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Jeffrey Vetsch
University of Minnesota

Daniel Kaiser
University of Minnesota

Gyles Randall
University of Minnesota

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Jeffrey Vetsch, assistant scientist, Southern Research and Outreach Center, University of Minnesota; Daniel Kaiser, Extension nutrient management specialist and assistant professor, Soil, Water, and Climate, University of Minnesota; and Gyles Randall, professor emeritus, Southern Research and Outreach Center and Dept. of Soil, Water, and Climate, University of Minnesota.

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 [ammonium polyphosphate (APP, 10-34-0) applied in furrow or APP and urea ammonium nitrate (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 (Vetsch and Randall, 2010). 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 ammonium thiosulfate (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 each spring in 2010 and 2011. One on a Webster clay loam soil at the Southern Research and Outreach Center, Waseca and another on a Mt Carroll silt loam near Rochester. All sites were planted to corn the previous year 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 about 2” off 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 test P and K at 3 of the 4 sites were in the high to very high range (Kaiser et al.), except at Rochester in 2011 where Bray P_1 = 13 ppm (medium) and exchangeable K = 68 ppm (low). Because of low soil test K, 120 lb K_2O/ac was injected mid-row at Rochester on June 9, 2011.

Corn was planted at 35,000 seeds/ac in early May in 2010 and mid-May in 2011. Weeds were controlled with a combination of pre and post emergence herbicide applications. Surface residue cover was measured using the line transect method. It ranged from only 12% at Rochester in 2011 to 45% at Waseca and averaged 34% across sites. 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, UAN was injected at various rates midway between the rows to give a total (planting + V2-3) N rate of 180 lb/ac in 2010 and 200 lb/ac in 2011. At the V7-8 growth stage of corn 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 and uptake in plant tissue. On the same dates, extended leaf plant heights from 10 random plants per plot were also measured. At R1, 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 by harvesting the center two rows of each plot with a research plot combine. Grain yields were calculated at 15.5% moisture.

Results and discussion

The 2010 growing season was warm and wet. Two months [June (9.64", 5.42" greater-than-normal) and September (12.66", 9.47" greater-than-normal)] set 96-year records for precipitation at Waseca (Table 1). The June + July total precipitation (16.25") and the growing season total (34.61") were also records. Growing season precipitation at the Rochester location was about 50% greater-than-normal. With much of the excess falling during the months of June, August, and September. At Waseca, growing degree units (GDU) for the entire growing season May 1 through October 3 (first frost) totaled 2,606 which was 8% greater-than-normal.

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. 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.

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

		Precipitation					
		Waseca		Rochester		Waseca GDUs	
Month	Year	Current	Normal[1/]	Current	Normal[1/]	Current	Normal[1/]
		- - - - - inches - - - - -		- - - - - inches - - - - -			
May	2010	3.27	3.93	3.72	3.66	363	332
June	2010	9.64	4.69	6.55	4.34	509	538
July	2010	6.61	4.42	3.81	4.53	691	655
Aug.	2010	2.43	4.75	6.49	4.66	698	597
Sept.	2010	12.66	3.67	9.62	3.66	320	348
May-Sept.	Total	34.61	21.46	30.19	20.85	2581	2470
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, 1981-2010.

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. Because of differences in climate and response to treatments, each location-year will be discussed separately.

Waseca 2010

Treatment effects on grain moisture and grain yields are presented in Table 2. Grain moisture was reduced 0.9 percentage points with APP (4 gal/ac vs 0 gal) and UAN (8 gal/ac vs 0 gal) application. Grain moisture was reduced 1.5 and 2.5 percentage points with the 2 and 4 gal/ac rate of ATS, respectively, compared with 0 gal of ATS and averaged across APP and UAN treatments. The driest grain (16.5%) was obtained when N, P, and S were applied at planting (treatment # 12). The wettest grain (20.7%) was found in the control plot (treatment # 1). Corn grain yields were not affected by the application of APP or UAN at planting, although APP and UAN application enhanced early growth and reduced grain moisture. Grain yields were 9 bu/ac greater than the control with 2 gal/ac of ATS, when averaged across APP and UAN treatments. Yields were not different between the 2 and 4 gal/ac rates of ATS. Applying 1 gal/ac of ATS and 4 gal/ac of APP in-furrow increased yields 12 bu/ac compared with APP alone (treatments 13 vs 7). A significant UAN×ATS interaction for grain yield showed a 19 bu/ac response to ATS when UAN was not applied, but no response to ATS when 8 gal/ac of UAN was applied at planting (data not shown).

