Enhancing Continuous Corn Production under High-Residue Conditions With Starter Fluid Fertilizer Combinations and Placements

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ABSTRACT

Continuous corn production using conservation tillage often results in less uniform and smaller early season growth along with lower grain yields and profitability. This is especially true on fine-textured and poorly drained soils in the northern part of the Corn Belt where decomposition of surface residues is slower and soil temps are colder. The primary objective of this study was to determine the effects of fluid starter fertilizer combinations and placement of 10-34-0 (APP), 28-0-0 (UAN), and 12-0-0-26 (ATS) on second-year corn production in reduced tillage/high-residue conditions. Two field experiments, one on a Webster clay loam soil at Waseca and another on an Mt Carroll silt loam near Rochester, were established in April of 2011. Twelve of the 14 total treatments comprised a factorial arrangement of rates of three fluid starter fertilizers: 0 or 4 gal/ac of APP, 0 or 8 gal/ac of UAN, and 0, 2, and 4 gal/ac of ATS. The APP was applied in-furrow with the seed while UAN and ATS were applied as a dribble band on the soil surface within 2" of the seed row. Corn was planted at 35,000 seeds/ac on May 17 at Waseca and May 19 at Rochester. At the V2 to V3 growth stage UAN was injected 3" deep midway between the rows to give a total (at planting + V2-3) N rate of 200 lb/ac on all plots. At V7 stage corn plants were harvested from each plot to determine dry matter yield, and the plant tissue was analyzed for N, P, K and S concentration. Grain yield and moisture content were determined by combine harvesting. Grain samples were analyzed for N, P, K and S concentration. A wet June and July followed by a dry August and September stressed corn and may have reduced yield potential. Crop response to treatments varied between locations. Early plant growth (plant heights and dry matter yields) were enhanced when N, P and S starter fertilizers as APP, UAN and ATS were applied at both sites. At Rochester, grain moisture was reduced 1.4 percentage points and grain yields were increased 4 bu/ac with 4 gal/ac of APP (16 lb P_2O_5/ac) applied in-furrow at planting, when averaged across UAN and ATS treatments. A 4 gal/ac rate of ATS (11.5 lb S/ac) increased corn yields 8 bu/ac compared with 0 gal/ac of ATS at Rochester. No grain yield responses to N, P, and S starter fertilizer treatments were found at Waseca.

INTRODUCTION

Crop rotations in the Midwest have changed from the traditional corn-soybean rotation to more corn-intensive rotations. Due to the expanding demand for corn to supply the ethanol industry and the increasing insect and disease challenges facing soybean producers, some farmers are switching to a corn-corn-soybean rotation or for some, continuous corn. These rotations produce large amounts of biomass (corn stover) that often remain on the soil surface with present day tillage systems. This is good in terms of erosion control, but can be a significant problem from the standpoint of seedbed preparation, early corn growth, and yield.

Corn dominated crop rotations present a huge tillage challenge to corn producers on many poorly drained, colder soils of the northern Corn Belt because corn yields following corn are generally reduced significantly when conservation tillage practices are used. Research by Randall and Vetsch (2010) has shown many of the early growth and yield problems associated with corn after corn could be eliminated by using conventional tillage (i.e. moldboard plow) in combination with fluid starter fertilizers. Generally, for most northern Corn Belt farmers the moldboard plow is not an option, because of increased potential for erosion, lack of equipment, or the labor/time needed to plow large acreages. This research also showed fluid starter fertilizers [APP (10-34-0) applied in furrow or APP and UAN (28-0-0) dribbled on the soil surface] significantly increased early growth of corn by 13 to 43% and corn yield by 5 to 7 bu/ac. This study did not address a commonly asked question, would dual placement (APP in furrow and UAN dribbled on the soil surface) further enhance corn production.

Continuous corn generally shows slow early growth, pale spindly plants, and reduced yields with reduced tillage systems. Sulfur deficiency in corn has contributed to some of these pale looking plants. Corn yield responses to sulfur have been reported on medium and fine-textured soils in Minnesota and Iowa. In Minnesota we have very little data on the optimum rate and placement of sulfur containing fluid starter fertilizers for corn. With increased costs and price volatility of fertilizers, farmers have questions about what products, placements, and rates give them the most "bang for their buck".

The objectives of this study were to: 1) determine the effects of fluid starter fertilizer combinations and placement of 10-34-0 (APP), 28-0-0 (UAN), and 12-0-0-26 (ATS) on second-year corn production in reduced tillage/high-residue conditions and 2) provide management guidelines on placement and rates of UAN, APP, and ATS combined as a starter for crop consultants, local advisors, and the fertilizer industry as they serve corn producers trying to meet the growing needs for corn grain by the ethanol industry and livestock producers.

EXPERIMENTAL PROCEDURES

Two field experiments were established in April of 2011. One on a Webster clay loam soil at the Southern Research and Outreach Center, Waseca, MN and another on a Mt Carroll silt loam six miles northeast of Rochester, Minnesota. Both sites were planted to corn in 2010 and were fall chisel plowed after harvest. Fourteen total treatments were arranged in a randomized, complete-block design with four replications. Twelve of the 14 treatments comprised a factorial combination of sources and rates of three fluid starter fertilizers: 0 or 4 gal/ac of APP (5+16+0, lb/ac of N, P_2O_5, and S, respectively); 0 or 8 gal/ac of UAN (24+0+0); and 0, 2, and 4 gal/ac of ATS (2 gal = 3+0+5.8 and 4 gal = 5+0+11.5). The APP fluid starter was applied in-furrow with the seed while UAN and ATS were applied as a dribble band on the soil surface within 2" of the seed row. Two additional treatments were included to measure crop response when adding 1 gal/ac of ATS in-furrow with 4 gal/ac of APP with and without 8 gal/ac of UAN dribbled on the soil surface. Each plot was 10' wide (4 30-inch rows) by 50' long. Soil samples (0-6" depth) were taken from each rep to characterize the research plot areas. Soil tests at Waseca averaged: pH = 5.9, organic matter = 7.2%, Bray P_1 = 47 ppm (very high) and exchangeable K = 264 ppm (very high) and at Rochester pH = 6.3, organic matter = 3.4%, Bray P_1 = 13 ppm (medium) and exchangeable K = 68 ppm (low).

