Investigation of Nitrogen and Fungicide Interactions across Stacked and Conventional Corn Hybrids

(Progress Report, all results preliminary and not complete)

Submitted to:

International Plant Nutrition Institute (IPNI)

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February 12, 2012

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Introduction and Rationale:

- Small-plot and field studies have shown variable yield responses to fungicides and nitrogen
- In Ontario, on-farm strip trials and experiments across hybrids have shown grain yields to increase by more than 3 t ha^{-1} with a fungicide application, especially in environments favorable for disease development on susceptible hybrids.
- Other studies have shown that the economic yield response of a fungicide depends on the hybrid, even in the presence of low disease (i.e., physiological effects)
- In addition to fungicide effects, nitrogen use efficiency (NUE) can vary across hybrids of different genetic platforms, more specifically, between triple-stacked with the corn rootworm trait, and conventional corn hybrids without the corn rootworm trait.
- Furthermore, characterization of NUE among commercial hybrids is not known; screening procedures need to be developed to assist plant breeders with identifying phenotypic traits that are associated with high NUE.
- Higher NUE may be partly associated with extending green leaf area; foliar fungicides tends to extend green leaf area in corn, therefore, fungicides may increase NUE (see example Figure 3)
- In summary, the return on fungicides is variable and depends on several factors including hybrid; research is needed to generate more accurate fungicide decisions, and how fungicides and hybrid affect NUE.

Objectives:

1. To characterize a sampling of commercial hybrids (single vs multiple traits; susceptible vs tolerant foliar disease) by fungicide response, nitrogen use efficiency (NUE), and their interactions
2. To determine whether hybrids respond differently to leaf disease control only (Headline and Proline) and physiological effects (Headline only)
3. To develop hybrid screening tools for NUE
4. To develop the tools for more accurate foliar fungicide decisions

Brief Methods:

- 3 Locations (Ridgetown, West Lorne, Exeter) were planted in 2010
- 3 Locations (Ridgetown, West Lorne, Belmont) were planted in 2011
- Previous crop: Ridgetown and West Lorne: winter wheat (no red clover); Exeter: soybean
- Experimental Design: Split-Strip Plot with 4 replications
- Main plot: 5 nitrogen rates (0, 45, 90, 135, and 180 kg N ha^{-1})
- Split plot: 12 hybrids – same hybrids all 3 locs [i.e., single trait (GT) vs stacked; disease tol vs sus]. See Table 1 for hybrid characteristics.
- Split-Strip: 3 Fungicide applied at VT-R1 (UTC, Headline, Proline)
- Total plots per location: 720
- 12 hybrids randomized within blocks; each hybrid 2-rows x 18-m in length; fungicides were stripped across the rows using a commercial JD 4760 field crop sprayer

Activities in 2010-2011

- Plots were successfully established at Ridgetown, West Lorne and Exeter in 2010, and Ridgetown, West Lorne, and Belmont in 2011. Plots were planted in ideal conditions early May 2010, and late May to early June 2011 because of wet weather during early and mid-May. In each year, the plots were overseeded then thinned to 80,000 plants ha^{-1} before V2. N was applied using UAN (28-0-0) between V3 and V4 both years. Fungicides were applied VT-R1 depending on hybrid maturity.

- Six hybrid-pairs were suggested by seed companies to represent a range of genetics and resistance against foliar diseases. The same hybrids were planted at all locations, with the exception of a replacement hybrid for the N-34N series in 2011.

- In 2010, saturated soil conditions after planting caused excessive variability in Reps 3 and 4 at Exeter, and Rep 3 at Ridgetown; therefore, the most intensive measurements were not conducted on these replications. Dry conditions shortened the grain fill period at all 3 locations. In 2011, plots at all locations were well-established. In spite of planting full-season hybrids late in 2011, all hybrids reached physiological maturity before a killing frost.

- Measurements and the status of sample processing are listed in Table 2.

- Key objectives to the measurements are listed in Table 3.

Preliminary Results

- Drought conditions occurred during the last half of the grain-fill period at all 3 locations in 2010. In 2011, plots were planted in June because of extended wet weather in May.

- Corn yields at all site locations were highly responsive to fertilizer N input (Table 4 and Figure 1). The magnitude of the response was different across hybrids at 3 of 6 locations over both years, which caused significant nitrogen by hybrid interaction at those locations (Table 4). These interactions were evident from the nitrogen response curves in Figure 1; curves were not labeled with hybrid in the preliminary analysis. Overall, when the data from all location-years were combined, the N by hybrid interaction was significant ($p=0.01$; Table 4).

