High Yielding Soybean: Genetic Gain and Nitrogen Limitation

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Summary

The United States and Argentina account for more than 50% of the global soybean production. Closing yield gaps (actual on-farm yield vs. genetic yield potential) would require an improvement in the use of the available resources. Overall, 50-60% of soybean nitrogen (N) demand is usually met by the biological nitrogen fixation (BNF) process. A scientific knowledge gap still exists related to the ability of the BNF process to satisfy soybean N demand at varying yield levels. The overall objective of this project is to study the contribution of N via utilization of varying N strategies under historical and modern soybean genotypes. Two field experiments were conducted during the 2016-2017 growing seasons: Rossville, KS (US) and Oliveros, Santa Fe (ARG). However, this report focuses on the 2016 results. Twenty-one historical and modern soybean genotypes were utilized with release decades between 1980s and 2010s. All seeds were inoculated and tested under three N management strategies: S1, non-N applied; S2, all N provided by fertilizer; and S3, late-N applied. The genetic improvement of soybean yield from the 1980s to 2010s was an overall increase of 30%, averaging results from US and ARG. Seed N content (N exported in seed) followed a similar trend for yield, while N concentration in seed was decreased as yields increased. Regarding N management for genotypes from all release decades, S2 (all N provided by fertilizer) generated up to a 20% increase in yields in the US and 5% in ARG. These results suggest that high yielding soybeans could be limited by N under specific growing conditions to express the yield potential.

Introduction

The United States (US) and Argentina (ARG) account for more than 50% of the global soybean production. In the US, more than 85% of the soybean area is located in the Corn Belt region, where corn-soybean rotation (>60%) is the main cropping system. In ARG, soybeans are primarily planted in the Rolling Pampas and Chaco regions, under rain-fed conditions, as monoculture, and in a lesser proportion in rotation with wheat and 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. Maximum soybean yields are dependent on a balanced nutrition, with N as one of the limitations for increasing soybean yields.

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The main N sources for the soybean plant are the BNF process and the soil (mineral or fertilizer). However, it has been documented that the 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. In this sense, the ability of the BNF process to supply N to high yield levels is still unknown.

Genetic improvement for soybeans has increased yields in the last 50 years, however, it has been achieved at the expense of the availability of N provided by the soil and the BNF process. If there is a limitation of N, the interaction between genotypes and limitation by N is not yet known. Therefore, it is valid to hypothesize that high-yielding soybean achieved through the process of genetic improvement will require a greater availability of N.

The objectives of this study were to:

1. Evaluate the yield performance and seed N content of historical and modern soybean genotypes released from the 1980s to 2010s.
2. Study the contribution of N under different N nutrition scenarios:
    a. Soybeans planted under normal production conditions, only inoculated;
    b. All N requirement met by N fertilization; and
    c. Inoculated but including an additional application of fertilizer N in reproductive stages.

Procedures

Experimental Sites

The project was conducted in two sites during the 2016-2017 growing seasons: Rossville (Kansas, US) and Oliveros (Santa Fe, Argentina). The current report focuses on the 2016 results.

Experimental Plots

The trials were conducted in experimental plots of 10-ft wide × 30-ft long with a seeding rate of 103,000 seeds/a at Rossville, (US). In Oliveros (ARG), the area of the plots was 8.5-ft wide × 23-ft long and with a seeding rate of 146,000 seeds/a.

Site Characteristics

Soil samples were collected before planting at 6- and 24-in. depths in the US. Parameters analyzed from samples collected at 6-in. depth were pH; Mehlich-P; cation exchange capacity (CEC); organic matter (OM); calcium, magnesium, and potassium availability; and for the soil samples at 24-in. depth, only N-nitrate (N-NO_3) concentration was evaluated. In ARG, all soil samples were collected at an 8-in. depth, parameters analyzed were pH, Bray P-1, OM, and N-NO_3 (Table 1).

