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Nitrogen Management to Increase Nutrient Use Efficiency and Corn Grain Yield

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OBJECTIVES:

1.) Investigate different nitrogen (N) fertilizer application methods, timings, and the use of fertilizer additives to improve the efficiency of nutrient uptake in corn.
2.) Determine the best timing, placement, and form of urea fertilizer to optimize corn grain yield in high-yield management systems.

BACKGROUND:

Greater nutrient use efficiency by corn could reduce fertilizer input costs, decrease the rate of nutrient loss, and enhance crop yields. Nutrient use efficiency can be enhanced by Best Management Practices that apply nutrients at the right rate, time, and place using the correct source.

Keeping nutrients stable and available to the plant increases nutrient use efficiency and may be achieved with fertilizer additives and/or localized placement. Placement of in-season fertilizer has been limited in the past to broadcasted dry fertilizers, foliar sprays, or liquid fertilizer applications in the center of the interrow. Recently, 360 Yield Center developed a product that allows for the ability to place a liquid nutrient solution on the soil surface directly next to the crop row called Y-drop. With rain or heavy dew, the architecture of the corn plant leaves creates a water funneling system that flows down to the base of plant and assists in incorporating the fertilizer into the ground. Research has shown that this stemflow can increase water partitioned to the base of plant from incident rainfall by 40-50% (Quinn and Laflen, 1983; Warner and Young, 1989). Placing the nutrients directly in the root zone increases the probability for the plant roots to take up and utilize those nutrients. This is especially important for N, as N tends to follow the movement of water vertically in the soil profile as opposed to horizontally (Mthandi et al., 2013). The placement of fertilizer near the growing plant creates a zone of high nutrient concentration directly in the rooting area to increase nutrient use efficiency and decrease nutrient loss.

Fertilizer additives have been shown to increase nutrient use efficiency, particularly for nitrogen. N-butyl-thiophosphoric trianide (NBPT) is a urease inhibitor currently marketed as Agrotain (Koch Agronomic Services, LLC, Wichita, KS). The mechanism urease inhibitors use is to lock onto the urease enzyme binding sites, preventing the enzyme from degrading the urease (Hendrickson, 1992). Nutrisphere (Verdesian Life Sciences, Cary, NC) is marketed as both a urease inhibitor and a nitrification inhibitor. Nutrisphere binds to copper ions necessary for the nitrification process by soil bacteria and also binds to nickel ions necessary for the formation and function of urease enzymes (Gordon, 2008). Additionally, humic acids, such as Hydra-Hume (Helena Chemical Company, Collierville, TN), Growth Boost, and Ultra Boost (SoilBiotics, Kankakee, IL), are compounds derived from Leonardites, commonly called humate or dry mined carbonaceous materials. These products are marketed as compounds that stabilize N as they provide organic material for the nitrogen fertilizer to bind to, therefore reducing the leaching and loss of N (Rose et al., 2014).

The fertility requirements for modern high-yielding corn have been recently identified (Bender et al., 2013). Nitrogen uptake by corn follows a sigmoidal pattern over time with two-thirds of the total plant uptake acquired by the VT/R1 growth stage (Bender et al., 2013). From V8 to R1, corn takes up N at a rate of 7 lbs of N Ac^{-1} day^{-1} for 21 continuous days. Matching corn nutritional needs by supplying nutrients at the right time and place is critical for optimizing nutrient use and grain yield. The overall goal of this research is to maximize corn grain yield through the use of innovative fertilizer enhancement products, application methods, and timing within high-yielding systems.

RESEARCH METHODOLOGY:

The experiment was implemented during 2016 at the Crop Sciences Research and Education Center in Champaign, IL and in southern IL at Harrisburg. These locations have been maintained weed- and disease-free, are level and well-drained, and are well-suited to provide evenly distributed soil fertility, pH, soil organic matter, and water availability. Experimental units were plots four rows wide and 37.5 feet in length with 30-inch row spacing. Plots were planted on 23 April 2016 in Champaign (silty clay loam, 4.2% organic matter; 21.8 meq/100g CEC, 5.9 pH, 26 ppm P, and 115 ppm K with Mehlich-3 extraction) and 4 May 2016 in Harrisburg (silt loam, 3.0% organic matter; 18.6 meq/100g CEC, 6.0 pH, 16 ppm P, and 133 ppm K with Mehlich-3 extraction). The field was planted to corn for the 4th straight year following soybeans in Champaign and corn following soybeans in Harrisburg. Both sites used conventional tillage. Plots were arranged using an RCBD with 6 replications. A total of 160 or 140 lbs of N Ac^{-1} was applied in Champaign and Harrisburg, respectively. Hybrid Croplan 6640, previously characterized as responsive to N and management, was planted at both sites to target a final stand of 34,000 plants Ac^{-1}.

