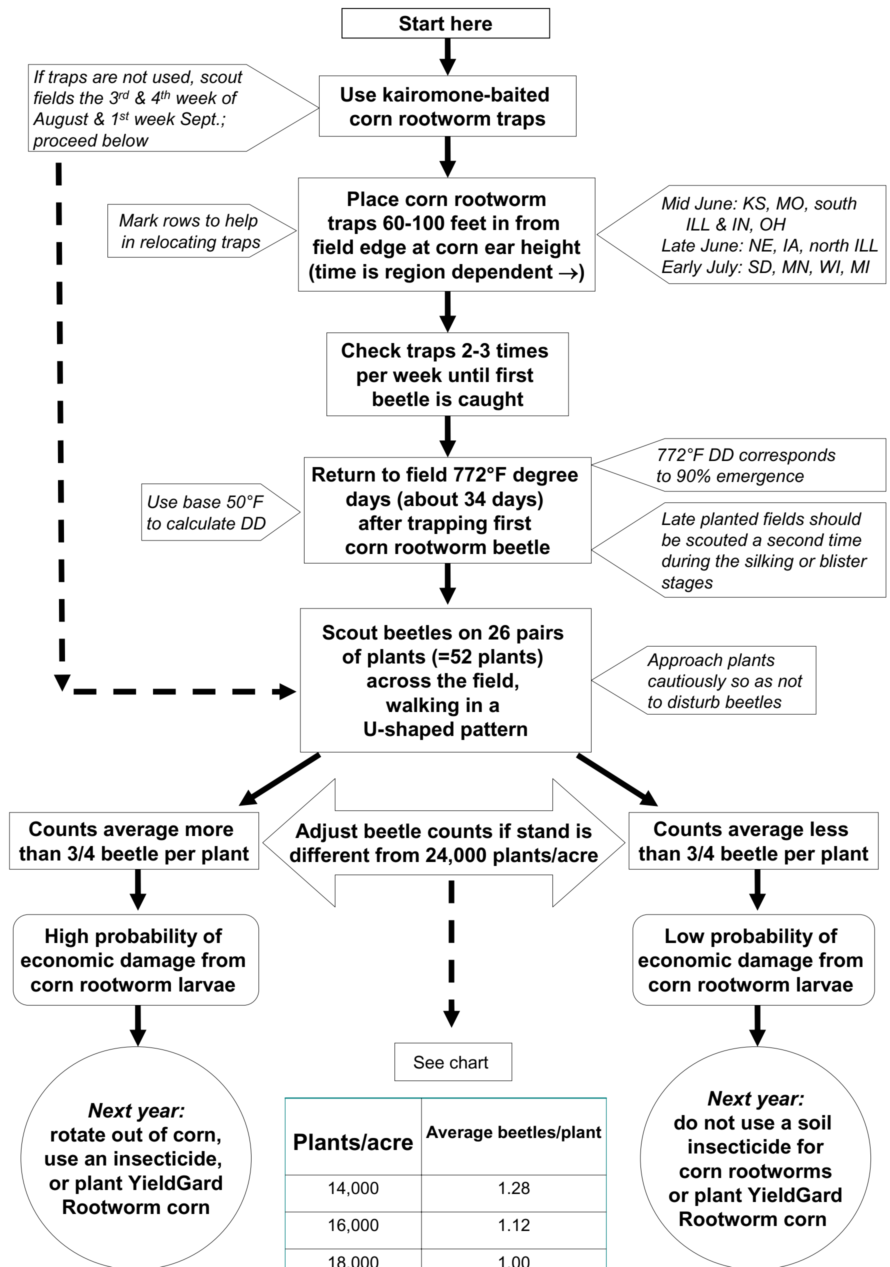
Conclusions

Yield trials demonstrated that under heavy rootworm pressure and moisture stress the lack of corn rootworm larval injury in YieldGard Rootworm corn resulted in substantially higher yields than corn without the Bt protein. As rootworm pressure and moisture deficits declined, the yield advantage of rootworm treatments, including genetically engineered corn, declined. Field trials also suggested that yields of YieldGard Rootworm were substantially better when corn was planted in April as opposed to mid May. While rainfall is difficulty to predict, the proposed and validated adult corn rootworm sampling program will help identify heavy rootworm infestations that will justify the cost of genetically engineered corn varieties or insecticidal treatment. Scouting may also help a grower decide where to plant the genetically engineered corn and where to place the required refuge so as to maximize the return on there investment.

