Genetic and Agronomic Approaches for Improving Corn Nitrogen Use and Productivity

Jason Haegele
University of Illinois at Urbana-Champaign

A corn hybrid's nitrogen (N) use and productivity are influenced by its grain yield at low N and its response to fertilizer N application. Evaluation of old and new hybrids (era hybrids) under various levels of N supply showed that improvement for grain yield at low N (1.1 bu acre–1 yr–1) has contributed to about two-thirds of the improvement in grain yield at high N (1.6 bu acre–1 yr–1). Grain yield at low N was mostly related to differences in genetic N utilization, which quantifies grain yield per unit of plant accumulated N. A more modest improvement in fertilizer N response (0.5 bu acre–1 yr–1) occurred, and this increase was associated with greater N uptake efficiency.

Current commercial hybrids vary widely for grain yield at low N (average range of 42 bu acre–1), N response (average range of 39 bu acre–1), and the optimum N rate (57% to 164% of the mean) at which this response occurs. N uptake is a predominant factor that influenced the response of grain yield to fertilizer N in era hybrids as well as current commercial hybrids. Fittingly, transgenic corn rootworm protected hybrids have improved N uptake efficiency and grain yield in some genetic backgrounds and environments.

In conclusion, genetic and agronomic approaches for improving corn N use and productivity should focus on i) grain yield at low N (stress tolerance and yield stability), and ii) enhancing fertilizer N use.

Genetic and Agronomic Approaches for Improving Corn Nitrogen Use and Productivity

Jason W. Haegele, PhD

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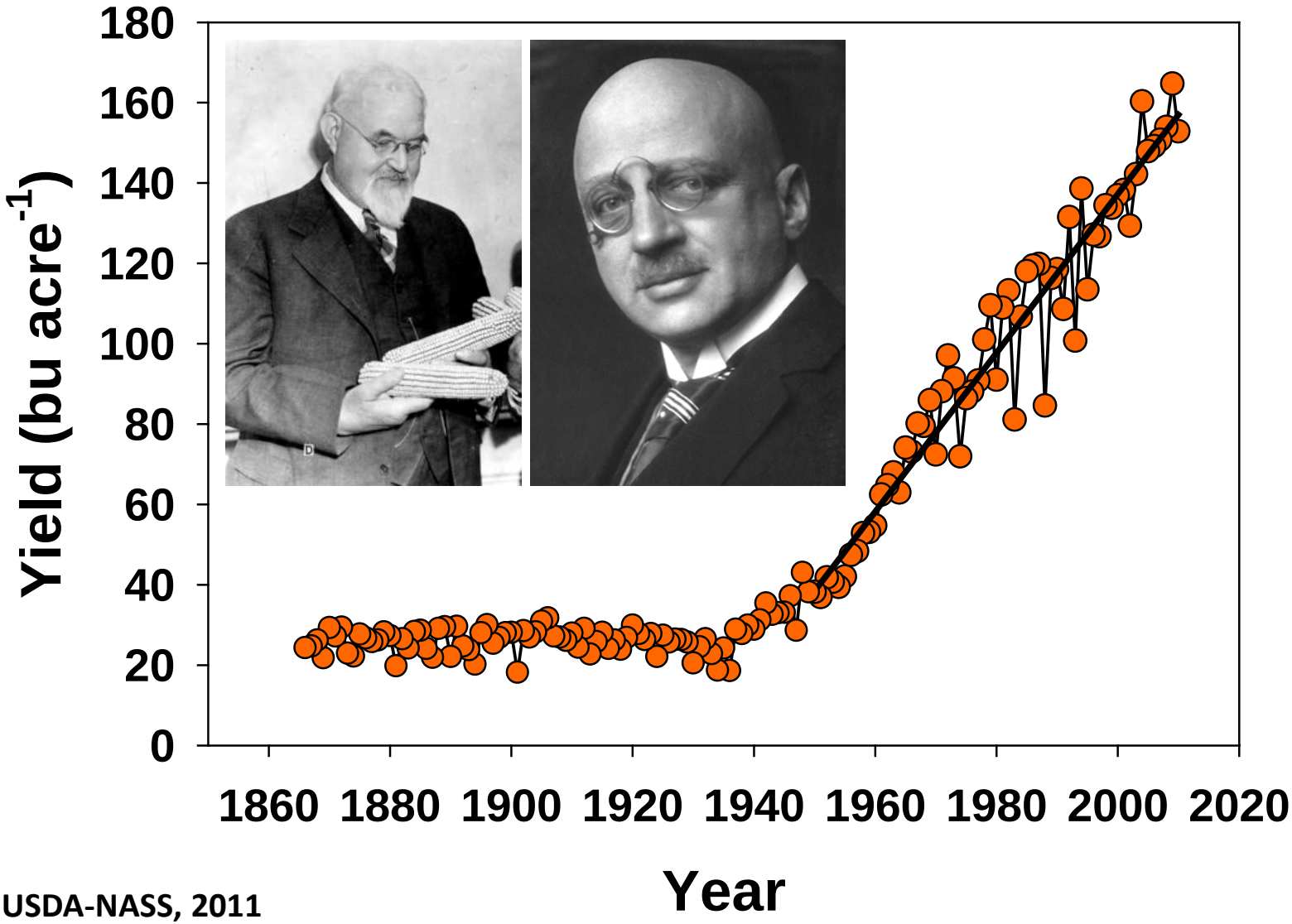
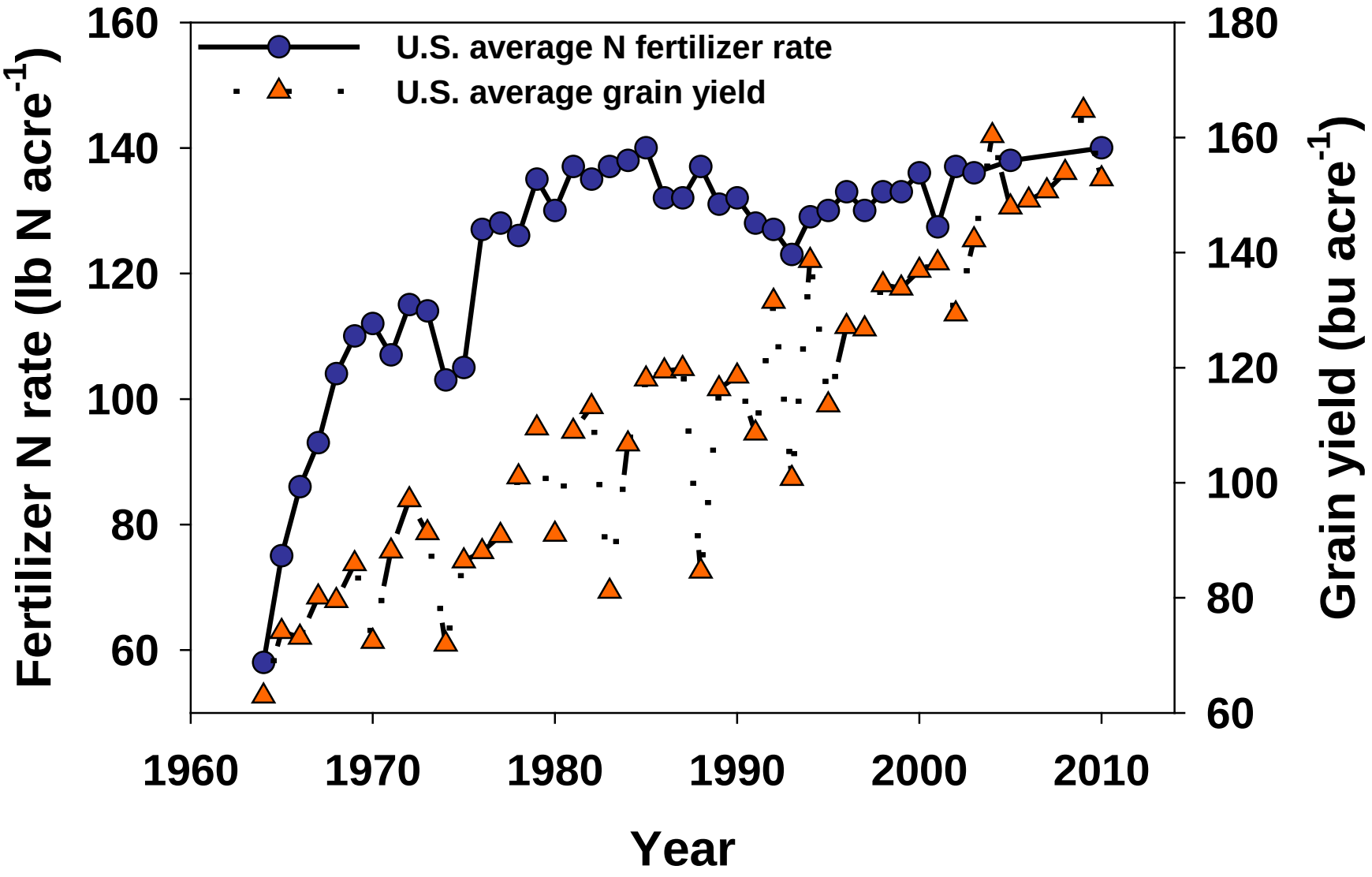
Crop Physiology

U.S. corn yield from 1866-2010



Sources: USDA-NASS, 2011
Harry S. Truman Library (Shull photo)
www.science.pfizer.com (Haber photo)

