Enhancing Continuous Corn Production in Conservation Tillage with Nitrogen, Phosphorus, and Sulfur Starter Fluid Combinations and Placements
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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 poly phosphate, 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. 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 in April of 2013. One on a Nicollet clay loam soil at the Southern Research and Outreach Center, Waseca, MN and another on Mt Carroll silt loam four miles east of Rochester, Minnesota. The Rochester site was soybean in 2010, corn in 2011 and corn in 2012; whereas the Waseca site had been corn since 2010. Both sites were fall chisel plowed after harvest in 2012.

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 2 inches from 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 ft. wide (4 30-inch rows) by 50 ft. long (40 ft. long at Rochester). Soil samples (0-6 inch depth) were taken from each rep to characterize the research plot areas. Soil tests at Waseca in 2013 averaged: pH = 5.5, organic matter = 4.9%, Bray P_1 = 22 ppm (very high) and exchangeable K = 163 ppm (very high) and at Rochester pH = 7.1, organic matter = 4.7%, Bray P_1 = 23 ppm (very high) and exchangeable K = 140 ppm (high).

Corn (DeKalb 52-04 RIB) was planted at 35,000 seeds/ac on May 14 (Waseca) and May 16 (Rochester). Weeds were controlled with a combination of pre (SureStart®) and post emergence (glyphosate) herbicides at labeled rates of application. Surface residue accumulation after planting averaged 58 and 36 at Waseca and Rochester, respectively. Wet field conditions delayed residue counts until June 19 at Rochester. In June stand counts were taken on the center two rows of each plot and plant stands were thinned to a uniform plant population. At V2-3 (June 8 at Waseca and June 17 at Rochester), UAN was injected 3 inches deep midway between the rows to give a total (at planting + at V2-3) N rate of 200 lb/ac on all plots. On June 28 at Waseca and July 1 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 25 at Waseca and July 31 at Rochester) SPAD meter readings were taken from the ear leaf of 30 plants in each plot. Relative leaf chlorophyll content (RLC) was calculated from these measurements. Grain yield and moisture content were determined on October 14 (Waseca) and November 5 (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.

Analysis of variance was used to determine significance of treatment means. A 0.10 level of significance is used throughout the report. Because of distinct differences in soils, each location (Waseca and Rochester) was analyzed separately. A mixed model with block and year (block only for 2013 data) as random effects and fluid starter fertilizer sources/rates as fixed effects were fitted to the data. Statistical analyses were performed using SAS Proc Mixed (SAS® 9.2, SAS Institute).

RESULTS AND DISCUSSION

2013 Waseca location

Weather data characterizing the 2013 growing season at Waseca are presented in Table 1 and Figure 1. These data were taken from the SROC weather station located 0.3 miles from the research site. The spring of 2013 was cool and wet with March, April, May and June temperatures being 7.3, 7.7, 3.3 and 1.2° less than normal at Waseca (March and April data not shown), while monthly precipitation exceeded the 30-year normal by 1.06, 2.99, 2.53 and 1.98 inches, respectively (Table 1). Rainfall was recorded on 18, 22 and 20 days in April, May and June, respectively, which made timely field operations and planting difficult (Figure 1). July had near normal temperatures and above normal precipitation; whereas, August and September precipitation totaled only 2.07 and 1.92 inches or 2.68 and 1.75 inches less than normal, respectively. Mild moisture stress was noted in the research plots in August and September. Growing season (May-September) precipitation totaled 22.41 inches or 0.95 inches more than normal. A warm August and September and a late frost resulted in growing degree units (GDUs) for the season being 9% greater than normal.

Corn grain yield, nutrient concentration and uptake data from one replication were discarded prior to statistical analysis because of variability. Several plots in this replication had low and somewhat variable yields which were not related to treatments. The cause of these poor data could not be determined with any certainty.

Treatment effects on plant height, coefficient of variation (CV) of plant height and whole plant dry matter yield are presented in (Table 2). Plant height was increased about 7% when APP was applied in-furrow and about 9% when UAN was applied as a surface band. Plant height CV, a measure of variability in plant height (lower CV = less variable plant height), was also reduced with APP and UAN application. A significant APP×UAN interaction for plant height showed plant heights were greatest with APP and UAN application, intermediate with either APP or UAN application and much less when neither APP or UAN were applied (data not shown). A significant APP×UAN ×ATS interaction for plant height CV showed plant height CV was greatest with the 0 gal/ac of APP + 0 gal/ac of UAN + 2 gal/ac of ATS treatment (#2) and least with the 4 gal/ac of APP + 8 gal/ac of UAN + 4 gal/ac of ATS and 4 gal/ac of APP + 0 gal/ac of UAN + 0 gal/ac of ATS treatments (#'s 12 and 7, respectively). Whole plant dry matter yields were increased 26 and 32% by the main effects of APP and UAN application, respectively. Greatest dry matter yields were obtained when all three starter fertilizers were applied (treatment # 11 and 12). Dry matter yields with treatment # 12 were 107% greater than the control treatment (#1). One gal/ac of ATS plus 4 gal/ac of APP applied in-furrow did not affect V7 plant heights or dry matter yields compared with 4 gal/ac of APP alone. The application of fluid fertilizers at planting resulted in dramatic visual differences (greater early growth and plant uniformity and a darker green color) in June and early July of 2013.

