Genetic Gain Via Nitrogen Interaction in Soybeans

Yield increases recorded in studies at U.S. and Argentina Sites.

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Summary: *The overall goal of this ongoing research is to study the contribution of different nitrogen (N) sources in high yielding soybean systems using diverse germplasm and production practices. Closing yield gaps (actual on-farm yield vs. genetic yield potential) in a long-term perspective will require an improvement in the use of the available resources, which must be attained via implementation of better management decisions. Soybean yield improvement (1980s vs. 2010s) represented 30% for sites located in the US and Argentina. Seed N content followed similar trends as yields, highest seed N content observed for 2010s genotypes, represented a 25% gain. Yield response to N fertilizer was observed in both locations, up to 20% increase in the US and 5% in Argentina. For the US, N fertilization increased protein concentration by 1.3% relative to only inoculated soybeans. In synthesis, N limitation impacted not only on seed yield but also on protein concentration for soybean production systems.*

The United States (US) and Argentina (ARG) account for more than 50 percent of the global soybean production (USDA 2016). In the US, more than 85% of the soybean area is located in the Corn Belt region, where corn-soybean rotation (>60 percent) is the main cropping system. In Argentina, soybeans are primarily planted in the Rolling Pampas and Chaco regions, under rain-fed conditions, as monoculture or in rotation with corn.

Soybean yield potential is genetically determined. Yield potential (Yp) can be attained under "ideal" conditions (genotype × environment × management practices, G × E × M), assuming no limitations of water and nutrient supply and absence of biotic and abiotic yield limiting factors (e.g., insects, diseases, etc.). Yield gaps between Yp and actual on-farm yield (YA) are primarily defined by crop management practices (e.g., row spacing, planting date, fungicide, and nutrient application, among others) and the interactions of those with the E (soil and weather factor). Maximum soybean yields are dependent on a balanced nutrition, with N nutrition as the main nutrient limiting soybean yields and seed quality (Ciampitti et al., 2016).

Interaction between soybean genotypes and fertilizer N response is not yet well understood. Rowntree et al. (2013) documented an annual genetic U.S. soybean yield gain of approximately 25 kg ha^{-1} for maturity group (MG) III released from 1920's to 2,000's when planted around May. Previously reported soybean yield gain was achieved in detriment of the protein concentration (Rowntree et al. 2013). Thus, it is valid to hypothesize that high yielding soybeans will need higher nutrient demand to sustain protein levels.

Soybean plants have the capacity of fixing N from the atmosphere. Biological N fixation (BNF) is the result of the conversion of atmospheric N2 into ammonia (NH_3), and later on into N-containing organic components that will become available to the plant (Wright & Lenssen, 2013). However, it had been documented that BNF process is not able to supply the total N requirement of the plant. Overall, only 50 to 60% of soybean N demand is usually met by the BNF process (Salvagiotti et al., 2008). An unanswered scientific knowledge is still related to the ability of the BNF process to satisfy soybean N demand at varying yield levels.

In summary, for the genotype × N interaction, the main question is "do high yielding soybeans need to be fertilized with N?" The understanding of genetic gain × N under high yield potential is a critical factor for advancing soybean yield improvement.

Objectives

The objectives of this study were to:

- Evaluate the yield performance and seed N content of historical and modern soybean genotypes released from the 1980s to 2010s
- Study the contribution of N in soybeans under different N nutrition scenarios: 1) soybeans planted under normal production conditions - only inoculated-, 2) all N requirements met by N fertilizer, and 3) inoculated with an additional N rate applied in reproductive stages.

Methodology

Sites. A total of 4 sites were evaluated during the 2016 growing season in Ottawa (East Central KS), Ashland Bottoms and Rossville (Central KS) in the United States (US), and Oliveros (Santa Fe province) in Argentina (ARG) (Figure 1).

Experimental design. The study was conducted on experimental plots with 10 ft. wide by 50 ft. long at Ottawa (Figure 2) and Ashland (US), and 10 ft. by 30 ft. long at Rossville (US). Target seeding rate was 140,000 seeds per acre at Ottawa, 180,000 seeds per acre at Ashland, and 103,000 seeds per acre at Rossville. At Oliveros (ARG), experimental plots were 8.5 ft wide and 23 ft long and seeding rate was 146,000 seeds per acre.