- There was no evidence to support the hypothesis that nitrogen response of triple-stacked hybrids containing the corn rootworm trait was different than hybrids from the same genetic background but without the trait (Table 5).

- MERN varied by hybrid within location from 101 to 180 kg N ha^{-1} (Tables 6 and 7). The range in estimated MERN values indicate that the N rate for optimizing grain yields depends on the hybrid. The stability of MERN within specific hybrids across different environments needs to be determined. Another step in the analysis will also include a determination of nitrogen use efficiencies for each hybrid.

- Leaf disease severity was extremely low in all hybrid-locations (data not shown), with <10% of leaves in the upper canopy infected with disease during the grain-fill period. There was evidence that corn yield response to foliar fungicides depended on the nitrogen rate at 3 of 6 locations, but when the data were combined across location-years, the data did not support a statistical or economically significant interaction (Table 8 and Figure 2).

- Average yield response to fungicide varied from 0.18 to 0.24 t ha^{-1} across hybrids (Table 9). There was no difference in yield between Headline and Proline. Some hybrids responded more to fungicide than others (Table 9).

Conclusions

- The major result of this project showed that yield response to nitrogen varied across 12 hybrids. However, there were no differences in response to nitrogen between triple-stacked hybrids with the corn rootworm and their glyphosate tolerant isoline. Overall, corn yield response to fungicide was lower than expected, perhaps due to abnormally dry conditions during grain-fill in 2010, or a shortened growing season (grain-fill period) in 2011. There was little evidence to suggest that the response to nitrogen was different with a fungicide application, or that the response to fungicide was higher at high nitrogen rates.

- This report presented corn yield response to hybrid, nitrogen, and fungicide. Based on differential yield responses to nitrogen, it is expected that NUE are different among the hybrids used in the study. The effect on grain corn quality will be determined. Harvest indices of both dry matter and nitrogen will be determined. Nitrogen uptake was measured at silking at harvest within each hybrid at all locations; these data will be used to develop a better of understanding of N cycling across various hybrids, and whether there is a correlation between these data and NUE. Although fungicide showed little impact on yield, impact on NUE is to be determined.

Table 1. Corn hybrids planted at all locations in 2010 and 2011.

Number	Company	Hybrid	Trait	Maturity (CHU)	Leaf Disease Rating
1++	NK Seeds	N34-GT	RR	2900	G
		N34N-3000GT	RR/CRW/CB		
2	Pioneer Hi-Bred	35F37	RR	3150	G
		35F44	RR/CRW/CB		
3	NK Seeds	N45A-GT	RR	3100	G-E
		N45A-3000GT	RR/CRW/CB		
4	DeKalb	DKC48-37	RR	2925	E
		DKC48-40	RR/CRW/CB		
5	Pride Seeds	A6842RR	RR	2950	VG
		A6843G3	RR/CRW/CB		
6	Pioneer Hi-Bred	PO125R	RR	3050	G
		PO125XR	RR/CRW/CB		
7**	NK Seeds	N39M-GT	RR	2975	F-G
		N39M-3000GT	RR/CRW/CB		

++, ** corn hybrids only used in 2010 and 2011, respectively.

Table 2. Status of measurements of 2010-2011 trials.