Nutrient concentrations and uptakes in V7 corn plants were affected by two of the treatment main effects in this study (Table 2). Applying APP reduced S concentration slightly and UAN application reduced N and S concentrations (likely due to the dilution effect). The dilution effect occurs when early growth increases dramatically, thus causing concentrations of some nutrients in the plant to decline. Significant APP×ATS and APP×UAN×ATS interactions for S concentration were influenced by the dilution effect. The significant APP×ATS interaction for S concentration showed the greatest S concentration with the control treatment (least growth), the lowest concentration with 4 gal/ac of APP alone and other treatment combinations being intermediate (data not shown). Sulfur concentrations were less than 0.20% in all treatments. Numerically the lowest S concentration occurred with 4 gal/ac of APP + 1 gal/ac of ATS applied in-furrow + 8 gal/ac of UAN applied as a surface dribble band treatment (# 14). These data suggest the 1 and 2 gal/ac rates of ATS were inadequate during the early part of the growing season. Greater than normal rainfall in May and June may have leached some SO_4^- below the rooting depth of these small V7 plants. The main effects of APP and UAN application increased nutrient uptake of V7 corn plants. Significant APP×UAN interactions for N, P, K and S uptake showed nutrient uptakes were greatest when both APP and UAN were applied, intermediate when either APP or UAN were applied and considerably less when APP or UAN were NOT applied at planting (data not shown). These data show how dramatically enhanced early growth from fluid starter fertilizer application can result in greater nutrient uptake of small corn plants.

Treatment effects on grain moisture, grain yield, initial plant stand, final plant population and relative leaf chlorophyll are presented in Table 3. Grain moisture at harvest was reduced slightly by the main effects of APP and ATS application at planting. Corn grain yields ranged from 206 to 226 bu/ac among treatments. Yields were not affected by the main effects of APP and UAN application; whereas, ATS application at 2 and 4 gal/ac increased grain yields 7 bu/ac, when averaged across the main effects of APP and UAN application. A significant UAN×ATS interaction for grain yield was related to the magnitude of the observed yield differences. When averaged across APP application, the 8 gal/ac of UAN + 2 gal/ac of ATS and 0 gal/ac of UAN + 4 gal/ac of ATS treatments had greater yields than other UAN + ATS combinations. An analysis of all 14 treatments found applying 4 gal/ac of APP + 1 gal/ac of ATS in-furrow did not affect corn grain yields when compared with 4 gal/ac of APP alone. Initial plant stands were reduced slightly (400 plants/ac) by the main effect of APP application. Application of UAN at planting increased RLC, when averaged across the main effects of APP and ATS application; moreover, ATS application increased RLC when averaged across APP and UAN application.

Treatment effects on the concentration and uptake of N, P, K and S in corn grain are presented in Table 4. Generally, starter fertilizer treatments had little or no affect on grain nutrient concentration and uptake except for APP application which increased grain N concentration and uptake. When averaged across the main effects of APP and UAN application, ATS application increased N, P and K uptake slightly, however, these differences were simply a result of greater grain yields as concentrations were not different. Significant UAN×ATS interactions for grain P and K uptake were of little agronomic consequence. Nutrient removal in corn grain averaged 116, 26, 33 and 9.1 lb of N, P (60 lb of P_2O_5), K (39 lb K_2O), and S per acre, respectively.

2013 Rochester location

The 2013 growing season at Rochester, like Waseca, was cool and wet in May and June (Table 1). These conditions delayed planting and resulted in slow early growth and development of the corn crop. Precipitation in July, August and September was less than normal, however, crop moisture stress did not affect corn production. Growing season precipitation totaled 22.99 inches, which was greater than normal for the period from May through September.