Corn (DeKalb 52-43 at Waseca and 51-85 at Rochester) was planted at 35,000 seeds/ac on May 17 (Waseca) and May 19 (Rochester). Weeds were controlled with a combination of pre (Surpass and Callisto) and post emergence (glyphosate) herbicide applications. Surface residue accumulation after planting averaged 39 and 12% at Waseca and Rochester, respectively. In early June stand counts were taken on the center two rows of each plot and were thinned to a uniform plant population. At V2 to V3 on June 9, UAN was injected 3" deep midway between the rows to give a total (at planting + at V2-3) N rate of 200 lb/ac on all plots. Because of low soil test K, 120 lb K_2O/ac was injected mid-row at Rochester on June 9. On June 30 at Waseca and June 29 at Rochester (V7 stage) 8 random plants from each plot were cut at ground level, dried, weighed to determine dry matter yield, ground, and analyzed for N, P, K and S concentration in plant tissue. On the same dates extended leaf plant heights from 10 random plants per plot were also measured. At R1 (July 29 at Waseca and August 3 at Rochester) SPAD meter readings were taken from the ear leaf of 30 plants in each plot. Relative leaf chlorophyll content was calculated from these measurements. Grain yield and moisture content were determined on October 3 (Waseca) and 21 (Rochester) by harvesting the center two rows of each plot with a research plot combine equipped with a weigh cell and moisture sensor. Grain yields were calculated at 15.5% moisture. Grain samples were saved, dried, ground, and analyzed for N, P, K and S.

RESULTS AND DISCUSSION

Waseca site

The 2011 growing season started out cool and wet at Waseca (Table 1). A wet April and May resulted in delayed planting and slow early growth of corn. Over 3 inches of rain occurred in the two week period after planting, which resulted in standing water on ½ of one of the four replications in the study. The standing water slowed germination, reduced stands, resulted in N loss, and generally increased variability in some plots. These plots were removed from the data set as outliers after an initial statistical evaluation of the data was completed. The months of May, June and July all had greater than normal precipitation. July was very warm, air temperatures averaged 5° greater than normal (data not shown). August and September were dry with precipitation for the two months totaling 6.64 inches below normal. The dry conditions in the latter part of the growing season probably reduced yields and increased variability in the data. Growing degree units (GDU) from May 1 through September 15 (first frost) were near normal.

Plant heights and whole plant dry matter yields were affected by all three of the treatment main effects in the factorial analysis of treatments 1-12 (Table 2). Heights and yields were increased when APP was applied in-furrow and when UAN and ATS were applied as a surface band. Plant heights were greatest with the 4 gal/ac rate of ATS. However, yields were not different among the 2 and 4 gal/ac rates of ATS, when averaged across APP and UAN treatment main effects. A significant APP×UAN×ATS interaction for plant height showed a large increase in plant height with increasing rates of ATS, when APP and UAN were not applied. Whereas, when APP and/or UAN were applied the plant height response to ATS was inconsistent. The significant APP×UAN×ATS interaction for dry matter yield was similar to what was found for plant height. One gal/ac of ATS plus 4 gal/ac or APP applied in-furrow did not affect V7 plant heights or yields compared with 4 gal/ac of APP alone. The application of fluid fertilizers at planting resulted in dramatic visual (early growth, vigor, and color) differences.

Nutrient concentrations and uptakes in V7 corn plants were affected by the treatment main effects in this study, however the data were quite variable probably due to the cool and wet conditions in late May and June (Table 2). Four gal/ac of APP increased uptake of N, P, K and S, whereas nutrient concentrations in V7 corn plants were not affected by APP. Eight gal/ac of UAN applied as a surface band reduced N, P and S concentrations (likely due to the dilution effect), when averaged across APP and ATS treatments. The dilution effect occurs when early growth increases dramatically, thus causing concentrations of some nutrients to decline. Nutrient uptakes were not affected by UAN application. Potassium concentration in V7 plants decreased slightly at the 2 gal/ac rate of ATS compared with the control. Sulfur concentrations were very low, significantly less than established critical level of 0.20%, but were not affected by ATS application. A significant APP×ATS interaction for S concentration showed S concentration was least with the 4 gal/ac of APP and 0 gal/ac of ATS treatment (data not shown). Phosphorus, K, and S uptakes were increased when ATS was applied as a surface band. The nutrient uptake responses to treatment main effects found in this study were generally a result of increased plant dry matter (yield responses) and not to increased nutrient concentration. Several significant two and three way interactions were found for nutrient uptake in V7 corn plants. Generally, the APP×UAN×ATS interactions for N, P and S uptake were explained by the response found for dry matter yield discussed earlier. However, the unusual response observed with treatment # 6 (low dry matter yield and very low S concentration and uptake), which cannot be explained by the authors, may have caused some of these interactions. Adding 1 gal/ac of ATS to 4 gal/ac of APP applied in-furrow, did not affect nutrient concentrations and uptakes in V7 corn plants, compared with 4 gal/ac of APP alone.