Historical N use and corn grain yield

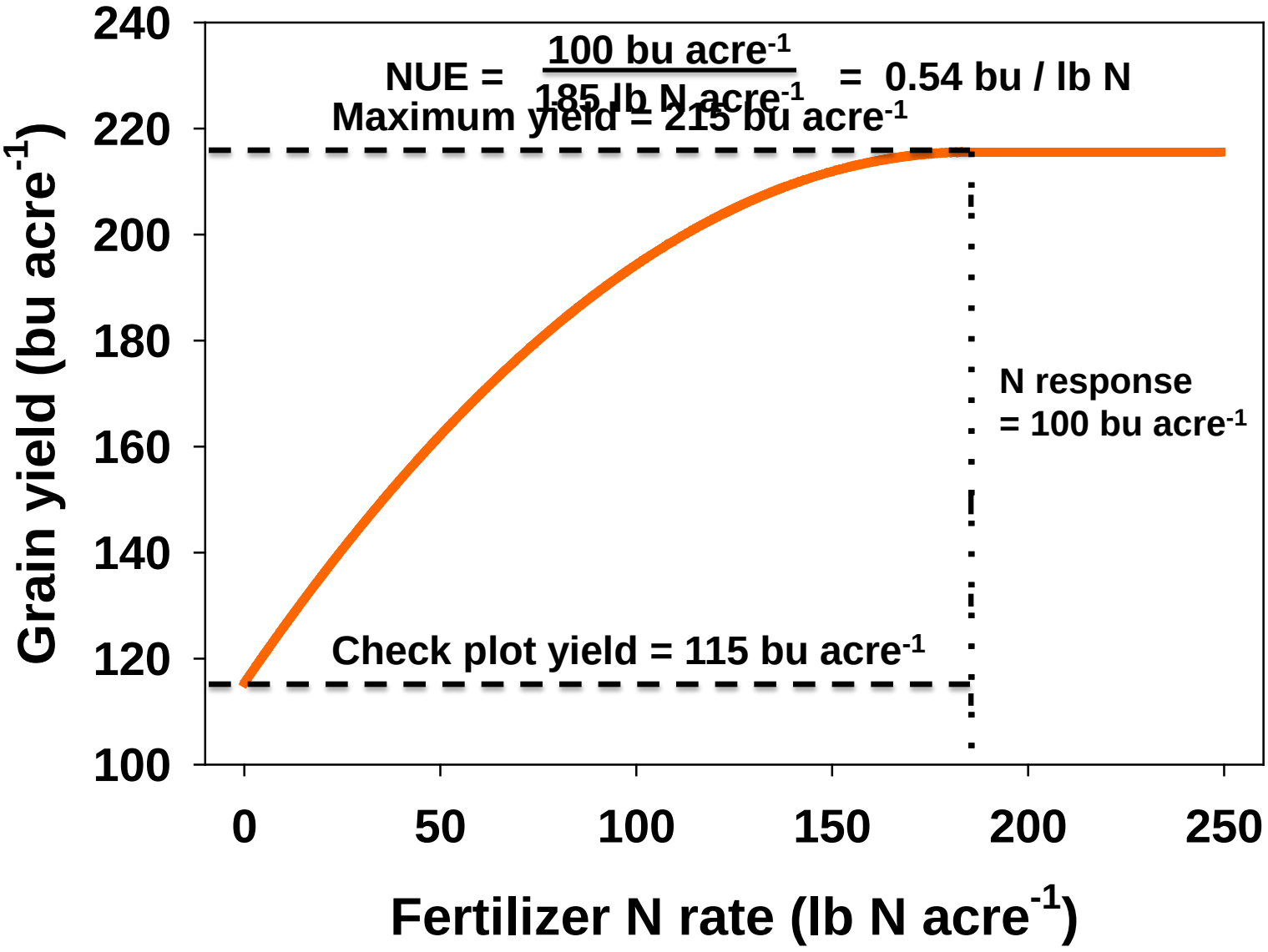


Sources: USDA-ERS and USDA-NASS, 2011

What is N use efficiency (NUE)?

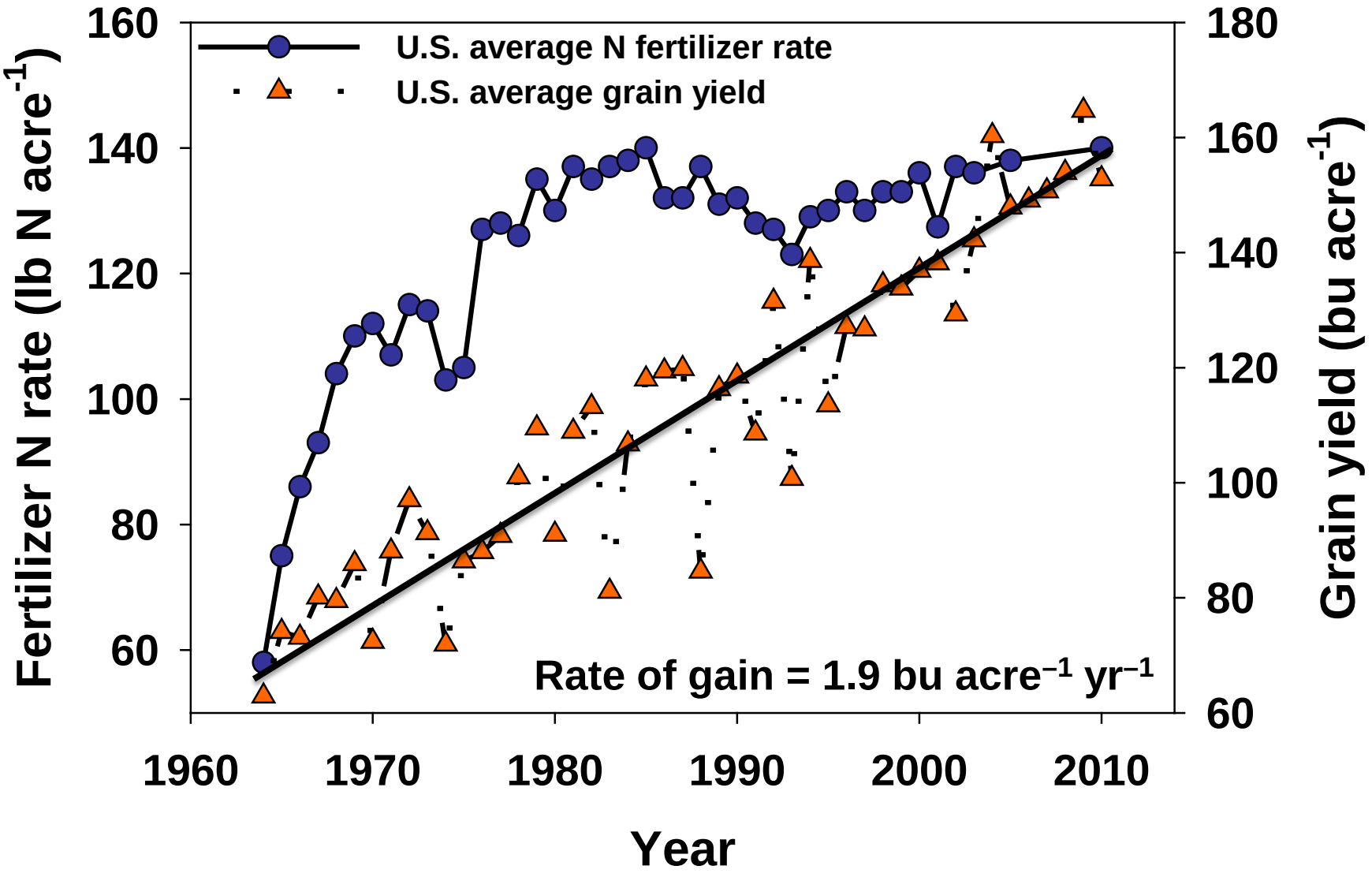
$$NUE = \frac{Yield_{+N} - Yield_{-N}}{N\ rate}$$

Typical N response curve for corn



Average of 49 commercial hybrids grown at Champaign, IL in 2008-2010.