Treatment effects on plant height, plant height CV and whole plant dry matter yields are presented in (Table 5). Plant height was increased 3% when APP was applied in-furrow and 4% when UAN was applied as a surface dribble band. When averaged across APP and UAN main effects, ATS application did not affect plant height and dry matter yield of V7 corn plants. Although significant differences in plant height and dry matter yields were observed at Rochester the magnitude of the early growth response was much less than at Waseca. Moreover, these data show the Rochester location (well drained silt loam soil) was somewhat less responsive to starter fertilizers early in the growing season compared with the Waseca location (poorly drained clay loam soil). A significant APP×UAN interaction for plant height showed plant heights were least when APP and UAN were not applied, while other treatment combinations were not significantly different. Plant height CV was reduced slightly with APP application, when averaged across the main effects of UAN and ATS application. Plant height CV was not affected by the main effects of UAN and ATS and there were no significant interactions. Dry matter yields of V7 corn plants were increased 11% when APP was applied in-furrow and 24% when UAN was applied as a surface dribble band. When averaged across APP and UAN main effects, ATS application did not affect plant height and dry matter yield of V7 corn plants. A significant APP×UAN interaction for dry matter yield showed: when averaged across ATS application, yields were greatest when only UAN or APP and UAN were applied, intermediate when only APP was applied and least when both APP and UAN were not applied (data not shown).

Nutrient concentrations in V7 corn plants were not affected by the treatment main effects and there were no significant interactions (Table 5). Nitrogen, P, K and S uptakes were increased by the main effects of APP and UAN application. Nitrogen uptake was slightly greater with 2 gal/ac of ATS compared with 4 gal/ac of ATS, when averaged across the main effects of APP and UAN application. Increases in nutrient uptake were primarily a result of increased dry matter yield as concentrations were not affected by treatments. Several significant interactions were observed for nutrient uptake in small plants. Generally, these interactions were a result of UAN application having the greatest effect on dry matter yields and subsequently nutrient uptake, APP application having an intermediate effect and ATS application having the least effect.

Treatment effects on grain moisture, grain yield, initial plant stand, final plant population and relative leaf chlorophyll content are presented in Table 6. Corn grain moisture was reduced slightly by the main effect of UAN application. Corn grain yields were increased 9 bu/ac with UAN application, when averaged across APP and ATS main effects. The main effects of APP and ATS application did not affect corn grain yields. The significant three-way interaction for corn grain yield cannot be logically explained by the authors. Initial plant stands and final plant populations were not affected by the main effects at Rochester in 2013. A significant UAN×ATS interaction for initial stand and final population showed stand was reduced from 800-1,200 plant/ac when both UAN and ATS were applied compared to when one or none were applied. Moreover, final plant populations were reduced from 400-600 plants/ac only when 8 gal of UAN and 2 gal of ATS were applied. Treatments that received 8 gal/ac of UAN and 2 gal/ac of ATS produced excellent yields; therefore, it's unlikely the small final plant population differences affected yields at this location. Relative leaf chlorophyll content at R1 was affected only by the main effect of ATS application. RLC increased when 4 gal/ac of ATS was applied compared with 0 and 2 gal/ac of ATS, when averaged across APP and UAN treatment main effects.

Treatment effects on the concentration and uptake of N, P, K and S in corn grain are presented in Table 7. Nutrient concentrations in corn grain generally were not affected by starter fertilizer treatments. However, APP application increased N concentration and uptake slightly. No other significant differences in concentration were found. Phosphorus, K and S uptake/removal in corn grain were greater with UAN application, when averaged across the main effects of APP and ATS application. These differences were a result of increased grain yields with UAN application. Significant APP×ATS interactions for P and K uptake were numerically small differences and of little agronomic importance. Nutrient removal in corn grain averaged 125, 28, 35 and 9.8 lb of N, P (64 lb of P_2O_5), K (42 lb K_2O), and S per acre, respectively.

2013 SUMMARY

A cool and wet spring delayed planting and early growth and development of corn in 2013. At Waseca, early growth and plant to plant uniformity of corn were greatly enhanced by fluid starter fertilizers and grain yields were increased 7 bu/ac with ATS (sulfur) application; whereas, at Rochester early growth (plant height and dry matter yield) was enhanced with APP and UAN application and grain yields were increased 9 bu/ac with UAN application. Key observations from the fourth and final year of this study include:

1) Similar to previous years, early growth of corn (plant height and dry matter yield at V7) was greatly enhanced when N, P and S fluid starter fertilizers as UAN, APP and ATS were applied at Waseca
2) Two or four gal/ac of ATS applied in a surface dribble band about 2-inches from the row increased corn grain yields 7 bu/ac compared with zero gal/ac of ATS, when averaged across the main effects of APP and UAN application.
3) Application of APP and UAN modestly increased early growth of V7 corn at Rochester.
4) Grain yields were 9 bu/ac greater when UAN was applied in a surface dribble band about 2-inches from the row at Rochester.
5) Applying APP and/or ATS did not affect grain yields at Rochester in 2012.
6) Grain moisture was reduced slightly with APP application at Waseca and by UAN application at Rochester.
7) Individual year results for the previous three years of the study (2010, 2011 and 2012) are available online.

