CAN FERTILIZER NITROGEN APPLICATIONS INCREASE PRODUCTIVITY OF SOYBEAN

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PRIMARY RESEARCH OBJECTIVE

Identify the best fertilizer source and the best time of application time to increase soybean yield with nitrogen fertilization.

BACKGROUND

Soybean [*Glycine max* (L.) Merr.] has largely been thought of as a rotational crop, which has lead to the crop being highly undermanaged. Although plant breeding has continued to improve the yield potential of soybean, current production practices have not kept up and are likely inadequate for optimal productivity, especially with regard to crop nutrition. Historically, it has been assumed that soybeans obtain their entire nitrogen (N) requirement via the nodules and biological N fixation, and that they produce excess N that can be used by the subsequent corn crop. However, recent findings suggest that soybean is only able to fix about half of its total N requirement (Salvagiotti et al., 2008 Field Crop Res. 108:1-13), with the remainder having to come from either mineralization of soil organic matter, residual N fertilizer left over from the previous corn crop, or from N fertilizer applied specifically for the soybean crop. Evaluating the soybean yield response to N fertilizer source will help develop a better understanding of N use and demand by soybean, while factoring in N fixation capability, soil supply, yield, and weather as a basis for developing N fertilizer recommendations for high yielding soybean.

RESEARCH METHODOLOGY

The experiment was conducted at three different locations in Illinois is 2015. In all cases corn was the previous crop and the conventional tillage was used. The HiSoy soybean varieties 31A32, 39A42, and 42A12 were selected based on maturity group for each location and planted in DeKalb, Champaign, and Harrisburg on May 21st, 23rd, and 3rd, respectively. Seed was planted to target a final population of 160,000 plants per acre^{-1} for all locations. The sites have been managed to be weed and disease-free, and are well suited for agricultural research. The drainage and topography of each site are optimal with P and K soil test levels in the adequate range, and with the appropriate soil pH and good water holding capacity. The plots were four rows wide, 36 feet in length with 30 inch row spacing. The two middle rows received the full N treatments and were harvested for yield, yield components and grain quality. The outer two rows were used to provide a border. The treatments were arranged in a randomized complete block design and replicated six times at each location. The trials were harvested on October 16th in DeKalb, on November 10th in Champaign, and on October 2nd in Harrisburg.

Nitrogen Applications

The seven N sources evaluated were: Ammonium Nitrate (AN, 34-0-0); Ammonium Sulfate (AMS, 21-0-0-24S); liquid Urea Ammonium Nitrate (UAN, 28-0-0); Urea (46-0-0); ESN (44-0-0, controlled release urea, Agrium U.S., Inc., Denver, Colorado); Limus Urea (contains the urease inhibitor Limus, BASF, Florham Park, New Jersey); and a mixture of Ammonium Nitrate + Potassium Nitrate + Ammonium Sulfate (30-0-7-2S); along with an unfertilized control. Each source was applied at four stages during soybean growth (preplant, V3, R1, and R3) (Table 1). The granular sources were broadcast applied by hand and not incorporated, while the liquid UAN source was applied using the bottle method by dripping the UAN + water mixture down the center between the rows. All sources were applied at 100 pounds of N per acre.

RESULTS

Pre-Planting Soil Test Results

Soil test levels determined prior to planting showed that all sites had adequate P and K fertility, but differed in their organic matter and residual nitrate (Table 2), suggesting the possibility for different responses to fertilizer applied N.

Weather Conditions

The 2015 soybean production year experienced near average temperatures, but above average Spring precipitation at all sites (Table 3). The entire state of Illinois experienced a record amount of precipitation in June (records dating back to 1886), and this was especially evident at Champaign, which received 8.4 inches of precipitation compared to the 30-year average of only 4.3 inches, and DeKalb which received 8.2 inches compared to an average of 4.1. However, following the above average precipitation in June, all sites experienced below average precipitation for July and August, and DeKalb was distinctly cooler than average for all months (Table 3).

