DO CORN HYBRID TRAITS 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 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 to 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 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.

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. Maximum yield N rate economic optimum N rate (EONR), and grain yield at the yield maximizing N rate or EONR was determined using regression analysis (PROC REG or PROC NLIN). The EONR for corn grain reflects several N fertilizer to corn grain price ratios including 0.05, 0.10, 0.15, and 0.20 reflecting, for example $5.00/bu corn grain and $0.25, $0.50, $0.75, and $1.00/lb N fertilizer, respectively.

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 greater 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 2008. Regression models for the yield response to applied N were fit for each hybrid each year. These models were used to calculate the N rate which maximized yield, along with the N rate and yield at the economic optimum N rate (EONR) for several N:corn price ratios (0.05, 0.10, 0.15, and 0.20) (Table 2). When the yield maximizing N rate (YMNR) was determined by combining all hybrids within a year, the YMNR was somewhat lower in 2009 compare to 2010 or 2008. This may be a result of heavy rainfalls in June and July 2008 and 2010, which may have resulted in some N loss. When comparing near isolines with and without the CRW trait, the YMNR and EONRs are sometimes greater in the CRW traited hybrid and sometimes lower for both Pioneer and DeKalb isolines and there were no trends that were consistent within or between years (Table 2). These data suggest that there may not be a relationship between CRW traited hybrids needing more or less N fertilizer than untraited hybrids.

There are numerous ways to define N use efficiency (NUE); however only a few are explored in this paper. One way to assess NUE is to measure the efficiency of converting N supplied by the soil only (zero fertilizer N) into yield. In 2008 and 2009 there was no significant difference between hybrids with regard to their yield at zero N (GY_{noN}) (Table 3). In 2010, hybrids 1 and 2 (Pioneer isoline pair) had significantly lower yield at zero N compared to other hybrids. It is uncertain why that isoline pair would perform poorly in 2010. Expressing the yield at zero N as a percentage of the yield obtained at 200 lb N/a is called relative yield (RGY_{200}). As with yield at zero N, relative yield was not significantly different between hybrids in 2008 or 2009, though relative yields were generally greater in 2008 compared to 2009. Relative yields in 2009 were generally a little lower than what is typically measured at the Arlington Ag Research Station. Hybrids 1 and 2 had significantly lower relative yield compared to other hybrids in 2010 with values of 49 and 44%, respectively, which are substantially less than expected.

The yield increase (over the yield at zero N) at 200 lb N/a (Δ $yield_{200}$) was not significantly different between hybrids in 2008 and 2009 (Table 3). In 2010 there were significantly different yield increases at 200 lb N/a between hybrids. This is largely the result of hybrids 1 and 2 having low yields at zero N, but having the third and fourth greatest maximum yield. For a given hybrid the yield increase at 200 lb N/a does vary somewhat between years. There is no obvious trend for hybrids with the CRW trait to have greater or less yield increase at 200 lb N/a.

Fertilizer N use efficiency (FNUE) is a measure of the amount of N required per bushel of grain. When FNUE is calculated at the 160 lb N/a rate, there are significant differences between hybrids in all years (Table 3). Hybrids 1 and 5 often have higher $FNUE_{160}$ while hybrids 3 and 6 often have lower $FNUE_{160}$. The FNUE calculated at the EONR for the 0.10 N:corn price ratio are generally lower than $FNUE_{160}$ because the $EONR_{0.10}$ is generally less than 160 lb N/a (Table 2) and the yield at $EONR_{0.10}$ is not much lower than yield at 160 lb N/a. Over all years, the $FNUE_{0.10}$ is often greatest for hybrids 6 and 8 while the $FNUE_{0.10}$ is often in the middle of the range for hybrids 1, 5, and 7. Agronomic efficiency (AE) calculated at 200 lb N/a was not significantly different between hybrids in 2008 or 2009. In 2010, hybrids 1 and 2 had significantly greater AE_{200} compared to most other hybrids, though they were not different than hybrid 6. Hybrids 1, 2, and 6 had greater AE_{200} because they had the largest yield increases at 200 lb N/a (over the yield at zero N).

Fertilizer N recovery efficiency (FNRE) is the percentage of fertilizer N applied that is taken up in the biomass (grain plus stover) minus biomass N uptake in the zero N treatment. FNRE was calculated at each N rate and then averaged over N rates for each hybrid. In 2008 there was no significant difference in FNRE between hybrids (Table 3). In 2009, hybrid 5 had the greatest FNRE but it was not significantly greater than hybrids 1 and 7. Hybrid 3 had the lowest FNRE, but it was not significantly different than hybrids 2 and 4. Samples collected in 2010 have not yet been analyzed for total N content.