Site characteristics. Soil samples were collected before planting at 6 and 24-inch depth for US locations (Ottawa, Ashland, and Rossville). Parameters analyzed from these samples collected at 6-inch depth were pH; Mehlich-P; cation exchange capacity (CEC); organic matter (OM); Ca, Mg, and K availability; and for the soil samples at 24-inch soil depth, only N-nitrate (N-NO_3) concentration. In Oliveros (ARG), all soil samples were collected at 8-inch soil depth, parameters analyzed were pH, Bray P1, OM, and N-NO_3 (Table 1).

Fertilizer applications. The fertilizer applications were performed using fluid urea ammonium nitrate (UAN at 32-0-0) at all sites as needed per each treatment combination. The three N strategies were the same at all locations. Strategy 1 (S1) was the common practice (control) with no N applied, only inoculated; strategy 2 (S2) all N was provided by fertilizer at a rate of 600 lbs. N ac^{-1}, equally split in 3 timings: planting, R1 and R3; and finally

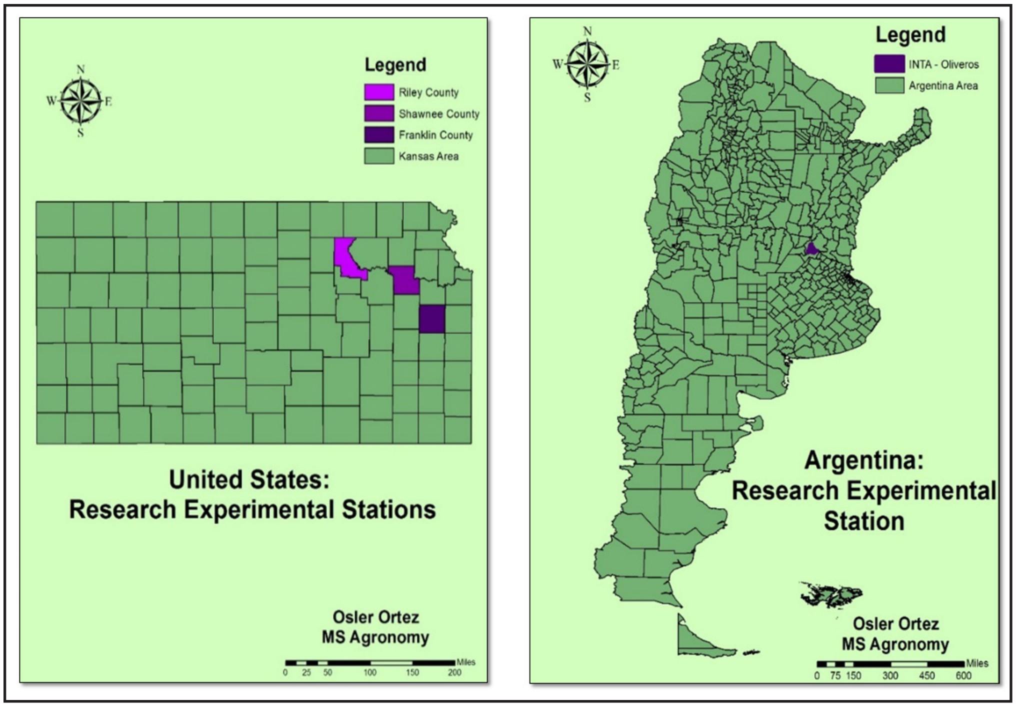

Figure 1. Map of the state of Kansas and Argentina highlighting all four sites conducted during 2016 growing season: Ottawa (Franklin Co., KS), Ashland (Riley Co., KS) and Rossville (Shawnee Co., KS) in US (left panel) and Oliveros (Santa Fe province) in ARG (right panel).

Figure 2. Experimental plots in Ottawa, Kansas 2016. No soybean history was recorded at this location for the past 20 years, 4 rows of corn non-N-fertilized were planted on the side as the check for the biological N fixation (BNF) determination.

Table 1. Pre-plant soil characterization for all sites in US and Argentina.

Soil parameters	Location			
	Ashland	Ottawa	Rossville	Argentina
pH	6.7	5.7	6.9	5.5
Mehlich P/Bray P1 (ppm)	22.0	14.0	21.0	12.0
CEC (meq/100g)	9.0	18.5	11.0	-
OM (%)	1.5	4.3	2.2	2.1
K (ppm)	181	80	153	-
Ca (ppm)	1599	2665	2074	-
Mg (ppm)	179	393	202	-
N-NO_3 (ppm)	2.5	5.0	3.0	6.3

Table 2. Genotypes and decade of release for all sites in US and Argentina.