Nutrient Applications

Treatment applications were designed to compare different nitrogen fertilizer additives, timing of application, and application methods, and are outlined in Table 1. Treatments either received all the N upfront at preplant as urea, or received a split application of N with 50 percent of the total N applied as urea at preplant followed by a sidedress application of 50 percent of the total N applied as UAN (Urea Ammonium Nitrate) at the V8 growth stage. Urea applied at preplant was broadcasted using a hand spreader. Treatments receiving all of the N upfront were coated with Agrotain, Nutrisphere, Hydra-Hume, or Ultra Boost, and compared to uncoated. Sidedress applications of UAN were made using the Y-drop technique placing nutrient solution on the soil surface directly next to the crop row. The UAN solution included Nutrisphere, Agrotain, Hydra-Hume, or Growth Boost, and was compared to no additive. The Y-drop sidedress UAN application was compared to a sidedress application of UAN broadcast sprayed on the soil surface between the rows using a backpack sprayer. All treatments were compared to an unfertilized check.

Parameters measured

Soil samples (0”-12” deep) were obtained from plot areas prior to planting to confirm fertility levels. Two weeks after the final treatment application, additional soil samples were acquired from each plot by collecting a core every 3 inches across the row and thoroughly mixing the cores to collect a sample. These samples were analyzed for NO_3^- and NH_4^+ concentration in the soil profile.

Ear leaves were measured at the R2 growth stage for green color intensity and potential plant health using a SPAD-502 Chlorophyll Meter (Konica Minolta Sensing Americas, Inc., Ramsey, NJ), averaging readings from the midleaf region of 10 plants per plot.

Total aboveground biomass sampling for N analysis was conducted at the R6 growth stage to quantify total N uptake throughout the growing season. Plant biomass was analyzed for N level, then nutrient accumulation in the plant was determined using total plant biomass accumulation and stover N concentration. Nitrogen concentration in the grain was calculated by converting protein concentration in the grain, obtained by NIT analysis, to N concentration. Total N in the grain was determined using total grain weight and grain N concentration. Total N uptake is the sum of total N in the grain and total N uptake in the stover. Nutrient use efficiencies were calculated for each treatment from the amount of fertilizer applied, total N uptake, and corn grain yield compared to the unfertilized check plot. Yield efficiency was calculated by subtracting the check plot yield from each treatment yield and dividing by the fertilizer N rate applied. Recovery efficiency was calculated by subtracting the total N uptake of the check plot plants from the total N uptake resulting from each treatment and dividing by the corresponding total N rate applied. Physiological yield efficiency was calculated by subtracting the check plot yield from each treatment yield and dividing by the difference between the total N uptake resulting from each treatment compared to the total N uptake of the check plot.

The center two rows of each plot were mechanically harvested for determination of grain yield and harvest moisture, and the yield subsequently standardized to bushels acre^{-1} at 15.5% moisture. Subsamples of the harvested grain were evaluated for yield components (individual kernel weight and kernel number) and for grain quality (protein, oil, and starch concentrations) by NIT. Kernel weight is presented at 0% moisture.

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Table 1. Treatment application schedule to evaluate the effect of nitrogen fertilizer additives, application methods, and timings on corn yield and nutrient use efficiency at Champaign and Harrisburg, IL in 2016.

Nutrient Source	Percent of Total N Applied	Additive Product	Application Method at Plant Growth Stage	
			Preplant	V8
	%			
Unfertilized	-	-	-	-
Urea	100	-	Broadcasted	-
Urea	100	Agrotain	Broadcasted	-
Urea	100	Nutrisphere	Broadcasted	-
Urea	100	Hydra-Hume	Broadcasted	-
Urea	100	Ultra Boost	Broadcasted	-
Urea	50	-	Broadcasted	-
UAN	50	-	-	Broadcast Sprayed
Urea	50	-	Broadcasted	-
UAN	50	-	-	Y-dropped
Urea	50	-	Broadcasted	-
UAN	50	Agrotain	-	Y-dropped
Urea	50	-	Broadcasted	-
UAN	50	Nutrisphere	-	Y-dropped
Urea	50	-	Broadcasted	-
UAN	50	Hydra-Hume	-	Y-dropped
Urea	50	-	Broadcasted	-
UAN	50	Growth Boost	-	Y-dropped

Results

The 2016 production year experienced ideal growing conditions in Champaign with average temperatures and timely rains of adequate amounts of rainfall throughout the growing season (Table 2). Harrisburg encountered above- average temperatures with irregular amounts of rainfall throughout much of the growing season (Table 2). Harrisburg experienced an extremely dry June followed by above- average rainfall in July and August (Table 2). As a result, corn grown in

Champaign experienced very little weather- induced heat or moisture stress while corn in Harrisburg was set back in June from little rainfall.