Literature Cited

Nowatzki, T. M., J. J. Tollefson and D. D. Calvin. 2002. Development and validation of models for predicting the seasonal emergence of corn rootworm (Coleoptera: Chrysomelidae) beetles in Iowa. Environmental Entomology 31: 864–873.

A Proposed Scouting Plan for Adult Corn Rootworms in Corn



Plants/acre	Average beetles/plant
14,000	1.28
16,000	1.12
18,000	1.00
20,000	0.90
22,000	0.81
24,000	0.75
26,000	0.69
28,000	0.64
30,000	0.60
32,000	0.56

Table 1. Average root-injury ratings, product consistency, percentage of lodging, and stand counts for planting-time insecticide treatments and YieldGard® Rootworm corn. Ames, IA, 2002.

Treatment	Placement	Node Injury[1] (0-3)	Percent Consistency[1]	Percent Lodging[1]	Stand Count[2]
YieldGard® Rootworm	—	0.01 a	100 a	0 a	29.25 a
Aztec 2.1G	T-band	0.16 ab	95 a	0 a	29.00 a
Lorsban 15G	T-band	0.38 ab	70 ab	0 a	29.25 a
Force 3G	T-band	0.51 b	45 b	0 a	27.00 b
Check[2]	—	1.90 c	0 c	58 b	29.25 a

[1] Numbers within a column sharing a common letter do not differ significantly according to Ryan's Q Test (P<0.05).

[2] Plant population per acre x 1,000.

Table 2. Average root-injury ratings, yield, and percentage of lodging for planting-time insecticide treatments and YieldGard Rootworm corn. Crawfordsville[1], IA, 2003.

Treatment	Placement	Node-Injury[2] (0-3)	Yield (bu/a)[2]	Percent Lodging[2]
YieldGard RW	Transgenic	0.16 a	144 a	0 a
Counter 20CR	T-band	0.25 a	98 c	0 a
Fortress 2.5G	Furrow	0.25 a	120 a-c	0 a
Aztec 4.67G	Furrow SB	0.28 a	103 c	0 a
Aztec 2.1G	Furrow	0.32 a	115 bc	0 a
Fortress 5G	Furrow SB	0.36 a	110 bc	0 a
Aztec 4.67G	T-band SB	0.37 a	114 bc	0 a
Force 3G	T-band	0.38 a	120 a-c	0 a
Lorsban 15G	T-band	0.49 a	104 bc	0 a
Force 3G	Furrow	0.50 a	118 a-c	0 a
Counter 20CR	Furrow	0.51 a	99 c	0 a
Aztec 2.1G	T-band	0.58 a	109 bc	0 a
Cruiser 5FS	ST	1.15 b	134 ab	0 a
Capture 2EC	T-band	1.31 b	90 c	16 ab
Poncho 1250	ST	1.45 b	105 bc	0 a
CHECK	----	2.14 c	100 c	32 b

[1] Planted May 14, 2003. The location had heavy rootworm pressure and insufficient moisture during larval feeding.

[2] Numbers within a column sharing a common letter do not differ significantly according to Ryan's Q Test (P<0.05).

Table 3. Average root-injury ratings, yield, and percentage of lodging for planting-time insecticide treatments and YieldGard Rootworm corn. Nashua[1], IA, 2003.

Treatment	**Placement**	**Node-Injury[2] (0-3)**	**Yield (bu/a)[2]**	**Percent Lodging[2]**
YieldGard RW	Transgenic	0.03 a	133 a	0 a
Aztec 2.1G	Furrow	0.23 ab	120 a-c	0 a
Aztec 4.67G	Furrow SB	0.30 a-c	117 a-c	0 a
Force 3G	Furrow	0.31 a-c	121 a-c	0 a
Aztec 4.67G	T-band SB	0.38 a-d	111 bc	0 a
Force 3G	T-band	0.39 a-d	128 ab	0 a
Aztec 2.1G	T-band	0.59 b-e	110 bc	0 a
Fortress 2.5G	Furrow	0.62 b-e	116 a-c	1 a
Counter 20CR	Furrow	0.78 c-f	111 bc	0 a
Counter 20CR	T-band	0.86 d-f	114 a-c	1 a
Fortress 5G	Furrow SB	0.91 ef	114 a-c	0 a
Poncho 1250	ST	1.07 ef	126 a-c	0 a
Capture 2EC	T-band	1.16 f	119 a-c	0 a
Lorsban 15G	T-band	1.23 f	107 bc	3 a
Cruiser 5FS	ST	1.84 g	121 a-c	33 b
CHECK	----	2.46 h	106 c	34 b