Location	Decade of release	Cultivar
Ottawa and Ashland US	1990	P39B82
	2000	93Y92
	2010	P34T43R2
Rossville US	1980	P3981, Williams 82 and 9391
	1990	9392 and 93B82
	2000	93Y92, 93B67 and 93M90
	2010	P34T43R2, P35T58R, P39T67R, 94Y23 and P31T11R
Oliveros ARG	1980	A4422 and Williams
	1990	A3910 and DM49
	2000	DM3700 and DM4800
	2010	NS4955 and SRM3988

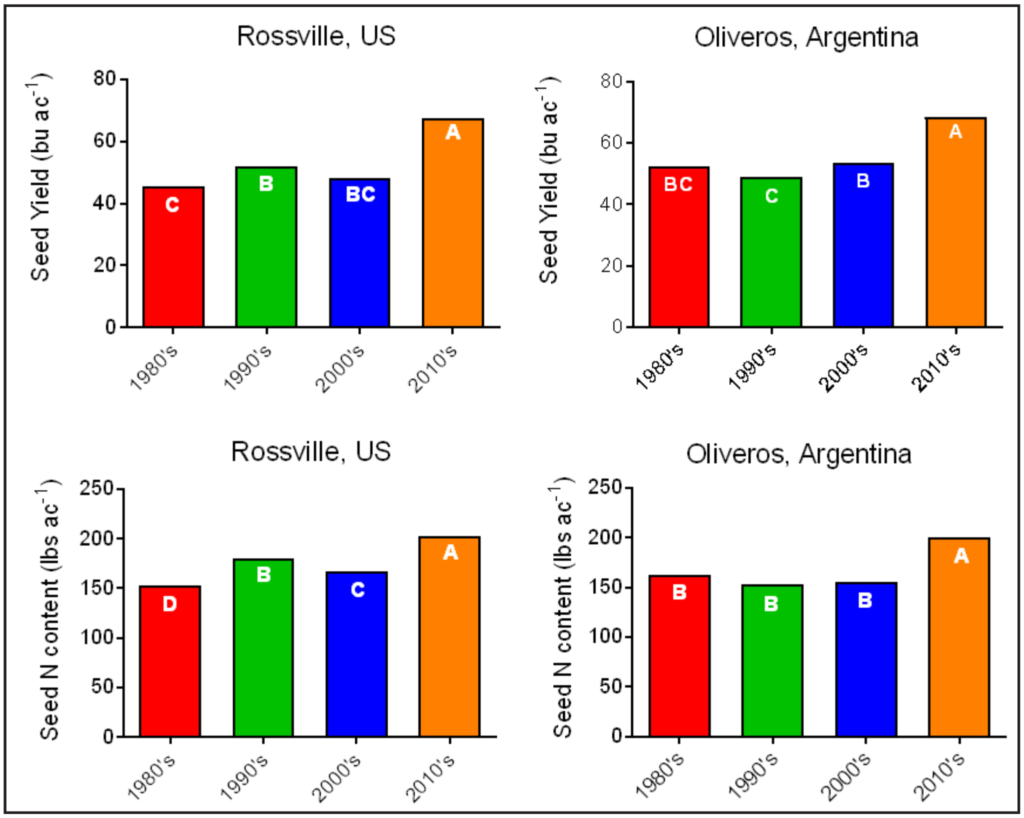

Figure 3. Genetic improvement for soybean genotypes, for yield (upper panels) and seed N content changes (lower panels) for 21 genotypes tested (1980's, 1990's, 2000's and 2010's) at Rossville (US) and Oliveros (ARG) during the 2016 growing season. Means followed by the same letter are not significantly different ($P \leq 0.05$).

strategy 3 (S3) with a late season N application of 50 lbs. N ac^{-1} at R3 stage in US and R4 in Argentina.

Genotypes. Twenty-one different genotypes were used during the 2016 growing season, 13 for US and 8 for ARG. Genotype-release-decades ranged from 1980's to 2010's (Table 2). Maturity groups (MGs) ranged between 3-4 at all sites and all seeds were inoculated at commercial rate before planting.