Table 2. Grain moisture and yield, plant stand, final plant population, relative leaf chlorophyll, plant height, dry matter yield and nutrient uptake at Waseca in 2010.

						Initial	Final	VT-R1	V7	Whole Plant Samples at V7				
	Fertilizer rate			Grain	Grain	Plant	Plant	Leaf	Plant		Uptake			
Trt	APP	UAN	ATS	H_2O	Yield	Stand	Pop.	Chloro	height	Yield	N	P	K	S
#	------- gal/ac --------			%	bu/ac	plants×10^3/ac		%	inch	lb/ac	---------- lb/ac -----------			
1	0	0	0	20.7	202	34.6	33.7	89.7	28.4	438	17.0	1.89	20.3	0.88
2	0	0	2	19.0	220	35.0	33.8	94.8	31.4	593	22.9	2.50	28.5	1.16
3	0	0	4	17.5	220	33.7	33.2	99.2	31.9	636	23.6	2.84	30.4	1.39
4	0	8	0	19.5	213	34.6	33.8	90.6	33.9	767	29.7	3.50	34.6	1.50
5	0	8	2	18.0	220	34.7	33.8	97.1	34.9	815	32.3	3.58	37.4	1.69
6	0	8	4	16.9	210	34.4	33.8	99.1	35.6	852	33.1	3.95	40.1	1.86
7	4	0	0	19.0	207	34.4	33.7	91.8	32.9	584	21.2	2.52	26.8	1.12
8	4	0	2	18.2	223	34.1	33.6	94.9	35.0	730	28.0	3.37	34.5	1.46
9	4	0	4	17.2	222	34.2	33.6	98.8	35.0	720	27.3	3.10	32.3	1.53
10	4	8	0	18.8	212	33.5	33.5	92.2	34.9	810	29.5	3.53	39.6	1.42
11	4	8	2	16.8	210	34.6	33.8	97.5	37.1	913	33.9	4.00	43.1	1.76
12	4	8	4	16.5	209	33.3	33.2	98.2	36.6	847	31.2	3.64	37.9	1.80
13	4	0	1*	18.6	219	33.6	33.4	94.2	34.7	749	28.3	3.31	35.0	1.44
14	4	8	1*	17.9	209	33.4	33.2	92.7	35.0	786	29.1	3.46	38.6	1.46
Stats for RCB design (all 14 treatments)														
P > F:				0.001	0.021	0.057	0.022	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Average LSD (0.10):				1.1	10	0.9	0.4	1.6	1.4	91	3.7	0.44	4.3	0.20
Stats for a Factorial Design (Treatments 1-12)														
APP (10-34-0) applied in-furrow														
None				18.6	214	34.5	33.7	95.1	32.7	683	26.4	3.04	31.9	1.41
4 gal/ac				17.7	214	34.0	33.5	95.6	35.3	767	28.5	3.36	35.7	1.51
P > F:				0.001	0.998	0.059	0.252	0.223	0.001	0.005	0.080	0.026	0.006	0.112
UAN (28-0-0) applied as a surface dribble band														
None				18.6	216	34.3	33.6	94.9	32.4	617	23.3	2.70	28.8	1.26
8 gal/ac				17.7	212	34.2	33.6	95.8	35.5	834	31.6	3.70	38.8	1.67
P > F:				0.002	0.193	0.566	0.963	0.022	0.001	0.001	0.001	0.001	0.001	0.001
ATS (12-0-0-26) applied as a surface dribble band														
None				19.5	209	34.3	33.7	91.1	32.5	650	24.3	2.86	30.3	1.23
2 gal/ac				18.0	218	34.6	33.7	96.1	34.6	763	29.3	3.36	35.9	1.52
4 gal/ac				17.0	215	33.9	33.4	98.8	34.8	764	28.8	3.38	35.1	1.64
P > F:				0.001	0.012	0.081	0.037	0.001	0.001	0.003	0.002	0.005	0.003	0.001
Average LSD (0.10):				0.5	5.1	0.5	0.2	0.8	0.7	59	2.41	0.28	2.7	0.13
Interactions (P > F)														
APP×UAN				0.675	0.194	0.248	0.035	0.736	0.001	0.187	0.062	0.056	0.452	0.052
APP×ATS				0.341	0.680	0.802	0.854	0.032	0.593	0.529	0.680	0.148	0.116	0.637
UAN×ATS				0.649	0.009	0.645	0.705	0.018	0.353	0.306	0.395	0.274	0.155	0.825
APP×UAN×ATS				0.488	0.719	0.109	0.026	0.872	0.383	0.886	0.922	0.973	0.840	0.916