#	STAGE	MEASUREMENT	# HYBRIDS	# N RATES	# FUNGICIDE	# LOCATIONS	Loc-Reps	# SAMPLES OR PLOTS	Status as of Feb 11, 2012
		total number of units --->	12	5	3	3	12	2160	
1	V6	basic soil analysis	1	1	1	3	12	12	frozen; to be analyzed
2	V6	PSNT 0-30 cm	1	1	3	3	12	36	frozen; to be analyzed
3	VT	final population (num plants/plot)	12	5	3	3	12	2160	completed
4	VT	SPAD readings	12	5	3	3	9	1620	completed
5	VT	Greenseeker (or other canopy sensor)	12	5	3	3	12	2160	completed
6	VT	whole-plant harvest (5 plants chopped/plot)	12	3	3	3	9	972	completed
7	VT	DM and N in whole-plant samples at VT	12	3	3	3	9	972	2010 completed; 2011 in March 2012
8	VT	leaf disease % coverage by disease (upper, ear, lower)	12	3	3	3	12	1296	completed
9	end Aug/R4	leaf disease % coverage by disease (upper, ear, lower)	12	3	3	3	12	1296	completed
10	R1	50% silking date	12	5	3	3	12	2160	completed
11	R1	50% pollen shed date	12	5	3	3	12	2160	completed
12	R5-LATE	Greenseeker (or other canopy sensor)	12	5	3	3	12	2160	subset tested; aborted due to poor repeatability
13	R6	whole-plant harvest (5 plants chopped/plot)	12	3	3	3	9	972	completed
14	R6	DM and N in aboveground stover; DM grain	12	3	3	3	9	972	completed
15	R6	Soil N 0-30 cm	1	5	3	3	12	180	frozen; to be analyzed
16	R6	stay green	12	5	3	3	12	2160	completed
17	R6	grain N	12	3	3	3	12	1296	2010 completed; rest completed March 2012
18	R6	grain yield	12	5	3	3	12	2160	completed
19	R6	pushtest	12	5	3	3	12	2160	completed
20	R6	harvest mc	12	5	3	3	12	2160	completed
21	R6	test wt	12	5	3	3	12	2160	completed
22	R6	1000 kernel wt	12	3	3	3	12	1296	completed
23	R6	VOMITOXIN in grain	12	1	3	3	12	432	completed

Table 3. Measurements objectives of 2010-2011 trials.

#	STAGE	MEASUREMENT	Objective
1	V6	basic soil analysis	standard practice
2	V6	PSNT 0-30 cm	N budgeting; to help explain N response curves with low fertilizer N input
3	VT	final population (num plants/plot)	differences in pops in some plots may help to explain outlier responses
4	VT	SPAD readings	indicator of N uptake and chlorophyll formation to VT across hybrids; baseline across fungicide treatments
5	VT	Greenseeker (or other canopy sensor)	NDVI=indicator of N uptake and chlorophyll formation to VT across hybrids; indicator of biomass accumulation; baseline across fungicide treatments
6	VT	whole-plant harvest (5 plants chopped/plot)	biomass determination; develop relationship with NDVI across hybrids and N tmts; determine C accumulation and N uptake efficiency to VT across hybrids; baseline across fungicide tmt
7	VT	DM and N in whole-plant samples at VT	
8	VT	leaf disease % coverage by disease (upper, ear, lower)	disease incidence and severity for developing spray decisions models
9	end Aug/R4	leaf disease % coverage by disease (upper, ear, lower)	disease response curves vs hybrid vs weather; evaluate fungicide efficacy
10	R1	50% silking date	days between silk and pollen shed an indicator of stress at VT/R1; document for spraying vs hybrid and N
11	R1	50% pollen shed date	
12	R5-LATE	Greenseeker (or other canopy sensor)	indicator of N uptake and chlorophyll formation in R-stages as affected by hybrid and fungicide effects
13	R6	whole-plant harvest (5 plants chopped/plot)	determine total C accumulation and N uptake across hybrids and fungicide; calc C and N accum from VT to maturity as affected by N, hybrid and fungicide; calculate harvest index; calculate N harvest index
14	R6	DM and N in aboveground stover; DM grain	
15	R6	Soil N 0-30 cm	for budgeting N dynamics
16	R6	stay green	estimate duration of functional leaf area as affected by N, hybrid, and fungicide
17	R6	grain N	N partitioning to grain across N, hybrid, and fungicide
18	R6	grain yield	yield response across tmts
19	R6	pushtest	aggressive method to measure stalk strength
20	R6	harvest mc	quality response across all tmts
21	R6	test wt	quality response across all tmts
22	R6	1000 kernel wt	Yield component; with plant population, yield, and kernel weight; calculate the ave # kernels per plant; determine source of yield responses
23	R6	VOMITOXIN in grain	effect of proline across hybrids and N rates

Table 4. Mixed model ANOVA of grain corn yield response to nitrogen rates across 12 hybrids at 3 locations in 2010 and 2011.

