DOES THE CORN ROOTWORM RESISTANT TRAIT AFFECT NITROGEN USE EFFICIENCY?

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Background

The number of acres planted to corn rootworm (*Diabrotica* spp.) (CRW) resistant corn (*Zea mays* L.) hybrids have increased in recent years. The CRW resistant corn hybrids may have a greater yield potential because of reduced stress from CRW larval feeding resulting in larger root systems. Many agronomists believe higher N rates are needed to achieve the greater yield potential associated with these hybrids. However, larger root systems of CRW resistant hybrids could result in greater N use efficiency and perhaps a reduced N fertilizer need compared to non-CRW resistant hybrids.

Corn yields have increased over time because of improved genetics and management (Duvick, 1984). O'Neill et al. (2004) found that newer corn hybrids exhibited greater grain yield response to applied fertilizer N and greater N fertilizer use efficiency compared to older (1970s) hybrids. Yields under N deficient conditions varied among individual hybrids and these yield differences were not related to hybrid era (older or newer). Their study included only two N rates (0 and 224 lb/a); thus, more detailed analysis regarding variability of the economic optimum N rate between hybrid eras could not be determined. Vanotti and Bundy (1994) reported that optimum N rates for corn were similar at high and low yield levels from a 24-yr corn N rate study conducted from 1967 to 1990 at Lancaster, Wisconsin. They concluded that conditions which promote high corn yields, such as adequate moisture and temperature, improve the efficiency of available N use by the crop and greater amounts of applied N are not needed. Whether the greater yield potential associated newer hybrids have a similar effect on N use efficiency and optimum N rates is unknown.

There is no record in the published literature of research focusing on the N use efficiency and N needs of CRW resistant vs. non-resistant corn hybrids. Research on the integration of corn hybrid traits, including CRW resistance, with various N management systems is in the preliminary stages at the University of Minnesota (Gyles Randall, personal communication). There has been some research conducted on the influence of N fertilizer on CRW larval feeding. Riedell et al. (1996) found that banded-split N applications resulted in a larger root system and greater tolerance to CRW larval feeding damage compared with broadcast-preplant N applications. However, Roth et al. (1995) found that N fertilizer timing (at planting, sidedress, or split) did not affect corn root damage ratings. In other research, leafy and non-leafy corn hybrids, which differ in their leaf canopy and root morphology, were found to respond similarly to N fertilizer (Costa et al., 2002; Subedi et al., 2006). The objective of this study is to determine if corn hybrids with the transgenic corn rootworm resistant gene vary in their N use efficiency and N need compared to non-resistant hybrids.

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Materials and Methods

A field research study was conducted in 2008, 2009, and 2010 at the University of Wisconsin Agricultural Research Station at Arlington on a Plano silt loam soil (fine-silty, mixed, superactive, mesic Typic Argiudoll). The study was conducted in a new field each year to avoid previous year treatment effects and where corn was planted for several years to increase the probability of moderate to severe corn rootworm pressure. Treatments consisted of eight corn hybrids and six nitrogen rates in a factorial of corn hybrid and N rate in a randomized complete block design with four replications. A description of corn hybrids is shown in Table 1. The corn hybrids included two pairs of hybrid isolines with and without the corn rootworm resistance gene (hybrids 1 and 2; hybrids 3 and 4), two of the overall best non-rootworm resistant hybrids available in Wisconsin (hybrids 5 and 6), and two of the overall best rootworm resistant hybrids available in Wisconsin (hybrids 7 and 8). The goal of using a suite of hybrids is to reflect isoline differences as well as real-world choices that growers make when selecting a hybrid. Unfortunately not all hybrids selected were available in each year of the study. Appropriate hybrid substitutions were made when necessary (Table 1). Nitrogen fertilizer (as NH_4NO_3 in 2008 and UAN-28% in 2009 and 2010) rates ranged from 0 to 200 lb N/acre in 40 lb N/acre increments and was applied early post-emergence broadcast (2008) or band-injected at about a 6-in. depth between rows (2009 and 2010).

