WILL ROOTWORM BT CORN SOLVE ALL OF OUR ROOTWORM CONTROL PROBLEMS?

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An easy way out with this paper would be answering "no" to the question posed in the title and leaving it at that. We suspect that virtually everyone who has ever had anything to do with corn rootworms would answer in the same fashion. However, it would be unfair to the Indiana CCA Conference organizers and the people attending the conference for us to provide an answer without providing justification for the answer. So, the intent of this paper is to explain why "no" is probably the only rational answer to the question, "Will rootworm Bt corn solve all of our rootworm control problems?"

The Expectations for New Technologies for Rootworm Control

Because corn rootworms have been the most economically threatening insect pests of corn in North America for decades, new technologies developed for their control are met with great anticipation. Great expectations began with registration of organochlorine compounds for use on corn in the 1950s for control of soil insect pests, including corn rootworm larvae. Because soil insect pests were primarily a concern in corn planted after corn, the effective and cheap organochlorine insecticides were a boon for continuous corn production. However, widespread use of organochlorines for rootworm control placed a lot of selection pressure on western corn rootworms, the most threatening of the rootworm species, which became resistant to the most commonly used products (Ball and Weekman, 1962).

Carbamate and organophosphorous insecticides began to replace organochlorine insecticides for rootworm control in the 1960s. These insecticides have been relatively effective for rootworm control for almost half a century, although trade names have changed along the way. During this time, however, several products (e.g., Amaze, Counter, Furadan) experienced tremendous sales followed by outright disappearance from the marketplace for various reasons (e.g., enhanced microbial degradation — Felsot, 1989).

When the tactic of controlling adult corn rootworms with insecticides to suppress oviposition was introduced, many corn producers in the Midwest switched from using prophylactic soil insecticides to the more scouting-intensive adult control alternative, especially in Nebraska. Western corn rootworm populations in Nebraska eventually became resistant to both carbaryl (a carbamate) and methyl parathion (an organophosporous compound) (Meinke et al., 1998), the two most widely used products to control adult corn rootworms.

All of the aforementioned "failures" of insect control technologies that were formerly effective for controlling corn rootworms resulted from widespread use — overuse in most instances — that placed considerable selection pressure on the rootworm population. In a more dramatic fashion, annual rotation of corn and soybean also placed selection pressure on corn rootworm populations, resulting in the development of variants of both the northern and western corn rootworm species. Variant northern corn rootworm populations circumvent annual crop rotation as a rootworm management tactic by prolonging egg diapause for more than one winter (Levine et al., 1992). Variant western corn rootworm adults oviposit in soybean and other crops (Levine et al., 2002), rendering crop rotation ineffective as a rootworm management tactic in several areas of the Midwest.

The preceding brief history brings us to the present, with the availability of transgenic Bt corn hybrids to control corn rootworm larvae. The development of transgenic Bt corn hybrids for rootworm control is the most exciting development in rootworm control technology in the past 50 years. Even before rootworm Bt corn hybrids were registered for commercial use, reports of excellent efficacy in university and company trials were virtually unanimous. Consequently, the availability of Bt corn for rootworm control was met with great enthusiasm, and the products (Monsanto's YieldGard Rootworm hybrids [Cry3Bb1 protein] and Dow/Pioneer's Herculex RW hybrids [Cry34Ab1/35Ab1]) have been marketed aggressively. Syngenta's Agrisure hybrids for rootworm control, expected to be commercialized in 2007, also will be marketed aggressively. The acreage of rootworm Bt corn has increased annually since the introduction of YieldGard Rootworm hybrids in 2003, and most experts anticipate a rapid rate of adoption of Bt corn for rootworm control.

Given the history of instances of resistance in rootworm populations, is there any doubt that corn rootworm populations have the capacity to become resistant to the *Bt* proteins expressed in Bt corn? Most scientists have little doubt that resistance to *Bt* in rootworm populations is possible. The United States Environmental Protection Agency (EPA) requires resistance management strategies for all Bt corn products, with hopes of delaying the onset of resistance in target insect populations. As history should have taught us by now, ignoring recommendations for resistance management while enthusiastically overusing an excellent product for rootworm control likely will have unwelcome consequences.

