Identifying resources in ex-PVP maize germplasm for improving nitrogen use efficiency

Crop Physiology

C. Cole Hendrix*, Jason W. Haegele, and Fred E. Below

University of Illinois Department of Crop Sciences, Urbana, IL; *e-mail address: hendrix1@illinois.edu

Introduction:

- The World Summit on Food Security stated that the world will need to increase its food production by 70% by 2050 in order to meet the demands of the growing world population (Food and Agriculture Organization of the United Nations, Declaration of the World Summit on Food Security, Rome, 16-18 Nov. 2009).
- The U.S. national corn production averaged over the last five years is 8.2 Mg ha^{-1} (www.USDA.gov, 2011), meaning that the U.S. national average will need to increase to 11.7 Mg ha^{-1}.
- This goal will be difficult to achieve without proper agronomic management (specifically nitrogen (N) management) and higher yielding corn hybrids.
- Improvement of maize N use efficiency has been limited by a lack of knowledge about the genetic bases for N use.
- General combining ability (GCA) or the average parental performance (additive genetic effect) is less sensitive to environmental influences, but does not predict full hybrid potential. Specific combining ability (SCA), or how a specific hybrid performs (non-additive genetic effects), is more true to hybrid genetic potential but can be highly affected by the environment.

Materials and methods:

- This experiment was conducted during 2011 at the University of Illinois Department of Crop Sciences Research and Education Center at Champaign-Urbana, IL. The soil type was a Drummer-Flanagan soil association (Typic Endoaquolls) with adequate P and K fertility.
- 10 ex-PVP inbred lines along with B73 and Mo17 were combined in a factorial pattern (Table 1). Historic mating patterns were maintained so male inbred lines were not inter-mated nor were female inbred lines. This resulted in 4 females X 8 males for 32 F_1 hybrids.

Table 1: Germplasm entries that span the genetic diversity of current US maize hybrids.

Type	Inbred	Patentee	Heterotic Group (HG)
Female	B73	None (Public)	SSS
	LH1	Holden's Foundation Seed	SSS
	PHG39	Pioneer Hi-Bred International	SSS/Amargo/Iodent
	PHJ40	Pioneer Hi-Bred International	SSS/Minn13
Male	LH123ht	Holden's Foundation Seed	Pioneer Hybrid 3535/Lancaster
	LH82	Holden's Foundation Seed	Pioneer Hybrid 3558/Minn13
	Mo17	None (Public)	Lancaster
	PH207	Pioneer Hi-Bred International	Iodent
	PHG35	Pioneer Hi-Bred International	Oh07-Midland/Iodent
	PHG47	Pioneer Hi-Bred International	Oh43
	PHG84	Pioneer Hi-Bred International	Oh07-Midland/848
	PHZ51	Pioneer Hi-Bred International	848

- Two row plots, replicated three times were planted on May 17th, 2011. The final plant density was approximately 79,000 ha^{-1} (32,000 acre^{-1}).
- N fertilizer treatments consisted of ammonium sulfate ($(NH_4)_2SO_4$; (21-0-0-24S)) incorporated in a diffuse band between the rows at V3-V4. Two N fertilizer rates were used (0 and 252 kg N ha^{-1}) to characterize low N tolerance (check plot yield) and maximum N response of each hybrid.
- Kernel number per m^2, individual kernel weight (mg), and yield were recorded. The yield of each plot was harvested by hand. Yields are reported as Mg ha^{-1} adjusted to 0% moisture concentration.

Question:

How do modern maize varieties from different heterotic groups (HG) respond to applied nitrogen?

Objectives:

1) Identify the yield components that are most responsive to increased nitrogen within various heterotic groups, and 2) identify where breeders should focus their efforts to improve maize nitrogen use efficiency (yield increase per unit of applied N).

Check Plot Yield:

Table 4: The check plot yield and yield component averages for the different HGs.

	HG Representative	Check Plot Yield (Mg ha^{-1})	Kernel Number (m^2)	Kernel Weight (mg)
Females	B73	4.66	2244	208
	LH1	3.85	1802	218
	PHG39	4.22	1842	234
	PHJ40	4.15	1901	218
Males	LH123HT	3.64	1681	227
	LH82	4.66	2330	198
	Mo17	3.89	1775	221
	PH207	4.25	2025	209
	PHG35	4.12	1811	234
	PHG47	4.73	2152	221
	PHG84	3.87	1721	225
	PHZ51	4.57	2083	222

Bottom Quartile | Low Middle Quartile | High Middle Quartile | Top Quartile

- In Table 4, the means for each of the components were separated by HG representatives and into quartiles to illustrate the yield component that was most used by each HG representative to achieve the GCA yield.
- For example: B73, LH82, PHG47, PHG39, and PHZ51 all had some of the highest means in each heterotic pool but B73, LH82, and PHG47 achieved their yield through high kernel number, PHG39 through high kernel weight, and PHZ51 utilized both components to achieve its yield.