Treatment effects on grain moisture, grain yield, and relative leaf chlorophyll content (RLC) are presented in Table 3. Grain was quite dry at harvest (October 3) considering the later than normal planting date (May 17). Application of APP or UAN at planting did not affect grain moisture at this site. Grain moisture increased 1.0 percentage point with 4 gal/ac of ATS compared with 0 gal/ac, when averaged across APP and UAN treatments. Corn grain yields were not affected by the application of APP, UAN or ATS at planting and there were no significant interactions. The wet spring followed by a dry August and September increased yield variability at this site. Yields ranged from 184 to 201 bu/ac. An *analysis of all 14 treatments found no significant differences for grain moisture and/or yield. Relative leaf chlorophyll content at R1 was not affected by any of the treatments at this site.*

Initial plant stand and final plant population were reduced 1200-1300 plants/ac with ATS fertilization, when averaged across APP and UAN treatments (Table 3). The cool and wet period after planting likely contributed to the stand reductions observed in these data. Highly significant APP×ATS and UAN×ATS interactions were found for initial stand and final plant population. When averaged across UAN rate, plant populations were greatest when APP and ATS were not applied. When APP was not applied, populations decreased linearly as the ATS rate increased; whereas, when APP was applied plant populations decreased with 2 gal/ac of ATS but not at the 4 gal/ac rate. These data showed under difficult climatic conditions ATS applied as a surface dribble band can reduce stand, however applying APP (in-furrow) plus ATS (dribble) did not reduce stand further. When averaged across APP rate, surface dribble banding UAN and ATS reduced plant populations compared with ATS alone (Figure 2b). Strangely, applying UAN without ATS increased populations. This interaction showed, unlike the response found with APP, applying UAN and ATS may increase the potential for stand reductions.

Treatment effects on the concentration and uptake of N, P, K and S in corn grain are presented in Table 4. Applying 4 gal/ac of APP at planting increased grain N concentration and uptake, but did not affect P, K and S on this very high P testing site. Grain N, P, K and S concentrations and uptakes were not affected by UAN applied as a surface dribble band at planting, when averaged across APP and ATS rates. Four gal/ac of ATS increased grain S concentration and uptake, when averaged across APP and UAN rates. Application of ATS did not affect grain N, P and K concentration and uptake. There were no highly ($P \leq 0.05$) significant interactions found for grain nutrient concentration and uptake.

Rochester site

The early part of the 2011 growing season at Rochester was cool but not as wet as Waseca (Table 1). Although the amounts were not great, frequent rains delayed planting and field operations in the area. July was warm and wet; precipitation totaled 4.66 inches greater than normal. August was dry, but September had near normal precipitation which aided late season grain fill and enhanced yields. Growing season precipitation totaled one inch below normal.

Generally, plant heights and whole plant dry matter yields were affected by all three of the treatment main effects in the factorial analysis of treatments 1-12 (Table 5). Heights and yields were increased when APP was applied in-furrow and when UAN was applied as a surface band. When averaged across APP and UAN rates, dry matter yields were greater with 4 gal/ac of ATS applied as a surface band compared with 0 or 2 gal/ac of ATS, although plant heights were not significantly greater (P-value = 0.105). No significant interactions were found for plant height and dry matter yield. These data were similar to the Waseca site and showed a consistent early growth and plant vigor advantage when fluid starter fertilizers were placed in or near the seed row at planting. Adding 1 gal/ac of ATS to 4 gal/ac of APP applied in-furrow had no affect on plant heights or dry matter yields compared with 4 gal/ac of APP alone.

Nutrient concentrations and uptakes in V7 corn plants were affected by the treatment main effects in this study (Table 5). An application of 4 gal/ac of APP at planting increased P concentration about 8% and decreased K concentration about 10%, when averaged across UAN and ATS rates. Moreover, APP application increased whole plant N, P, K and S uptake. Surface banding UAN increased N and P concentration and reduced K concentration, when averaged across APP and ATS treatments. Nitrogen, P and S uptake in V7 plants were increased by UAN application at planting. Sulfur concentration increased as the rate of ATS increased in the starter fertilizer, when averaged across APP and UAN treatments. Similar to APP and UAN application, ATS applied at planting decreased K concentration slightly. ATS application increased N, P and S uptake in V7 corn plants. No significant interactions were found for nutrient concentration and uptake. Applying 1 gal/ac of ATS and 4 gal/ac of APP in-furrow increased S concentration in whole plants compared with 4 gal/ac of APP alone.

Treatment effects on grain moisture, grain yield, initial plant stand, final plant population and relative leaf chlorophyll content (RLC) are presented in Table 6. Grain moisture was reduced 1.4 percentage points when APP was applied at planting. A significant APP×ATS interaction for grain moisture showed when APP was not applied ATS reduced grain moisture slightly. However when APP was applied grain moisture was considerably less and applying ATS did not further reduce moisture (data not shown). Corn grain yield increased 4 bu/ac with 4 gal/ac of APP compared with 0 gal/ac of APP, when averaged across UAN and ATS treatments. Yield was greater (202 bu/ac) with 4 gal/ac of ATS compared with 2 gal/ac (196 bu/ac) and 0 gal/ac (194 bu/ac) of ATS, when averaged across APP and UAN treatments. Applying 1 gal/ac of ATS and 4 gal/ac of APP in-furrow had no affect on grain yields compared with 4 gal/ac of APP alone. Initial plant stand and final plant populations were reduced slightly (≤600 plant/ac) with APP application. The 4 gal/ac rate of ATS also reduced initial stand about 500 plants/ac. These small reductions would not have affected grain yields. No Significant interactions were found for corn grain yield, initial plant stand and final plant population. Relative leaf chlorophyll content at R1 was greater with 2 and 4 gal/ac of ATS compared with 0 gal/ac of ATS. A highly significant APP×UAN interaction for RLC showed when APP was not applied, UAN application reduced RLC. However when APP was applied, UAN application increased RLC (data not shown). A significant APP×ATS interaction for RLC showed when APP was not applied, 2 and 4 gal/ac of ATS increased RLC compared with 0 gal/ac of ATS; Whereas when APP was applied, RLC increased as the rate of ATS increased (data not shown).