Soil test P and K levels were interpreted as either high or excessively high according to Wisconsin nutrient application guidelines (Laboski et al., 2006). Soil pH and organic matter values averaged 7.0 and 3.6%, respectively. The sites were chisel plowed in fall or spring and the seedbed was prepared for planting using a soil finisher in spring. Preplant soil nitrate test (PPNT) samples collected in spring indicated minimal carryover NO_3-N content in the soil profile (0-3 ft) from the previous year. Corn was planted in early May with 30-inch row spacing at 34,000 to 36,000 seeds/acre with 3-gal./a 10-34-0 pop-up starter fertilizer in the furrow (2008) or no starter fertilizer (2009 and 2010) and 4.4 lb/acre of soil insecticide (Force 3G) in a T-band. Conventional herbicides were used to control weeds. Initial plot size was four-rows wide (10 ft.) and 25-ft long in 2008 and 40-ft long in 2009 and 2010. Plot lengths were trimmed to 20-ft in 2008 and 30-ft in 2009 and 2010 and corn plants within each plot were counted and thinned to a uniform stand density (30,350 plants/acre in 2008 and 2009; 34,294 plants/acre in 2010) at the V4 to V5 corn growth stage. Corn rootworm ratings were determined by digging 20 roots of the standard nontransgenic hybrid (#6) planted without soil insecticide. Corn rootworm ratings were conducted in late July. The average rating was 1.12 in 2008, 0.19 in 2009, and 1.50 in 2010 using the 0 to 3 node-injury scale (Oleson et al., 2005). Corn biomass (silage) yield was determined by hand harvesting six plants at physiological maturity. Corn grain yield was determined by harvesting all ears from the middle two rows from each plot using a plot combine in late October or early November. Corn grain yields are reported 15.5% moisture. Grain and silage samples were ground and analyzed for total N content and total N uptake was determined.

For each hybrid in each year, N use efficiency was calculated using the following measures:

Relative $yield_{200}$ = (yield at 0 lb N/a ÷ yield at 200 lb N/a) x 100

Partial factor $productivity_{160}$ = yield at 160 lb N/a ÷ 160 lb N/a

Agronomic N fertilizer $efficiency_{160}$ = (yield at 160 lb N/a – yield at 0 lb N/a) ÷ 160 lb N/a

Internal N use $efficiency_{160}$ = yield at 160 lb N/a ÷ biomass N uptake at 160 lb N/a

Physiological $efficiency_{160}$ = (yield at 160 lb N/a – yield at 0 lb N/a) ÷ (biomass N uptake at 160 lb N/a – biomass N uptake at 0 lb N/a)

Fertilizer N recovery efficiency$_{160}$ = (biomass N uptake at 160 lb N/a – biomass N uptake at 0 lb N/a) ÷ 160 lb N/a

The 160 lb N/a rate was used in the N use efficiency calculations because that is the experimental N rate closest to the University of Wisconsin recommended N rate of 170 lb N/a. The 200 lb N/a rate was used to calculate relative yield because there were a few hybrids that had a plateau N rate greater than 160 lb N/a. Data were analyzed using PROC MIXED for the appropriate experimental design (SAS Institute, 2002). Significant mean treatment differences were evaluated using Fisher's protected LSD test at the 0.10 probability level. Yield response to N data were fit to quadratic plateau, linear plateau, quadratic and linear models using regression analysis (PROC REG or PROC NLIN). The best fit model based on R^2 value was chosen to represent the response function. The yield at zero N, the plateau N rate (N rate where maximum yield was achieved), and the yield at the plateau N rate were calculated from the response function.

Results and Discussion

The 2008 and 2009 growing seasons with cooler than normal with July 2009 being noteworthy in that the average air temperature was 5.9 degrees below the 30-year average. The 2010 growing season temperatures were slightly warmer than 30-year averages. The 2008 and 2010 growing seasons had above-average precipitation amounts with June and July rainfall at 10.6 (2008) and 9.0 (2010) inches above the long-term average. On the other hand, 2009 was slightly drier than normal in July.

The yield response to applied N for each hybrid in each is shown in Figure 1. The overall yield levels in 2009 were lower than 2008 or 2010 and are likely a result of the cooler growing season in 2009. The yield when no N fertilizer was applied was greatest in 2008, least in 2009, and intermediate in 2010.

There are numerous ways to define N use efficiency (NUE); however only a few are explored in this paper as a means to evaluate the effect of the corn rootworm (CRW) resistance trait on NUE. Relative yield is a measure of how well a hybrid converts mineralized soil N to grain yield. Agronomic N fertilizer recovery efficiency is a measure of how much N fertilizer was converted to grain yield. Internal N use efficiency evaluates the grain yield obtained per pound of N taken up by the crop. There was no significant difference in relative yield, agronomic N fertilizer efficiency, or internal N use efficiency between CRW traited hybrids of an isoline pair compared to non-traited hybrids for any given year (Table 2).