The study yielded an average of 165 bu Ac^{-1} with significant effects of location, treatment, and the interaction between location and treatment on yield (Table 3). Champaign yielded an average of 36 bu Ac^{-1} greater than Harrisburg, with weather likely playing the largest role for the lower yields in Harrisburg (Table 4). Kernel number and kernel weight are components of grain yield. The dry conditions in June hindered crop growth during key growth stages when the plant is determining the amount of potential kernels that it will produce, resulting in a significant decrease in kernel number and yield compared to the Champaign location (Table 4). On average, split-applying N resulted in an 8% yield decrease compared to applying all of the N upfront before planting (Table 5). The lower fertility rate applied at preplant hindered plant growth at an early growth stage, which was not recovered with the later N supplementation. This finding implies that the corn plants detected the fertility available early in the season, which thereby set the growth trajectory for the remainder of the growing season. The treatments that only applied half of the N upfront resulted in an average reduction of 235 kernels m^{-2}, suggesting that the plant growth was constrained when the number of kernel rows was being determined (Table 5). Kernel weight also significantly decreased from split-applying N, suggesting that N availability limited photosynthesis during grain filling (Table 5). When investigating further the efficacy of the sidedress treatments, using the Y-drop technique for fertilizer placement significantly increased yield by 7 bu Ac^{-1}, on average, compared to broadcast spraying UAN (Table 5). By placing the nutrient directly next to the crop row, the plant utilized nitrogen better and produced more yield.

When evaluating the fertilizer additives averaged across both locations, Nutrisphere- coated urea tended to have the greatest effect on grain yield, compared to the other fertilizer additives tested, significantly increasing corn grain yield by 7 bu ac^{-1} over the non-coated urea control (Table 5, significance hidden in table due to rounding). The use of humic acid products, Hydra-Hume and Ultra Boost, applied at preplant did not significantly affect grain yield, however, they tended to decrease kernel number and increase kernel weight (Table 5). The carbonaceous materials potentially bound to the N making the latter less available early in the growing season but subsequently released the N during grain filling. The use of fertilizer additives with UAN at the V8 growth stage did not significantly affect yield, as the additives tended to play a bigger role on grain yield when coated on urea at preplant (Table 5). Nutrisphere- coated urea applied at preplant in Champaign produced the highest yield across both trials achieving 207 bu Ac^{-1} (Table 6).

Both treatment and location had significant affects on total plant biomass accumulation and total N uptake throughout the growing season (Table 7). The Champaign environment resulted in greater plant biomass accumulation compared to the Harrisburg location, possibly caused by the dry June in southern Illinois (Table 8). Plants at the Champaign location accumulated significantly more N in both the grain and the stover compared to those at the Harrisburg site (Table 8). On average, split-applying N resulted in a 14% reduction in plant biomass accumulation and a decrease of 24 lbs Ac^{-1} of total N uptake throughout the growing season compared to plant receiving all the N upfront (Table 9). The same amount of total N fertilizer was applied for the upfront and split-applied N treatments, however, in this study, plants receiving the split-applied N treatment had less total N uptake, which results in more N remaining in the soil and therefore subject to environmental losses. The issue of less plant N recovery under split- N fertilization conditions is a major environmental concern.

The use of all fertilizer additives, at planting or sidedress, likely kept the nitrogen more available and tended to increase plant N accumulation, but the latter did not always translate into an increase in yield (Table 5 and 9). The use of Hydra-Hume or Ultra Boost coated on urea at planting led to the greatest amount of plant biomass accumulation at the Champaign location but not at the Harrisburg location (Table 10). The dry conditions at the southern location in June potentially limited the release of the N from the organic matter until more precipitation fell in July. Nitrogen released from Ultra Boost- coated urea applied at preplant was taken up in the greatest amount at the Champaign site, with a total plant accumulation of 167 lbs of N Ac^{-1} (Table 10).