Rootworm Bt Corn in Illinois, 2003-2005

In this section of the paper, we will focus on our own experiences with rootworm Bt corn in research trials. We began evaluating the efficacy of rootworm Bt corn hybrids in our standard efficacy trials in 2003. The locations of these trials during 2003-2005 were near DeKalb (northern Illinois), Monmouth (northwestern Illinois), and Urbana (eastern Illinois). We added a fourth site in 2006 (Perry, western Illinois). In Illinois, we are in a unique position to be able to assess the performance of rootworm control products in areas that are different regarding the variant western corn rootworm:

- Has been established for at least a decade (Urbana).
- Has become established over the past five years (DeKalb).
- Is just becoming established (Monmouth).

This situation seems to have had a significant impact on our results.

2003

A quick review of our data from 2003 revealed that the performance of a YieldGard Rootworm (YGRW; MON 863) corn hybrid "provided excellent control of corn rootworms at all three sites" in 2003 (Steffey and Schroeder, 2004), with average root ratings (1-6 root rating scale — Hills and Peters, 1971) of 1.45, 2.05, and 1.35 in the trials near DeKalb, Monmouth, and Urbana, respectively. The average root ratings on the 1-6 root rating scale reflected scarring of the roots by rootworm larvae, with some pruning noted on individual roots dug from the trial near Monmouth.

2004

In July 2004, we observed lodging in our YGRW plots in the standard rootworm control trial near Urbana. (The trial in Urbana had been planted approximately one month earlier in 2004 [April 19] than in 2003 [May 13].) We discovered that the level of rootworm larval injury to the YGRW corn hybrid in the Urbana experiment was greater than anticipated, with an average root rating of 3.15 on the 1-6 scale when the roots were evaluated on July 10. We dug and evaluated more roots from the YGRW plots (as well as from other selected plots) during the first week of August, and the average root rating was 3.6 (1-6 rating scale). We also used the more modern 0-3 node injury rating scale (Oleson et al., 2005) to evaluate the roots from the YGRW plots, and the average node injury rating for YGRW was 1.35. Both ratings indicated a significant level of root pruning (approximately 1½ nodes of roots pruned). Details about this trial were documented by Gray and Steffey (2004, 2005).

2005
In 2005, the average node injury ratings (Oleson et al., 2005) for the YGRW hybrid in our three trials were 0.7, 0.04, and 0.19 on July 26, July 25, and July 13 at DeKalb, Monmouth, and Urbana, respectively. At these same three sites, the average node injury ratings were 0.87, 0.08, and 0.74 on August 15 (DeKalb, Monmouth) and August 11 (Urbana). These results were documented and explained in detail in Estes et al. (2005) and Gray et al. (2006).

We also planted and evaluated a YGRW corn hybrid trial in Urbana in 2005. There were nine YGRW hybrids and one non-Bt DeKalb hybrid (untreated check) in the trial. We were given the hybrids by Monsanto Company, but we were not given the hybrids' specific information. The YGRW hybrids were indicated as hybrids A through I. Two of the hybrids had failed Monsanto's in-house screening and had not been commercialized. Rootworm larval injury was assessed on all hybrids with the 0-3 node injury scale on two dates, July 20 and August 10. The average node injury ratings among commercially available YGRW hybrids ranged from 0.16 to 0.75 on July 20 and from 0.19 to 0.93 on August 10. The average node injury ratings in the untreated check on July 20 and August 10 were 2.09 and 1.91 — approximately two nodes of roots destroyed. These results were documented and explained in detail in Gray et al. (2005) and Gray et al. (2006).