FOUR-YEAR (2010–2013) SUMMARY

Waseca location

Words to describe the weather during the 2010–2013 growing seasons at Waseca would be unusual and record breaking. It's highly unlikely we could go through a four-year period and find more contrasting years for research. In 2010, the growing season and June + July precipitation was the wettest on record. Two thousand eleven was a fairly typical spring in southern Minnesota. It started out cool and wet and then turned warm, but unfortunately it was too dry later in the year for optimum corn production. The 2012 growing season got an early start because of record warm temperatures in March. Excellent conditions for planting and early crop growth were observed in April, May and June, however July and August brought very little rainfall. Drought significantly affected crops throughout the Corn Belt and in southern Minnesota. The spring of 2013 was very cool and wet which delayed planting and included a significant snowfall on May 2 for parts of south-central and most of southeastern Minnesota.

Treatment effects on plant height, CV of plant height and whole plant dry matter yield for the four-year study period (2010–2013) are presented in (Table 8). Plant heights were increased 8, 9 and 5% by the main effects of APP, UAN and ATS (4 gal/ac rate of ATS) application, respectively, when averaged across other main effects. Plant height CV was reduced when APP and UAN were applied although ATS application had no effect. A significant APP×UAN interaction for plant height showed plant heights were greatest when APP and UAN were applied, slightly less when APP or UAN were applied and considerably less when APP and UAN were not applied. The significant three-way APP×UAN×ATS interaction for plant height was related to the magnitude of the growth response which was somewhat different depending on the fluid fertilizer. The addition of UAN (24 lb N/ac) alone increased plant heights the most. This suggests N was responsible for much of the early growth response at Waseca and since all three fertilizer sources in this study contained some nitrogen the magnitude of the response likely was affected by the amount, placement and rate of the fluid fertilizer source applied or the amount, placement and rate of N in that source. A significant APP×UAN interaction for plant height CV showed CV was greatest without APP or UAN application and was considerably less with APP and/or UAN application. The authors have no logical explanation for the significant three-way APP×UAN×ATS interaction for plant height CV, but it's probably related to the significant three-way interaction for plant height. Whole plant dry matter yields were increased 18, 26 and 13% by the main effects of APP, UAN and ATS application, respectively, when averaged across other main effects. An analysis of individual treatments found the numerically greatest dry matter yields were obtained when all three starter fertilizers were applied (treatment #'s 11 and 12). Yields of V6-7 corn plants were 81-85% greater in these treatments (N+P+S) compared with the control treatment. These data show how fluid starter fertilizers (APP, UAN and ATS) enhanced early growth and plant uniformity of continuous corn grown with conservation tillage practices on poorly-drained glacial till soils in Minnesota. Adding 1 gal/ac of ATS to 4 gal/ac of APP applied in-furrow did not affect plant heights or yields compared with 4 gal/ac of APP alone.

Treatment effects on nutrient concentration and uptake in V6-7 corn plants for the four-year study period are presented in Table 8. Nitrogen and S concentrations in small plants decreased slightly when APP was applied at planting, when averaged across UAN and ATS main effects. Sulfur concentration in small plants decreased slightly when UAN was applied; whereas, N concentration decreased when ATS was applied at planting. No other significant differences were found for nutrient concentration in V6-7 corn plants. However, significant APP×ATS interactions were found for N and S concentration. The interaction for N showed N concentration was greatest when APP or ATS were NOT applied (less early growth greater concentration) and less with other treatment combinations (greater early growth lower concentration). A significant APP×ATS interaction for S showed S concentration was least with 4 gal/ac of APP + 0 gal/ac of ATS treatments and greater with other treatment combinations. Sulfur concentrations were low or marginal in some treatments. Numerically the lowest S concentration (0.167%) occurred with the 4 gal/ac of APP + 8 gal/ac of UAN + 0 gal/ac of ATS treatment (# 10). This treatment had excellent early growth, but did not receive S (ATS) fertilizer. Generally, all fertilizer treatment main effects increased nutrient uptake of V6-7 corn plants. Although these responses were primarily due to increased dry matter yields as concentrations were rarely different. These data show how dramatically enhanced early growth from fluid starter fertilizer application can result in greater nutrient uptake of small corn plants. A significant APP×UAN interaction for P and K uptake showed uptake was greatest with APP and UAN application, intermediate with APP or UAN application and least when APP and ATS were not applied.