Yield Results

Averaged across all three locations, yield of the control (unfertilized) treatments was 71.7 bu $acre^{-1}$ (Table 4). When averaged over the three locations, all fertilizer sources applied at all application times significantly increased yield except for AMS applied preplant and at V3, urea applied preplant, ESN applied at V3, and the mixture of AN, KN and AMS applied at preplant and at V3 (Tables 4 and 5). In no instance did any N source applied at any time decrease yield (Tables 4 and 5). Among the various N sources, AN resulted in the greatest yield increases (range of 4.0 to 5.7 bushels $acre^{-1}$) followed by UAN (range of 3.1 to 4.1 bushels $acre^{-1}$), where both sources significantly increased yield at all application times. All the N sources increased yield when applied at the R1 or R3 growth stages.

When examining the individual locations, variation in N source and the application time that gave the greatest increase was evident, suggesting that soil and weather conditions play a large role in the response of the individual N sources (Table 6). In DeKalb, applications of AN, Limus Urea, and AN+KN+AMS at the R1 growth stage led to yield increases greater than 11 bu $acre^{-1}$, while in Champaign, applications of AN, AMS, Urea, Limus Urea, and AN+KN+AMS at the R3 growth stage resulted in yield increases of 5.2 to 7.9 bu $acre^{-1}$ (Table 6). In Harrisburg, applications of AN, AMS, UAN, ESN, Limus Urea, and AN+KN+AMS at the R3 growth stage resulted in a 4.7 to 8.4 bu $acre^{-1}$ yield increase (Table 6).

Based on the yield results from the 2015 growing season, the late-season application of N (specifically during the R1 and R3 soybean growth stages) produced the greatest yield response. However, substantial yield increases depending upon a given location, N source, and/or application time suggests that certain N sources may respond better to certain soil types and environmental conditions, and offers an opportunity to fine-tune the N applications to increase soybean yield. The greater response from reproductive-stage applications may be due to the abundant precipitation during vegetative growth at all locations in 2015, and potentially could mean that earlier N applications may be more effective in other years.

Yield Components and Seed Compositions

Yield components (seed number and individual seed weight) were influenced by the N sources, the timing of N application, and the location (Tables 7 and 8). Although both seed number and seed weight were enhanced by the addition of fertilizer N, yield increases resulting from N fertilization tended to be more closely associated with increases in seed weight then seed number. For example, the large yield increases observed from N fertilization in DeKalb (Table 6) were primarily due to increases in seed weight (Table 8), and surprisingly were mainly associated with the vegetative (preplant and V3) and the early reproductive (R1) applications. Other large yield increases observed from R3 fertilizer applications in Champaign and Harrisburg were also primarily the result of heavier individual seed weighs (Tables 6 and 8). Similar to grain yield, none of N fertilizer additions decreased seed number or seed weight (Tables 7 and 8).

In general, N application did not affect grain quality, except for the R3 application at Harrisburg where most N sources resulted in higher concentrations of oil (Tables 9 and 10). There were sporadic increases in grain oil at the other locations when N was applied at R1 or R3, but in no instance did N applied preplant or at V3 alter oil (Table 9). Conversely, while also sporadic, N-induced increases in grain protein concentration tended to be more associated with early N applications, especially at Harrisburg where ESN and Limus Urea applied prelant and urea and Limus Urea applied at V3 increased grain protein concentration (Table 10).

Table 1. Dates of the N source applications for each of the three Illinois locations in 2015.

	Soybean growth stage at time of N application			
Location	**Preplant**	**V3**	**R1**	**R3**
DeKalb	**May 21st**	**June 26th**	**July 9th**	**July 30th**
Champaign	**May 22nd**	**June 22nd**	**July 2nd**	**July 23rd**
Harrisburg	**May 2nd**	**June 9th**	**June 25th**	**July 11th**

Table 2. Pre-planting soil properties (0-6 inches) at three Illinois locations used to evaluate the response of soybean to fertilizer applied N in 2015. Values are the average of six replications at each location.