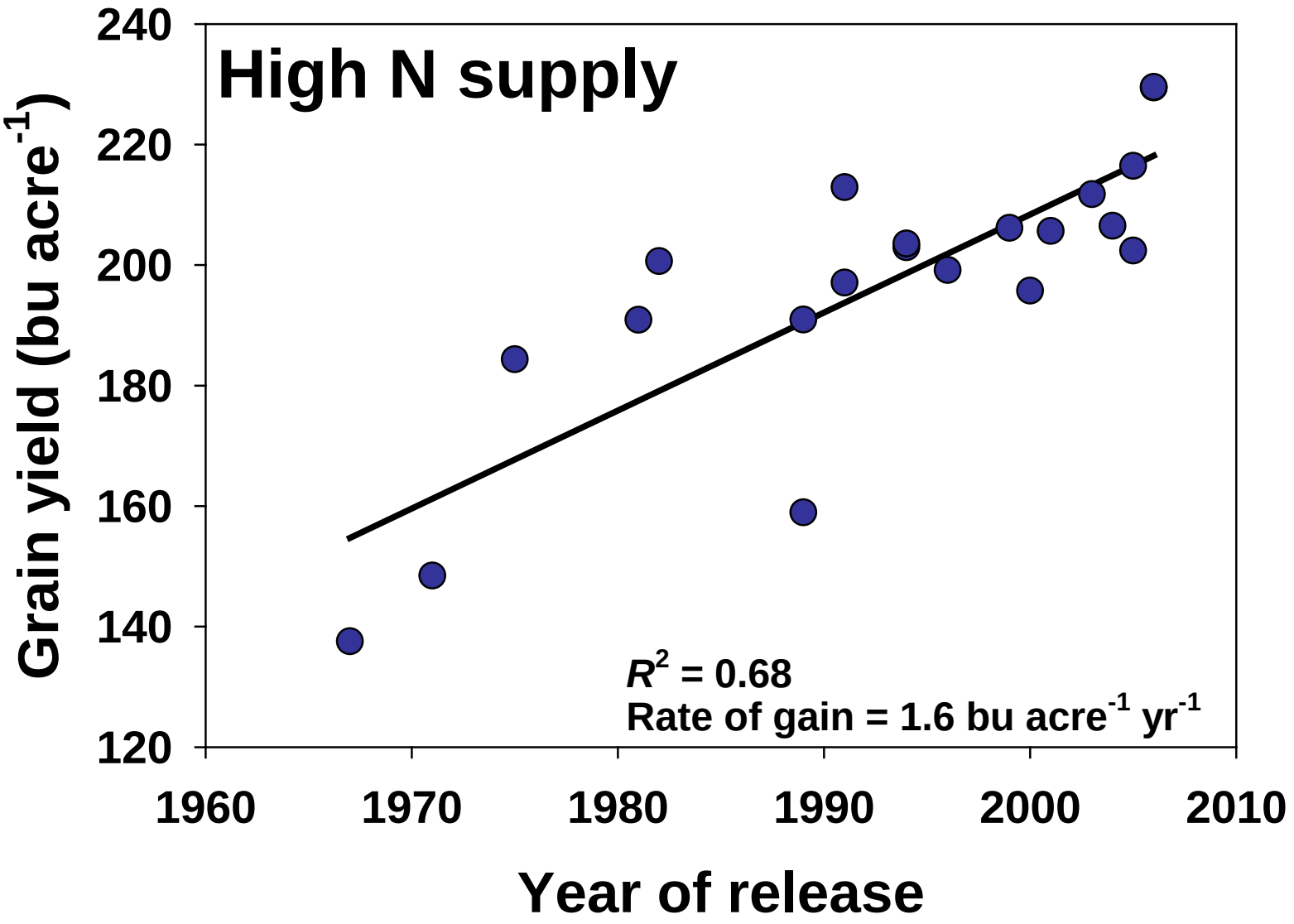
Historical N use and corn grain yield



Sources: USDA-ERS and USDA-NASS, 2011

Crop Physiology

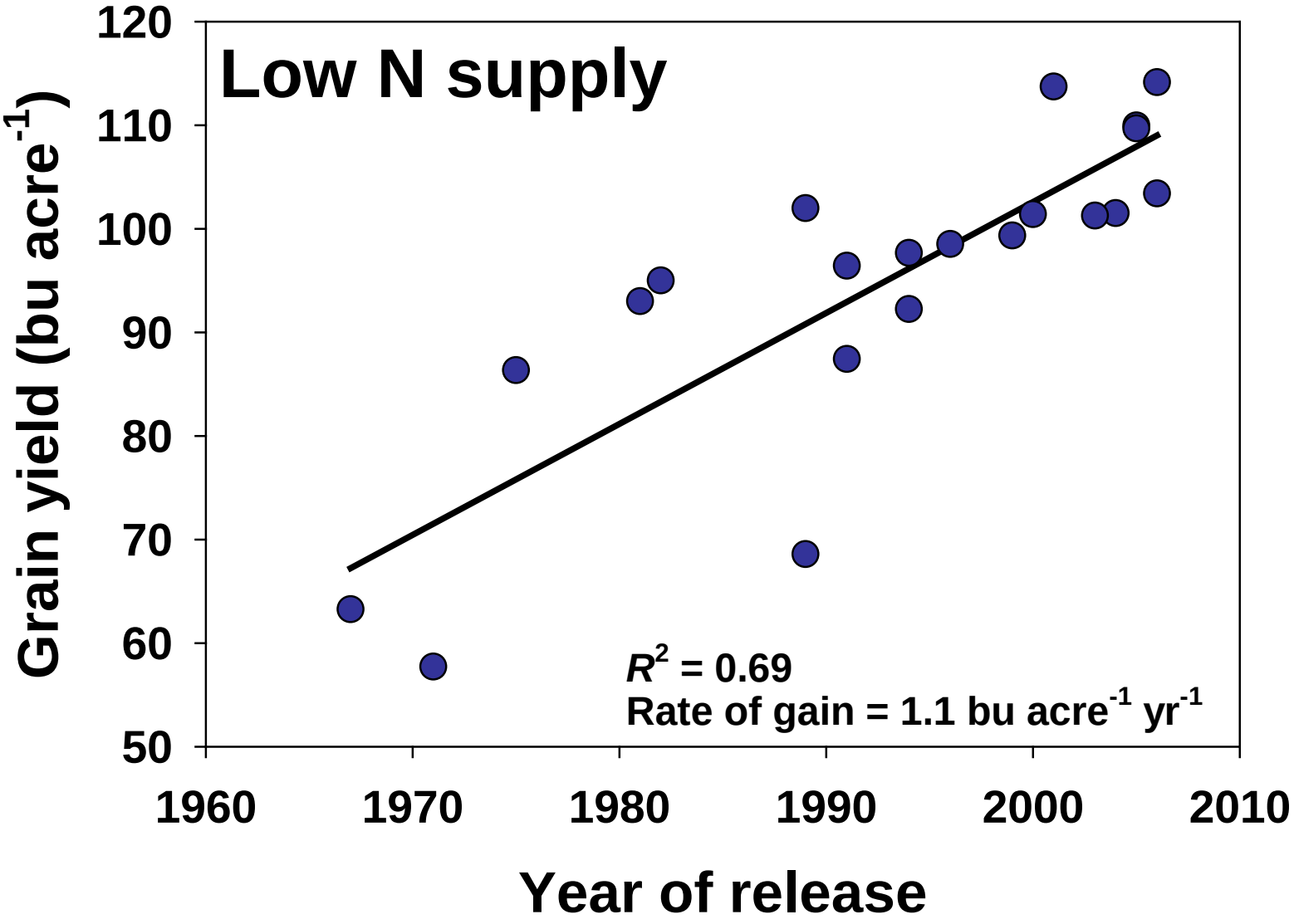
Yield advances at high N supply



Twenty-one hybrids grown at 225 lb N acre^{-1} at Champaign, IL in 2009 and 2010.

Crop Physiology

Yield advances at low N supply



Twenty-one hybrids grown at 0 lb N acre^{-1} at Champaign, IL in 2009 and 2010.

Crop Physiology

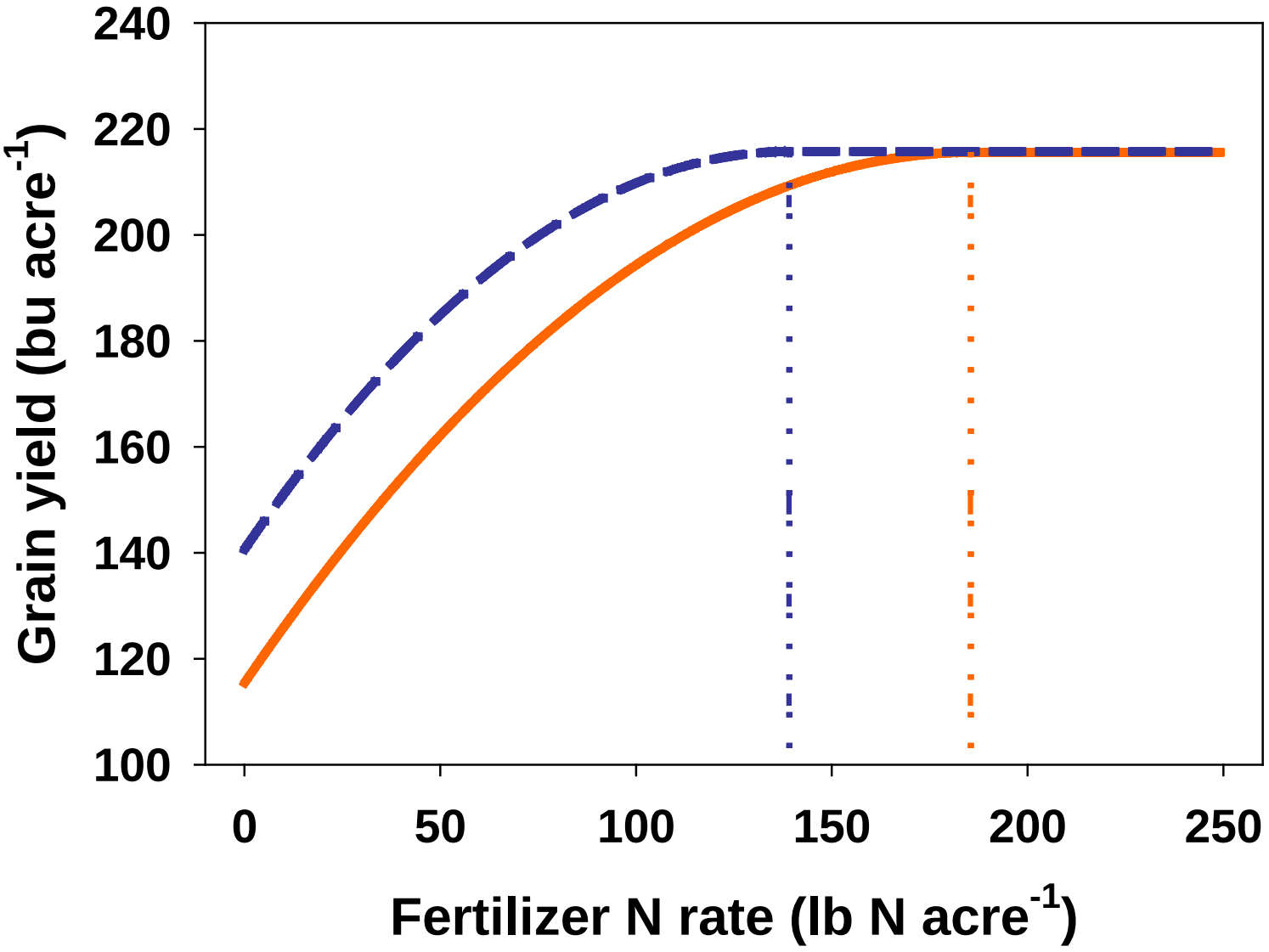
Summary of era hybrid study

Era	Entries	Grain Yield			NUE
		0 lb N	225 lb N	Response	
	n	bu acre^{-1}			kg kg$_N^{-1}$
1970s	3	70	156	86	18
1980s	4	90	186	96	20
1990s	6	96	203	107	22
2000s	8	107	213	106	23
Genetic gain (yr^{-1})		1.1	1.6	0.5	0.16