EFFECT	2010			2011			Across All Locations
	Exeter	Ridgetown	West Lorne	Belmont	Ridgetown	West Lorne	
	-- *P* > F --						
HYBRID (H)	<0.0001	0.35	<0.0001	<0.0001	0.02	0.0018	<0.0001
NITROGEN (N)	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
N^2	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
N*H	0.0002	0.85	0.42	<0.0001	0.01	0.18	0.014
N^2 * H	0.01	0.78	0.67	0.0003	0.03	0.19	0.51

N and N^2 represent linear and quadratic coefficients of nitrogen rates in the regression model

N*F and N^2 * F represent interactions of linear and quadratic coefficients with fungicide

Table 5. Mixed model ANOVA of grain corn yield response to nitrogen rates across triple-stacked (CRW) and RR-hybrids at 3 locations in 2010 and 2011.

EFFECT	2010			2011			Across All Locations
	Exeter	Ridgetown	West Lorne	Belmont	Ridgetown	West Lorne	
	-- *P* > F --						
Trait (T)	0.05	0.19	0.85	0.52	0.11	0.74	0.65
Hybrid within T	<0.0001	<0.0001	<0.0001	<0.0001	0.19	0.0006	<0.0001
NITROGEN (N)	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
N^2	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
N*T	0.45	0.42	0.27	0.31	0.35	0.51	0.59
N^2 * T	0.98	0.64	0.28	0.45	0.25	0.37	0.39

N and N^2 represent linear and quadratic coefficients of nitrogen rates in the regression model

N*F and N^2 * F represent interactions of linear and quadratic coefficients with fungicide

Table 6. Coefficients of quadratic equations for yield responses to N across hybrids in 2010.

Year	Loc	Hybrid	Quadratic Coefficients			MERN
			a	b	c	
2010	Exeter	35F37	5878	84.3	-0.283	138
2010	Exeter	35F44	5171	97.6	-0.329	138
2010	Exeter	A6842RR	5629	83.4	-0.323	119
2010	Exeter	A6843G3	6526	64.1	-0.250	115
2010	Exeter	DKC48-37	6259	71.8	-0.278	117
2010	Exeter	DKC48-40	4803	93.1	-0.342	126
2010	Exeter	N45A-3000GT	5183	96.7	-0.347	130
2010	Exeter	N45A-GT	5851	85.8	-0.306	129
2010	Exeter	PO125R	4897	118.8	-0.496	113
2010	Exeter	PO125XR	4488	116.4	-0.426	129
2010	Ridgetown	35F37	10183	27.9	-0.071	149
2010	Ridgetown	35F44	10153	22.3	-0.029	180
2010	Ridgetown	A6842RR	9737	16.7	-0.033	153
2010	Ridgetown	A6843G3	9380	30.0	-0.093	126
2010	Ridgetown	DKC48-37	9661	34.5	-0.138	101
2010	Ridgetown	DKC48-40	9644	25.4	-0.082	114
2010	Ridgetown	N45A-3000GT	8858	40.1	-0.155	108
2010	Ridgetown	N45A-GT	9397	24.9	-0.064	144
2010	Ridgetown	PO125R	10138	23.9	-0.084	103
2010	Ridgetown	PO125XR	9483	36.2	-0.113	131
2010	West Lorne	35F37	6474	71.7	-0.240	135
2010	West Lorne	35F44	6326	77.4	-0.255	139
2010	West Lorne	A6842RR	5710	72.1	-0.260	126
2010	West Lorne	A6843G3	6518	75.8	-0.318	109
2010	West Lorne	DKC48-37	6314	62.2	-0.204	136
2010	West Lorne	DKC48-40	6239	67.2	-0.252	120
2010	West Lorne	N45A-3000GT	4667	83.5	-0.277	139
2010	West Lorne	N45A-GT	4957	77.7	-0.263	135
2010	West Lorne	PO125R	5902	77.5	-0.285	125
2010	West Lorne	PO125XR	5779	82.0	-0.283	133

MERN maximized at the highest N rate tested of 180 kg N ha^{-1}

Table 7. Coefficients of quadratic equations for yield responses to N across hybrids in 2011.