Treatment effects on the concentration and uptake of N, P, K and S in corn grain are presented in Table 7. Sulfur uptake in corn grain increased slightly with 4 gal/ac of APP applied at planting, when averaged across UAN and ATS treatments. Grain N concentration increased slightly when UAN was applied as a surface dribble band at planting, when averaged across APP and ATS rates. Sulfur concentration and uptake in corn grain increased as the rate of ATS increased, when averaged across APP and UAN rates. Nitrogen concentration in corn grain was reduced with 4 gal/ac of ATS compared with 2 gal/ac of ATS. Several significant interactions were found for grain nutrient concentration and uptake. Generally, these differences were small and of little agronomic importance.

2011 SUMMARY

A cool and wet spring delayed planting and slowed early growth and development of corn. Warm and wet conditions in July produced rapid growth, which allowed for the crop to "catch up" after a slow start to the growing season. Less than normal late summer rainfall, especially at Waseca, probably reduced yield potential. Crop response to the treatments varied between locations. At Waseca early growth and vigor were enhanced with fluid starter fertilizers but grain yields were not affected; Whereas, at Rochester early growth and grain yield were enhanced by starter treatments. Key observations from the second year of this 3-year study include:

1) *Early plant growth (plant heights and dry matter yields) were enhanced when N, P and S starter fertilizers as APP, UAN and ATS were applied at Waseca and Rochester sites.*
2) *Grain moisture was reduced 1.4 percentage points when APP was applied at Rochester. At Waseca grain moisture at harvest was very low and responses to treatments were inconsistent.*
3) *At Rochester on a medium testing P soil, corn grain yields increased 4 bu/ac with APP (phosphorus fertilization) compared with no APP.*
4) *Corn grain yields increased 8 bu/ac with the 4 gal/ac rate of ATS (sulfur fertilization) at Rochester compared with 0 gal/ac of ATS.*
5) *No grain yield responses to N, P and S starter fertilizers were found at Waseca in 2011. Cool and wet conditions early, followed by a very dry August and September increased variability and likely limited yields at this site.*
6) *For results from the 2010 study see Vetsch et al., 2011 (available online).*

2010–2011 SUMMARY

Treatment effects on corn grain moisture, grain yield and plant height by location (Waseca and Rochester) and year (2010 and 2011) are summarized in Table 8. Applying 4 gal/ac of APP in-furrow: 1) reduced grain moisture at three of four location-years; 2) increased grain yield at one of four location-years (4 bu/ac increase at Rochester in 2011); and 3) increased plant height at the V7 growth stage in all four location-year comparisons. Applying 8 gal/ac of UAN as a surface band: 1) reduced grain moisture in two of four location-years; 2) did not affect corn grain yield; and 3) increased plant height in three of four location-year comparisons. Applying ATS as a surface band: 1) reduced grain moisture in one of four location-years; 2) increased grain yield at two of four location-years (6-9 bu/ac at Waseca in 2010 and an 8 bu/ac with 4 gal/ac of ATS at Rochester in 2011); and 3) increased plant height in two of four location-year comparisons. A combination of N, P and S fluid starter fertilizers as APP, UAN and ATS increased plant height by 21% compared with the control (data not shown).

During this study period, applying APP and ATS independently or in combination had the greatest likelihood for increasing corn grain yields. Applying UAN as a nitrogen starter fertilizer did not affect grain yield in this study. Generally, APP, ATS and UAN applied as starter fertilizers increased early growth and vigor of continuous corn under reduced tillage and may reduce grain moisture at harvest.

ACKNOWLEDGEMENT

Grateful appreciation is extended to the Minnesota Agricultural Fertilizer Research and Education Council and the Fluid Fertilizer Foundation for funding this research.

REFERENCES

Randall and Vetsch. 2010. Enhancing continuous corn production under high-residue conditions with starter fluid fertilizer combinations and placements. Online: http://sroc.cfans.umn.edu/prod/groups/cfans/@pub/@cfans/@sroc/@research/documents/asset/cfans_asset_181506.pdf

Vetsch, Kaiser and Randall. 2011. Enhancing continuous corn production in conservation tillage with nitrogen, phosphorus, and sulfur starter fluid combinations and placements. Online: http://sroc.cfans.umn.edu/prod/groups/cfans/@pub/@cfans/@sroc/@research/documents/article/cfans_article_314086.pdf

Table 1. Precipitation at Waseca and Rochester and growing degree units (GDUs) at Waseca.

		Precipitation					
		Waseca		Rochester		Waseca GDUs	
Month	Year	2011	Normal[1/]	2011	Normal[1/]	2011	Normal[1/]
		- - - - - inches - - - - -		- - - - - inches - - - - -			
May	2011	4.67	3.93	2.72	3.66	299	332
June	2011	5.19	4.69	3.24	4.34	538	538
July	2011	7.21	4.42	9.19	4.53	790	655
Aug.	2011	0.92	4.75	1.89	4.66	617	597
Sept.	2011	0.86	3.67	2.82	3.66	238	348
May-Sept.	Total	18.85	21.46	19.86	20.85	2482	2470

[1/] 30-Yr normal, 1971-2010.

Table 2. Early growth, yield, nutrient concentration and uptake of V7 corn plants at Waseca.