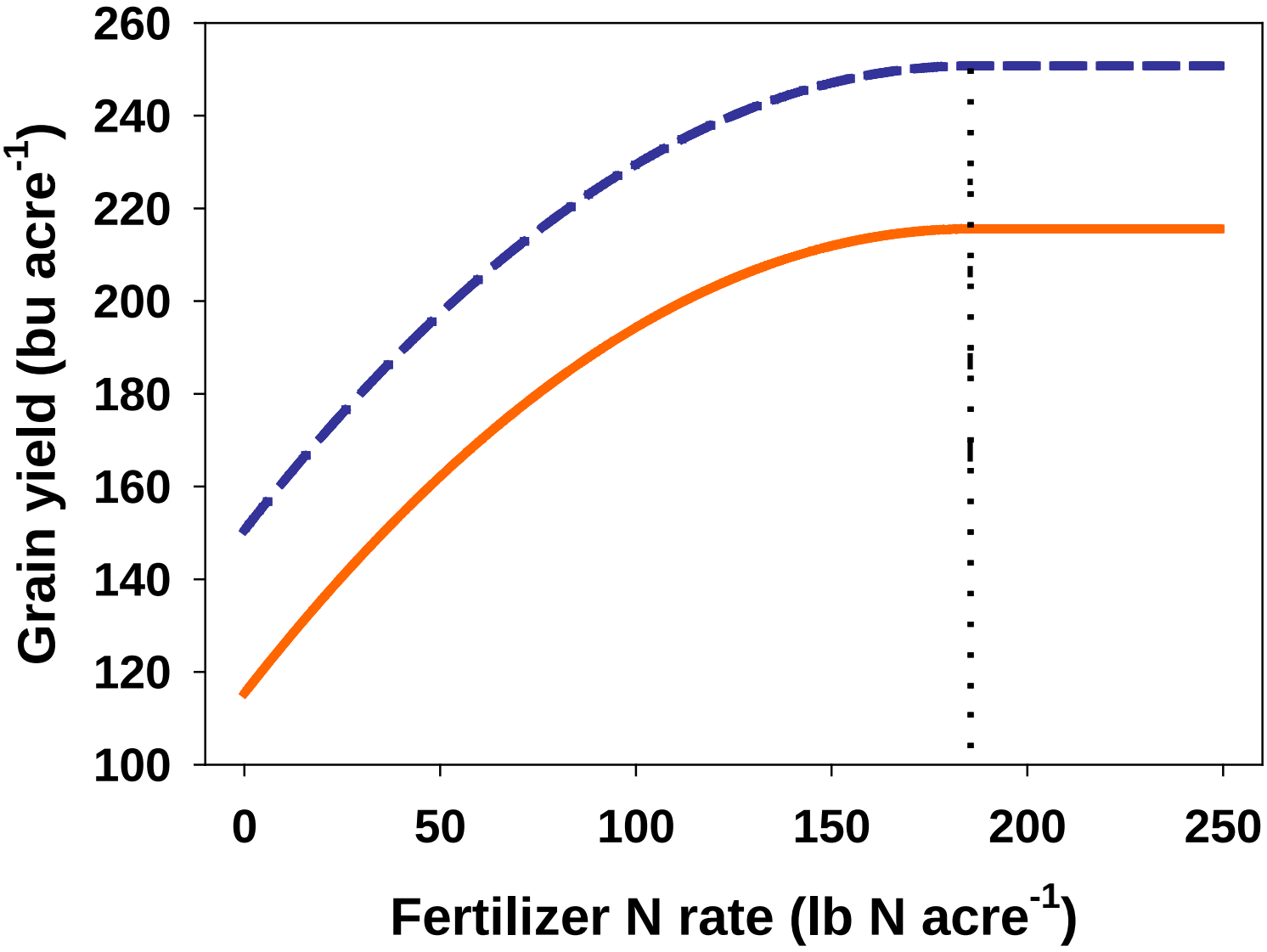
Twenty-one hybrids evaluated at Champaign, IL in 2009 and 2010. Means ± standard error.

Crop Physiology

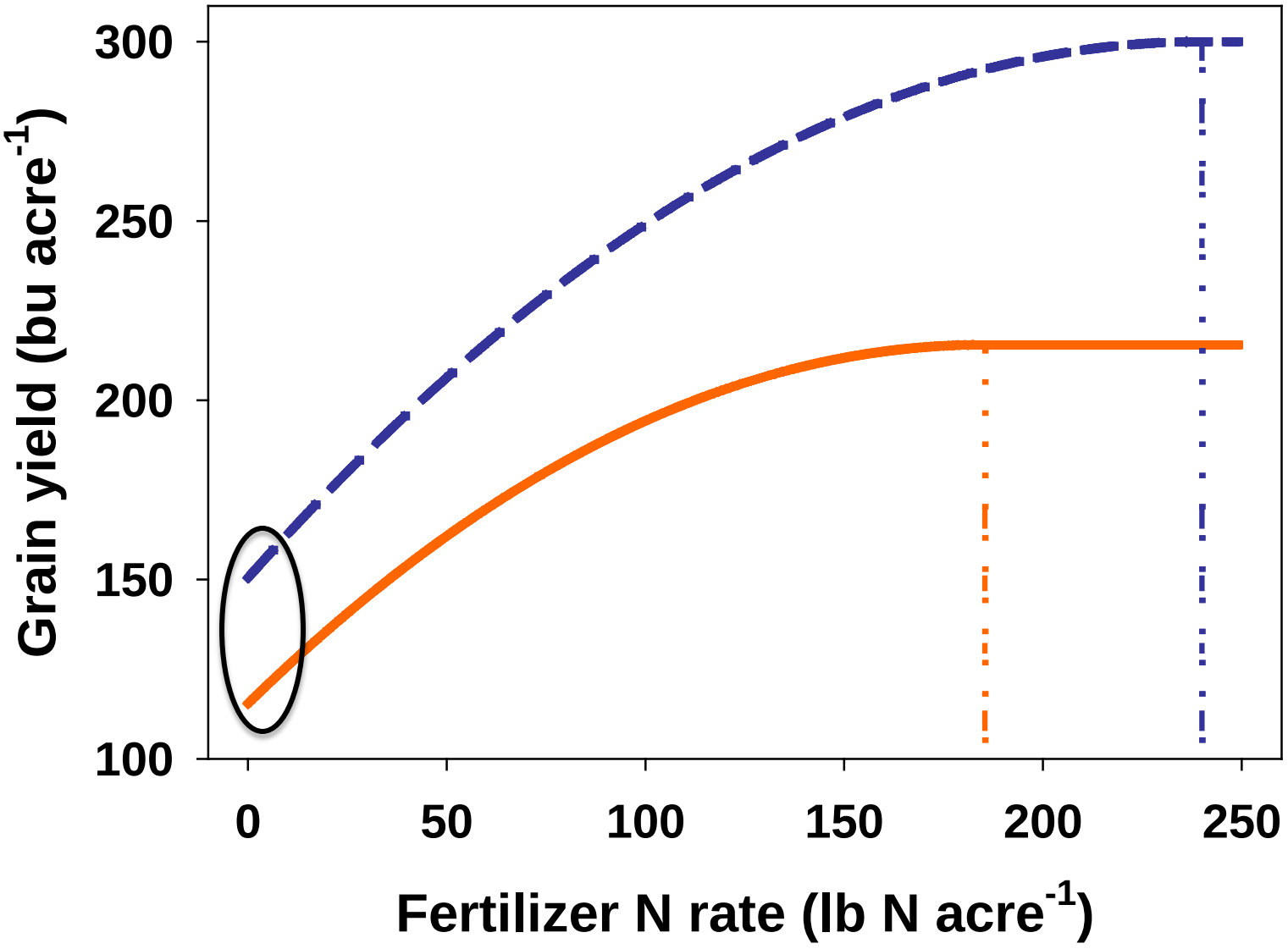
Same yield with 25% less N



Increased yield with same rate of N



N response curve of the future?



Crop Physiology

Correlation of traits with grain yield at low N supply (era hybrids)

Trait	Correlations with grain yield
Kernel number	0.93***
Kernel weight	0.37
N uptake	0.39
Genetic utilization	0.73***