Nutrient use efficiency calculations make use of the unfertilized check plots as a reference point, which utilized an average uptake of 52 lbs of N Ac^{-1} to achieve a final grain yield of 67 bu Ac^{-1} (Table 5 and 9). The N acquired by the unfertilized check plot plants was supplied from the soil through mineralization. Yield efficiency (i.e., NUE) is the relationship between yield and the rate of fertilizer applied. Recovery efficiency and physiological efficiency are both components of yield efficiency and either one of them can affect the overall nutrient use efficiency. Recovery efficiency is the amount of fertilizer applied N that is 'recovered' or taken up by the plant (i.e., N uptake efficiency). Physiological efficiency calculates how well the plants utilized the absorbed N to produce yield (i.e., N utilization efficiency). Treatment and location had significant effects on both yield efficiency and recovery efficiency (Table 11). Plants at the Champaign location recovered a greater percentage of the applied N and also produced a higher average yield in relation to the amount of N applied (Table 12). On average, plants recovered the applied N 17% more efficiently when all the N was applied upfront compared to split-applying the same amount of N (Table 13). In addition, applying all of the N upfront resulted in 15% greater yield efficiency compared to split-applying N (Table 13). Physiological efficiency, as expected, was significantly higher when split-applying the N because plants utilize accumulated N more efficiently at lower absorbed N levels (Table 13). Using fertilizer additives with UAN Y-dropped at sidedress did not significantly affect nutrient use efficiency at either location (Table 14). However at Harrisburg, fertilizing with Agrotain- coated urea at preplant increased recovery efficiency while Nutrisphere- coated urea increased both yield efficiency and recovery efficiency compared to supplying N with only non-coated urea (Table 14).

In-season measurements, both SPAD and soil sampling, were used to quantify plant greenness and the amount of N in the soil. Nitrogen fertility treatment had a significant effect on in- season plant leaf greenness (SPAD) and soil total N concentration (Table 15). Location also significantly affected total N concentration in the soil, with Champaign having 53% higher soil N concentration compared to the Harrisburg location (Table 15 and 16). The greater soil N concentration at Champaign is likely from a combination of weather conditions, soil organic matter, and cultural practices. When averaged across both locations, Nutrisphere-, Hydra-Hume-, and Ultra Boost- coated urea applied at preplant significantly increased total N concentrations in the soil 2 weeks after the sidedress application compared to the non-coated urea (Table 17). In addition, Hydra-Hume and Growth Boost added to UAN and applied at sidedress increased the leaf greenness at the R2 growth stage at both locations (Table 18). Although the greater leaf greenness did not translate into an increase in grain yield, it indicates the potential to capture more sunlight later in the growing season during grain filling. Total N uptake tended to be a better indication of grain yield than biomass, SPAD readings, or total N concentration in the soil.

The results from this study document the importance of proper fertilizer source, placement, and timing on grain yield and the efficiency of nutrient uptake in corn. Fertilizer additives tended to have a larger impact on nitrogen uptake and grain yield when coated on urea at preplant then when applied with UAN at sidedress. When sidedressing, placing the nutrient solution directly next to the crop row resulted in greater yields than when the solution was broadcasted down the center of the row. Fertilizer application timing played the largest role in nutrient uptake and grain yield. Applying all of the N fertilizer upfront before planting was most beneficial to crop growth and final grain yield compared to split-applying the N 50% upfront and 50% sidedressed. This finding implies that the plant needs to have a certain amount of fertility upfront to set the trajectory for the rest of the growing season and may not recover if lacking N at an early growth stage. These farming practices can be used in conjunction in high-yield management systems to optimize nutrient use efficiency and grain yield.

Table 2. Precipitation and temperature during the production season at Champaign and Harrisburg, IL in 2016 compared to the 30-year average. Data obtained from the Illinois State Water Survey.

	Precipitation (in)		**Temperature (°F)**	
Month	**2016**	**30-Year Average**	**2016**	**30-Year Average**
	Champaign, IL			
April	3.8	3.6	53	52
May	4.7	4.9	62	63
June	5.7	4.3	74	72
July	4.4	4.7	75	75
August	4.1	3.9	75	73
September	5.5	3.1	70	66
	Harrisburg, IL			
April	2.7	4.4	58	57
May	5.6	5.1	64	66
June	1.8	4.5	77	75
July	8.3	3.8	79	78
August	5.3	3.0	77	77
September	3.2	3.1	72	69

Table 3. Test of fixed effects for grain yield, yield components (kernel number and kernel weight), and grain quality (oil, protein, starch) for corn grown at Champaign and Harrisburg, IL in 2016.