In 2010, end-of-season stalk nitrate samples were collected approximately two weeks after black layer. When applied N rates are within 20 lb N/a of the EONR at the 0.10 N:corn price ratio, stalk nitrate values had a range of 650 ppm (Fig. 2). The increase in stalk nitrate values between the N rate that was within 20 lb N/a of the EONR and the next highest N rate varied with hybrid. These data demonstrate that different hybrids may not have very similar stalk nitrate values at the EONR.

Summary

There was some variation in yield levels and EONRs between years and between hybrids. The preliminary results of this data analysis show that regardless of the metric used to assess N use efficiency, there does not appear to be a consistent trend for hybrids with the CRW trait to have greater or lesser N use efficiency, overall yield level, or EONR. As the 2010 data set is completed, additional data analysis will be completed.

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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. Nitrogen rate required to achieve maximum yield along with the economic optimum N rate (EONR) and estimated yield at four N:corn price ratios for each hybrid each year along with the average overall hybrids in a given year. These N rates and yield are calculated from the yield response to N regression equations for each hybrid and all hybrids together (average).

Year	Max. yield		N:Corn price ratio † 0.05		0.10		0.15		0.20	
Hybrid	N rate	Yield	EONR	Yield	EONR	Yield	EONR	Yield	EONR	Yield
	lb/a	bu/a	lb/a	bu/a	lb/a	bu/a	lb/a	bu/a	lb/a	bu/a
2008										
1	164	227	155	227	146	226	137	225	128	223
2	131	234	131	234	131	234	131	234	131	234
3	128	250	128	250	128	250	128	250	128	250
4	175	227	163	227	150	226	138	225	126	222
5	130	212	124	211	118	211	112	210	107	209
6	119	239	119	239	119	239	119	239	119	239
7	130	230	130	230	130	230	130	230	130	230
8	185	234	175	234	165	233	155	232	145	230
Ave.	177	233	167	233	157	232	147	231	138	229
2009										
1	149	194	142	194	136	193	130	192	123	191
2	168	205	160	204	152	204	144	203	136	201
3	188	216	178	216	168	215	159	214	149	212
4	172	213	165	213	158	213	150	212	143	210
5	115	188	112	188	108	188	104	187	100	187
6	200	217	200	217	191	216	181	215	171	213
7	172	211	164	210	157	210	149	209	142	207
8	131	201	125	200	120	200	115	199	109	198
Ave.	157	204	150	204	143	203	136	202	129	201
2010										
1	176	246	170	246	164	246	157	245	151	244
2	145	234	141	233	137	233	133	233	129	232
3	156	231	148	231	140	231	132	230	124	228
4	119	224	115	224	111	224	107	223	103	222
5	153	225	146	225	139	224	132	223	125	222
6	200	251	200	251	200	251	200	251	200	251
7	129	233	124	233	120	232	115	232	111	231
8	199	248	188	248	178	247	167	246	157	244
Ave.	164	236	157	236	150	235	144	234	137	233

† Example of N:corn price ratio: $5.00/bu corn grain and $0.25/lb N (0.05), $0.50/lb N (0.10), $0.75/lb N (0.15), or $1.00/lb N (0.20).

Table 3. Effect of corn hybrid on grain yield with no N applied (GY_{noN}), relative grain yield (RGY_{200}†), delta grain yield (Δ $yield_{200}$‡), fertilizer N use efficiency (FNUE¶), agronomic efficiency (AE§), and fertilizer N recovery efficiency (FNRE‡‡)in each year of the study.