Treatments

The treatments evaluated were a combination of three N strategies combined with soybean genotypes from different release decades. The N strategies were: strategy 1 (S1): Non-N as traditional management (control) without application of N, only inoculation; strategy 2 (S2): Full-N with all the N required by the plant was applied as fertilizer (600 lb N/a), the total amount was equally distributed at three times during the growing season: planting, flowering (R1), and pod formation (R3-R4); and strategy 3 (S3): Late-N with a late application of 50 lb N/a at the R3 in Rossville, and at R4 growth stage in Oliveros. Applications were top-dressed to the soil using drop tubes with the liquid source of urea-ammonium nitrate (UAN, 32-0-0). Twenty-one genotypes were evaluated in total with release decades between the 1980s to 2010s. The maturity groups ranged from 3.0 to 4.0 for these two locations. Prior to sowing, all seeds were inoculated with recommended commercial rate.

Results

Yield Gain and Nitrogen Content in Seed as Related to Release Decades

The factors evaluated in this study did not show a statistical significant interaction ($P \leq 0.05$) for any of the evaluated variables, so the results are described according to the main factors–N fertilization and genotypes.

In Rossville (US), seed yields ranged from 33 to 76 bu/a and at Oliveros (ARG) from 40 to 70 bu/a (Figure 2, A and B). In both sites, the modern genotypes released in the 2010 decade recorded the highest production levels compared to those released in the previous decades (1980s, 1990s, and 2000s). When comparing the average yield across all three fertilization strategies for the modern versus the older varieties, yield increased by 33% in Rossville and by 28% in Oliveros.

Regarding the N exported in seeds, the results ranged between 111 and 240 lb N/a in Rossville and 129 to 209 lb N/a in Oliveros (Figure 2, C and D). Nitrogen exported in the seed followed a similar fashion as portrayed by the yield trait, with the largest amount of N removed by the modern genotypes (2010s). An increase of 25% in Rossville and 24% in Oliveros was observed in the N export, when comparing general means of the 2010 decade to the rest and as a general average of the three fertilization treatments.

Nitrogen concentration levels in the seed (as a function of its dry basis) for both locations, as an average for the genotypes grouped according to release decades, and as a general mean of the three fertilization strategies are presented in Figure 2, E and F. In Rossville, seed N concentration ranged between 5.5 and 7.2%. Greater seed N concentration was observed with the genotypes of the 1980s, 1990s and 2000s; while the lowest level was observed with genotypes of the 2010 release decade. For Oliveros, seed N concentration was lower than that observed in Rossville and ranged between 5.1 and 6.4%. The lowest level of seed N concentration was found with the genotypes of the 2000 and 2010 decades.

Yield Gain and Nitrogen Content in Seed as Related to Nitrogen Availability

In general, when averaging the genotypes of all four release decades, the greater availability of N in the cycle through the sequential addition of 600 lb of N/a presented a positive impact on yields in both Rossville and Oliveros ($P \leq 0.05$) locations (Figure 3). In Rossville, the S2 (Full-N, 600 lb) increased seed yield by 20% as compared to S1 (without N fertilization, control). The descending order of yielding results in Rossville was recorded as follows: S2 (Full-N) >> S3 (Late-N) >> S1 (Non-N), with S1 being the strategy that produced the lowest yield levels in this environment. In Oliveros, the positive response in yields to the S2 strategy was 5% increase in yields when compared to the S1 and S3. For this site, S1 and S3 did not result in significant differences between them. In general terms, yield response to full N fertilization was consistent throughout all evaluated genotypes, this indicates the potential N limitation to satisfy plant nutrient demand at both medium (> 45 bu/a) and high (> 67 bu/a) yield levels.