Treatment effects on grain moisture, grain yield, plant stand, final plant population and relative leaf chlorophyll content for the four-year study period are presented in Table 9. Grain moisture was reduced slightly (0.5 percentage points) with APP application, when averaged across UAN and ATS treatments. No significant interactions for grain moisture were found. Averaged across years, corn grain yields were not affected by the main effects of APP and UAN application at planting and there were no significant interactions. Yields were 4 bu/ac greater when 2 of 4 gal/ac of ATS was applied at planting compared with 0 gal/ac. An analysis of individual treatments showed the 0 gal/ac of APP + 0 gal/ac of UAN + 4 gal/ac of ATS treatment (# 3) increased corn yields 11 bu/ac compared with the control treatment (0 gal/ac of APP + 0 gal/ac of UAN + 0 gal/ac of ATS treatment). The dramatic and consistent early growth responses observed in this study due to APP and UAN application at planting did not affect grain yields, when averaged across years. However unusual weather during the study period, 2 of 4 years had moderate drought stress late in the growing season (2011 and 2012) and 2 of 4 years had very wet springs (2010 and 2014), affected yields and yield variability. Initial plant stand, final plant population and relative leaf chlorophyll content were not affected by treatment main effects at this location. Significant APP×ATS and UAN×ATS interactions for RLC showed RLC was considerable less (2-3 percentage points) in treatment combinations without ATS and with the 2 gal/ac rate of ATS without APP or UAN application. An analysis of all 14 treatments found adding 1 gal/ac of ATS to 4 gal/ac of APP did not affect grain yields compared with 4 gal/ac of APP alone.

Treatment effects on the concentration and uptake of N, P, K and S in corn grain for the four-year study period (2010–2012) are presented in Table 10. Concentration and uptake/removal of N, P and K in corn grain were generally not affected by treatment main effects. Except for K concentration, which increased slightly with UAN application, when averaged across the main effects of APP and ATS application. Grain S concentration and uptake/removal increased as ATS application rate increased, when averaged across APP and UAN treatment main effects. There were a few significant interactions found for grain nutrient concentration and uptake. Generally the differences were very small and were related to the control treatment having the least concentration or uptake of a given nutrient. Averaged across years and treatments, nutrient removal in corn grain averaged 120, 26, 36 and 8.6 lb of N, P (60 lb of P_2O_5), K (43 lb K_2O), and S per acre, respectively.

Rochester location

The growing season weather at Rochester was: extraordinarily wet in 2010, wet in May and June of 2011 and 2014, and aside from a few extended dry periods nearly ideal in 2012. Unlike Waseca, Rochester received significantly greater rainfall in the summers of 2011 and 2012, which resulted in excellent crop growth and development and less yield variability.

Treatment effects on plant height, plant height CV and whole plant dry matter yield for the four-year period of the study (2010–2012) are presented in (Table 11). Plant heights were increased 7% by the main effect of APP application, when averaged across the main effects of UAN and ATS application. Moreover, plant heights and dry matter yields of V6-7 corn plants increased slightly with UAN application, when averaged across APP and ATS treatment main effects. Plant height CV was not significantly affected by any of the treatment main effects, however a significant three-way interaction was found. This interaction was the result of inconsistent responses to treatment main effects and has no logical explanation. A significant APP×UAN interaction for plant height and dry matter yields showed heights and yields were statistically similar with APP and/or UAN application, but were significantly less when both APP and UAN were NOT applied. Numerically, the smallest plant heights and dry matter yields were found in the control treatment (# 1) that did not receive any starter fertilizer; whereas, the greatest dry matter yields were found in treatment # 12 (4 gal of APP + 8 gal of UAN + 4 gal of ATS per acre). Averaged across years, treatment # 12 increased dry matter yields of V6-7 corn plants about 48%, compared with the control treatment. These data showed starter fertilizers generally enhanced early growth and dry matter yield of continuous corn grown with conservation tillage practices on a well drained loess soils in southeast Minnesota. However, the early growth response was somewhat less and not as consistent as on the poorly drained glacial till soil at Waseca. Adding 1 gal/ac of ATS to 4 gal/ac of APP applied in-furrow did not affect V6-7 plant heights or yields compared with 4 gal/ac of APP alone.

Treatment effects on nutrient concentration and uptake in V6-7 corn plants for the four-year study period (2010–2012) are presented in Table 11. Sulfur concentration in V6-7 corn plants was greater with the 4 gal/ac ATS rate compared with the 0 and 2 gal/ac ATS rates, when averaged across APP and UAN treatment main effects. No other significant differences were found for nutrient concentration in V6-7 corn plants. Nitrogen, P and S uptakes increased with UAN application, when averaged across APP and ATS treatment main effects. Sulfur uptake was slightly greater with the 4 gal/ac rate of ATS compared with the 0 gal/ac rate of ATS. An analysis of all 14 treatments found significant differences among treatments for

S concentration and N, P and S uptake in V6-7 corn plants. Sulfur concentration was numerically greatest with the 4 gal/ac rate compared with the 2 gal/ac rate in all treatment combinations. Averaged across 4-years, S concentrations were generally sufficient in all treatments, suggesting greater S availability in loess soils with about 4% organic matter compared with glacial till soils with about 5-6% organic matter. However, hybrid and other environmental factors may have contributed to the observed differences between locations. Numerically the greatest N, P, K and S uptake in V6-7 corn plants occurred with the 4 gal/ac of APP + 8 gal/ac of UAN + 4 gal/ac of ATS treatment (# 12).