		Yield Component		Grain Quality		
Source of Variation	**Yield**	**Kernel Number**	**Kernel Weight**	**Oil**	**Protein**	**Starch**
			P > F			
Treatment (T)	<.0001	<.0001	<.0001	0.0022	<.0001	<.0001
Location (L)	<.0001	<.0001	0.7302	0.9460	0.0093	0.9730
T x L	<.0001	<.0001	0.0238	0.0496	0.0044	0.1134

Table 4. Grain yield, yield components (kernel number and kernel weight), and grain quality (oil, protein, starch) averaged across all fertility treatments as influenced by location for corn grown at Champaign and Harrisburg, IL in 2016. Grain yield is presented at 15.5% moisture, kernel weight is presented at 0% moisture.

		Yield Component		Grain Quality		
Location	**Yield**	**Kernel Number**	**Kernel Weight**	**Oil**	**Protein**	**Starch**
	bu Ac^{-1}	seed m^{-2}	mg seed^{-1}		%	
Champaign	183	4457	217	3.8	7.1	73.6
Harrisburg	147	3598	216	3.8	6.7	73.6
LSD (α = 0.10)	6	143	NS†	NS	0.2	NS

† NS, non- significant.

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Table 5. Grain yield, yield components (kernel number and kernel weight), and grain quality (oil, protein, starch) as influenced by fertility treatment for corn averaged over two locations in 2016. Grain yield is presented at 15.5% moisture, kernel weight is presented at 0% moisture.

		Yield Component		Grain Quality		
Treatment	**Yield**	**Kernel Number**	**Kernel Weight**	**Oil**	**Protein**	**Starch**
	bu Ac^{-1}	seed m^{-2}	mg $seed^{-1}$		%	
No Applied N	67	1964	181	3.93	6.09	74.21
Upfront N (Urea)	181	4330	222	3.79	7.03	73.61
+ Agrotain	185	4444	222	3.77	7.24	73.36
+ Nutrisphere	188	4481	224	3.76	7.36	73.24
+ Hydra-Hume	178	4192	225	3.78	7.23	73.41
+ Ultra Boost	179	4272	223	3.89	7.13	73.28
50/50 Split N						
UAN Broadcasted	163	4034	215	3.73	6.85	73.38
UAN Y-dropped	170	4172	216	3.78	6.69	73.69
+ Agrotain	167	4047	220	3.67	6.87	73.78
+ Nutrisphere	168	4096	218	3.74	6.76	73.74
+ Hydra-Hume	172	4157	219	3.73	6.68	73.79
+ Growth Boost	167	4144	215	3.66	6.81	73.88
LSD ($\alpha = 0.10$)	7	196	7	0.11	0.20	0.35

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Table 6. Grain yield, yield components (kernel number and kernel weight), and grain quality (oil, protein, starch) as influenced by fertility treatment for corn grown at Champaign and Harrisburg, IL in 2016. Grain yield is presented at 15.5% moisture, kernel weight is presented at 0% moisture.

		Yield Component		Grain Quality		
Treatment	**Yield**	**Kernel Number**	**Kernel Weight**	**Oil**	**Protein**	**Starch**
	bu Ac^{-1}	seed m^{-2}	mg $seed^{-1}$	%		
			Champaign			
No Applied N	63	1857	182	3.92	6.12	74.40
Upfront N (Urea)	203	4802	224	3.71	7.48	73.50
+ Agrotain	205	4867	226	3.69	7.27	73.63
+ Nutrisphere	207	4873	227	3.91	7.45	73.00
+ Hydra-Hume	198	4554	231	3.82	7.41	73.50
+ Ultra Boost	202	4873	220	3.90	7.47	72.98
50/50 Split N						
UAN Broadcasted	182	4597	210	3.74	6.85	73.53
UAN Y-dropped	190	4569	220	3.79	6.93	73.63
+ Agrotain	189	4574	221	3.63	7.19	73.85
+ Nutrisphere	189	4611	218	3.72	6.88	73.78
+ Hydra-Hume	193	4604	223	3.79	6.92	73.52
+ Growth Boost	184	4702	208	3.60	7.00	74.00
LSD ($\alpha = 0.10$)	11	329	11	0.15	0.33	0.50
			Harrisburg			
No Applied N	70	2070	180	3.93	6.07	74.02
Upfront N (Urea)	160	3859	221	3.88	6.58	73.72
+ Agrotain	165	4020	219	3.84	7.22	73.08
+ Nutrisphere	169	4088	220	3.62	7.27	73.48
+ Hydra-Hume	159	3830	220	3.73	7.05	73.32
+ Ultra Boost	157	3671	227	3.88	6.78	73.57
50/50 Split N						
UAN Broadcasted	144	3472	221	3.72	6.85	73.23
UAN Y-dropped	150	3775	211	3.76	6.45	73.75
+ Agrotain	145	3520	219	3.71	6.55	73.70
+ Nutrisphere	147	3581	218	3.75	6.63	73.70
+ Hydra-Hume	150	3710	215	3.68	6.43	74.05
+ Growth Boost	150	3587	223	3.71	6.62	73.77
LSD ($\alpha = 0.10$)	8	219	7	0.16	0.24	0.50