Rootworm Bt Corn in Illinois, 2006
In 2006, we were able to compare rootworm injury to a YGRW hybrid with rootworm injury to Herculex RW and/or Herculex XTRA hybrids in our standard efficacy trials. The data from the Perry location indicated very little rootworm injury in the untreated check, so the data are not presented in this paper. Because we focus on rootworm Bt corn in this paper, only an excerpt of the data are presented in tables 1-3. In addition, data for Herculex RW hybrids are not presented in this paper. All of the data are presented in the 2006 *On Target* report, our annual summary of field crop insect management trials, which is available on the Web at http://www.ipm.uiuc.edu/ontarget/2006report.pdf.

We conducted another YGRW corn hybrid trial at both the Monmouth and Urbana locations, and we established a Herculex RW corn hybrid trial for the first time at the Urbana location. These data are presented in their entirety in this paper (tables 4-6).

Without providing a lot of detail, we can state that the data from all of our rootworm research trials suggest that levels of root protection provided by YGRW hybrids vary from year to year and from location to location. Although YGRW corn hybrids have generally provided good root protection against corn rootworm larvae in our trials over time and locations, there have been exceptions. The amount of rootworm larval injury to YGRW corn hybrids was greater than expected at the Urbana location in 2004 and 2006 (Table 3), in particular, and in DeKalb in 2005. The results from the YGRW corn hybrid trials in 2005 and 2006 indicate that the level of root protection varies among YGRW hybrids and that the average node injury ratings tend to increase from July to August (Tables 4 and 5) (verified in the scientific literature by Vaughn et al., 2005). Hybrids D and F failed Monsanto's in-house screening test and were not commercialized, so the level of rootworm larval injury to those hybrids was not surprising. However, the level of rootworm injury to several commercially available hybrids in the Urbana trial in August (Table 5) was greater than 0.5 — hybrids A, C, E, G, H, I, and K. All of the average node injury ratings for commercially available YGRW hybrids in the Monmouth and Urbana trials increased from July to August (tables 4 and 5)The mean node injury rating for hybrid K in the Monmouth trial was 0.75 (Table 4).

Of significant interest to us is that, in general, the level of rootworm larval injury to YGRW corn hybrids in the Urbana trial (Table 5) was noticeably greater than the level of rootworm larval injury to the same hybrids in the Monmouth trial (Table 4) in 2006. This trend also was obvious in the standard corn rootworm efficacy trials in 2004, 2005, and especially 2006 (Tables 2 and 3). We have speculated that the variant western corn rootworm, which is firmly established in the Urbana area, may be responsible for the greater level of injury in Urbana than in Monmouth. There is evidence in the scientific literature that the variant western corn rootworm is more difficult to kill with the *Bt* protein than the "normal" western corn rootworm (Siefgried et al., 2005). We believe that the level of corn rootworm larval injury to YGRW corn at the Urbana location deserves attention.

Herculex RW and Herculex XTRA corn hybrids provided a good level of root protection against corn rootworm larvae in all three of our standard efficacy trials in 2006 (Tables 1-3). The mean node injury ratings for Herculex XTRA on July 17 and August 8 in Urbana were 0.47 and 0.37, significantly lower than the mean node injury ratings for YGRW (0.96 and 1.46 on July 17 and August 8, respectively). However, we believe that it is important to point out that the mean node injury rating for Herculex XTRA on July 17, 2006, in Urbana, was equivalent to the mean node injury rating for YGRW on July 10, 2004, in Urbana. The latter node injury rating captured plenty of attention in 2004. Two Mcyogen and two Pioneer Herculex hybrids also provided very good control of corn rootworm larvae in the Herculex hybrid trial in Urbana (Table 6), and the mean node injury ratings did not tend to increase from July to August.