Partial factor productivity is the grain yield obtained per pound of N fertilizer. The non-traited hybrid from the Pioneer isoline pair (hybrid 2) had a partial factor productivity that was significantly greater than the traited hybrid (hybrid 1) in 2009, but was significantly lower in 2010. For all other hybrid pair comparisons in the Pioneer or DeKalb isolines, there was no significant difference. Physiological efficiency is the grain yield increase per increase in total N uptake. The only significant differences in physiological efficiency occurred in 2010; where the CRW traited hybrid had significantly greater physiological efficiency in the Pioneer isoline pair, but had significantly lower physiological efficiency in the DeKalb isoline pair. Fertilizer N recovery efficiency is a measure of how much N fertilizer was recovered in the whole plant. The CRW trait only significantly affected fertilizer N recovery efficiency for the Pioneer isoline pair in 2009 and 2010, where the traited hybrid had significantly greater efficiency in 2009 and significantly lesser efficiency in 2010. When comparing all CRW traited hybrids to all non-traited hybrids, there was no significant difference for any measure of NUE.

For a given hybrid or group of hybrids, there were annual differences between years for the various measures of NUE (Table 2). Overall these data suggest that environment has a greater impact on NUE than the CRW resistance trait.

Using the grain yield response to N fertilizer applied functions, all CRW traited and non-traited hybrids were compared for their effect on yield when no N fertilizer was applied, the N rate where yield plateaued (plateau N rate), and the yield at the plateau N rate (maximum yield) in each year of the study and when all years were combined (Table 4). Overall, CRW traited hybrids yielded significantly more when no N was applied. This suggests that CRW traited hybrids are more effective at using mineralized soil N in a low N environment compared to non-traited hybrids. The plateau N rate was not significantly different for non-CRW hybrids compared to CRW hybrids. There was also no significant trend for CRW-traited hybrids to yield more (greater yield at plateau N rate) than non-traited hybrids.

Summary

There was some variation in yield levels and the plateau N rate between years and between hybrids. Corn rootworm resistant hybrids had greater yield when no fertilizer N was applied, suggesting a greater ability to use mineralized soil N. However, this efficiency in a low N environment did not result in a greater yield level when N was applied or a lower N requirement. There was no significant difference between all CRW traited and untraited hybrids with regard to any measure of N use efficiency. When specific CRW isolines were compared, there was neither a significant difference between traited and untraited hybrids nor a clear trend for traited hybrids to have greater N use efficiency. While in some years there was moderate CRW pressure, the use of insecticide on all hybrids minimized any differences that might have occurred because of choice of CRW management. Popular press articles suggesting a lower N requirement and/or higher yield level for CRW traited hybrids may be basing conclusions on trials where there was poor control of CRW in non-traited hybrids compared to traited hybrids.

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Table 1. Description of corn hybrid used each year of the study. The hybrids include two pairs of hybrid isolines with and without the corn rootworm resistance gene (hybrids 1 and 2; hybrids 3 and 4), two of the overall best non-rootworm resistant hybrids available in Wisconsin (hybrids 5 and 6), and two of the overall best rootworm resistant hybrids available in Wisconsin (hybrids 7 and 8).

Hybrid no.	Hybrid i.d.	Brand	Hybrid	Relative maturity (CRM)	Traits †
1	Bt-CR 1	Pioneer	P35F44	105	HX (CB & CRW); RR2; LL
2	Isoline 1	Pioneer	P35F37	105	RR2
3	Bt-CR 2	DeKalb	DKC52-59	102	YG-VT3 (CB & CRW); RR2
4	Isoline 2	DeKalb	DKC52-62	102	RR2
5	Standard Bt-CB	2008: NK	N58-D1	107	YG (CB)
		2009: NK	N58-D1	107	YG (CB)
		2010: Renk	RK670	103	YG (CB)
6	Standard nontransgenic	2008: Pioneer	35A30	106	None
		2009: Pioneer	35F38	105	None
		2010: Pioneer	35F38	105	None
7	Bt-CR (Mon863) 1	2008: Renk	R698RRYGRW	104	YG (CRW); RR
		2009: DeKalb	DKC55-24 (VT3)	105	YG-VT3 (CB & CRW); RR
		2010: DeKalb	DKC55-24 (VT3)	105	YG-VT3 (CB & CRW); RR
8	Bt-CR (Mon863) 2	Dairyland	Stealth-4006	106	YG (CRW); RR2