Location	Soil Series	OM	CEC	pH	NO_3^-	NH_4^+	P	K	Ca	Mg
		%	meq $100g^{-1}$		----------------------		ppm		-------------------	
DeKalb	**Flanagan-Drummer**	**4.5**	**21**	**6.3**	**18**	**3.8**	**18**	**111**	**2692**	**722**
Champaign	**Flanagan-Drummer**	**3.5**	**17**	**6.3**	**20**	**2.7**	**38**	**139**	**2191**	**402**
Harrisburg	**Reesville-Patton**	**2.9**	**20**	**6.1**	**7**	**3.7**	**19**	**135**	**2516**	**486**

Table 3. Precipitation and temperature during the production season at three Illinois locations in 2015 compared to the 30-year average.

	Precipitation (in)		Temperature (°F)	
Month	**2015**	**30-Year Average**	**2015**	**30-Year Average**
		DeKalb		
April	**3.8**	**3.3**	**48**	**52**
May	**5.2**	**4.6**	**59**	**63**
June	**8.2**	**4.1**	**66**	**72**
July	**2.0**	**4.4**	**68**	**75**
August	**2.5**	**4.4**	**69**	**73**
September	**2.2**	**3.3**	**53**	**66**
		Champaign		
April	**3.1**	**3.6**	**54**	**52**
May	**5.6**	**4.9**	**67**	**63**
June	**8.4**	**4.3**	**72**	**72**
July	**2.8**	**4.7**	**73**	**75**
August	**2.7**	**3.9**	**71**	**73**
September	**5.9**	**3.1**	**71**	**66**
		Harrisburg		
April	**6.2**	**4.4**	**58**	**57**
May	**2.4**	**5.1**	**67**	**66**
June	**6.8**	**4.5**	**75**	**75**
July	**2.7**	**3.8**	**78**	**78**
August	**1.4**	**3.0**	**73**	**77**
September	**2.5**	**3.1**	**70**	**69**

Table 4. Effect of N source and timing of N application on grain yield averaged across three Illinois locations in 2015. The unfertilized control treatment averaged 71.7 bushels acre^{-1}.

	Application Time			
N Source	**Preplant**	**V3**	**R1**	**R3**
	---------- bushels acre^{-1} ----------			
Unfertilized control	**73.0**	**71.5**	**70.9**	**71.5**
AN	**77.0***	**75.7***	**76.2***	**77.2***
AMS	**75.7**	**73.1**	**74.4***	**74.7***
UAN	**76.5***	**75.6***	**74.7***	**74.6***
Urea	**75.3**	**74.4***	**74.1***	**74.6***
ESN	**76.2***	**74.2**	**75.2***	**74.6***
Limus Urea	**74.6**	**74.8***	**74.6***	**75.7***
AN+KN+AMS	**75.6**	**72.9**	**75.4***	**75.1***

***significantly different than unfertilized control within an application time, $P \leq 0.10$.**
AN is ammonium nitrate, AMS ammonium sulfate, UAN is liquid urea and ammonium nitrate, ESN is controlled release environmentally smart N, Limus Urea is urea treated with the urease inhibitor Limus, and AN+KN+ AMS is a mixture of ammonium nitrate, potassium nitrate and ammonium sulfate.

Table 5. Increases in grain yield by different N sources within an application time averaged over three Illinois locations in 2015.