Table 5: The check plot yield and yield component averages for the 32 hybrids created from combining the HG representatives.

Female	Male	Check Plot Yield (Mg ha^{-1})	Kernel Number (m^2)	Kernel Weight (mg)
B73	LH123HT	4.57	2257	202
B73	LH82	4.79	2451	194
B73	Mo17	4.34	2164	200
B73	PH207	4.80	2237	214
B73	PHG35	4.53	2091	217
B73	PHG47	5.42	2755	196
B73	PHG84	3.69	1639	223
B73	PHZ51	5.11	2356	216
LH1	LH123HT	3.51	1808	225
LH1	LH82	4.54	2265	199
LH1	Mo17	4.38	2009	217
LH1	PH207	3.51	1738	200
LH1	PHG35	2.90	1201	241
LH1	PHG47	4.41	1897	231
LH1	PHG84	3.20	1433	223
LH1	PHZ51	4.32	2066	208
PHG39	LH123HT	3.36	1367	245
PHG39	LH82	5.15	2452	208
PHG39	Mo17	3.49	1447	242
PHG39	PH207	4.38	1976	220
PHG39	PHG35	4.45	1994	243
PHG39	PHG47	4.49	1861	240
PHG39	PHG84	4.11	1693	243
PHG39	PHZ51	4.32	1946	234
PHJ40	LH123HT	3.10	1293	238
PHJ40	LH82	4.15	2154	192
PHJ40	Mo17	3.33	1478	224
PHJ40	PH207	4.33	2150	201
PHJ40	PHG35	4.61	1957	235
PHJ40	PHG47	4.61	2096	219
PHJ40	PHG84	4.50	2118	210
PHJ40	PHZ51	4.53	1962	229

- The heritabilities of the GCA yield components are demonstrated in Table 5, which separates the average SCA yield and its components for the 32 different hybrids.
- There is a distinct trend found within the HG representatives B73 and PHG39 in their abilities to maintain high kernel numbers and weights, respectively, regardless of their mated partner.
- It should also be noted that the highest yielding hybrids were also the hybrids that generally had the highest kernel number.
- This indicates that at low N, seed number is the primary factor in achieving higher yields.
- If the breeding objective is to breed for high yielding hybrids in low N environments, it would be advantageous to start with high kernel number potential on both sides of the heterotic pattern (e.g., B73 x PHG47).

How Does Check Plot Yield Relate to Maximum Yield Potential?

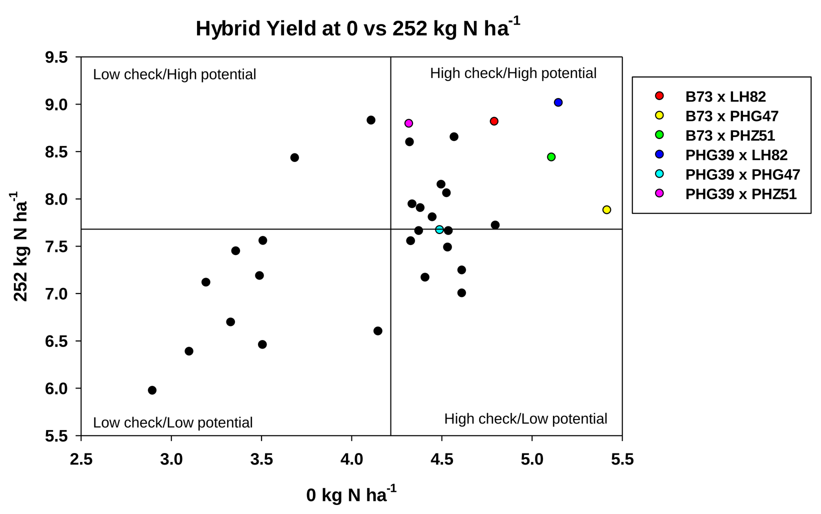

Figure 1: Average grain yields at 0 and 252 kg N ha^{-1} for each of the 32 hybrids. Each point represents an individual hybrid. The colored points represent the hybrids from the HG combinations that were used in previous examples. The vertical and horizontal lines represent the average yield at 0 and 252 kg N ha^{-1}, respectively.

- There is an upward trend in maximum yield potential based upon the hybrid's check plot yield.
- Two of the highest yielding hybrids (PHG39 x LH82 and PHG39 x PHZ51) were combinations between two inbred parents that had complementary yield components.
- The lowest yielding hybrid (PHG39 x PHG47) combined two inbred parents with complementary yield components; however, PHG47 had a lesser kernel number response compared to LH82.
- This highlights the importance of combining complementary yield components from appropriate HGs.
- High kernel number appears to be a prerequisite for higher yield, and the ability to add to kernel weight becomes beneficial when there is enough N supply to maximize kernel number.