				V7	Whole Plant Samples at V7 (June 30)								
	Fertilizer rate			Plant		Concentration				Uptake			
Trt	APP	UAN	ATS	height	Yield	N	P	K	S	N	P	K	S
#	----	gal/ac	-----	inch	lb/ac	--------------	%	--------------		----------	lb/ac	-----------	
1	0	0	0	30.2	577	3.53	0.398	4.82	0.177	20.4	2.30	27.8	1.02
2	0	0	2	32.0	675	3.36	0.419	4.57	0.179	23.1	2.86	31.1	1.22
3	0	0	4	37.2	828	3.45	0.436	5.10	0.174	29.3	3.59	44.3	1.43
4	0	8	0	35.4	729	3.56	0.375	4.87	0.167	25.9	2.73	35.5	1.21
5	0	8	2	36.0	791	3.26	0.402	4.42	0.171	27.4	3.20	35.5	1.41
6	0	8	4	35.4	716	2.75	0.368	5.07	0.148	19.9	2.61	36.4	1.06
7	4	0	0	35.5	742	3.46	0.417	4.82	0.166	25.8	3.05	35.6	1.23
8	4	0	2	38.3	863	3.47	0.420	4.81	0.169	30.2	3.63	41.5	1.47
9	4	0	4	37.0	822	3.47	0.416	4.97	0.179	28.3	3.41	40.9	1.46
10	4	8	0	37.3	837	2.78	0.366	4.95	0.135	25.1	3.21	43.1	1.21
11	4	8	2	35.4	822	3.32	0.406	4.72	0.170	27.3	3.33	38.8	1.39
12	4	8	4	39.0	876	3.13	0.391	4.74	0.168	27.6	3.42	41.4	1.48
13	4	0	1*	36.9	755	3.35	0.412	4.78	0.172	25.2	3.10	36.0	1.30
14	4	8	1*	34.8	811	2.90	0.410	4.75	0.153	23.5	3.32	38.6	1.24
Stats for RCB design (all 14 treatments)													
P > F:				0.001	0.001	0.024	0.038	0.205	0.022	0.040	0.001	0.001	0.028
Average LSD(0.10):				2.0	103	0.39	0.034	NS	0.020	5.2	0.46	5.1	0.24
Stats for a Factorial Design (Treatments 1-12)													
APP (10-34-0) applied in-furrow													
None				34.3	719	3.32	0.400	4.81	0.169	24.3	2.88	35.1	1.22
4 gal/ac				37.1	827	3.27	0.403	4.84	0.164	27.4	3.34	40.2	1.37
P > F:				0.001	0.001	0.895	0.731	0.765	0.347	0.027	0.001	0.000	0.022
UAN (28-0-0) applied as a surface dribble band													
None				35.0	751	3.46	0.418	4.85	0.174	26.2	3.14	36.9	1.30
8 gal/ac				36.4	795	3.13	0.385	4.80	0.160	25.5	3.08	38.4	1.29
P > F:				0.010	0.083	0.006	0.001	0.554	0.008	0.602	0.618	0.171	0.860
ATS (12-0-0-26) applied as a surface dribble band													
None				34.6	721	3.33	0.389	4.86	0.161	24.3	2.82	35.5	1.17
2 gal/ac				35.4	787	3.35	0.412	4.63	0.172	27.0	3.25	36.7	1.37
4 gal/ac				37.1	810	3.20	0.403	4.97	0.167	26.3	3.26	40.8	1.36
P > F:				0.001	0.014	0.240	0.112	0.013	0.212	0.194	0.004	0.001	0.014
Average LSD (0.10):				1.0	51	NS	NS	0.19	NS	NS	0.23	2.3	0.12
Interactions (P > F)													
APP×UAN				0.042	0.818	0.781	0.724	0.908	0.922	0.582	0.854	0.753	0.853
APP×ATS				0.272	0.547	0.097	0.991	0.088	0.033	0.964	0.496	0.026	0.691
UAN×ATS				0.016	0.041	0.208	0.343	0.549	0.364	0.042	0.019	0.001	0.150
APP×UAN×ATS				0.001	0.031	0.225	0.263	0.780	0.345	0.023	0.014	0.023	0.058

* One gal/ac rate of ATS applied in-furrow with seed and 10-34-0.

Table 3. Grain moisture and yield, plant stand, final plant population, and relative leaf chlorophyll at Waseca.

						Initial	Final	VT-R1
	Fertilizer rate			Grain	Grain	Plant	Plant	Leaf
Trt	APP	UAN	ATS	H_2O	Yield	Stand	Pop.	Chloro
#	-------	gal/ac	-------	%	bu/ac	plants×10^3/A		%
1	0	0	0	18.1	194	32.8	32.8	98.1
2	0	0	2	18.6	194	31.7	31.7	97.6
3	0	0	4	18.7	191	30.8	30.8	98.4
4	0	8	0	17.4	199	33.2	33.1	96.4
5	0	8	2	18.3	192	31.4	31.4	97.4
6	0	8	4	19.9	194	30.5	30.5	97.4
7	4	0	0	17.7	197	31.4	31.4	97.1
8	4	0	2	17.9	197	32.6	32.5	97.5
9	4	0	4	18.6	199	32.3	32.3	97.8
10	4	8	0	17.7	194	32.8	32.8	97.4
11	4	8	2	17.6	203	29.9	29.9	99.1
12	4	8	4	18.1	201	31.8	31.8	96.0
13	4	0	1*	18.2	197	31.0	31.0	99.0
14	4	8	1*	17.8	184	30.1	30.1	97.4
Stats for RCB design (all 14 treatments)								
P > F:				0.270	0.181	0.001	0.001	0.198
Average LSD (0.10):				NS	NS	1.3	1.3	NS
Stats for a Factorial Design (Treatments 1-12)								
APP (10-34-0) applied in-furrow								
None				18.5	194	31.7	31.7	97.6
4 gal/ac				17.9	198	31.8	31.8	97.5
P > F:				0.108	0.170	0.708	0.735	0.796
UAN (28-0-0) applied as a surface dribble band								
None				18.3	195	31.9	31.9	97.8
8 gal/ac				18.2	197	31.6	31.6	97.3
P > F:				0.785	0.662	0.300	0.314	0.301
ATS (12-0-0-26) applied as a surface dribble band								
None				17.8	196	32.6	32.5	97.3
2 gal/ac				18.1	197	31.4	31.4	97.9
4 gal/ac				18.8	196	31.3	31.3	97.4
P > F:				0.046	0.824	0.005	0.004	0.494
Average LSD (0.10):				0.7	NS	0.6	0.6	NS
Interactions (P > F)								
APP×UAN				0.649	0.685	0.409	0.459	0.238
APP×ATS				0.519	0.156	0.011	0.010	0.301
UAN×ATS				0.642	0.768	0.015	0.018	0.178
APP×UAN×ATS				0.333	0.212	0.088	0.094	0.368