An Eye to the Future

The root ratings for YGRW corn hybrids in our standard rootworm control trials in 2004, 2005, and 2006 indicate that YGRW corn is not impervious to rootworm larval injury. Because the expression of the *Bt* protein in YGRW corn was first characterized as a low to moderate dose, some rootworm larval injury to YGRW hybrids was expected. However, the level of injury that has occurred to YGRW corn hybrids in our Urbana trials has been greater than expected. The trend for the node injury ratings to increase from July to August seems to suggest that the level of expression of the *Bt* protein declines during the growing season (Vaughn et al., 2005). We certainly do not believe, and there is no evidence to suggest that western corn rootworms have developed resistance to the *Bt* protein expressed in YGRW hybrids. However, it is obvious that YGRW corn is not a silver bullet for corn rootworms, as many people may have hoped. It is just as unlikely that Herculex RW or the soon-to-be-registered Agrisure RW corn is a silver bullet. We should not have expected the efficacy of any of the rootworm Bt corn products to be unassailable, and it is disingenuous to suggest otherwise.

Although our research has revealed some interesting results, we do not operate our program in a vacuum. Although we cannot document numbers and locations of cornfields, there have been reports of less-than-acceptable rootworm control with YGRW hybrids. We have not received reports of less-than-acceptable rootworm control with Herculex RW hybrids, but Herculex RW hybrids have been planted on limited acres for only one year. Time will tell whether all rootworm Bt products eventually are challenged by western corn rootworm larvae, particularly in areas where the variant is established.

So, will rootworm Bt corn solve all of our rootworm control problems? No, and we should not expect them to do so. We strongly encourage implementation of resistance management strategies for all Bt corn products as required by the EPA. We believe that the longevity of Bt corn for rootworm control rests strongly with the willingness of corn producers to adhere to resistance management strategies and to avoid overuse.

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Table 1. Evaluation of products to control corn rootworm larvae, DeKalb[1], University of Illinois, 2006

Product	Rate	Placement	Mean Node Injury Rating[2,3], July 25	Mean Node Injury Rating[2,4], August 8
Aztec 2.1G	6.7 oz/1,000 ft	Band	0.58 gh	0.78 c
Herculex XTRA Pioneer 34A18 + Poncho 250	--- 0.25 mg a.i./seed	In seed On seed	0.08 i	0.19 d
Poncho 1250	1.25 mg a.i./seed	On seed	1.24 cde	1.42 b
YGRW DeKalb 61-68	---	In seed	0.49 h	0.41 d
Untreated check, DeKalb 61-72	---	---	2.07 ab	2.15 a

Table 2. Evaluation of products to control corn rootworm larvae, Monmouth[1], University of Illinois, 2006

Product	Rate	Placement	Mean Node Injury Rating[2,3], July 24	Mean Node Injury Rating[2,4], August 8
Aztec 2.1G	6.7 oz/1,000 ft	Band	0.23 fg	0.41 c
Herculex XTRA Pioneer 34A18 + Poncho 250	--- 0.25 mg a.i./seed	In seed On seed	0.24 g	0.52 c
Poncho 1250	1.25 mg a.i./seed	On seed	1.65 b	1.72 b
YGRW DeKalb 61-68	---	In seed	0.39 d–g	0.59 c
Untreated check, DeKalb 61-72	---	---	2.98 a	2.82 a

Table 3. Evaluation of products to control corn rootworm larvae, Urbana[1], University of Illinois, 2006

Product	Rate	Placement	Mean Node Injury Rating[2,3], July 17	Mean Node Injury Rating[2,4], August 8
Aztec 2.1G	6.7 oz/1,000 ft	Band	0.68 fgh	0.63 d
Herculex XTRA Pioneer 34A18 + Poncho 250	--- 0.25 mg a.i./seed	In seed On seed	0.47 h	0.37 d
Poncho 1250	1.25 mg a.i./seed	On seed	1.97 cd	2.35 b
YGRW DeKalb 61-68	---	In seed	0.96 ef	1.46 c
Untreated check, DeKalb 61-72	---	---	2.95 a	3.00 a

Footnotes for Tables1, 2, and 3
[1]Planting dates were April 27, May 4, and April 28 for DeKalb, Monmouth, and Urbana, respectively.
[2]Mean node-injury ratings are based upon the 0-3 node-injury scale (Oleson et al., 2005) and are derived from ratings of five individual roots per treatment in each of four replications.
[3]The mean node injury ratings are excepted from a larger data set in which means followed by the same letter do not differ significantly (P = 0.05, Duncan's New Multiple Range Test).
[4]Means followed by the same letter do not differ significantly (P = 0.05, Duncan's New Multiple Range Test).