Year/ Hybrid	GY_{noN}	RGY_{200}	Δ $yield_{200}$	$FNUE_{160}$	$FNUE_{0.10}$	AE_{200}	$AE_{0.10}$	FNRE
	bu/a	%	bu/a	lb N/bu	lb N/bu	bu/lb N	bu/lb N	%
2008								
1	155	68	74	0.74 abc	0.65	0.37	0.49	63
2	168	72	66	0.70 bcd	0.56	0.33	0.50	42
3	175	70	77	0.67 d	0.51	0.39	0.59	54
4	169	74	58	0.70 bcd	0.66	0.29	0.38	57
5	142	66	74	0.79 a	0.56	0.37	0.58	62
6	144	60	96	0.69 cd	0.50	0.48	0.80	83
7	163	68	77	0.75 ab	0.57	0.38	0.52	61
8	152	66	79	0.70 bcd	0.71	0.40	0.49	78
p	0.22	0.56	0.55	0.04	NA††	0.58	NA	0.11
2009								
1	106	54	91	0.85 a	0.70	0.46	0.64	70 ab
2	117	56	92	0.80 bc	0.75	0.46	0.57	59 bc
3	127	60	88	0.74 d	0.78	0.44	0.52	53 c
4	113	53	102	0.76 d	0.74	0.51	0.63	63 bc
5	102	56	81	0.85 a	0.57	0.41	0.80	81 a
6	106	48	114	0.77 cd	0.88	0.57	0.58	66 b
7	113	54	97	0.76 d	0.75	0.49	0.62	70 ab
8	123	60	81	0.83 ab	0.60	0.40	0.64	67 b
p	0.30	0.46	0.23	<0.01	NA	0.21	NA	0.02
2010								
1	123 bc #	49 cd	129 a	0.67 bc	0.67	0.65 a	0.75	
2	105 c	44 d	136 a	0.70 ab	0.59	0.68 a	0.93	
3	154 a	66 a	79 c	0.71 ab	0.61	0.40 c	0.55	
4	137 ab	60 ab	93 bc	0.70 ab	0.50	0.47 bc	0.78	
5	142 ab	62 ab	88 c	0.73 a	0.62	0.44 c	0.59	
6	136 ab	54 bc	115 ab	0.67 bc	0.80	0.58 ab	0.58	
7	144 ab	63 ab	87 c	0.70 ab	0.52	0.44 c	0.73	
8	157 a	63 ab	91 bc	0.66 c	0.72	0.46 bc	0.51	
p	<0.01	<0.01	<0.01	0.07	NA	<0.01	NA	

† RGY_{200} = (grain yield in unfertilized treatment / yield at the 200 lb N/a rate) x 100.

‡ Δ $yield_{200}$ = grain yield at the 200 lb N/a rate– grain yield at 0 lb N/a.

¶ $FNUE_{160}$ = (lb N/a applied / grain yield) at 160 lb N/a rate.$FNUE_{0.10}$ = (lb N/a / grain yield) at at economic optimum N rate for the 0.01 N:corn price ratio.

§AE_{200} = Δ $yield_{200}$ / 200 lb N/a. $AE_{0.01}$ = Δ $yield_{0.10}$ / economic optimum N rate for the 0.10 N:corn price ratio.

‡‡FNRE = ((total N uptake in fertilized treatment - total N uptake in unfertilized treatment) / N fertilizer rate) x 100. This is the average over all N rates for a given hybrid.

Mean values in columns for each year followed by the same letter are not significantly different at the 0.10 probability level using Fisher's protected LSD test.

†† NA, not applicable. These parameters were calculated from regression response functions and statistical comparisons were not made.