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

Treatment effects on plant stand, final population and relative leaf chlorophyll content (RLC) are presented in Table 2. Initial plant stand was reduced slightly (500 plants/ac) with APP fertilization, when averaged across UAN and ATS treatments. Initial stand and final plant population were affected by ATS application in this study, but the differences were generally very small and would not have affected corn production. When 1 gal/ac of ATS and 4 gal/ac of APP were applied in-furrow (treatment # 13), initial plant stand and final plant population trended lower, but they were not significantly less than 4 gal/ac of APP alone (treatment # 7). Significant interactions for final plant population were found, but the differences were small about 300 plants/ac and would not have influenced corn production. Relative leaf chlorophyll content at VT-R1 increased slightly with 8 gal/ac of UAN applied at planting compared with 0 gal of UAN, when averaged across APP and ATS treatments. The 2 and 4 gal/ac rates of ATS increased RLC 5.0 and 7.7 percentage points, respectively, compared with the control (0 gal/ac), when averaged across APP and UAN treatments. One gal/ac of ATS and 4 gal/ac of APP applied in-furrow increased RLC significantly compared with 4 gal/ac of APP alone. No difference in RLC was found when the 1 gal/ac of ATS plus 4 gal/ac of APP applied in-furrow treatment (# 13) was compared to the 4 gal/ac of APP applied in-furrow plus 2 gal/ac of ATS applied as a surface dribble band treatment (# 8). The significant APP×ATS interaction for RLC showed without ATS, APP increased RLC slightly (1-2 percentage points). Whereas with ATS at 2 or 4 gal/ac, APP application had no affect on RLC (data not shown). The significant UAN×ATS interaction for RLC was similar to the APP×ATS interaction. It showed at the 0 and 2 gal/ac rates of ATS, UAN application increased RLC slightly, whereas at the 4 gal/ac rate of ATS, UAN application had no affect on RLC (data not shown). These data show a small amount of N at planting, either from APP applied in-furrow or UAN applied as a surface dribble band, increased VT-R1 RLC values slightly in the absence of ATS. However when ATS was applied, the response in RLC was significantly large and masked any effect of APP or UAN. Interestingly, the 1 and 2 gal/ac rates of ATS resulted in corn plants that were pale (significantly less RLC) when compared to the 4 gal/ac rate, but these treatments produced similar grain yields as the 4 gal/ac treatments. This suggests at this site only a small amount of S (1 gal/ac of ATS = 2.9 lb S/ac) applied in the seed furrow at planting was needed to get a yield response on this high organic matter soil.

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. The 4 gal/ac rate of ATS did not increase heights or yields above the 2 gal/ac rate, when averaged across APP and UAN treatment main effects. A significant APP×UAN interaction for plant height was explained by the magnitude of the response in plant height when fertilized with one vs both of these nutrients. Plant heights increased about 4” when fertilized with either UAN or APP, compared with plots without UAN and APP. Whereas plant heights increased only 2” when fertilized with both UAN and APP, compared with either UAN or APP. The 1 gal/ac of ATS plus 4 gal/ac or APP applied in-furrow treatment increased V7 plant heights and yields compared with 4 gal/ac of APP alone.

Nutrient uptakes in V7 corn plants were affected by the treatment main effects in this study (Table 2). Applying 4 gal/ac of APP in-furrow increased N, P, and K uptake, when averaged across UAN and ATS treatments. Nitrogen, P, K and S uptakes in corn plants were increased when UAN and ATS were applied at planting. Generally the nutrient uptake responses to treatment main effects found in this study were a result of small plant DM yield responses to treatments and not to increased nutrient concentrations. Significant APP×UAN interactions for N, P and S uptake in V7 corn plants were a result of increased growth and have the same explanation as the APP×UAN interaction for plant height in the previous paragraph (data not shown).

Waseca 2011

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 (data not shown). 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. 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.