Table 4. Evaluation of YGRW hybrids for control of corn rootworm larvae, Monmouth, University of Illinois, 2006

Hybrid[1]	Mean Node Injury Rating[2,3], July 24	Percentage Consistency[4], July 24	Mean Node Injury Rating[2,3], August 8	Percentage Consistency[4], August 8
A	0.19 de	100	0.34 e	93
B (check)	2.63 a	0	2.74 a	0
C	0.06 e	100	0.22 e	98
D (not commercialized)	0.76 c	53	1.09 c	41
E	0.20 de	90	0.42 e	90
F (not commercialized)	1.00 b	35	1.44 b	18
G	0.16 de	95	0.38 e	90
H	0.22 de	88	0.41 e	82
I	0.11 de	100	0.23 e	98
J	0.15 de	95	0.45 e	83
K	0.30 d	98	0.75 d	65

Table 5. Evaluation of YGRW hybrids for control of corn rootworm larvae, Urbana, University of Illinois, 2006

Hybrid[1]	Mean Node Injury Rating[2,3], July 20	Percentage Consistency[4], July 20	Mean Node Injury Rating[2,3], August 7	Percentage Consistency[4], August 7
A	0.39 d	88	0.86 c	54
B (check)	2.52 a	0	2.68 a	0
C	0.24 d	95	0.62 d	83
D (not commercialized)	0.79 c	48	1.50 b	10
E	0.29 d	93	0.89 c	58
F (not commercialized)	1.21 b	10	1.92 b	0
G	0.34 d	95	0.83 c	63
H	0.36 d	88	0.83 c	65
I	0.41 d	87	0.79 c	60
J	0.14 d	100	0.66 c	75
K	0.36 d	90	0.91 c	55

Footnotes for Tables 4 and 5

[1]All hybrids (A-K) were provided by Monsanto Company. The genetic background and identification of the hybrids are unknown by University of Illinois personnel and are identified only by letter.
[2]Mean node-injury ratings are based upon the 0–3 node-injury scale (Oleson et al., 2005) and are derived from ratings of ten individual roots per treatment in each of four replications.
[3]Data were transformed (Log ([root rating] + 1)) for analysis. However, actual means are shown. Means followed by the same letter do not differ significantly (P = 0.05, Duncan’s New Multiple Range Test).
[4]Percentage of roots with a node-injury rating < 1.0.

Table 6. Evaluation of Herculex Rootworm (HxRW) hybrids for control of corn rootworm larvae, Urbana, University of Illinois, 2006

Hybrid[1]	Mean Node Injury Rating[2,3], July 19	Percentage Consistency[4], July 19	Mean Node Injury Rating[2,3], August 7	Percentage Consistency[4], August 7
Dow A	0.09 cd	100	0.18 bc	100
Dow B	0.17 c	100	0.42 b	88
Dow C (untreated check)	2.90 a	0	2.94 a	0
Pioneer A	0.06 d	100	0.18 bc	100
Pioneer B	0.07 d	100	0.14 c	100
Pioneer C (untreated check)	2.58 b	4	2.90 a	0

Footnotes for Table 6

[1]Three HxRW hybrids (A-C) and were provided by both Dow AgroSciences and Pioneer. The genetic background and identification of the hybrids are unknown by University of Illinois personnel and are identified only by letter.
[2]Mean node-injury ratings are based upon the 0-3 node-injury scale (Oleson et al., 2005) and are derived from ratings of six individual roots per treatment in each of four replications.
[3]Data were transformed (arcsine square root) for analysis. However, actual means are shown. Means followed by the same letter do not differ significantly (P = 0.05, Duncan's New Multiple Range Test).
[4]Percentage of roots with a node-injury rating < 1.0.