In conclusion, increases in seed yield were documented when comparing the progress of historical genotypes (1980s) to modern genotypes (2010s) in Rossville (+33%) and Oliveros (+28%). Although the seed N concentration with modern genotypes was lower in Rossville and Oliveros (12 and 5%, respectively), the export of N (via seed N removal) per unit area increased (25% in Rossville and 24% in Oliveros), with the increase primarily related to yield improvement. The response of seed yield to the N application, when comparing the extreme conditions of Full-N (without limitation of N) versus the Non-N (control) varied between 20% (Rossville) to 5% (Oliveros). The N strategy utilized in this experiment (i.e. distributed application of a high fertilizer N rate) should help to determine whether the availability of N is a limiting factor at varying yielding conditions in soybean.

Table 1. Soil characterization before planting for the 2016 growing season

	Location	
Soil variable	Rossville, United States	Oliveros, Argentina
pH	6.9	5.5
P Mehlich-3/P Bray-1 (ppm)	21.0	12.0
CEC (meq/100 g)	11.0	---
Organic matter (%)	2.2	2.1
Potassium (ppm)	153	---
Calcium (ppm)	2074	---
Magnesium (ppm)	202	---
$N\text{-}NO_3$ (ppm)	3.0	6.3

CEC = cation exchange capacity.

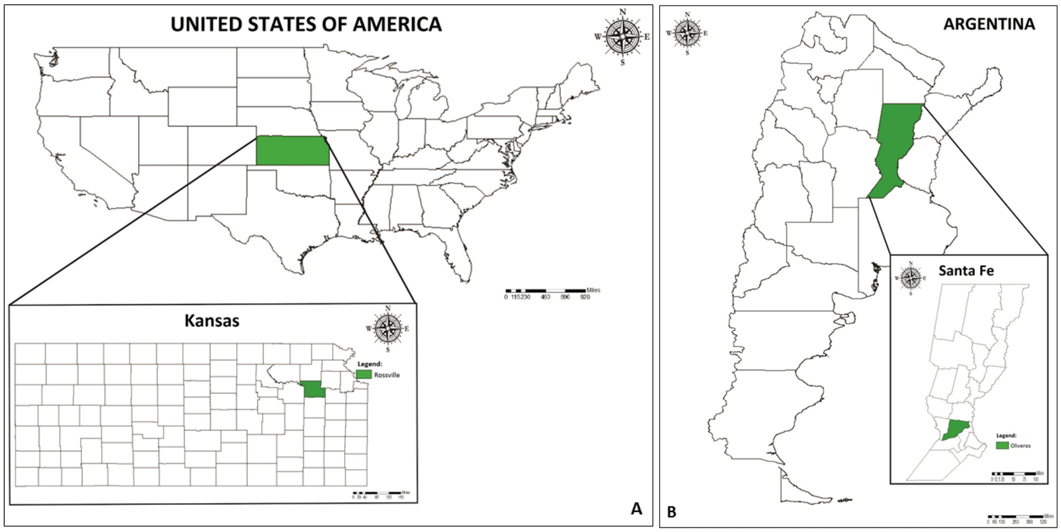

Figure 1. Map highlighting the two sites where the experiment was conducted during 2016-2017 growing seasons: Rossville (Kansas, US) (A) and Oliveros (Santa Fe, ARG) (B).