*** $P \leq 0.001$

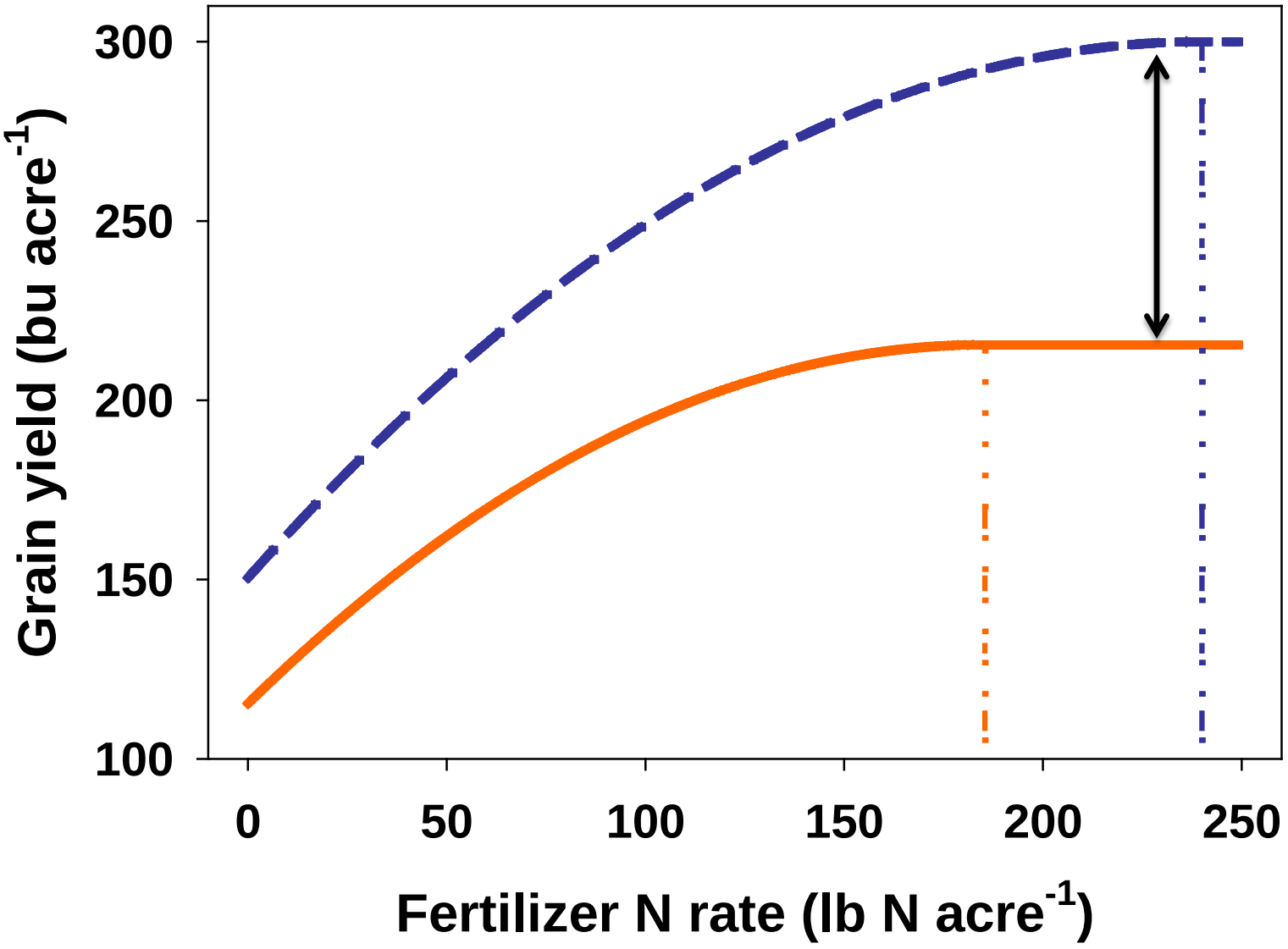
$$\text{Genetic utilization} = \frac{\text{Yield}_{-N}}{\text{Plant N}_{-N}}$$

Crop Physiology

Improved genetic utilization measured in the era hybrid panel

Decade	N uptake at low N supply	Genetic utilization
	g plant^{-1}	kg kg^{-1}
1970s	0.9	57
1980s	0.9	61
1990s	0.9	63
2000s	0.9	66
Slope (yr^{-1})	NS	0.24

N response curve of the future?



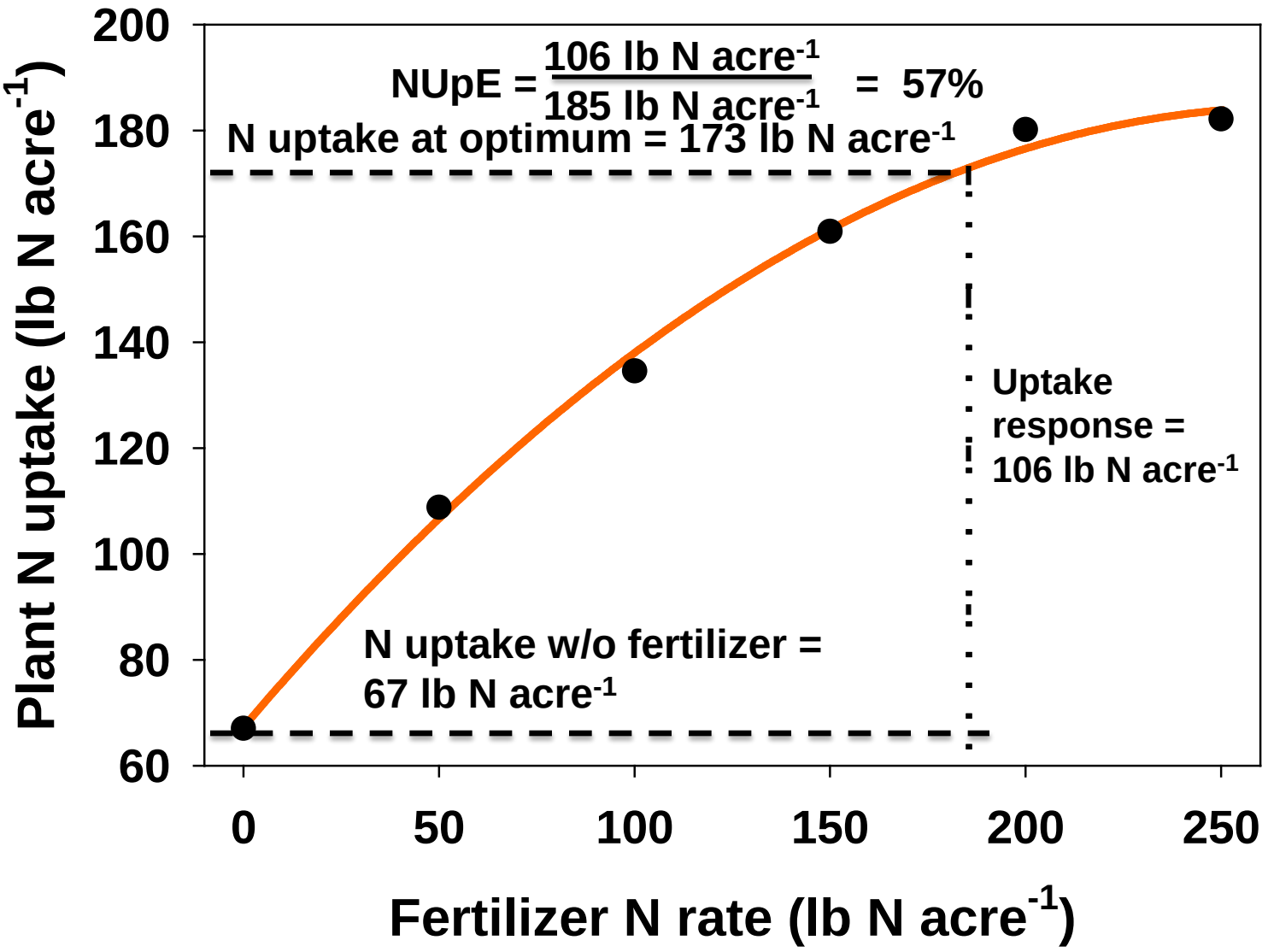
Crop Physiology

NUE is a product of uptake and utilization

$$\text{NUpE} = \frac{\text{Uptake}_{+N} - \text{Uptake}_{-N}}{\text{N rate}}$$

$$\text{NUtE} = \frac{\text{Yield}_{+N} - \text{Yield}_{-N}}{\text{Uptake}_{+N} - \text{Uptake}_{-N}}$$

What is N uptake efficiency?



Averages of 49 commercial hybrids grown at Champaign, IL in 2008-2010.

Correlation of traits with grain yield at high N supply (era hybrids)

Trait	Correlations with grain yield
Kernel number	0.89***
Kernel weight	0.55**
N uptake	0.71***
N uptake efficiency	0.68***

** $P \leq 0.01$, *** $P \leq 0.001$

$$\text{N uptake efficiency} = \frac{\text{Uptake}_{+N} - \text{Uptake}_{-N}}{\text{N rate}}$$

Crop Physiology

Improved N use and uptake efficiencies (era hybrids)

Decade	N use efficiency	N uptake efficiency
	kg kg^{-1}	%
1970s	18	40
1980s	20	49
1990s	22	50
2000s	23	52
Slope (yr^{-1})	0.16	0.3

N utilization efficiency was approximately 45 kg_{grain} kg_{plantN}^{-1} across all decades.

Crop Physiology

Variation for grain yield at low N and N response in commercial hybrids

	Grain yield at low N		N response†	
Year	Average	Range	Average	Range
	bu acre^{-1}			
2008	135	107 – 158	81	58 – 102
2009	94	77 – 111	139	120 – 152
2010	111	92 –	96	71 –