How Was the Maximum Yield Achieved?

Yield Response = Yield at 252 kg N ha^{-1} – Yield at 0 kg N ha^{-1}

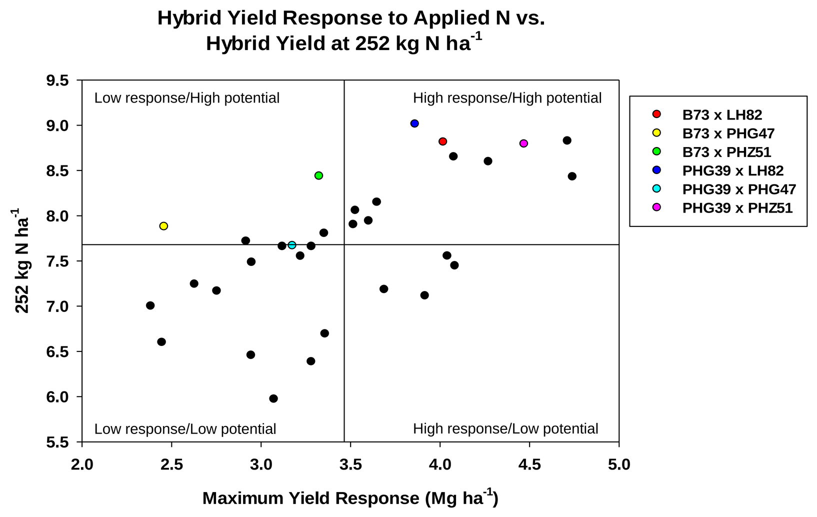

Figure 2: Grain yield at 252 kg N ha^{-1} versus maximum yield response to N. Each point represents an individual hybrid (n = 32). The colored points represent hybrids from the HG combinations that were used in previous examples. The vertical and horizontal lines represent the mean N response and maximum grain yield, respectively.

- Figure 2 demonstrates the general trend that higher yields are achieved through a greater response to applied N.
- Using the agronomic definition of N use efficiency (NUE; increase in yield per unit of applied N), hybrids with a large response are also more N use efficient. They can achieve greater yields with the same amount of N input.
- The next step in improving NUE is to identify component traits that can be improved.

- According to Table 6, B73 and PHG35 hybrids respond to N application by increasing kernel number and kernel weight, respectively.
- The complementary nature of combining HGs with contrasting yield component strategies is again shown in how the hybrids responded to applied N.

Table 6: Mean yield and yield component responses to applied N for the six discussed hybrids. (Quartiles were calculated with the other 26 hybrids in the data set)

Female	Male	Yield Response to Applied N (Mg ha^{-1})	Kernel Number Response (m^2)	Kernel Weight Response (mg)
B73	LH82	4.02	2075	0
B73	PHG47	2.46	1050	12
B73	PHZ51	3.33	1355	10
PHG39	LH82	3.86	1246	34
PHG39	PHG47	3.18	1073	21
PHG39	PHZ51	4.47	1189	45

Important notes:

- ❑ B73 hybrids seem to have an inability to add to their kernel weight.
- ❑ PHG39 x LH82 and PHG39 x PHZ51 both had a high response to N due to the hybrids' abilities to increase both kernel number and kernel weight.

Is There a Best Strategy for Future NUE Improvement?

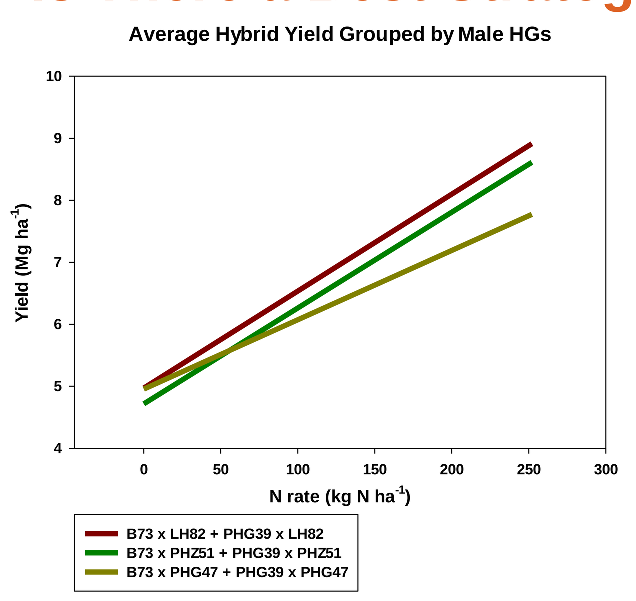

Figure 3: The yield for the six hybrids of discussion were averaged over their respective male HG for the 0 and 252 kg N ha^{-1} treatment levels.