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Table 7. Test of fixed effects for R6 plant stover biomass, grain and stover N concentration, grain and stover N content, and total plant N uptake for corn grown at Champaign and Harrisburg, IL in 2016.

Source of Variation	Biomass	N Concentration		N Content		Total N Uptake
		Grain	Stover	Grain	Stover	
			P > F			
Treatment (T)	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
Location (L)	<.0001	0.0093	0.2862	<.0001	0.0015	<.0001
T x L	0.0079	0.0044	0.2126	<.0001	0.0305	<.0001

Table 8. R6 plant stover biomass, grain and stover N concentration, grain and stover N content, and total plant N uptake averaged across all fertility treatments as influenced by location for corn grown at Champaign and Harrisburg, IL in 2016. Plant stover biomass is presented at 0% moisture.

Location	Biomass	N Concentration		N Content		Total N Uptake
		Grain	Stover	Grain	Stover	
	lbs Ac^{-1}	%		lbs Ac^{-1}		
Champaign	7018	1.13	0.55	99	39	139
Harrisburg	5405	1.07	0.53	75	29	104
LSD (α = 0.10)	277	0.03	NS†	4	3	5

† NS, non- significant.

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Table 9. R6 plant stover biomass, grain and stover N concentration, grain and stover N content, and total plant N uptake as influenced by fertility treatment for corn averaged across two locations in 2016. Plant stover biomass is presented at 0% moisture.

		N Concentration		N Content		
Treatment	**Biomass**	**Grain**	**Stover**	**Grain**	**Stover**	**Total N Uptake**
	lbs Ac^{-1}	%		lbs Ac^{-1}		
No Applied N	5142	0.97	0.41	31	22	52
Upfront N (Urea)	6557	1.13	0.55	97	36	133
+ Agrotain	6758	1.16	0.62	101	42	144
+ Nutrisphere	6597	1.18	0.62	105	41	146
+ Hydra-Hume	7020	1.16	0.64	96	45	141
+ Ultra Boost	6863	1.14	0.57	98	41	139
50/50 Split N						
UAN Broadcasted	5157	1.10	0.50	84	25	110
UAN Y-dropped	5680	1.07	0.49	86	28	114
+ Agrotain	6403	1.10	0.55	86	36	122
+ Nutrisphere	6160	1.08	0.52	86	32	119
+ Hydra-Hume	6215	1.07	0.54	87	34	121
+ Growth Boost	5982	1.09	0.48	86	29	115
LSD (α = 0.10)	678	0.03	0.07	5	6	9

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Table 10. R6 plant stover biomass, grain and stover N concentration, grain and stover N content, and total plant N uptake as influenced by fertility treatment for corn grown at Champaign and Harrisburg, IL in 2016. Plant stover biomass is presented at 0% moisture.

Treatment	Biomass	N Concentration		N Content		Total N Uptake
		Grain	Stover	Grain	Stover	
	lbs Ac^{-1}	%		lbs Ac^{-1}		
			Champaign			
No Applied N	5705	0.98	0.41	29	24	54
Upfront N (Urea)	6652	1.20	0.62	115	42	156
+ Agrotain	7046	1.16	0.60	113	42	155
+ Nutrisphere	7278	1.19	0.61	117	44	161
+ Hydra-Hume	7739	1.19	0.67	107	51	158
+ Ultra Boost	8195	1.19	0.64	114	53	167
50/50 Split N						
UAN Broadcasted	5692	1.10	0.48	94	28	122
UAN Y-dropped	6447	1.11	0.49	100	31	131
+ Agrotain	7696	1.15	0.59	100	46	146
+ Nutrisphere	7676	1.10	0.53	99	41	140
+ Hydra-Hume	7542	1.11	0.53	101	41	142
+ Growth Boost	6544	1.12	0.46	97	30	127
LSD (α = 0.10)	1079	0.05	0.10	9	10	15
			Harrisburg			
No Applied N	4578	0.97	0.41	32	19	51
Upfront N (Urea)	6462	1.05	0.47	80	30	110
+ Agrotain	6470	1.15	0.64	90	42	132
+ Nutrisphere	5917	1.16	0.64	93	38	131
+ Hydra-Hume	6301	1.13	0.61	85	38	123
+ Ultra Boost	5531	1.09	0.51	81	28	109
50/50 Split N						
UAN Broadcasted	4622	1.10	0.51	75	23	98
UAN Y-dropped	4913	1.03	0.49	73	24	98
+ Agrotain	5109	1.05	0.50	72	26	98
+ Nutrisphere	4645	1.06	0.50	74	23	97
+ Hydra-Hume	4888	1.03	0.55	73	27	100
+ Growth Boost	5419	1.06	0.50	75	27	103
LSD (α = 0.10)	841	0.04	0.09	5	7	9