	Application Time			
N Source	**Preplant**	**V3**	**R1**	**R3**
	---------- Δ bushels acre^{-1} ----------			
AN	**4.0***	**4.2***	**5.3***	**5.7***
AMS	**2.7**	**1.6**	**3.5***	**3.2***
UAN	**3.5***	**4.1***	**3.8***	**3.1***
Urea	**2.3**	**2.9***	**3.2***	**3.1***
ESN	**3.2***	**2.7**	**4.3***	**3.1***
Limus Urea	**1.6**	**3.3***	**3.7***	**4.2***
AN+KN+AMS	**2.6**	**1.4**	**4.5***	**3.6***

***significantly different than unfertilized control within an application time, $P \leq 0.10$.**
AN is ammonium nitrate, AMS ammonium sulfate, UAN is liquid urea and ammonium nitrate, ESN is controlled release environmentally smart N, Limus Urea is urea treated with the urease inhibitor Limus, and AN+KN+ AMS is a mixture of ammonium nitrate, potassium nitrate and ammonium sulfate.

Table 6. Effect of N source and timing of application on changes in grain yield at DeKalb, Champaign, and Harrisburg, IL in 2015. For each location, values in parenthesis represent the unfertilized control yields. Positive values are indicative of yield increases and negative values of yield decreases.

	Application Time			
N Source	**Preplant**	**V3**	**R1**	**R3**
	---------- Δ bushels acre^{-1} ----------			
	DeKalb (Unfertilized control= 63.2 bu acre^{-1})			
AN	**7.9***	**6.9***	**11.4***	**3.1**
AMS	**2.8**	**2.5**	**5.6***	**-1.5**
UAN	**0.3**	**4.5**	**9.4***	**0.4**
Urea	**0.7**	**2.8**	**5.7***	**0.8**
ESN	**0.7**	**4.9***	**6.8***	**1.1**
Limus Urea	**-0.4**	**1.9**	**11.3***	**-0.9**
AN+KN+AMS	**0.8**	**3.6**	**11.4***	**-1.3**
	Champaign (Unfertilized control= 73.3 bu acre^{-1})			
AN	**3.5**	**4.0**	**4.2**	**7.9***
AMS	**3.7**	**2.0**	**4.3**	**6.5***
UAN	**2.7**	**2.2**	**1.8**	**4.3**
Urea	**3.0**	**1.9**	**3.6**	**5.2***
ESN	**2.4**	**2.4**	**3.0**	**3.2**
Limus Urea	**0.0**	**3.1**	**3.2**	**5.3***
AN+KN+AMS	**2.7**	**2.7**	**2.7**	**6.9***
	Harrisburg (Unfertilized control= 78.8 bu acre^{-1})			
AN	**0.4**	**1.6**	**0.1**	**6.2***
AMS	**1.4**	**0.2**	**0.3**	**4.8***
UAN	**7.3***	**5.4***	**0.1**	**4.7***
Urea	**2.9**	**3.9**	**0.2**	**3.5**
ESN	**6.3***	**0.6**	**2.8**	**5.1***
Limus Urea	**5.1***	**4.8***	**-3.6**	**8.4***
AN+KN+AMS	**4.2**	**-2.1**	**0.7**	**5.4***

*** significantly different than unfertilized control within an application time, $P \leq 0.10$**
AN is ammonium nitrate, AMS ammonium sulfate, UAN is liquid urea and ammonium nitrate, ESN is controlled release environmentally smart N, Limus Urea is urea treated with the urease inhibitor Limus, and AN+KN+ AMS is a mixture of ammonium nitrate, potassium nitrate and ammonium sulfate.

Table 7. Effect of N source and timing of N application on seed number at DeKalb, Champaign, and Harrisburg, IL in 2015. For each location, values in parenthesis represent the number of seeds produced by the unfertilized control plots.