Treatment effects on grain moisture, grain yield, initial stand, final plant population and relative leaf chlorophyll content for the four-year study period (2010–2012) are presented in Table 12. Grain moisture was reduced slightly by the main effect of ATS application and strong trends were found for reduced grain moisture with APP and UAN application. Significant interactions for grain moisture generally showed moisture was greatest when no starter fertilizer was applied and moisture was significantly less when some combination of APP, UAN and ATS was applied. Averaged across years, corn grain yields were not affected by the main effects of APP, UAN or ATS application at planting and there were no significant interactions at the Rochester location. An analysis of all 14 treatments found no significant differences for grain yield. When averaged across years, yields ranged from 216–222 bu/ac.

Initial plant stand and final plant population were reduced slightly when APP was applied in-furrow (Table 12). These differences were small and would not have affected grain yields, however, they did occur in 2 of 4 years at this location (data not shown). A significant APP×UAN interaction for final plant population showed populations were reduced about 230 plants/ac when APP and/or UAN were applied compared to when APP and UAN were not applied. An analysis of all 14 treatments found significant differences for initial plant stand and final plant populations. Numerically the lowest plant stands and populations were observed with the 4 gal/ac of APP + 1 gal/ac of ATS applied in-furrow + 8 gal/ac of UAN applied as a surface dribble band treatment (# 14). The final plant population for this treatment (# 14) was significantly less than any other treatment. These data suggest combinations of fluid starter fertilizers that contain 1 gal/ac of ATS in-furrow with 4 gal/ac of APP may reduce stands on silt loam soils in Minnesota. Relative leaf chlorophyll content was greater with ATS application compared to without ATS application, when averaged across APP and UAN treatment main effects. An analysis of all 14 treatments showed RLC was least with the 0 gal/ac of APP + 8 gal/ac of UAN + 0 gal/ac of ATS treatment (# 4) and generally RLC was greater in treatments with ATS.

Treatment effects on the concentration and uptake of N, P, K and S in corn grain during the four-year study period (2010–2013) are presented in Table 13. Generally, treatment main effects had little or no affect on nutrient concentrations and uptakes/removals of N, P, K and S in corn grain when averaged across years at this location. The few significant differences that were observed (APP application increased grain S concentration and UAN application increased grain N uptake/removal) were very small, only about a 1% increase. Several significant two-way interactions (APP×UAN, APP×ATS and UAN×ATS) for grain concentration and uptake were found in these data. Generally, these interactions had one of three explanations: 1) the treatment combination that received both fluid fertilizers in question had significantly greater nutrient concentrations and/or uptakes; 2) the treatment combination that received neither fluid fertilizer had considerably lower concentrations and/or uptakes; or 3) a change in rate of ATS (example from 0 to 2 or 2 to 4 gal/ac) in combination with another fluid source (APP or UAN) would result in a very small but opposite change in concentration and/or uptake. Generally, these interactions were of little or no agronomic significance. Nutrient removal in corn grain averaged 121, 26, 37 and 9.1 lb of N, P (61 lb of P_2O_5), K (45 lb K_2O), and S per acre, respectively.

FOUR-YEAR (2010–2013) SUMMARY OF TREATMENT MAIN EFFECTS

Waseca location

The application of 4 gal/ac of APP in-furrow on a glacial till soil at Waseca: 1) did not affect grain yield on these very high P-testing soils with pH≤7.0; 2) reduced grain moisture in 3 of 4 yr (individual year data from 2010–2012 not shown in this report) and for the 4–yr average; and 3) increased plant height and/or dry matter yield of V6-7 corn plants in 4 of 4 yr and for the 4-yr average while also reducing plant height CV (variability in plant height).

The application of 8 gal/ac of UAN in a surface dribble band about 2 inches from the corn row: 1) reduced grain moisture in 2 of 4 yr; 2) did not affect corn grain yield; 3) dramatically increased plant height and DM yield in 4 of 4 yr and for the 4-yr average; and 4) reduced 4-yr average plant height CV.

The application of ATS at 2 or 4 gal/ac in a surface dribble band: 1) reduced grain moisture in 2 of 4 yr; 2) increased grain yield in 2 of 4 yr (6-9 bu/ac in 2010 and 7 bu/ac in 2013) and for the 4-yr average (4 bu/ac); and 3) increased plant height and/or DM yield in 4 of 4 yr and for the 4-yr average.