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 3). 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.

Nutrient 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 3). Four gal/ac of APP increased uptake of N, P, K and S. 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. Adding 1 gal/ac of ATS to 4 gal/ac of APP applied in-furrow, did not affect nutrient uptakes in V7 corn plants, compared with 4 gal/ac of APP alone.

Rochester 2010

Treatment effects on grain moisture, grain yield, initial plant stand, final plant population, and relative leaf chlorophyll content are presented in Table 4. Grain moisture was reduced 0.9 percentage points with 4 gal/ac of APP compared with 0 gal/ac, when averaged across UAN and ATS treatments. Application of UAN reduced grain moisture slightly (0.3 percentage points), when averaged across APP and ATS treatments. Three significant interactions (APP×ATS, UAN×ATS and APP×UAN×ATS) were found for corn grain moisture. Generally these interactions showed when APP was not applied, grain moisture was reduced with ATS with or without UAN. However, when APP was applied, the grain moisture response to ATS with or without UAN was erratic. Corn yields only ranged from 207 to 213 bu/ac across all 14 treatments in this study. No significant differences were found among treatments, and there were no interactions. No differences in final plant population were found among treatment main effects. At VT-R1 RLC ranged from 94.6 to 99.1% and was not affected by the main effects of APP and UAN application. The 2 and 4 gal/ac rates of ATS increased RLC about 1 percentage point compared with the 0 gal/ac rate of ATS, when averaged across APP and UAN main effects.

Treatment effects on early growth of small corn plants harvested on June 24 (V7-8 stage) are presented in Table 4. Plant heights and dry matter yields were increased with 4 gal/ac of APP applied in-furrow compared with 0 gal/ac, when averaged across UAN and ATS treatments. Plant heights and dry matter yields were not affected by the main effects of UAN and ATS application, and there were no significant interactions. This suggests the early growth response at this site was primarily due to P in the APP starter. Adding 1 gal/ac of ATS to 4 gal/ac of APP in-furrow had no effect on plant height and dry matter yield compared with APP alone. The large increase in dry matter yield with APP fertilization observed in this study, resulted in increased N, P, K, and S uptake compared with plots that did not get APP. Adding 1 gal/ac of ATS to 4 gal/ac of APP in-furrow, generally did not affect nutrient uptakes in small corn plants compared with APP alone. The highly significant APP×ATS interactions for K uptake in V7-8 corn plants showed without APP, K uptake declined when ATS was applied. Whereas with APP, K uptake increased as the rate of ATS increased (data not shown). Lowest K uptakes were found when APP was not applied and 4 gal/ac of ATS was applied (data not shown). These results were not found at the S-responding Waseca site.

Table 3. Grain moisture and yield, plant stand, final plant population, relative leaf chlorophyll, plant height, dry matter yield, and nutrient uptake at Waseca in 2011.