Results

Weather information. Seasonal precipitation, maximum (max) and minimum (min) temperatures and solar radiation values were documented throughout the entire 2016 growing season at all sites. In the US, similar mean temperatures were observed with max of 91, 87, and 89°F and min of 46, 47, and 44°F for Ashland, Ottawa, and Rossville, respectively. Cumulative precipitation was higher in the high yielding environments (Ashland and Rossville) with 28 and 32 inches compared to the low yielding environment (Ottawa) with 21 inches. In Oliveros, maximum temperatures were close to those in the US at 90°F but minimum temperatures were higher at 63°F. Cumulative precipitation was similar to the US high yield environments, totaling 27 inches. Solar radiation indexes were similar across locations with 82, 76, and 83 × 1,000 cumulative Langley's (Ly), except at Ottawa with 58,000 Ly.

Nodulation. Nodule counts were compiled for Ottawa and Ashland (US locations) during the 2016 growing season. Roots were collected at V4 stage and results were expressed in nodules per plant. Nitrogen strategies showed statistical effects ($P \leq 0.05$) for this trait. Overall, Ashland presented a higher number of nodules per plant (17) than Ottawa (11) (a site without soybean history for the last 20 years). As expected, S2 resulted with the lowest number of nodules per plant at both locations (5-6 nodules per plant at Ottawa and Ashland).

Genetic gain. Twenty-one soybean genotypes from different releases were used in this experiment. Results in this article will be focused on Rossville (US) and Oliveros (Argentina). Seed yields ranged from 46 to 68 bu ac^{-1} at Rossville and from 49 to 68 bu ac^{-1} at Oliveros. Superior yields were observed for modern soybean genotypes (2010's) at both Rossville and Oliveros, while lower yields for genotypes released in the 1980's and 1990's (Figure 3 upper

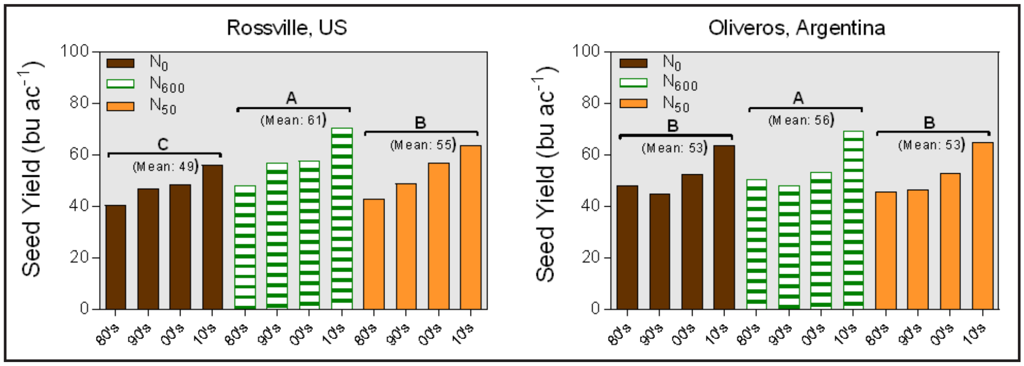

Figure 4. Seed yield for soybean genotypes released from 1980's to 2010's evaluated under three fertilizer N strategies at Rossville (US) and Oliveros (ARG) during the 2016 growing season. Means followed by different letter are significantly different ($P \leq 0.05$).

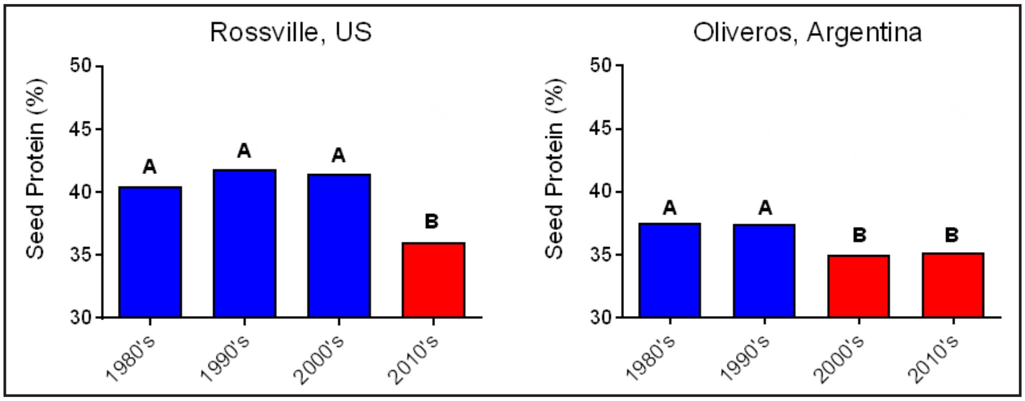

Figure 5. Seed protein (%) changes for 21 soybean genotypes grouped in four release decades at Rossville (US) and Oliveros (ARG) during the 2016 growing season. Means followed by the same letter are not significantly different ($P \leq 0.05$).