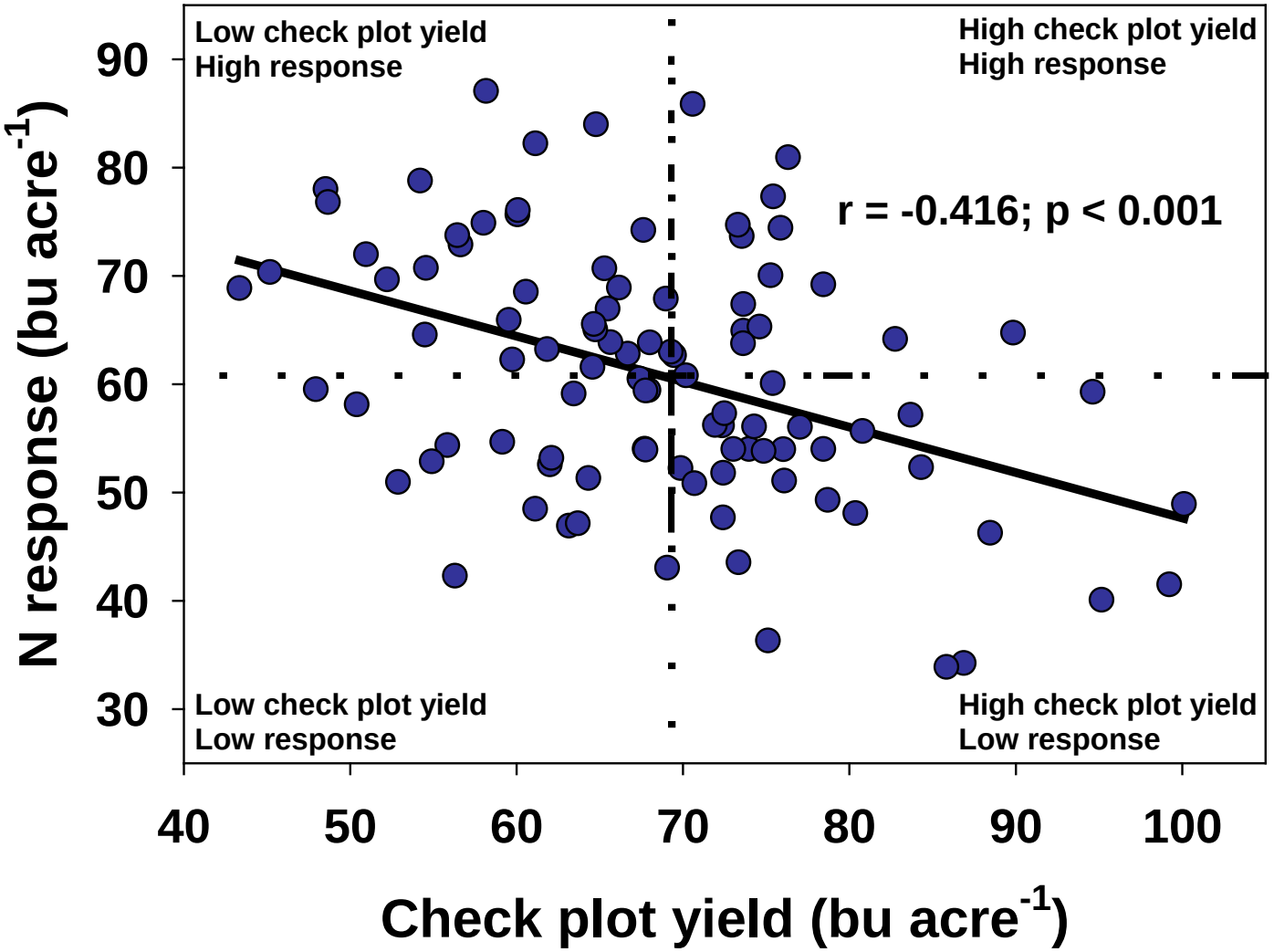
† N response calculated at 250 lb N acre^{-1}.

49 commercial hybrid entries grown at Champaign, IL between 2008 & 2010.

Crop Physiology

A challenge for breeders?

The negative relationship between grain yield at low N and N response



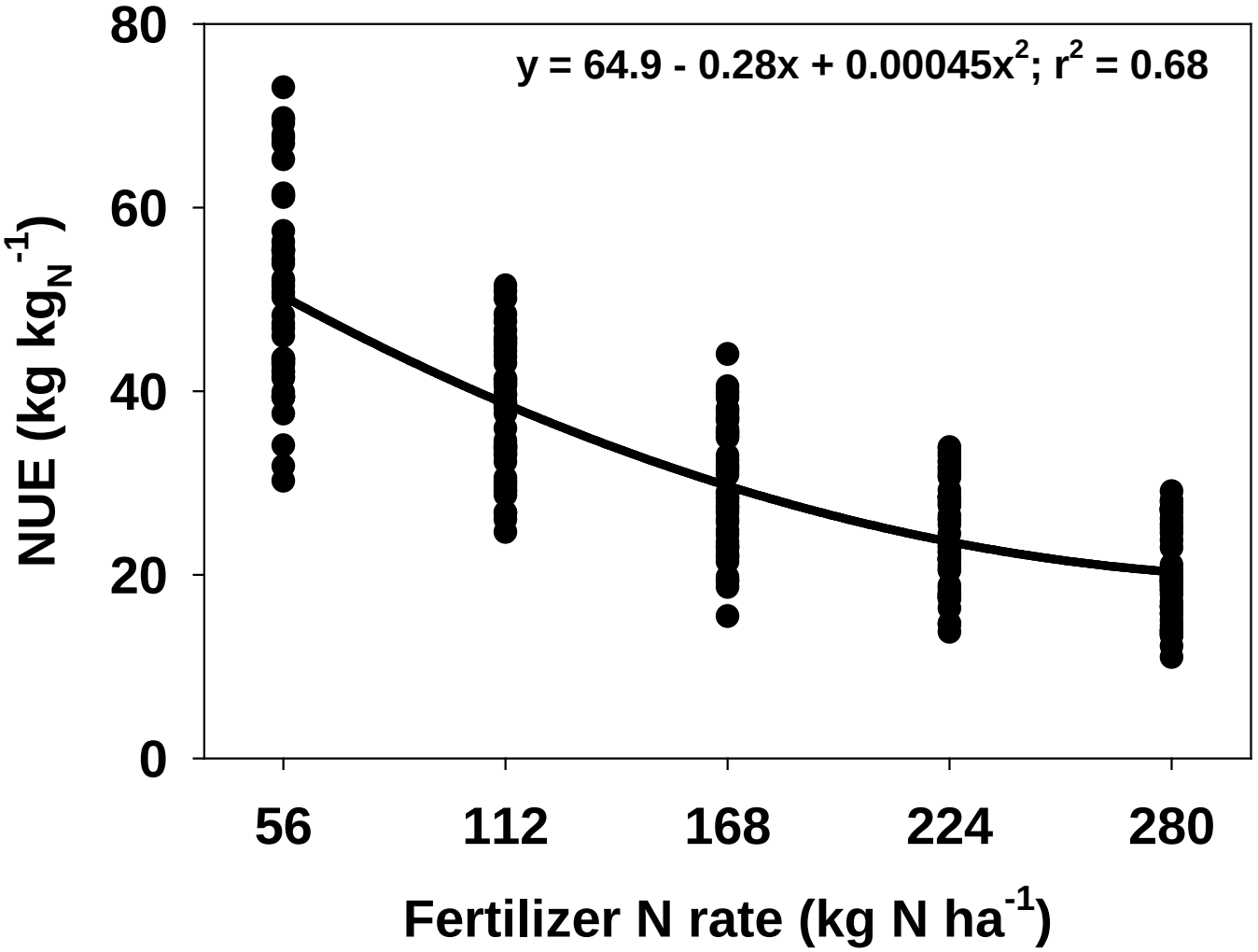
Each point represents an individual IBMRIL x DAS tester hybrid (*n* = 100) grown at Champaign, IL in 2008.

Variation for biologically optimum N rate and NUE in commercial hybrids

	Optimum N rate		NUE at optimum	
Year	Average	Range	Average	Range
	—— lb N acre^{-1} ——		—— kg kg$_N^{-1}$ ——	
2008	143	107 – 233	26	15 – 35
2009	231	183 – 270	29	26 – 33
2010	155	88 – 229	30	19 – 48
Means	176	118	28	19

49 commercial hybrid entries grown at Champaign, IL between 2008 & 2010.

NUE declines with increasing N supply



49 commercial hybrid entries grown at Champaign, IL between 2008 & 2010.

Crop Physiology

Which N rate is most predictive of NUE at the optimum N rate for yield?

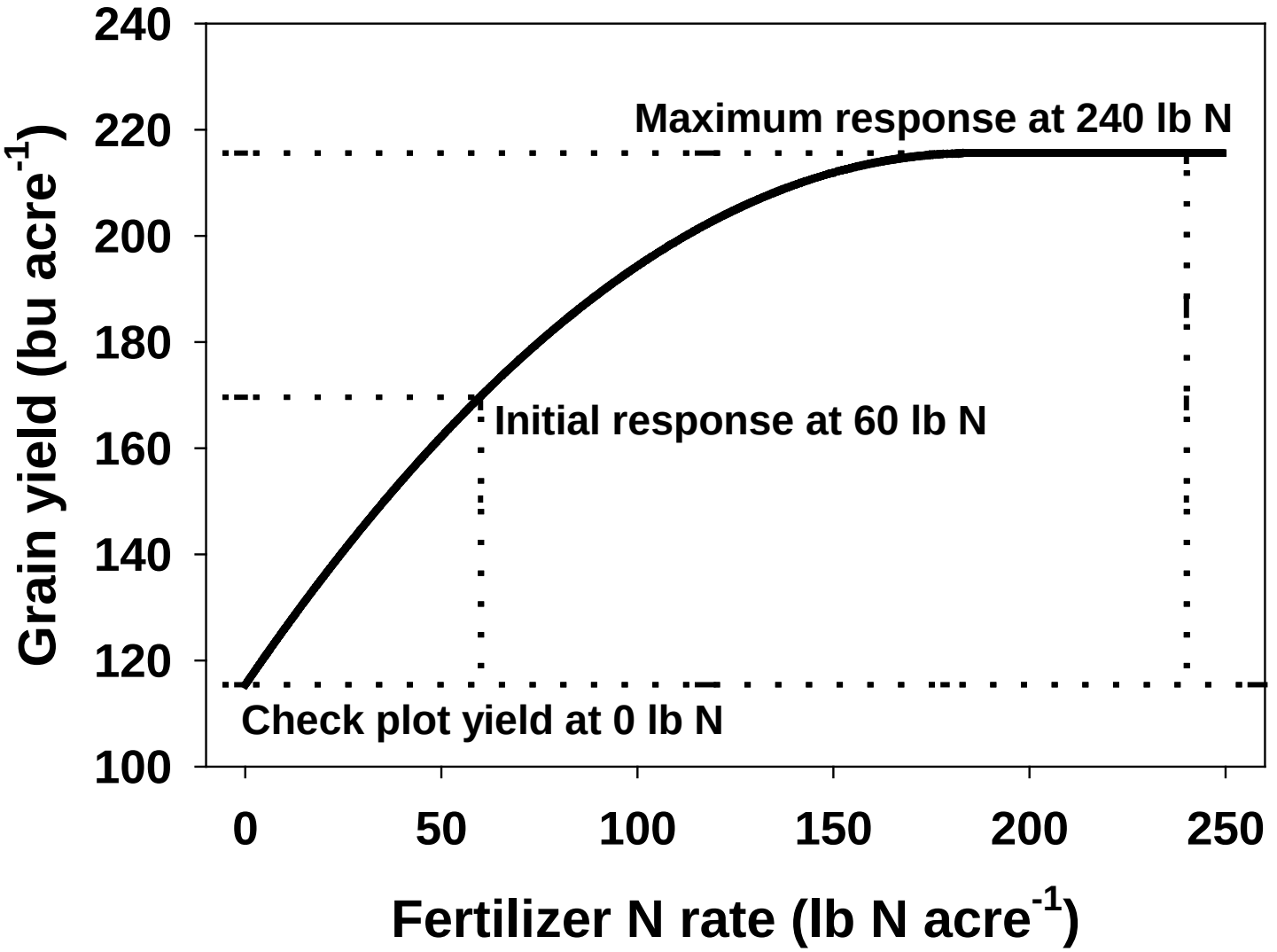
	Correlations with NUE at optimum N rate		
N rate	**2008**	**2009**	**2010**
kg N ha^{-1}			
56	0.81***	0.34	0.79***
112	0.87***	0.60*	0.72***
168	0.40	0.34	0.29
224	0.65**	0.08	0.18
280	0.44	–0.12	0.30