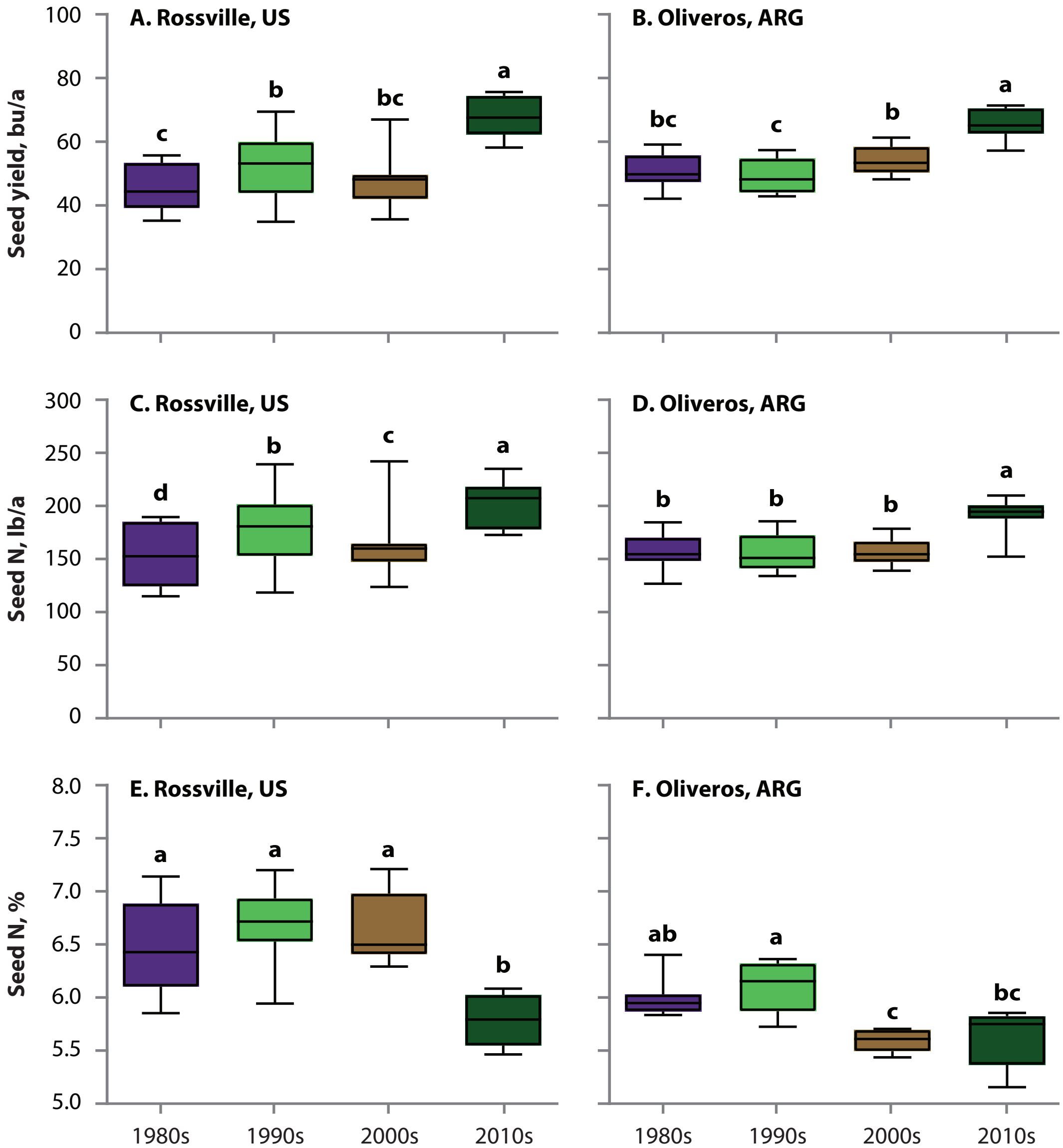

Figure 2. Soybean yield expressed in bushels/a at 13.5% moisture content (A and B), nitrogen (N) exported in seed in lb/a on dry basis (C and D) and N concentration in the seed expressed as a percentage with dry basis (E and F). Different letters indicate significant differences between decades ($P \leq 0.05$).