						Initial	Final	VT-R1	V7	Whole Plant Samples at V7				
	Fertilizer rate			Grain	Grain	Plant	Plant	Leaf	Plant		Uptake			
Trt	APP	UAN	ATS	H_2O	Yield	Stand	Pop.	Chloro	height	Yield	N	P	K	S
#	------ gal/ac -------			%	bu/ac	plants×10^3/A		%	inch	lb/ac	---------- lb/ac -----------			
1	0	0	0	18.1	194	32.8	32.8	98.1	30.2	577	20.4	2.30	27.8	1.02
2	0	0	2	18.6	194	31.7	31.7	97.6	32.0	675	23.1	2.86	31.1	1.22
3	0	0	4	18.7	191	30.8	30.8	98.4	37.2	828	29.3	3.59	44.3	1.43
4	0	8	0	17.4	199	33.2	33.1	96.4	35.4	729	25.9	2.73	35.5	1.21
5	0	8	2	18.3	192	31.4	31.4	97.4	36.0	791	27.4	3.20	35.5	1.41
6	0	8	4	19.9	194	30.5	30.5	97.4	35.4	716	19.9	2.61	36.4	1.06
7	4	0	0	17.7	197	31.4	31.4	97.1	35.5	742	25.8	3.05	35.6	1.23
8	4	0	2	17.9	197	32.6	32.5	97.5	38.3	863	30.2	3.63	41.5	1.47
9	4	0	4	18.6	199	32.3	32.3	97.8	37.0	822	28.3	3.41	40.9	1.46
10	4	8	0	17.7	194	32.8	32.8	97.4	37.3	837	25.1	3.21	43.1	1.21
11	4	8	2	17.6	203	29.9	29.9	99.1	35.4	822	27.3	3.33	38.8	1.39
12	4	8	4	18.1	201	31.8	31.8	96.0	39.0	876	27.6	3.42	41.4	1.48
13	4	0	1*	18.2	197	31.0	31.0	99.0	36.9	755	25.2	3.10	36.0	1.30
14	4	8	1*	17.8	184	30.1	30.1	97.4	34.8	811	23.5	3.32	38.6	1.24
<u>Stats for RCB design (all 14 treatments)</u>														
P > F:				0.270	0.181	0.001	0.001	0.198	0.001	0.001	0.040	0.001	0.001	0.028
Average LSD (0.10)				NS	NS	1.3	1.3	NS	2.0	103	5.2	0.46	5.1	0.24
<u>Stats for a Factorial Design (Treatments 1-12)</u>														
APP (10-34-0) applied in-furrow														
None				18.5	194	31.7	31.7	97.6	34.3	719	24.3	2.88	35.1	1.22
4 gal/ac				17.9	198	31.8	31.8	97.5	37.1	827	27.4	3.34	40.2	1.37
P > F:				0.108	0.170	0.708	0.735	0.796	0.001	0.001	0.027	0.001	0.000	0.022
UAN (28-0-0) applied as a surface dribble band														
None				18.3	195	31.9	31.9	97.8	35.0	751	26.2	3.14	36.9	1.30
8 gal/ac				18.2	197	31.6	31.6	97.3	36.4	795	25.5	3.08	38.4	1.29
P > F:				0.785	0.662	0.300	0.314	0.301	0.010	0.083	0.602	0.618	0.171	0.860
ATS (12-0-0-26) applied as a surface dribble band														
None				17.8	196	32.6	32.5	97.3	34.6	721	24.3	2.82	35.5	1.17
2 gal/ac				18.1	197	31.4	31.4	97.9	35.4	787	27.0	3.25	36.7	1.37
4 gal/ac				18.8	196	31.3	31.3	97.4	37.1	810	26.3	3.26	40.8	1.36
P > F:				0.046	0.824	0.005	0.004	0.494	0.001	0.014	0.194	0.004	0.001	0.014
Average LSD (0.10)				0.7	NS	0.6	0.6	NS	1.0	51	NS	0.23	2.3	0.12
Interactions (P > F)														
APP×UAN				0.649	0.685	0.409	0.459	0.238	0.042	0.818	0.582	0.854	0.753	0.853
APP×ATS				0.519	0.156	0.011	0.010	0.301	0.272	0.547	0.964	0.496	0.026	0.691
UAN×ATS				0.642	0.768	0.015	0.018	0.178	0.016	0.041	0.042	0.019	0.001	0.150
APP×UAN×ATS				0.333	0.212	0.088	0.094	0.368	0.001	0.031	0.023	0.014	0.023	0.058

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

Rochester 2011

Treatment effects on grain moisture, grain yield, initial plant stand, final plant population and relative leaf chlorophyll content (RLC) are presented in Table 5. 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).

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 uptakes in V7 corn plants were affected by the treatment main effects in this study (Table 5). Four gal/ac of APP applied at planting increased whole plant N, P, K and S uptake. Nitrogen, P and S uptake in V7 plants were increased by UAN and ATS application at planting. No significant interactions were found for nutrient uptake.

Summary

Starter fertilizer treatment effects on continuous corn production across sites and years include:

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 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.

Table 4. Grain moisture and yield, plant stand, final plant population, relative leaf chlorophyll, plant height, dry matter yield and nutreint uptake at Rochester in 2010.