* $P \leq 0.05$; ** $P \leq 0.01$, *** $P \leq 0.001$

49 commercial hybrid entries grown at Champaign, IL between 2008 & 2010.

Crop Physiology

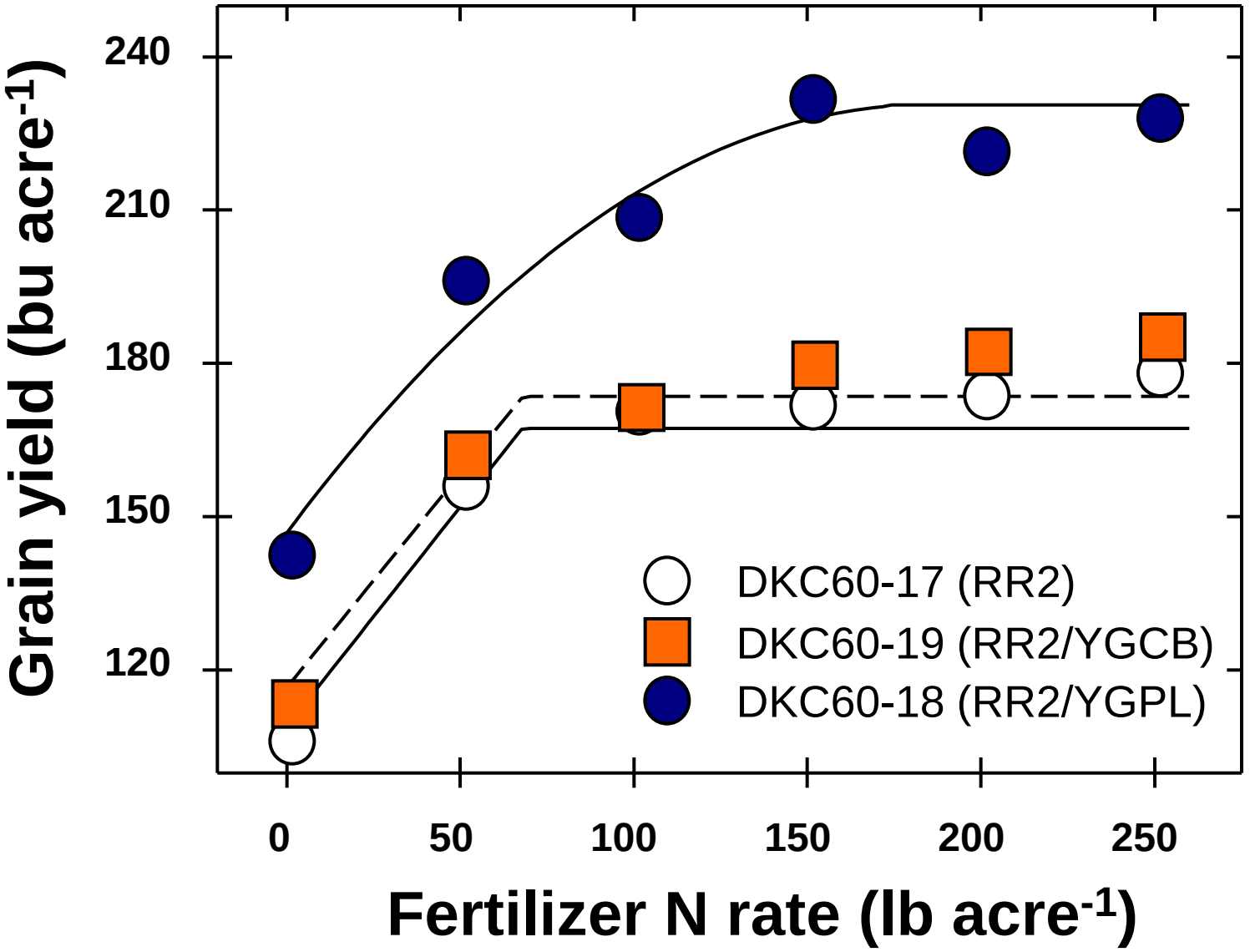
N treatments for characterizing key features of the N response curve



Haegele, J.W., R.H. Beck, T.A. Peterson, and F.E. Below. Contrasting nitrogen use and plant density response phenotypes of maize hybrids. In preparation.

Crop Physiology

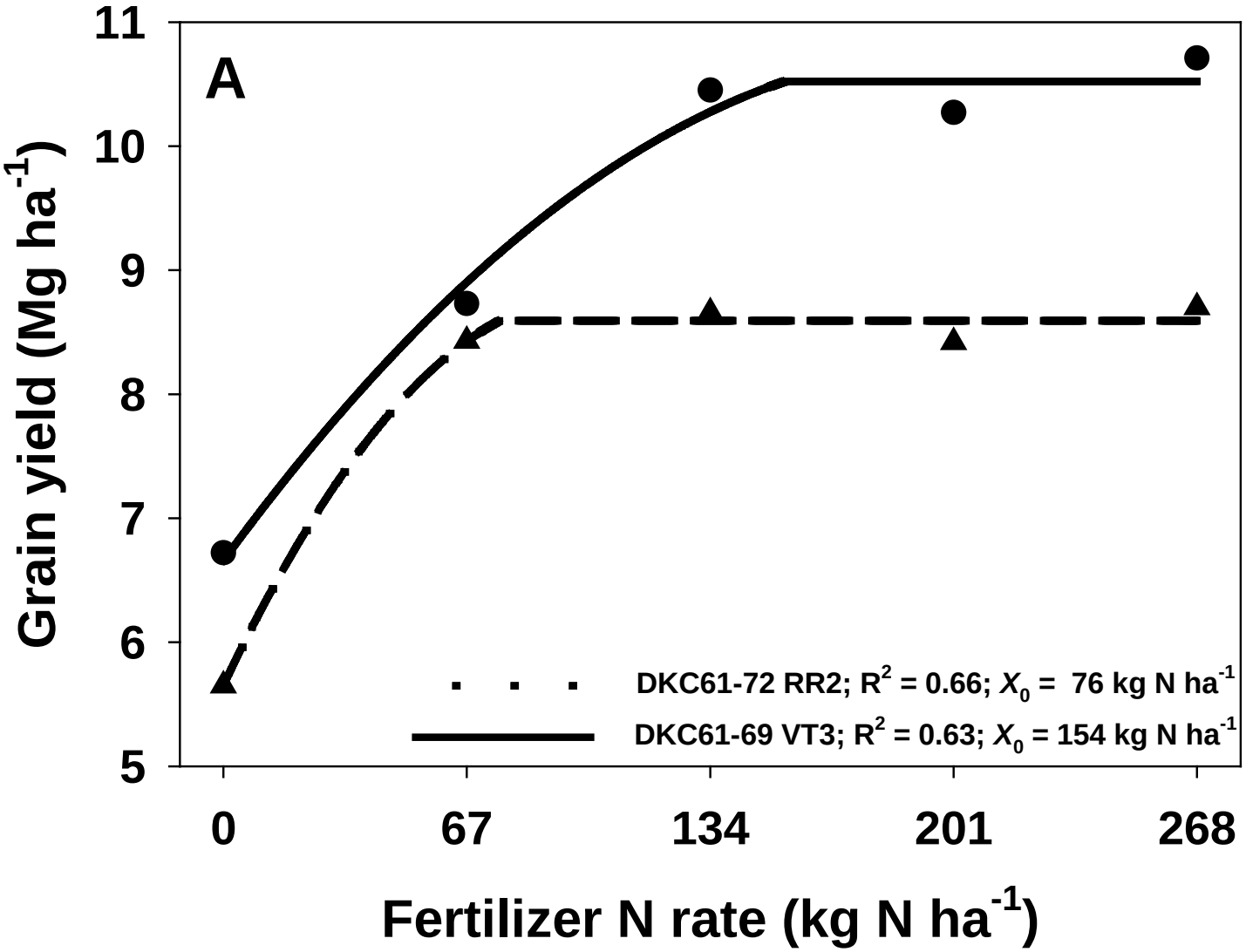
Impact of biotechnology on N use



Hybrids evaluated at Champaign, IL in 2006.