* One gal/ac rate of ATS applied in-furrow with seed.

Table 4. Nutrient concentration and uptake in the corn grain at Waseca.

	Fertilizer rate			Grain concentration				Nutrient uptake in grain			
Trt	APP	UAN	ATS	N	P	K	S	N	P	K	S
#	------	gal/ac	-------	--------------	%	--------------		-------------	lb/ac	-------------	
1	0	0	0	1.15	0.25	0.38	0.079	105	23.3	34.5	7.3
2	0	0	2	1.15	0.27	0.39	0.082	105	24.6	35.6	7.5
3	0	0	4	1.20	0.26	0.38	0.084	109	23.8	34.1	7.6
4	0	8	0	1.15	0.26	0.38	0.079	108	24.3	35.6	7.4
5	0	8	2	1.19	0.27	0.39	0.079	108	24.6	35.6	7.1
6	0	8	4	1.09	0.26	0.40	0.085	100	24.2	36.8	7.8
7	4	0	0	1.21	0.25	0.37	0.080	113	23.3	34.6	7.4
8	4	0	2	1.20	0.26	0.37	0.081	111	23.8	34.5	7.5
9	4	0	4	1.20	0.26	0.38	0.085	112	24.1	35.3	7.9
10	4	8	0	1.16	0.26	0.38	0.079	104	23.5	33.5	7.0
11	4	8	2	1.20	0.27	0.38	0.081	115	25.8	36.8	7.8
12	4	8	4	1.17	0.27	0.38	0.085	111	25.2	36.2	8.1
13	4	0	1*	1.15	0.28	0.39	0.081	107	26.1	35.8	7.6
14	4	8	1*	1.12	0.26	0.37	0.083	97	22.6	32.6	7.3
Stats for RCB design (all 14 treatments)											
P > F:				0.062	0.943	0.848	0.161	0.017	0.705	0.409	0.020
Average LSD (0.10):				0.06	NS	NS	NS	8	NS	NS	0.5
Stats for a Factorial Design (Treatments 1-12)											
APP (10-34-0) applied in-furrow											
None				1.15	0.26	0.39	0.081	106	24.1	35.4	7.4
4 gal/ac				1.19	0.26	0.38	0.082	111	24.3	35.2	7.6
P > F:				0.042	0.610	0.203	0.768	0.018	0.848	0.807	0.107
UAN (28-0-0) applied as a surface dribble band											
None				1.18	0.26	0.38	0.082	109	23.8	34.8	7.5
8 gal/ac				1.16	0.26	0.39	0.081	108	24.6	35.7	7.5
P > F:				0.117	0.307	0.232	0.713	0.443	0.225	0.172	0.993
ATS (12-0-0-26) applied as a surface dribble band											
None				1.17	0.26	0.38	0.079	107	23.6	34.5	7.3
2 gal/ac				1.18	0.27	0.38	0.080	110	24.7	35.6	7.5
4 gal/ac				1.16	0.26	0.38	0.085	108	24.3	35.6	7.9
P > F:				0.540	0.548	0.513	0.001	0.558	0.393	0.369	0.001
Average LSD (0.10):				NS	NS	NS	0.002	NS	NS	NS	0.2
Interactions (P > F)											
APP×UAN				0.959	0.558	0.862	0.640	0.758	0.638	0.631	0.925
APP×ATS				0.969	0.912	0.800	0.964	0.491	0.791	0.693	0.198
UAN×ATS				0.078	0.987	0.807	0.769	0.242	0.974	0.537	0.533
APP×UAN×ATS				0.149	0.995	0.718	0.790	0.128	0.684	0.362	0.127

* One gal/ac rate of ATS applied in-furrow with seed and 10-34-0.

Table 5. Early growth, yield, nutrient concentration and uptake of V7 corn plants at Rochester.