[1] Planted April 26, 2003. The location had heavy rootworm pressure and insufficient moisture during larval feeding.
[2] Numbers within a column sharing a common letter do not differ significantly according to Ryan's Q Test ($P<0.05$).

Table 4. Average root-injury ratings, yield, and percentage of lodging for planting-time insecticide treatments and YieldGard® Rootworm corn. Sutherland[1], IA, 2003.

Treatment	Placement	Node-Injury[2] (0-3)	Yield (bu/a)[2]	Percent Lodging[2]
YieldGard RW	Transgenic	0.01 a	197 ab	0 a
Counter 20CR	T-band	0.04 a	188 b	0 a
Counter 20CR	Furrow	0.05 a	198 ab	0 a
Force 3G	T-band	0.08 a	196 ab	0 a
Aztec 4.67G	T-band SB	0.10 ab	196 ab	0 a
Force 3G	Furrow	0.11 ab	201 ab	0 a
Fortress 5G	Furrow SB	0.11 ab	211 a	0 a
Aztec 2.1G	T-band	0.12 ab	191 ab	0 a
Fortress 2.5G	Furrow	0.13 ab	196 ab	0 a
Aztec 2.1G	Furrow	0.14 ab	202 ab	0 a
Aztec 4.67G	Furrow SB	0.16 ab	199 ab	0 a
Lorsban 15G	T-band	0.19 ab	193 ab	0 a
Capture 2EC	T-band	0.45 bc	201 ab	0 a
Poncho 1250	ST	0.58 c	208 ab	0 a
Cruiser 5FS	ST	1.07 d	199 ab	0 a
CHECK	----	1.24 d	191 ab	1 b

[1] Planted May 2, 2003. The location had moderate rootworm pressure and adequate moisture during larval feeding.

[2] Numbers within a column sharing a common letter do not differ significantly according to Ryan's Q Test ($P<0.05$).

Table 5. Growing season rainfall and deviation from normal in 2003.

Month	Crawfordsville		Nashua		Sutherland	
	rainfall	DFN	rainfall	DFN	rainfall	DFN
April	2.59	+0.55	3.84	+0.43	1.78	-1.04
May	6.48	+2.63	3.89	-0.45	3.80	+0.10
June	4.30	+0.03	6.09	+1.18	8.12	+3.69
July	1.77	-2.43	2.99	-1.68	5.51	+1.40
August	0.87	-2.89	0.49	-4.39	0.44	-4.19
Totals	16.01	-2.11	17.30	-4.91	17.64	-0.04

Table 6. YieldGard® Rootworm root ratings[1] for three planting Dates. Boone, IA, 2003.

Plot	Treatment	Planting Date		
		April 24	May 8	May 20
1	YieldGard RW	0.02	0.06	0.00
	non*Bt* corn	3.00	3.00	2.94
2	YieldGard RW	0.02	0.20	0.02
	non*Bt* corn	1.70	2.86	0.92

[1] Average of five roots per plot using the Iowa 0-3 scale.

Table 7. YieldGard® Rootworm grain yields[1] (bushels per acre) for three planting dates. Boone, IA, 2003.

Plot	Treatment	Planting Date		
		April 24	May 8	May 20
1	YieldGard RW	161.8	152.3	144.7
	non*Bt* corn	133.0	131.9	139.9
	YGRW vs. nonBt	*+28.8*	*+20.4*	*+4.8*
2	YieldGard RW	213.8	167.3	159.1
	non*Bt* corn	198.6	156.0	153.1
	YGRW vs. nonBt	*+15.2*	*+11.3*	*+6.0*

[1] Plots were unreplicated, four rows wides, 100 feet long, with the center two rows machine harvested and adjusted to 15.5% moisture.