Crop Physiology

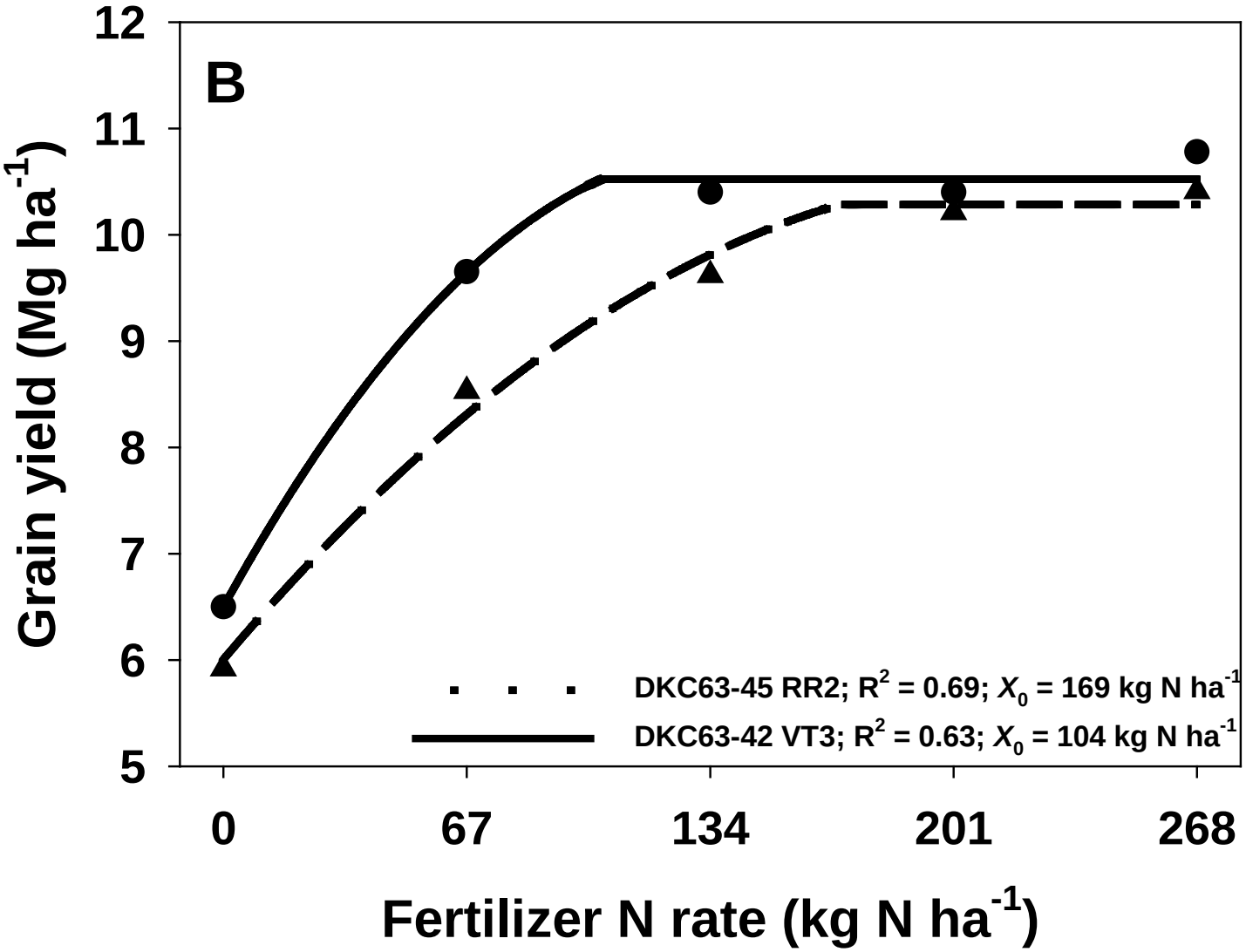
Increased grain yield at low N and a greater response to fertilizer N



Haegele, J.W., and F.E. Below. 2013. Crop Sci. 53:585-594.

Crop Physiology

Improved initial N response to fertilizer N



Haegele, J.W., and F.E. Below. 2013. Crop Sci. 53:585-594.

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Improved N uptake and use efficiency of Bt hybrids with corn rootworm resistance trait

	N uptake efficiency		N use efficiency	
Hybrid	**2008**	**2009**	**2008**	**2009**
	$kg_{plantN}\ kg_{fertN}^{-1}$		$kg_{grain}\ kg_{fertN}^{-1}$	
DKC61-72 RR2	0.59 ± 0.07	0.71 ± 0.04	14.4 ± 1.3	23.7 ± 1.9
DKC61-69 VT3	0.77 ± 0.04	0.78 ± 0.04	26.8 ± 2.0	23.1 ± 2.6
DKC63-45 RR2	0.69 ± 0.05	0.73 ± 0.09	28.4 ± 1.1	31.2 ± 5.1
DKC63-42 VT3	0.91 ± 0.02	0.48 ± 0.06	48.9 ± 1.1	27.5 ± 5.1

Haegele, J.W., and F.E. Below. 2013. Crop Sci. 53:585-594.

Response to the Herculex XTRA trait in the IBM RIL population

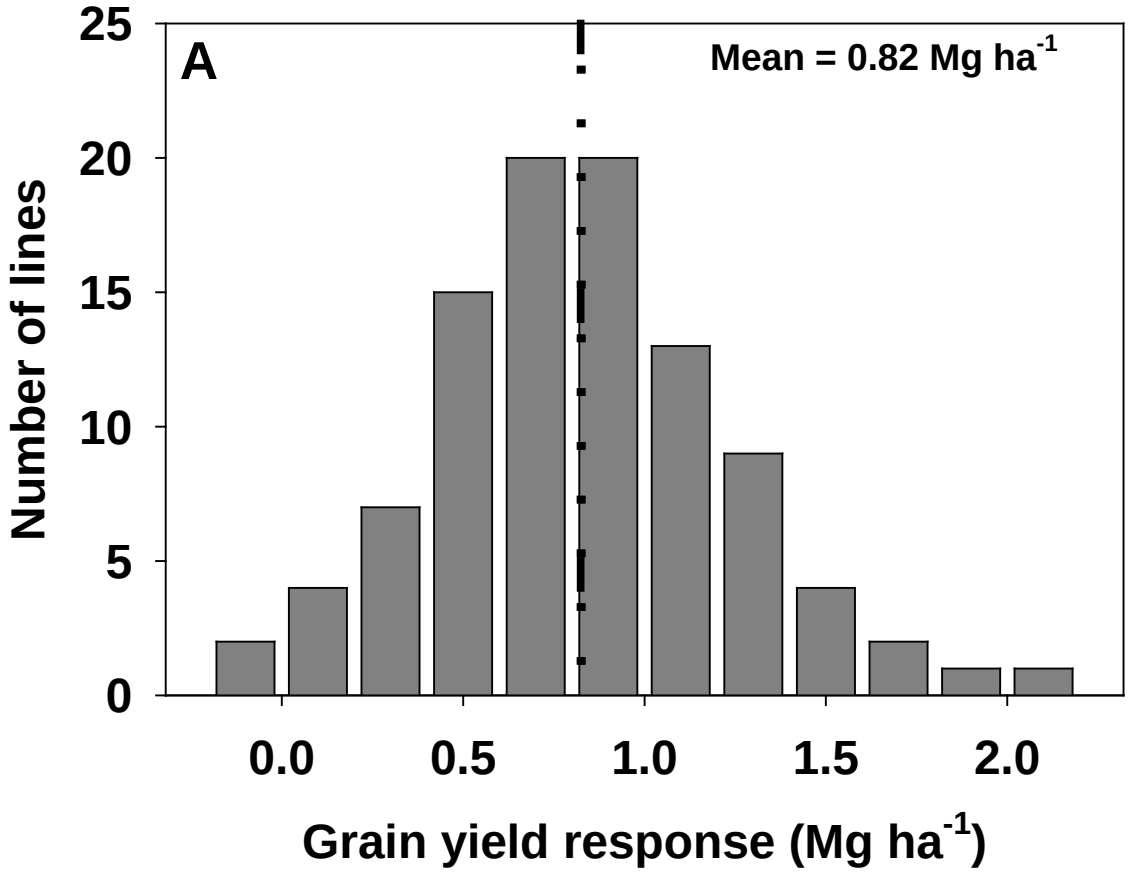
N rate	Male tester	Grain yield	N uptake	N uptake efficiency
lb N acre^{-1}		bu acre^{-1}	g plant^{-1}	%
0	non-HXX	71 d	0.7 d	—
0	HXX	87 c	0.8 c	—
225	non-HXX	174 b	2.3 b	44 b
225	HXX	189 a	2.5 a	47 a

† Treatment means within a column followed by the same letter are not significantly different (α = 0.05).

Two year means of IBMRIL lines (*n* = 98) crossed to near-isogenic testers. Evaluated under two levels of N at Champaign, IL in 2008 and 2009.

Crop Physiology

Variation for response to Herculex XTRA



Response = Hybrid with HXX trait – Hybrid without HXX trait

Two year means of IBMRIL lines (*n* = 98) crossed to near-isogenic testers.
Evaluated under two levels of N at Champaign, IL in 2008 and 2009.

Crop Physiology

Conclusions

1. **Nitrogen use of corn has already been improved, and will continue to be improved, by genetic selection for grain yield.**

2. **Genetic, agronomic, and biotech strategies should focus on accelerating improvement of low N tolerance and response to fertilizer N.**
    - **These improvements are needed to meet the present goal of doubling average corn yields.**

Publications

1. Haegele, J.W., and F.E. Below. 2013. Transgenic corn rootworm protection increases grain yield and nitrogen use of maize. Crop Sci. 53:585-594.

2. Haegele, J.W., K.A. Cook, D.M. Nichols, and F.E. Below. Changes in nitrogen use associated with genetic improvement for grain yield of maize hybrids released in different decades. Crop Sci. In press.

3. http://cropphysiology.cropsci.illinois.edu/research/NUE.html