				V7	Whole Plant Samples at V7 (June 24)								
	Fertilizer rate			Plant		Concentration				Uptake			
Trt	APP	UAN	ATS	height	Yield	N	P	K	S	N	P	K	S
#	---- gal/ac -----			inch	lb/ac	-------------- % --------------				---------- lb/ac -----------			
1	0	0	0	27.3	375	3.54	0.226	2.90	0.200	13.3	0.85	10.9	0.75
2	0	0	2	27.5	413	3.50	0.247	2.62	0.220	14.5	1.02	10.9	0.90
3	0	0	4	28.9	461	3.60	0.250	2.64	0.216	16.6	1.16	12.1	1.00
4	0	8	0	28.1	423	3.62	0.253	2.64	0.207	15.2	1.07	11.2	0.87
5	0	8	2	30.2	575	3.49	0.264	2.48	0.208	20.0	1.51	14.2	1.19
6	0	8	4	30.2	556	3.64	0.259	2.39	0.218	20.1	1.46	13.2	1.21
7	4	0	0	32.1	632	3.47	0.258	2.57	0.194	21.9	1.64	16.2	1.23
8	4	0	2	32.6	551	3.53	0.263	2.44	0.210	19.5	1.45	13.4	1.15
9	4	0	4	33.3	746	3.49	0.266	2.30	0.210	26.0	1.98	17.1	1.56
10	4	8	0	33.4	651	3.64	0.289	2.42	0.199	23.6	1.87	15.7	1.29
11	4	8	2	34.0	693	3.61	0.265	2.12	0.208	25.0	1.84	14.7	1.44
12	4	8	4	33.1	731	3.74	0.287	2.17	0.222	27.4	2.10	16.2	1.63
13	4	0	1*	31.4	608	3.55	0.276	2.31	0.211	21.6	1.70	14.2	1.28
14	4	8	1*	33.4	693	3.68	0.298	2.12	0.211	25.5	2.07	14.8	1.47
Stats for RCB design (all 14 treatments)													
P > F:				0.001	0.001	0.095	0.004	0.006	0.020	0.001	0.001	0.023	0.001
Average LSD(0.10):				1.9	102	0.15	0.026	0.32	0.013	3.2	0.36	3.2	0.23
Stats for a Factorial Design (Treatments 1-12)													
APP (10-34-0) applied in-furrow													
None				28.7	467	3.57	0.250	2.61	0.211	16.6	1.18	12.1	0.99
4 gal/ac				33.1	667	3.58	0.271	2.34	0.207	23.9	1.81	15.6	1.38
P > F:				0.001	0.001	0.720	0.001	0.002	0.156	0.001	0.001	0.001	0.001
UAN (28-0-0) applied as a surface dribble band													
None				30.3	530	3.52	0.252	2.58	0.208	18.6	1.35	13.4	1.10
8 gal/ac				31.5	605	3.62	0.269	2.37	0.210	21.9	1.64	14.2	1.27
P > F:				0.011	0.007	0.011	0.005	0.015	0.523	0.001	0.002	0.358	0.007
ATS (12-0-0-26) applied as a surface dribble band													
None				30.2	520	3.57	0.256	2.63	0.200	18.5	1.36	13.5	1.03
2 gal/ac				31.1	558	3.53	0.260	2.41	0.211	19.7	1.46	13.3	1.17
4 gal/ac				31.4	623	3.62	0.265	2.37	0.217	22.5	1.68	14.6	1.35
P > F:				0.105	0.009	0.186	0.459	0.028	0.001	0.005	0.016	0.375	0.001
Average LSD (0.10):				NS	54	NS	NS	0.17	0.006	1.9	0.18	NS	0.12
Interactions (P > F)													
APP×UAN				0.419	0.321	0.091	0.994	0.943	0.340	0.669	0.594	0.337	0.583
APP×ATS				0.484	0.159	0.507	0.204	0.999	0.741	0.244	0.123	0.230	0.237
UAN×ATS				0.407	0.127	0.416	0.395	0.976	0.148	0.239	0.493	0.409	0.369
APP×UAN×ATS				0.628	0.739	0.789	0.612	0.698	0.661	0.882	0.909	0.940	0.874

* One gal/ac rate of ATS applied in-furrow with seed and 10-34-0.

Table 6. Grain moisture and yield, plant stand, final plant population, and relative leaf chlorophyll at Rochester.

						Initial	Final	VT-R1
	Fertilizer rate			Grain	Grain	Plant	Plant	Leaf
Trt	APP	UAN	ATS	H_2O	Yield	Stand	Pop.	Chloro
#	-------	gal/ac	-------	%	bu/ac	plants×10^3/A		%
1	0	0	0	21.8	193	35.2	34.7	97.4
2	0	0	2	21.4	194	35.6	34.8	98.3
3	0	0	4	20.8	198	34.9	34.4	98.0
4	0	8	0	22.0	188	35.8	34.7	94.7
5	0	8	2	20.6	194	35.6	34.7	97.2
6	0	8	4	21.0	205	34.5	34.4	96.9
7	4	0	0	19.8	197	34.8	34.6	96.7
8	4	0	2	20.4	198	34.7	34.2	96.6
9	4	0	4	19.7	203	34.4	34.3	98.1
10	4	8	0	19.8	196	34.7	34.4	96.0
11	4	8	2	19.7	199	35.1	34.7	98.4
12	4	8	4	20.0	204	34.7	34.5	99.4
13	4	0	1*	20.6	199	35.1	34.5	98.1
14	4	8	1*	19.9	196	34.4	34.3	98.7
Stats for RCB design (all 14 treatments)								
P > F:				0.001	0.011	0.244	0.430	0.001
Average LSD (0.10):				0.8	7	NS	NS	1.4
Stats for a Factorial Design (Treatments 1-12)								
APP (10-34-0) applied in-furrow								
None				21.3	195	35.3	34.6	97.1
4 gal/ac				19.9	199	34.7	34.4	97.5
P > F:				0.001	0.011	0.025	0.086	0.167
UAN (28-0-0) applied as a surface dribble band								
None				20.6	197	34.9	34.5	97.5
8 gal/ac				20.5	198	35.1	34.6	97.1
P > F:				0.501	0.718	0.570	0.596	0.200
ATS (12-0-0-26) applied as a surface dribble band								
None				20.9	194	35.1	34.6	96.2
2 gal/ac				20.5	196	35.2	34.6	97.6
4 gal/ac				20.4	202	34.6	34.4	98.1
P > F:				0.117	0.001	0.083	0.216	0.001
Average LSD (0.10):				NS	3	0.5	NS	0.6
Interactions (P > F)								
APP×UAN				1.000	0.908	0.673	0.275	0.001
APP×ATS				0.027	0.624	0.513	0.649	0.141
UAN×ATS				0.084	0.179	0.794	0.517	0.026
APP×UAN×ATS				0.908	0.435	0.523	0.219	0.817

* One gal/ac rate of ATS applied in-furrow with seed.