	Application Time			
N Source	**Preplant**	**V3**	**R1**	**R3**
	------------------------------------- seed number m^{-2} ------------------------------			
	DeKalb (Unfertilized control= 2528 m^{-2})			
AN	**2782***	**2681**	**2655**	**2721***
AMS	**2576**	**2575**	**2500**	**2578**
UAN	**2552**	**2584**	**2600**	**2554**
Urea	**2594**	**2535**	**2513**	**2557**
ESN	**2605**	**2737***	**2636**	**2592**
Limus Urea	**2505**	**2462**	**2642**	**2507**
AN+KN+AMS	**2590**	**2561**	**2627**	**2534**
	Champaign (Unfertilized control= 2487 m^{-2})			
AN	**2559**	**2589**	**2575**	**2639***
AMS	**2568**	**2477**	**2579**	**2590**
UAN	**2614**	**2530**	**2554**	**2563**
Urea	**2583**	**2546**	**2575**	**2652***
ESN	**2563**	**2663***	**2594**	**2558**
Limus Urea	**2464**	**2554**	**2545**	**2626**
AN+KN+AMS	**2529**	**2566**	**2495**	**2595**
	Harrisburg (Unfertilized control= 3253 m^{-2})			
AN	**3299**	**3278**	**3295**	**3387**
AMS	**3317**	**3327**	**3352**	**3329**
UAN	**3465***	**3394**	**3341**	**3367**
Urea	**3343**	**3322**	**3368**	**3305**
ESN	**3394**	**3252**	**3396**	**3320**
Limus Urea	**3399**	**3358**	**3224**	**3407**
AN+KN+AMS	**3400**	**3167**	**3340**	**3391**

***significantly different than unfertilized control within an application time, $P \leq 0.10$**
AN is ammonium nitrate, AMS ammonium sulfate, UAN is liquid urea and ammonium nitrate, ESN is controlled release environmentally smart N, Limus Urea is urea treated with the urease inhibitor Limus, and AN+KN+ AMS is a mixture of ammonium nitrate, potassium nitrate and ammonium sulfate.

Table 8. Effect of N source and timing of N application on on seed weight at DeKalb, Champaign, and Harrisburg, IL in 2015. For each location, values in parenthesis represent the individual seed weight produced by the unfertilized control plots.

	Application Time			
N Source	**Preplant**	**V3**	**R1**	**R3**
	------------------------------------ **seed weight mg^{-1}** ------------------------------			
	DeKalb (Unfertilized control= 146.5 mg^{-1})			
AN	**155.5***	**153.0***	**155.7***	**145.7**
AMS	**156.3***	**148.8**	**151.5**	**145.0**
UAN	**152.5***	**153.4***	**154.3***	**148.9**
Urea	**150.9**	**152.4***	**151.0**	**149.9**
ESN	**149.8**	**145.7**	**146.5**	**148.4**
Limus Urea	**153.3***	**154.6***	**156.2***	**149.1**
AN+KN+AMS	**151.1**	**152.4***	**154.1***	**147.3**
	Champaign (Unfertilized control= 172.7 mg^{-1})			
AN	**177.6***	**175.3**	**176.8**	**178.3***
AMS	**177.1***	**178.2***	**176.8**	**178.0***
UAN	**172.3**	**175.2**	**172.7**	**175.3**
Urea	**175.0**	**173.1**	**175.0**	**171.2**
ESN	**174.9**	**170.6**	**173.1**	**172.7**
Limus Urea	**174.9**	**175.1**	**175.0**	**173.2**
AN+KN+AMS	**177.7***	**173.5**	**175.7**	**178.8***
	Harrisburg (Unfertilized control= 140.3 mg^{-1})			
AN	**141.3**	**142.5**	**142.7**	**144.7***
AMS	**142.4**	**138.0**	**140.5**	**144.6***
UAN	**146.3***	**144.2**	**142.9**	**140.8**
Urea	**143.7**	**144.7***	**139.8**	**143.4**
ESN	**147.6***	**141.9**	**143.1**	**145.6***
Limus Urea	**145.3***	**144.7**	**139.3**	**147.6***
AN+KN+AMS	**143.7**	**140.7**	**141.9**	**143.1**

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Table 9. Effect of N source and timing of N application on the concentration of grain oil at DeKalb, Champaign, and Harrisburg, IL in 2015. For each location, values in parenthesis represent the concentration of grain oil produced by the unfertilized control plots.