Table 11. Test of fixed effects for nutrient use efficiency (yield efficiency, recovery efficiency, and physiological efficiency) for corn grown at Champaign and Harrisburg, IL in 2016.

Source of Variation	Yield Efficiency	Recovery Efficiency	Physiological Efficiency
		P > *F*	
Treatment (T)	<.0001	<.0001	<.0001
Location (L)	0.0025	0.0094	0.8074
T x L	0.9486	0.0217	0.0636

Table 12. Nutrient use efficiency (yield efficiency, recovery efficiency, and physiological efficiency) averaged across all fertility treatments as influenced by location for corn grown at Champaign and Harrisburg, IL in 2016.

Location	Yield Efficiency	Recovery Efficiency	Physiological Efficiency
	bu lb^{-1}	%	bu lb^{-1}
Champaign	0.82	65	1.34
Harrisburg	0.60	46	1.36
LSD (α = 0.10)	0.08	10	NS†

† NS, non- significant.

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Table 13. Nutrient use efficiency (yield efficiency, recovery efficiency, and physiological efficiency) as influenced by fertility treatment for corn averaged across two locations in 2016.

Treatment	Yield Efficiency	Recovery Efficiency	Physiological Efficiency
	bu lb^{-1}	%	bu lb^{-1}
Upfront N (Urea)	0.76	60	1.30
+ Agrotain	0.78	68	1.17
+ Nutrisphere	0.80	69	1.18
+ Hydra-Hume	0.74	65	1.19
+ Ultra Boost	0.74	63	1.25
50/50 Split N			
UAN Broadcasted	0.63	43	1.53
UAN Y-dropped	0.68	46	1.53
+ Agrotain	0.66	51	1.43
+ Nutrisphere	0.67	49	1.39
+ Hydra-Hume	0.69	50	1.44
+ Growth Boost	0.66	46	1.44
LSD ($\alpha = 0.10$)	0.04	7	0.14

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Table 14. Nutrient use efficiency (yield efficiency, recovery efficiency, and physiological efficiency) as influenced by fertility treatment for corn grown at Champaign and Harrisburg, IL in 2016.

Treatment	Yield Efficiency	Recovery Efficiency	Physiological Efficiency
	bu lb^{-1}	%	bu lb^{-1}
		Champaign	
Upfront N (Urea)	0.87	72	1.24
+ Agrotain	0.89	71	1.27
+ Nutrisphere	0.90	75	1.22
+ Hydra-Hume	0.84	73	1.26
+ Ultra Boost	0.87	80	1.13
50/50 Split N			
UAN Broadcasted	0.74	48	1.60
UAN Y-dropped	0.79	54	1.49
+ Agrotain	0.79	64	1.35
+ Nutrisphere	0.79	61	1.27
+ Hydra-Hume	0.81	62	1.40
+ Growth Boost	0.76	52	1.48
LSD (α = 0.10)	0.07	11	0.20
		Harrisburg	
Upfront N (Urea)	0.64	47	1.36
+ Agrotain	0.68	65	1.07
+ Nutrisphere	0.71	64	1.13
+ Hydra-Hume	0.63	57	1.11
+ Ultra Boost	0.62	46	1.38
50/50 Split N			
UAN Broadcasted	0.53	37	1.46
UAN Y-dropped	0.57	37	1.56
+ Agrotain	0.53	37	1.51
+ Nutrisphere	0.55	37	1.51
+ Hydra-Hume	0.57	39	1.48
+ Growth Boost	0.57	41	1.40
LSD (α = 0.10)	0.06	8	0.20

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Table 15. Test of fixed effects for mid-season (R2) leaf greenness and soil $N0_3^-$ concentration, soil NH_4^+ concentration, and total soil N concentration obtained 2 weeks after the sidedress application for corn grown at Champaign and Harrisburg, IL in 2016.