Year	Loc	Hybrid	Quadratic Coefficients			MERN
			a	b	c	
2011	Belmont	35F37	7996	65.8	-0.131	180
2011	Belmont	35F44	8014	63.7	-0.130	180
2011	Belmont	A6842RR	8493	71.9	-0.231	141
2011	Belmont	A6843G3	8744	41.9	-0.076	180
2011	Belmont	DKC48-37	9120	39.5	-0.066	180
2011	Belmont	DKC48-40	8517	58.7	-0.161	162
2011	Belmont	N39M-3000GT	7301	95.9	-0.335	133
2011	Belmont	N39M-GT	6361	100.3	-0.340	138
2011	Belmont	N45A-3000GT	8746	45.8	-0.098	180
2011	Belmont	N45A-GT	8963	46.4	-0.090	180
2011	Belmont	PO125R	7113	98.2	-0.284	161
2011	Belmont	PO125XR	7768	76.2	-0.183	180
2011	Ridgetown	35F37	7772	77.2	-0.266	133
2011	Ridgetown	35F44	9511	26.5	-0.034	180
2011	Ridgetown	A6842RR	8979	50.0	-0.191	114
2011	Ridgetown	A6843G3	8538	46.2	-0.114	174
2011	Ridgetown	DKC48-37	7801	66.4	-0.247	121
2011	Ridgetown	DKC48-40	8550	52.0	-0.172	132
2011	Ridgetown	N39M-3000GT	8150	72.8	-0.256	129
2011	Ridgetown	N39M-GT	8228	58.4	-0.193	134
2011	Ridgetown	N45A-3000GT	8825	50.1	-0.151	144
2011	Ridgetown	N45A-GT	8029	62.5	-0.219	127
2011	Ridgetown	PO125R	7971	39.2	-0.057	180
2011	Ridgetown	PO125XR	7452	71.7	-0.220	148
2011	West Lorne	35F37	5580	69.3	-0.184	170
2011	West Lorne	35F44	5287	64.9	-0.164	178
2011	West Lorne	A6842RR	6205	51.7	-0.174	130
2011	West Lorne	A6843G3	7634	35.2	-0.078	180
2011	West Lorne	DKC48-37	6212	48.4	-0.102	180
2011	West Lorne	DKC48-40	5080	64.5	-0.176	164
2011	West Lorne	N39M-3000GT	6008	46.8	-0.077	180
2011	West Lorne	N39M-GT	6332	39.0	-0.077	180
2011	West Lorne	N45A-3000GT	6372	34.6	-0.004	180
2011	West Lorne	N45A-GT	6148	44.3	-0.054	180
2011	West Lorne	PO125R	5555	56.9	-0.101	180
2011	West Lorne	PO125XR	6106	37.7	-0.003	180

MERN maximized at the highest N rate tested of 180 kg N ha^{-1}

Table 8. Mixed model ANOVA of grain corn yield response to nitrogen rates across 3 fungicide treatments at 3 locations in 2010 and 2011.

EFFECT	2010			2011			Across All Locations
	Exeter	Ridgetown	West Lorne	Belmont	Ridgetown	West Lorne	
	----------	----------	----------	P > F	----------	----------	
FUNGICIDE (F)	0.019	0.11	0.23	0.62	0.002	0.46	0.12
NITROGEN (N)	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
N^2	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
N*F	0.07	0.02	0.61	0.14	0.03	0.35	0.82
N^2 * F	0.11	0.02	0.61	0.15	0.09	0.25	0.98

N and N^2 represent linear and quadratic coefficients of nitrogen rates in the regression model

N*F and N^2 * F represent interactions of linear and quadratic coefficients with fungicide

Table 9. Coefficients of quadratic equations for yield responses to N across fungicide treatments.

Year	Loc	Fungicide	Quadratic Coefficients			MERN
			a	b	c	
2010	Exeter	Headline	5975	82.5	-0.297	128
		Proline	5323	90.5	-0.332	127
		UTC	5109	100.4	-0.384	122
2010	Ridgetown	Headline	9285	40.0	-0.146	114
		Proline	9864	19.2	-0.035	180
		UTC	9841	25.3	-0.077	121
2010	W. Lorne	Headline	5799	75.7	-0.267	130
		Proline	6107	71.6	-0.248	131
		UTC	5752	77.5	-0.282	126
2011	Belmont	Headline	7932	72.3	-0.196	167
		Proline	8185	70.4	-0.203	157
		UTC	8183	58.2	-0.132	180
2011	Ridgetown	Headline	8560	52.1	-0.151	150
		Proline	8651	49.2	-0.153	139
		UTC	7727	67.2	-0.226	134
2011	W. Lorne	Headline	6215	48.2	-0.095	180
		Proline	6083	54.9	-0.132	180
		UTC	5858	44.3	-0.066	180
Average		Headline	7320	60.3	-0.180	149
		Proline	7430	58.2	-0.180	143
		UTC	7110	59.7	-0.180	148

Table 10. Corn yield response to foliar fungicide by corn hybrid, averaged across nitrogen rates and 6 location-years.