						Initial	Final	VT-R1	V7	Whole Plant Samples at V7				
	Fertilizer rate			Grain	Grain	Plant	Plant	Leaf	Plant		Uptake			
Trt	APP	UAN	ATS	H_2O	Yield	Stand	Pop.	Chloro	height	Yield	N	P	K	S
#	------ gal/ac -------			%	bu/ac	plants×10^3/A		%	inch	lb/ac	---------- lb/ac -----------			
1	0	0	0	17.9	207	34.4	34.2	96.9	37.2	1464	52.2	6.33	63.2	2.93
2	0	0	2	17.6	207	35.2	34.4	98.4	35.7	1337	47.9	5.50	42.3	2.74
3	0	0	4	17.3	211	35.0	34.4	96.8	36.1	1361	48.8	5.66	43.1	2.96
4	0	8	0	17.6	208	34.4	33.9	94.6	37.3	1629	56.8	6.55	63.1	3.34
5	0	8	2	17.0	209	34.7	34.3	97.8	37.0	1577	55.2	6.19	49.8	3.32
6	0	8	4	16.7	207	34.3	33.9	99.1	37.4	1464	52.9	5.90	44.8	3.40
7	4	0	0	16.3	209	33.9	33.7	97.1	38.9	1897	64.1	7.45	67.3	3.69
8	4	0	2	17.3	210	34.2	33.9	96.8	40.6	1949	63.8	8.12	84.8	3.83
9	4	0	4	16.1	210	35.1	34.5	97.9	40.6	1888	65.8	7.71	66.2	3.85
10	4	8	0	16.5	210	34.2	34.1	98.1	39.3	1756	58.2	6.99	61.6	3.42
11	4	8	2	16.0	211	35.2	34.5	98.3	39.9	1992	68.8	7.86	63.5	4.16
12	4	8	4	17.0	211	34.3	34.0	96.9	40.8	2057	71.0	8.42	94.5	4.30
13	4	0	1*	16.8	209	34.3	34.0	97.7	40.4	1907	64.1	7.67	74.9	3.55
14	4	8	1*	16.4	213	33.4	33.4	96.2	40.4	1987	65.5	7.96	76.8	3.90
Stats for RCB design (all 14 treatments)														
P > F:				0.001	0.938	0.020	0.038	0.031	0.001	0.016	0.048	0.049	0.049	0.024
Average LSD (0.10):				0.7	NS	0.8	0.5	1.8	2.0	389	12.6	1.67	26.3	0.73
Stats for a Factorial Design (Treatments 1-12)														
APP (10-34-0) applied in-furrow														
None				17.4	208	34.7	34.2	97.3	36.8	1472	52.3	6.02	51.0	3.12
4 gal/ac				16.5	210	34.5	34.1	97.5	40.0	1923	65.3	7.76	73.0	3.88
P > F:				0.001	0.211	0.431	0.550	0.581	0.001	0.001	0.001	0.001	0.001	0.001
UAN (28-0-0) applied as a surface dribble band														
None				17.1	209	34.6	34.2	97.3	38.2	1649	57.1	6.80	61.2	3.33
8 gal/ac				16.8	209	34.5	34.1	97.5	38.6	1746	60.5	6.98	62.8	3.66
P > F:				0.081	0.952	0.531	0.595	0.735	0.389	0.213	0.210	0.572	0.750	0.035
ATS (12-0-0-26) applied as a surface dribble band														
None				17.1	209	34.2	34.0	96.7	38.2	1687	57.8	6.83	63.8	3.35
2 gal/ac				17.0	209	34.8	34.3	97.8	38.3	1714	58.9	6.92	60.1	3.51
4 gal/ac				16.8	210	34.7	34.2	97.7	38.7	1693	59.6	6.92	62.1	3.63
P > F:				0.332	0.881	0.058	0.147	0.067	0.652	0.954	0.853	0.964	0.844	0.310
Average LSD (0.10):				NS	NS	0.4	NS	0.9	NS	NS	NS	NS	NS	NS
Interactions (P > F)														
APP×UAN				0.191	0.625	0.134	0.103	0.401	0.363	0.345	0.462	0.561	0.804	0.316
APP×ATS				0.071	0.953	0.824	0.596	0.041	0.174	0.287	0.226	0.136	0.024	0.290
UAN×ATS				0.015	0.767	0.100	0.098	0.414	0.914	0.734	0.546	0.762	0.201	0.489
APP×UAN×ATS				0.031	0.699	0.286	0.419	0.008	0.660	0.596	0.652	0.651	0.108	0.637

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

Table 5. Grain moisture and yield, plant stand, final plant population, relative leaf chlorophyll, plant height, dry matter yield and nutrient uptake at Rochester in 2011.