† CB, corn borer; CRW, corn rootworm; HX, HerculexXtra; LL, Liberty Link; RR, Roundup Ready; YG, Yield Guard;

Table 2. Effect of corn rootworm (CRW) resistant trait on relative grain yield, partial factor productivity, and agronomic N fertilizer efficiency as determined by hybrid pairs of near isolines (hybrid 1 v 2 and hybrid 3 v 4) and all hybrids with and without the CRW trait.

Hybrid	Relative $Yield_{200}$			Partial Factor $Productivity_{160}$			Agronomic N Fertilizer $Efficiency_{160}$		
	2008	2009	2010	2008	2009	2010	2008	2009	2010
	%			bu/ lb N fertilizer			Δbu/ lb N fertilizer		
1	68a†	54b	49b	1.40a	1.18b	1.49a	0.43b	0.52ab	0.72a
2	72a	56b	44c	1.47a	1.25b	1.44a	0.41b	0.53b	0.78a
P‡	ns	ns	ns	ns	*	*	ns	ns	ns
3	70	60	66	1.54a	1.35b	1.42a	0.45	0.55	0.46
4	74a	53b	60b	1.47a	1.32c	1.43b	0.42b	0.61a	0.57a
P	ns	ns	ns	ns	ns	ns	ns	ns	ns
All CRW	68a	57b	60b	1.45a	1.26b	1.47a	0.44b	0.53a	0.57a
All Non-CRW	67a	53b	54b	1.44a	1.27b	1.43a	0.47b	0.58a	0.62a
P	ns	ns	ns	ns	ns	ns	ns	ns	ns

†Within a row for a given measure of N use efficiency, values with the same lowercase letter are not significantly different (*P*<0.10) between years.
‡*P*, the significance level (*P*<0.10) of the column comparison between hybrids is either: ns, not significant; or *, significant.

Table 3. Effect of corn rootworm (CRW) resistant trait on internal N use efficiency, physiological efficiency, and fertilizer N recovery efficiency as determined by hybrid pairs of near isolines (hybrid 1 v 2 and hybrid 3 v 4) and all hybrids with and without the CRW.

Hybrid	Internal N Use $Efficiency_{160}$			Physiological $Efficiency_{160}$			Fertilizer N Recovery $Efficiency_{160}$		
	2008	2009	2010	2008	2009	2010	2008	2009	2010
	bu/ lb N uptake			Δbu/ Δlb N uptake			Δlb N uptake/ lb N fertilizer		
1	0.97	1.03	0.94	0.86	0.85	1.09	0.57	0.60	0.67
2	1.00b†	1.10a	0.94c	0.91	0.95	0.89	0.47b	0.54b	0.87a
P‡	ns	ns	ns	ns	ns	*	ns	*	*
3	1.02a	1.05a	0.91b	0.76	0.91	0.68	0.57	0.64	0.66
4	1.01b	1.09a	0.91c	0.66c	1.01a	0.85b	0.66	0.60	0.70
P	ns	ns	ns	ns	ns	*	ns	ns	ns
All CRW	1.01b	1.06a	0.94c	0.81	0.92	0.87	0.58	0.59	0.66
All Non-CRW	1.03b	1.07a	0.92c	0.95	0.95	0.87	0.52b	0.61b	0.74a
P	ns	ns	ns	ns	ns	ns	ns	ns	ns

†Within a row for a given measure of N use efficiency, values with the same lowercase letter are not significantly different (*P*<0.10) between years.
‡P, the significance level (*P*<0.10) of the column comparison between hybrids is either: ns, not significant; or *, significant.

Table 4. Effect of corn rootworm (CRW) resistant trait on the yield at zero N, plateau N rate, and yield at the plateau N rate. Comparison of all hybrids with and without the CRW trait were based on yield response functions.