Source of Variation	Leaf Greenness	Soil Concentration NO_3^-	NH_4^+	Total N
	P > F			
Treatment (T)	<.0001	0.0091	0.1747	0.0150
Location (L)	0.5854	<.0001	<.0001	<.0001
T x L	0.0042	0.1195	0.3525	0.0657

Table 16. Mid-season (R2) leaf greenness and soil $N0_3^-$ concentration, soil NH_4^+ concentration, and total soil N concentration obtained 2 weeks after the sidedress application averaged across all fertility treatments as influenced by location for corn grown at Champaign and Harrisburg, IL in 2016.

Location	Leaf Greenness	Soil Concentration NO_3^-	NH_4^+	Total N
	units	ppm		
Champaign	50.8	19.7	15.4	35.1
Harrisburg	51.4	10.9	11.0	22.8
LSD ($\alpha = 0.10$)	2.0	2.9	1.7	3.9

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Table 17. Mid-season (R2) leaf greenness and soil $N0_3^-$ concentration, soil NH_4^+ concentration, and total soil N concentration obtained 2 weeks after the sidedress application as influenced by fertility treatment for corn averaged across two locations in 2016.

		Soil Concentration		
Treatment	**Leaf Greenness**	**NO_3^-**	**NH_4^+**	**Total N**
	units		ppm	
No Applied N	32.7	5.2	9.2	14.4
Upfront N (Urea)	53.3	11.8	12.2	24.0
+ Agrotain	54.7	16.7	10.4	29.8
+ Nutrisphere	51.8	20.8	13.7	34.4
+ Hydra-Hume	52.1	20.9	14.8	35.7
+ Ultra Boost	52.6	20.7	13.8	34.5
50/50 Split N				
UAN Broadcasted	54.7	17.3	14.7	32.0
UAN Y-dropped	50.7	13.4	13.3	26.7
+ Agrotain	52.5	13.4	13.0	26.4
+ Nutrisphere	49.6	12.5	11.3	23.8
+ Hydra-Hume	54.2	12.8	16.1	31.6
+ Growth Boost	54.1	18.2	15.9	34.1
LSD ($\alpha = 0.10$)	2.1	7.0	4.1	9.7

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Table 18. Mid-season (R2) leaf greenness and soil $N0_3^-$ concentration, soil NH_4^+ concentration, and total soil N concentration obtained 2 weeks after the sidedress application as influenced by fertility treatment for corn grown at Champaign and Harrisburg, IL in 2016.

Treatment	Leaf Greenness	Soil Concentration		
		NO_3^-	NH_4^+	Total N
	Units	ppm		
		Champaign		
No Applied N	28.2	4.8	8.6	13.4
Upfront N (Urea)	54.5	16.5	13.7	30.2
+ Agrotain	54.5	19.0	11.0	30.0
+ Nutrisphere	52.6	23.7	14.7	38.3
+ Hydra-Hume	50.7	28.7	16.5	45.2
+ Ultra Boost	53.8	33.8	20.3	54.2
50/50 Split N				
UAN Broadcasted	55.0	17.0	17.3	34.3
UAN Y-dropped	51.2	17.5	17.7	35.2
+ Agrotain	52.7	17.7	16.0	33.7
+ Nutrisphere	48.8	15.2	13.5	28.7
+ Hydra-Hume	53.6	17.0	17.3	34.3
+ Growth Boost	53.9	26.0	17.7	43.7
LSD (α = 0.10)	2.5	13.6	6.2	17.1
		Harrisburg		
No Applied N	37.2	5.5	9.8	15.3
Upfront N (Urea)	52.1	7.2	10.7	17.8
+ Agrotain	54.8	14.3	9.8	29.7
+ Nutrisphere	51.0	17.8	12.7	30.5
+ Hydra-Hume	53.5	13.2	13.0	26.2
+ Ultra Boost	51.5	7.5	7.3	14.8
50/50 Split N				
UAN Broadcasted	54.5	17.7	12.0	29.7
UAN Y-dropped	50.2	9.3	8.8	18.2
+ Agrotain	52.3	9.2	10.0	19.2
+ Nutrisphere	50.4	9.8	9.2	19.0
+ Hydra-Hume	54.8	8.5	14.8	28.8
+ Growth Boost	54.2	10.3	14.2	24.5
LSD (α = 0.10)	3.3	4.1	5.4	9.0

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