	Application Time			
N Source	**Preplant**	**V3**	**R1**	**R3**
	---------- oil % ----------			
	DeKalb (Unfertilized control= 18.2%)			
AN	**18.1**	**18.2**	**18.2**	**18.2**
AMS	**18.2**	**18.4**	**18.5***	**18.2**
UAN	**18.2**	**18.2**	**18.2**	**18.3**
Urea	**18.2**	**18.2**	**18.3**	**18.1**
ESN	**18.2**	**18.2**	**18.3**	**18.1**
Limus Urea	**18.2**	**18.1**	**18.3**	**18.3**
AN+KN+AMS	**18.2**	**18.3**	**18.2**	**18.3**
	Champaign (Unfertilized control= 19.2%)			
AN	**19.1**	**19.0**	**19.3**	**19.3**
AMS	**19.1**	**19.2**	**19.2**	**19.1**
UAN	**19.3**	**19.1**	**19.3**	**19.4**
Urea	**19.2**	**19.2**	**19.3**	**19.3**
ESN	**19.2**	**19.2**	**19.3**	**19.1**
Limus Urea	**19.3**	**19.3**	**19.4**	**19.5***
AN+KN+AMS	**19.0**	**19.2**	**19.4**	**19.3**
	Harrisburg (Unfertilized control= 20.0%)			
AN	**20.0**	**19.9**	**20.0**	**20.2***
AMS	**20.0**	**20.1**	**20.3***	**20.3***
UAN	**19.8**	**19.9**	**19.9**	**20.3***
Urea	**19.9**	**19.8**	**20.0**	**20.2***
ESN	**19.9**	**19.9**	**20.1**	**20.0**
Limus Urea	**19.9**	**19.8**	**20.1**	**20.2***
AN+KN+AMS	**19.9**	**20.1**	**20.2**	**20.3***

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Table 10. Effect of N source and timing of N application on the concentration of grain protein at DeKalb, Champaign, and Harrisburg, IL in 2015. For each location, values in parenthesis represent the concentration of grain protein produced by the unfertilized control plots.

	Application Time			
N Source	**Preplant**	**V3**	**R1**	**R3**
	------------------------------------- **protein %** ------------------------------			
	DeKalb Unfertilized control= 34.1%)			
AN	**34.4**	**34.3**	**34.3**	**34.2**
AMS	**34.3**	**33.7**	**33.7***	**34.1**
UAN	**34.3**	**34.3**	**34.1**	**34.2**
Urea	**34.1**	**33.9**	**34.0**	**34.3**
ESN	**34.2**	**34.0**	**34.0**	**34.3**
Limus Urea	**34.2**	**34.3**	**34.4**	**34.9***
AN+KN+AMS	**34.0**	**34.1**	**34.2**	**34.1**
	Champaign (Unfertilized control= 34.6%)			
AN	**35.0***	**34.8**	**34.5**	**34.7**
AMS	**34.7**	**34.5**	**34.6**	**35.0***
UAN	**34.3**	**34.6**	**34.4**	**34.2**
Urea	**34.6**	**34.7**	**34.5**	**34.2**
ESN	**34.6**	**34.4**	**34.4**	**34.5**
Limus Urea	**34.6**	**34.5**	**34.4**	**34.2**
AN+KN+AMS	**34.7**	**34.4**	**34.3**	**34.6**
	Harrisburg Unfertilized control= 34.4%)			
AN	**34.4**	**34.6**	**34.3**	**34.4**
AMS	**34.4**	**34.3**	**34.0**	**34.3**
UAN	**34.6**	**34.6**	**34.5**	**34.0**
Urea	**34.6**	**34.8***	**34.3**	**34.3**
ESN	**34.8***	**34.5**	**34.4**	**34.5**
Limus Urea	**34.7***	**34.7***	**34.3**	**34.4**
AN+KN+AMS	**34.6**	**34.3**	**34.2**	**34.2**

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