Year	Yield at zero N		Yield at plateau N rate		Plateau N rate	
	CRW	Non-CRW	CRW	Non-CRW	CRW	Non-CRW
	——— bu/a ———		——— bu/a ———		——— lb N/a ———	
2008	161	154	235	228	152	139
2009	115	110	206	206	160	164
2010	145a	130b	240	234	165	154
Average of all years	140a	131b	227	223	159	152

†Within a row for a given measure of the N response function, values with the same lowercase letter are not significantly different (*P*<0.10) between CRW traited and untraited hybrids.

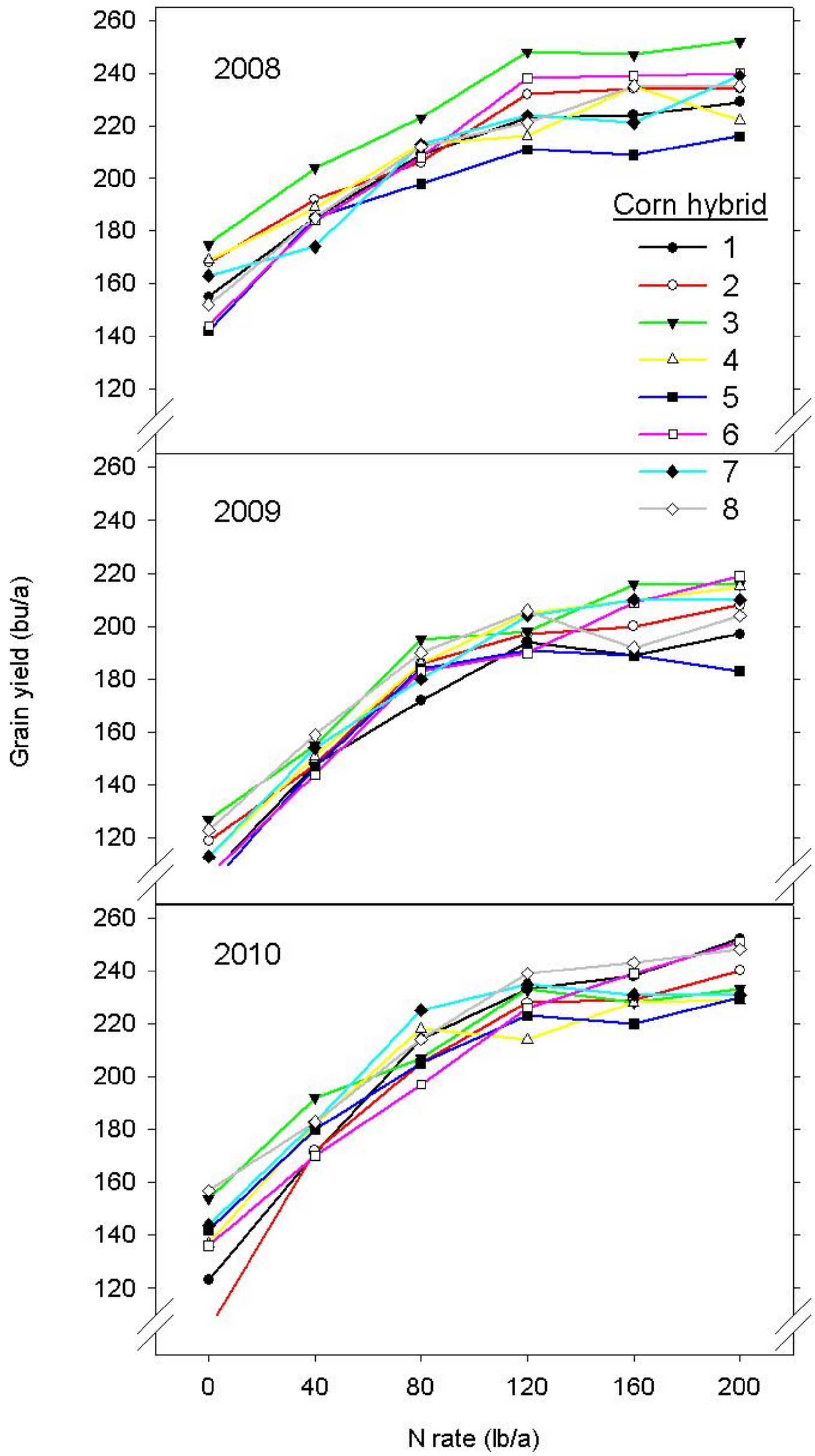

Figure 1. Relationship between N rate and grain yield for eight corn hybrids, 2008 to 2010.