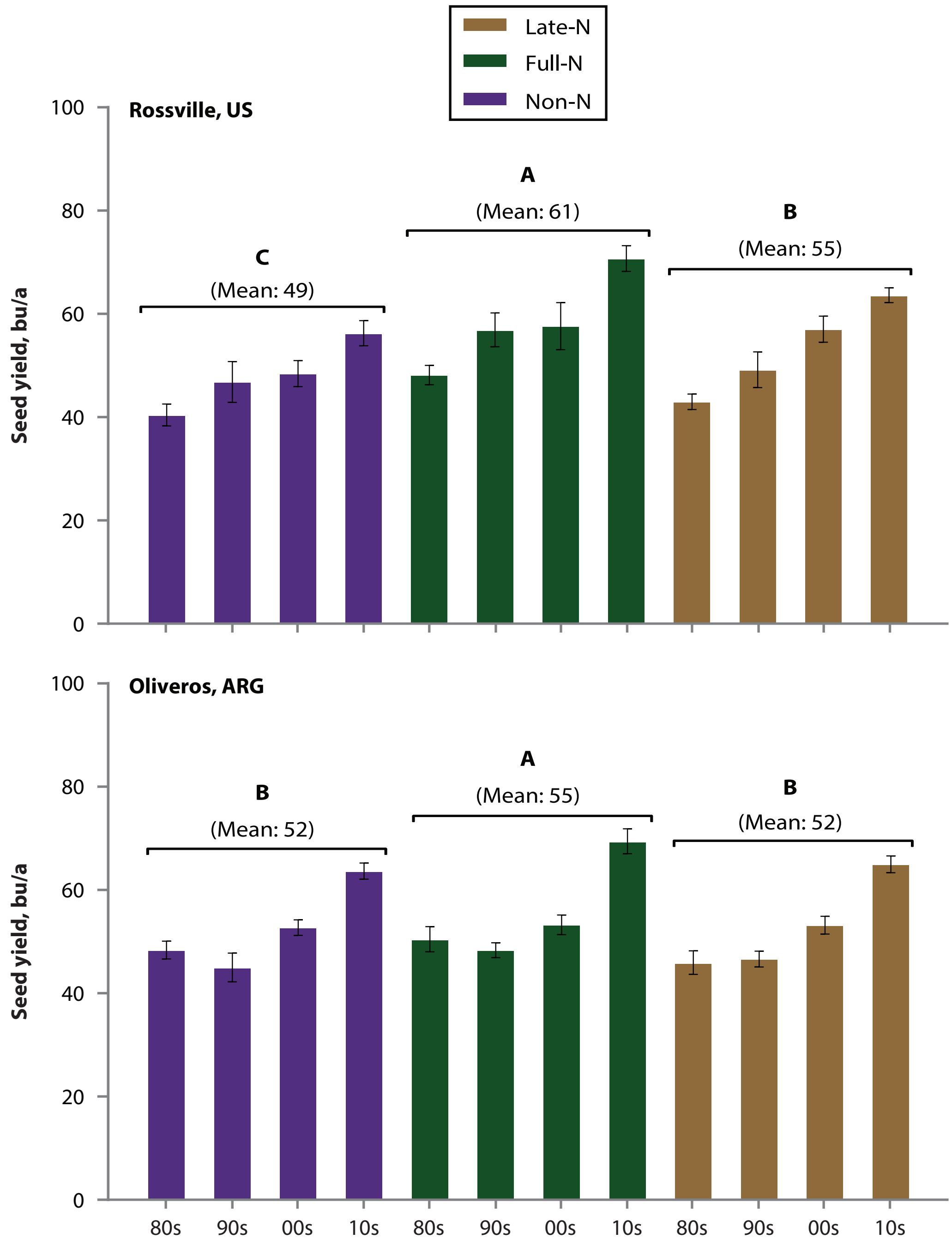

Figure 3. Yield expressed in bushels/a at 13.5% moisture content in soybeans for genotypes released between the 1980s to 2010s and under three management strategies of nitrogen (N) 1) Non-N without N applied; 2) Full-N with 600 lb N/a, and 3) 50 lb N/a applied in the R3 stage at Rossville (US) and R4 stage at Oliveros (ARG) in the 2016 growing season. Different letters indicate significant differences between management strategies of N ($P \leq 0.05$) as general means when pulling together the release decades.