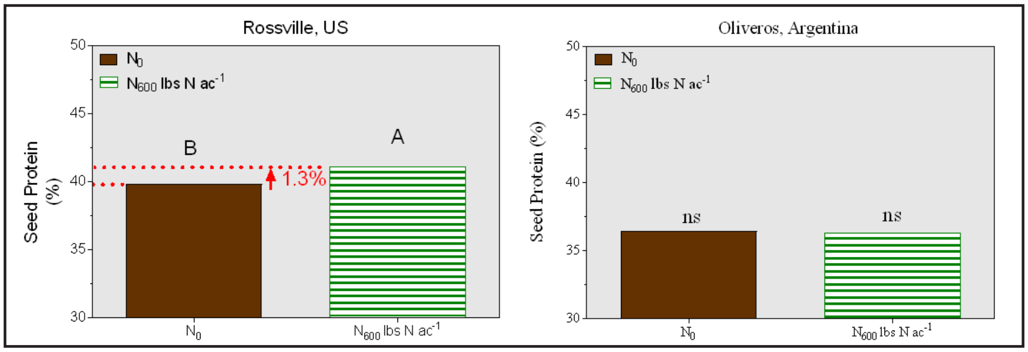

Figure 6. Effect of fertilizer N application (zero-N versus 600 lbs N ac-1 applied) on seed protein (%) for 21 genotypes at Rossville (US) and Oliveros (ARG) during the 2016 growing season. Means followed by different letter are significantly different ($P \leq 0.05$).

section). Yield improvement represented 33% yield gain at Rossville and 28% at Oliveros, comparing historical versus 2010 genotypes. Regarding seed N content, results ranged from 153 to 203 lbs. N ac^{-1} at Rossville and 153 to 200 lbs. N ac^{-1} at Oliveros (Figure 3, lower section). Seed N content followed a similar fashion as portrayed by yield trait, superior seed N content for modern soybean genotypes (2010s). Historical N content changes showed comparable gain, 25% and 24% increase at Rossville and Oliveros, comparing historical versus 2010's genotypes.

Nitrogen response. Yield response to fertilizer N application was recorded at both Rossville and Oliveros ($P \leq 0.05$). The S2 (600 lbs. N ac^{-1}) increased seed yields 20% at Rossville and 5% at Oliveros, relative to S1 treatment (Figure 4). At Rossville, S2 yielded better than S3, with the lowest yield documented for S1. At Oliveros, S2 yielded higher than S1 and S3 compared to S1 and S2 and did not statistically differ for the yield parameter. Yield response to N fertilization (600 and 50 lbs. N ac^{-1}) was consistent across genotypes, implying an important role of N fertilization in addressing soybean nutrient demand at different yield levels.

Protein levels. Historical protein concentration levels in seeds ranged from 36 to 42% at Rossville and 35 to 38% at Oliveros. Protein concentration was negatively affected as yield improved, with lower protein levels observed for the 2000 and 2010 genotypes (Figure 5). A decrease of approximately 5.8% in protein concentration was recorded at Rossville site when comparing 2010 versus the rest of the genotypes tested. At Oliveros, a similar comparison resulted only in a decrease in protein concentration of 2.4%.

When looking at N effect in protein levels in seed, N application showed a statistical effect ($P \leq 0.05$) only at Rossville (Figure 6). Regardless of genotypes and release decades, an increase of 1.3% of protein in seed was observed with the S2 (600 lbs. N ac^{-1}) treatment at this location.

Summing up

Soybean yield improvement represented 33% at Rossville (US) and 28% at Oliveros (ARG) when comparing historical and modern 2010 genotypes.

Seed N content followed a similar trend as yields and highest seed N content were observed for 2010 genotypes, representing a 25% gain at Rossville and 24% at Oliveros.

Yield response to N fertilization was observed at both Rossville and Oliveros, with S2 (600 lbs. N ac=1) increasing yields 20% at Rossville and 5% at Oliveros.

A tradeoff was documented for yield and protein, with protein concentration negatively impacted as yields improved. Overall decrease in protein concentrations of 5.8% at Rossville and 2.4 % at Oliveros were documented in this study.

At Rossville, S2 treatment improved protein levels, with protein concentration increasing 1.3% relative to the S1 treatment (only inoculated).

Nitrogen limitation impacted not only on seed yield but also protein concentration for soybean production systems.

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