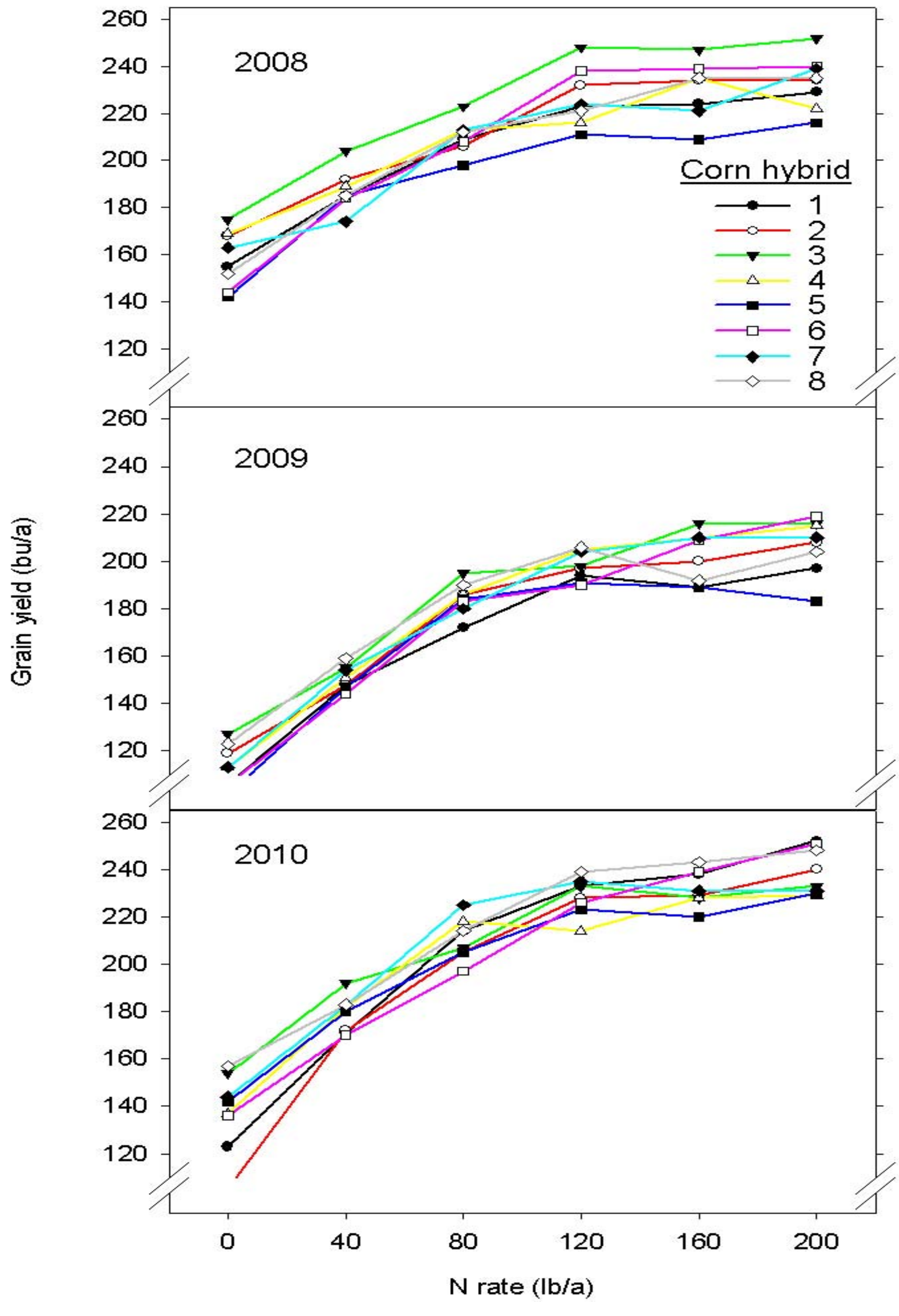

Figure 1. Relationship between N rate and grain yield for eight corn hybrids, 2008 to 2010.

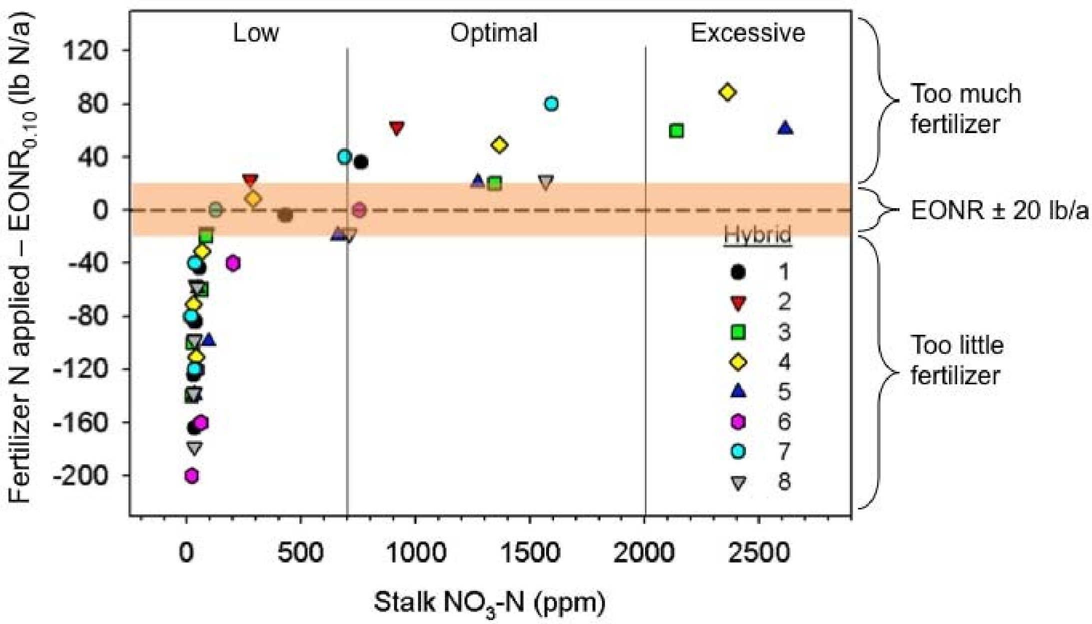

Figure 2. Relationship between over or under application of N compared to the economic optimum N rate at the 0.10 N:corn price ratio ($EONR_{0.10}$) and end-of-season stalk nitrate concentration for each hybrid in 2010.