- Figure 3 summarizes what we have identified as the best strategy for improving NUE based upon actual data.

1. Check plot yield: A high check plot yield is required to tolerate spatial and temporal losses of N (e.g., LH82 hybrids). On average, low check plot hybrids will still yield less even with ample N compared to high check plot hybrids (PHZ51 vs LH82 hybrids). A high check plot is also representative of greater N utilization. High check plot hybrids may be more efficient at acquiring and utilizing limited soil N.
2. N response: Increased NUE results from larger responses to applied N (e.g., LH82 hybrids).
3. Primary Yield Component: As illustrated in Figure 1 and Table 5, kernel number and kernel weight characteristics should be optimized for maximum yield and N use. Combining HGs that have complementary yield components is a promising strategy.

Is There a Benchmark Hybrid?

From this population, PHG39 x LH82 would be a suitable benchmark hybrid to use as a check hybrid in future NUE screening trials.

- The hybrid is formed from combining HGs with complementary yield component traits.
- It has a high check plot yield.
- It responds very well to applied N.
- These traits culminate with PHG39 x LH82 being the highest yielding hybrid in this trial.

It may be possible to improve NUE over the PHG39 x LH82 hybrid benchmark by identifying more modern germplasm from the SSSS/Amargo/Iodent and the Pioneer Hybrid 3558/Minn13 HGs in the most recently released Ex-PVP germplasm found on the GRIN website.

ANOVA Separation of Means:

Table 2: ANOVA table for grain yield at the different N rates. Data analyzed using PROC MIXED (SAS 9.3).

Yield (Mg ha^{-1})	Type	MSE	P value‡
N Rate (kg N ha^{-1})	Female	2.687272	0.0002
0	Male	1.990376	<0.0001
	Hybrid	0.701708	0.0216
252	Female	5.616756	0.0007
	Male	2.611127	0.0096
	Hybrid	0.993134	ns

- Due to only the male and female main effects being significant, the analysis indicates that GCA was more important at the 252 kg N ha^{-1} rate.
- The hybrid main effect showed a significant difference at the 0 kg N ha^{-1} level suggesting that SCA was the most influential factor.
- This indicates that there are significant differences between the HGs within the male and female heterotic pools.

Table 3. Significant differences between hybrids within the parental genotypes at the two different N rates and their minimum and maximum yields.

Parental Genotype	0 Kg N ha^{-1} Hybrid Yield Range (Mg ha-1) Min	Max	P Value	252 Kg N ha^{-1} Hybrid Yield Range (Mg ha-1) Min	Max	P Value
B73	3.07	6.38	**0.0409**	5.95	10.40	0.6155
LH1	2.30	4.89	**0.0037**	5.25	9.48	**0.0363**
PHG39	3.13	6.00	**0.0146**	5.94	10.01	0.1187
PHJ40	2.85	5.40	**0.0091**	5.72	9.58	0.1829
LH123HT	2.79	5.64	**0.0206**	5.72	10.40	**0.0408**
LH82	3.76	6.00	0.2267	5.77	9.91	**0.0083**
Mo17	2.85	4.72	0.0635	5.94	9.05	0.3034
PH207	3.05	5.18	0.0727	5.94	8.50	0.3108
PHG35	2.48	5.88	**0.0018**	5.25	8.71	0.0973
PHG47	4.05	6.38	0.1553	6.42	8.78	0.7024
PHG84	2.30	5.40	0.0579	5.75	9.82	0.1518
PHZ51	3.69	5.32	0.3309	6.77	10.01	0.8036

- The significant differences found within each of the female HGs indicates that there are significant differences in SCA within every HG.
- This indicates that there is more genetic variation within the male side of the heterotic pattern than on the female side.
- There is also greater yield variability at the higher N rate due to environmental influences, which leads to an inability to separate means based on genetic potential.

Conclusions:

- Differences in the average parental performance (GCA) can be detected at every N level, but individual hybrid (SCA) performance is of greater importance at low N levels (Table 2).
- Based on the various GCA estimations, there was less changing of rank and more significant differences between the male lines when compared to the female lines suggesting that there is less genetic variation found within the female HGs than within the male HGs (Table 3).
- Yield and yield components are relatively heritable at low N (Table 5).
- There is a generally positive trend in the relationship between check plot yield and maximum yield (Figure 1).
- The hybrids with the largest N responses simultaneously increased kernel number and kernel weight (Figure 2 and Table 6).
- Focusing on these key aspects, breeders should focus on increased yield at low N, as well as optimizing kernel number and kernel weight responses to N. Greater genetic variation for these traits may be present in male HG germplasm.
- Lastly, hybrids with these ideal characteristics are already in the market. Now the goal is to improve them beyond their current state.