						Initial	Final	VT-R1	V7	Whole Plant Samples at V7				
	Fertilizer rate			Grain	Grain	Plant	Plant	Leaf	Plant		Uptake			
Trt	APP	UAN	ATS	H_2O	Yield	Stand	Pop.	Chloro	height	Yield	N	P	K	S
#	------- gal/ac --------			%	bu/ac	plants×10^3/A		%	inch	lb/ac	---------- lb/ac -----------			
1	0	0	0	21.8	193	35.2	34.7	97.4	27.3	375	13.3	0.85	10.9	0.75
2	0	0	2	21.4	194	35.6	34.8	98.3	27.5	413	14.5	1.02	10.9	0.90
3	0	0	4	20.8	198	34.9	34.4	98.0	28.9	461	16.6	1.16	12.1	1.00
4	0	8	0	22.0	188	35.8	34.7	94.7	28.1	423	15.2	1.07	11.2	0.87
5	0	8	2	20.6	194	35.6	34.7	97.2	30.2	575	20.0	1.51	14.2	1.19
6	0	8	4	21.0	205	34.5	34.4	96.9	30.2	556	20.1	1.46	13.2	1.21
7	4	0	0	19.8	197	34.8	34.6	96.7	32.1	632	21.9	1.64	16.2	1.23
8	4	0	2	20.4	198	34.7	34.2	96.6	32.6	551	19.5	1.45	13.4	1.15
9	4	0	4	19.7	203	34.4	34.3	98.1	33.3	746	26.0	1.98	17.1	1.56
10	4	8	0	19.8	196	34.7	34.4	96.0	33.4	651	23.6	1.87	15.7	1.29
11	4	8	2	19.7	199	35.1	34.7	98.4	34.0	693	25.0	1.84	14.7	1.44
12	4	8	4	20.0	204	34.7	34.5	99.4	33.1	731	27.4	2.10	16.2	1.63
13	4	0	1*	20.6	199	35.1	34.5	98.1	31.4	608	21.6	1.70	14.2	1.28
14	4	8	1*	19.9	196	34.4	34.3	98.7	33.4	693	25.5	2.07	14.8	1.47
<u>Stats for RCB design (all 14 treatments)</u>														
P > F:				0.001	0.011	0.244	0.430	0.001	0.001	0.001	0.001	0.001	0.023	0.001
Average LSD (0.10):				0.8	7	NS	NS	1.4	1.9	102	3.2	0.36	3.2	0.23
<u>Stats for a Factorial Design (Treatments 1-12)</u>														
APP (10-34-0) applied in-furrow														
None				21.3	195	35.3	34.6	97.1	28.7	467	16.6	1.18	12.1	0.99
4 gal/ac				19.9	199	34.7	34.4	97.5	33.1	667	23.9	1.81	15.6	1.38
P > F:				0.001	0.011	0.025	0.086	0.167	0.001	0.001	0.001	0.001	0.001	0.001
UAN (28-0-0) applied as a surface dribble band														
None				20.6	197	34.9	34.5	97.5	30.3	530	18.6	1.35	13.4	1.10
8 gal/ac				20.5	198	35.1	34.6	97.1	31.5	605	21.9	1.64	14.2	1.27
P > F:				0.501	0.718	0.570	0.596	0.200	0.011	0.007	0.001	0.002	0.358	0.007
ATS (12-0-0-26) applied as a surface dribble band														
None				20.9	194	35.1	34.6	96.2	30.2	520	18.5	1.36	13.5	1.03
2 gal/ac				20.5	196	35.2	34.6	97.6	31.1	558	19.7	1.46	13.3	1.17
4 gal/ac				20.4	202	34.6	34.4	98.1	31.4	623	22.5	1.68	14.6	1.35
P > F:				0.117	0.001	0.083	0.216	0.001	0.105	0.009	0.005	0.016	0.375	0.001
Average LSD (0.10):				NS	3	0.5	NS	0.6	NS	54	1.9	0.18	NS	0.12
Interactions (P > F)														
APP×UAN				1.000	0.908	0.673	0.275	0.001	0.419	0.321	0.669	0.594	0.337	0.583
APP×ATS				0.027	0.624	0.513	0.649	0.141	0.484	0.159	0.244	0.123	0.230	0.237
UAN×ATS				0.084	0.179	0.794	0.517	0.026	0.407	0.127	0.239	0.493	0.409	0.369
APP×UAN×ATS				0.908	0.435	0.523	0.219	0.817	0.628	0.739	0.882	0.909	0.940	0.874

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

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