Hybrid	Yield Response of Fungicide			
	Headline	P>F	Proline	P>F
	t ha^{-1}		t ha^{-1}	
35F37	0.32	+	0.13	ns
35F44	0.23	ns	0.10	ns
A6842RR	0.11	ns	0.29	ns
A6843G3	0.21	ns	0.12	ns
DKC48-37	0.24	ns	0.18	ns
DKC48-40	0.31	+	0.27	+
N39M-3000GT	0.09	ns	0.00	ns
N39M-GT	0.65	**	0.46	+
N45A-3000GT	0.15	ns	0.22	ns
N45A-GT	0.22	ns	0.34	+
PO125R	0.01	ns	0.07	ns
PO125XR	0.28	ns	0.01	ns
Average	0.24	+	0.18	+

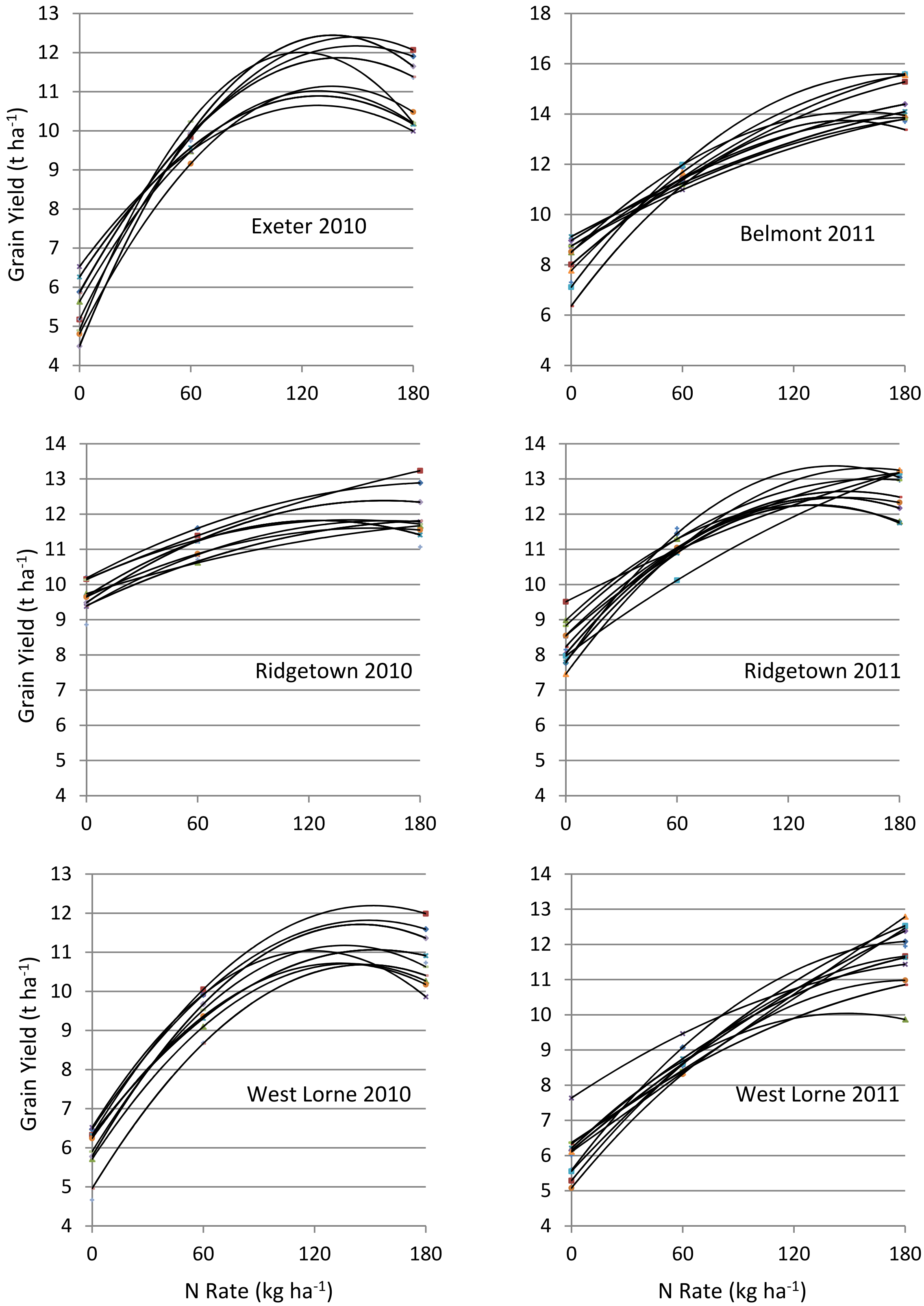

Figure 1. Corn yield response to N rates across 10-12 hybrids at 3 locations 2010 and 2011.