Rochester location

The application of 4 gal/ac of APP in-furrow on a loess soil at Rochester in Southeast Minnesota: 1) increased grain yield in 1 of 4 yr and decreased yield in 1 of 4 yr; 2) reduced grain moisture in 2 of 4 yr (individual year data from 2010–2012 not shown in this report); and 3) increased plant height and/or dry matter yield of V6-7 corn plants in 4 of 4 yr and for the 4-yr average.

The application of 8 gal/ac of UAN in a surface dribble band about 2 inches from the corn row: 1) reduced grain moisture in 2 of 4 yr; 2) increased corn grain yield in 1 of 4 yr (9 bu/ac in 2013); and 3) increased plant height and DM yield in 4 of 4 yr and for the 4-yr average.

The application of ATS at 2 or 4 gal/ac in a surface dribble band: 1) reduced the 4-yr average grain moisture; 2) increased grain yield in 1 of 4 yr (8 bu/ac with 4 gal/ac rate in 2011); and 3) had little to no effect on plant heights and/or dry mater yields of V6-7 corn plants.

CONCLUSIONS

The response of corn to fluid starter fertilizer was inconsistent in this study. Starter fertilizers containing N, P and S applied as UAN, APP and ATS generally increased early growth while reducing plant variability of corn grown following corn in reduced tillage. Applying APP, UAN and ATS either independently or in combination sometimes reduced grain moisture at harvest. Grain yields were increased by ATS application (likely a sulfur response) in 2 of 4 years and for the 4-year average at Waseca (1 of 4 years at Rochester). These data suggest yield responses to fluid starter fertilizer may be more likely on poorly drained glacial till soils in south-central MN, compared with the well drained loess soils of southeast MN.

Although only a few positive corn grain yield responses were found in this study, consistent responses in early growth, reduced grain moisture at harvest and reduced plant to plant variability were observed, especially on the poorly drained glacial till soil at Waseca. Collectively these responses should increase yield potential of corn after corn grown in high residue environments and help to narrow the yield gap between corn after corn and corn after soybean.

ACKNOWLEDGEMENT

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Table 1. Precipitation at Waseca and Rochester and growing degree units (GDUs) at Waseca in 2013.

	Precipitation					
	Waseca		Rochester		Waseca GDUs	
Month	2013	Normal[1/]	2013	Normal[1/]	2013	Normal[1/]
	- - - - - inches - - - - -		- - - - - inches - - - - -			
May	6.46	3.93	8.97	3.66	274	332
June	6.67	4.69	5.70	4.34	517	538
July	5.29	4.42	2.58	4.53	666	655
Aug.	2.07	4.75	3.79	4.66	598	597
Sept.	1.92	3.67	1.95	3.66	462	348
May-Sept. Total	22.41	21.46	22.99	20.85	2518	2470