Table 7. Nutrient concentration and uptake in the corn grain at Rochester.											
	Fertilizer rate			Grain concentration				Nutrient uptake in grain			
Trt	APP	UAN	ATS	N	P	K	S	N	P	K	S
#	------ gal/ac -------			-------------- % --------------				------------- lb/ac -------------			
1	0	0	0	1.18	0.23	0.37	0.072	108	21.3	33.4	6.6
2	0	0	2	1.19	0.22	0.35	0.073	109	20.1	32.2	6.7
3	0	0	4	1.18	0.22	0.34	0.076	110	20.1	31.8	7.1
4	0	8	0	1.21	0.24	0.38	0.068	108	21.5	33.4	6.0
5	0	8	2	1.21	0.25	0.38	0.073	111	23.3	35.2	6.7
6	0	8	4	1.15	0.24	0.37	0.076	111	23.2	35.4	7.3
7	4	0	0	1.17	0.27	0.40	0.070	109	25.4	37.7	6.5
8	4	0	2	1.17	0.22	0.35	0.074	109	20.4	33.1	6.9
9	4	0	4	1.17	0.25	0.38	0.078	112	24.4	36.5	7.5
10	4	8	0	1.21	0.23	0.35	0.065	113	20.8	32.1	6.0
11	4	8	2	1.23	0.23	0.36	0.073	115	21.6	33.6	6.9
12	4	8	4	1.18	0.23	0.37	0.082	114	22.2	35.2	7.9
13	4	0	1*	1.17	0.25	0.37	0.076	110	23.2	35.2	7.2
14	4	8	1*	1.19	0.24	0.36	0.070	110	21.8	33.0	6.5
Stats for RCB design (all 14 treatments)											
P > F:				0.235	0.286	0.203	0.001	0.856	0.255	0.159	0.001
Average LSD (0.10):				NS	NS	NS	0.004	NS	NS	NS	0.5
Stats for a Factorial Design (Treatments 1-12)											
APP (10-34-0) applied in-furrow											
None				1.18	0.23	0.36	0.073	109	21.6	33.6	6.7
4 gal/ac				1.19	0.24	0.37	0.074	112	22.5	34.7	7.0
P > F:				0.829	0.588	0.578	0.412	0.131	0.245	0.141	0.060
UAN (28-0-0) applied as a surface dribble band											
None				1.18	0.24	0.37	0.074	110	22.0	34.1	6.9
8 gal/ac				1.20	0.24	0.37	0.073	112	22.1	34.1	6.8
P > F:				0.050	0.876	0.992	0.238	0.157	0.861	0.968	0.498
ATS (12-0-0-26) applied as a surface dribble band											
None				1.19	0.24	0.37	0.069	109	22.3	34.1	6.3
2 gal/ac				1.20	0.23	0.36	0.073	111	21.4	33.5	6.8
4 gal/ac				1.17	0.23	0.36	0.078	112	22.5	34.7	7.5
P > F:				0.075	0.412	0.438	0.001	0.476	0.433	0.442	0.001
Average LSD (0.10):				0.02	NS	NS	0.002	NS	NS	NS	0.2
Interactions (P > F)											
APP×UAN				0.177	0.011	0.008	0.647	0.367	0.010	0.008	0.750
APP×ATS				0.742	0.310	0.293	0.040	0.969	0.317	0.353	0.253
UAN×ATS				0.174	0.113	0.131	0.030	0.726	0.068	0.045	0.015
APP×UAN×ATS				0.863	0.674	0.611	0.348	0.923	0.633	0.685	0.810

* One gal/ac rate of ATS applied in-furrow with seed and 10-34-0.

Table 8. Corn grain moisture, yield and plant height as affected by treatment main effects by location and year.

	Waseca location						Rochester location					
	Grain moisture		Grain yield		Plant height		Grain moisture		Grain yield		Plant height	
Main effect	2010	2011	2010	2011	2010	2011	2010	2011	2010	2011	2010	2011
	%		bu/ac		inch		%		bu/ac		inch	
APP (10-34-0) in-furrow												
None	18.6a	18.5a	214a	194a	32.7a	34.3a	17.4a	21.3a	208a	195a	36.8a	28.7a
4 gal/ac	17.7b	17.9a	214a	198a	35.3b	37.1b	16.5b	19.9b	210a	199b	40.0b	33.1b
UAN (28-0-0) surface dribble-band												
None	18.6a	18.3a	216a	195a	32.4a	35.0a	17.1a	20.6a	209a	197a	38.2a	30.3a
8 gal/ac	17.7b	18.2a	212a	197a	35.5b	36.4b	16.8b	20.5a	209a	198a	38.6a	31.5b
ATS (12-0-0-26) surface dribble-band												
None	19.5a	17.8a	209a	196a	32.5a	34.6a	17.1a	20.9a	209a	194a	38.2a	30.2a
2 gal/ac	18.0b	18.1a	218b	197a	34.6b	35.4a	17.0a	20.5a	209a	196a	38.3a	31.1a
4 gal/ac	17.0c	18.8b	215b	196a	34.8b	37.1b	16.8a	20.4a	210a	202b	38.7a	31.4a