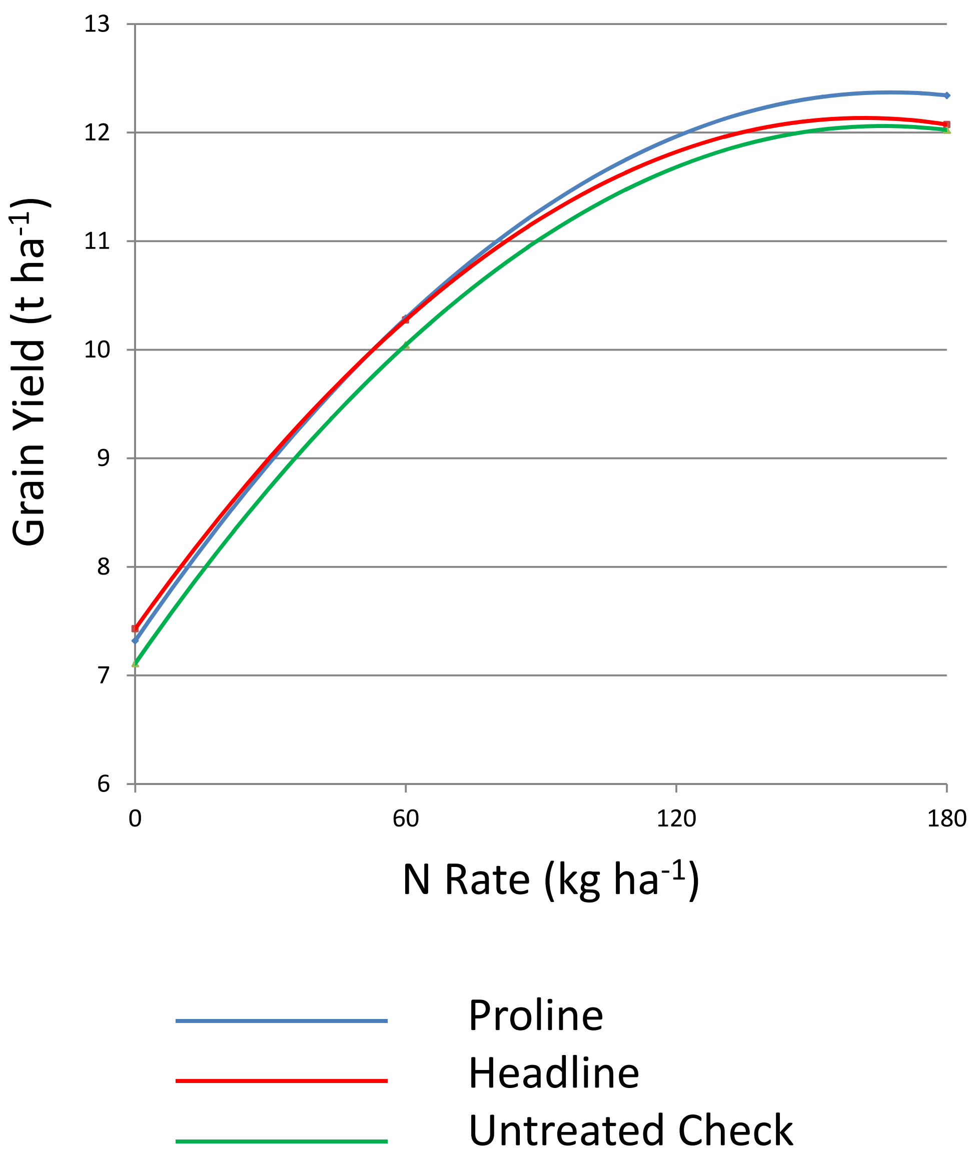

Figure 2. Average corn yield response to nitrogen rate and foliar fungicide across 12 hybrids and 6 location-years in 2010 and 2011.