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

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

				V7	CV of	Whole Plant Samples at V7 (June 28)								
	Fertilizer rate			Plant	Plant		Concentration				Uptake			
Trt	APP	UAN	ATS	height	height	Yield	N	P	K	S	N	P	K	S
#	----	gal/ac	-----	inch	%	lb/ac	-------------	%	-------------		----------	lb/ac	-----------	
1	0	0	0	30.2	7.2	418	3.94	0.336	3.78	0.190	16.4	1.42	15.9	0.79
2	0	0	2	30.3	9.7	489	3.83	0.302	3.91	0.170	18.6	1.48	19.1	0.83
3	0	0	4	32.5	7.3	489	3.91	0.324	3.69	0.181	19.1	1.59	18.1	0.88
4	0	8	0	35.4	6.2	689	3.75	0.342	3.93	0.170	25.9	2.36	27.0	1.17
5	0	8	2	36.1	5.9	731	3.71	0.342	3.74	0.171	27.0	2.48	27.3	1.24
6	0	8	4	35.7	8.0	750	3.51	0.321	3.62	0.175	26.3	2.40	27.2	1.31
7	4	0	0	35.5	4.9	674	3.69	0.315	3.88	0.164	25.0	2.13	26.1	1.10
8	4	0	2	34.5	6.6	712	3.69	0.327	3.77	0.171	26.2	2.32	26.8	1.21
9	4	0	4	35.8	7.5	698	3.73	0.311	3.63	0.166	26.1	2.17	25.5	1.16
10	4	8	0	35.8	7.4	769	3.87	0.321	3.73	0.170	29.8	2.47	28.9	1.31
11	4	8	2	36.6	5.5	784	3.54	0.321	3.74	0.169	27.7	2.52	29.3	1.32
12	4	8	4	37.4	4.8	864	3.54	0.306	3.80	0.160	30.7	2.64	32.8	1.39
13	4	0	1*	34.6	6.1	722	3.90	0.340	3.78	0.173	28.1	2.44	27.2	1.25
14	4	8	1*	35.5	5.7	755	3.46	0.315	3.65	0.158	25.8	2.38	28.0	1.18
Stats for RCB design (all 14 treatments)														
P > F:				<0.001	0.016	<0.001	0.042	0.244	0.880	0.001	<0.001	<0.001	<0.001	<0.001
Average LSD(0.10):				1.3	2.0	96	0.27	0.027	0.31	0.010	3.8	0.36	4.3	0.18
Stats for a Factorial Design (Treatments 1-12)														
APP (10-34-0) applied in-furrow														
None				34.9	6.5	674	3.71	0.328	3.77	0.172	24.9	2.21	25.4	1.15
4 gal/ac				35.9	6.2	765	3.67	0.319	3.72	0.166	28.1	2.44	28.6	1.27
P > F:				<0.001	0.014	<0.001	0.141	0.128	0.759	0.001	<0.001	<0.001	<0.001	<0.001
UAN (28-0-0) applied as a surface dribble band														
None				35.4	6.6	693	3.75	0.327	3.74	0.171	25.9	2.26	26.0	1.18
8 gal/ac				35.5	6.0	746	3.63	0.321	3.75	0.167	27.0	2.39	28.0	1.24
P > F:				<0.001	0.077	<0.001	0.035	0.336	0.808	0.073	<0.001	<0.001	<0.001	<0.001
ATS (12-0-0-26) applied as a surface dribble band														
None				35.3	6.9	701	3.67	0.315	3.69	0.170	25.6	2.20	25.9	1.18
2 gal/ac				35.3	6.1	714	3.80	0.330	3.83	0.169	27.2	2.35	27.3	1.20
4 gal/ac				35.7	5.9	746	3.60	0.326	3.72	0.167	26.7	2.42	27.8	1.24
P > F:				0.015	0.661	0.100	0.181	0.303	0.190	0.491	0.557	0.545	0.439	0.231
Average LSD (0.10):				0.7	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Interactions (P > F)														
APP×UAN				<0.001	0.346	0.004	0.162	0.250	0.838	0.138	0.022	0.003	0.007	0.017
APP×ATS				0.795	0.567	0.855	0.814	0.386	0.645	0.061	0.658	0.987	0.759	0.887
UAN×ATS				0.102	0.044	0.617	0.189	0.471	0.629	0.527	0.672	0.975	0.462	0.821
APP×UAN×ATS				0.106	0.015	0.736	0.458	0.318	0.213	0.045	0.689	0.611	0.359	0.806

* 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.

Trt	Fertilizer rate APP	UAN	ATS	Grain H_2O	Grain Yield	Initial Plant Stand	Final Plant Pop.	R1 Leaf Chloro
#	-------	gal/ac	-------	%	bu/ac	plants×10^3/A		%
1	0	0	0	18.4	211.1	34.8	34.3	96.0
2	0	0	2	18.1	205.9	34.9	34.3	95.3
3	0	0	4	18.2	223.9	34.5	34.1	98.5
4	0	8	0	18.4	211.2	35.0	34.3	96.8
5	0	8	2	17.8	226.2	34.7	34.2	98.5
6	0	8	4	18.1	218.4	34.4	33.9	98.2
7	4	0	0	18.0	214.0	34.3	34.2	95.9
8	4	0	2	18.1	219.3	34.5	34.2	96.8
9	4	0	4	17.7	220.4	34.7	34.3	98.4
10	4	8	0	18.1	209.5	34.1	33.8	97.1
11	4	8	2	18.2	223.1	34.7	34.5	98.9
12	4	8	4	17.7	212.4	33.8	33.6	98.0
13	4	0	1*	17.9	210.7	34.1	34.0	97.9
14	4	8	1*	18.0	206.4	33.8	33.7	96.5
Stats for RCB design (all 14 treatments)								
P > F:				0.080	0.055	0.287	0.298	0.014
Average LSD (0.10):				0.4	11.1	NS	NS	1.7
Stats for a Factorial Design (Treatments 1-12)								
APP (10-34-0) applied in-furrow								
None				18.1	218.8	34.6	34.2	97.5
4 gal/ac				17.9	213.7	34.2	34.0	97.8
P > F:				0.025	0.909	0.046	0.287	0.475
UAN (28-0-0) applied as a surface dribble band								
None				18.1	219.1	34.6	34.2	98.1
8 gal/ac				18.0	213.5	34.1	33.9	97.2
P > F:				0.524	0.714	0.307	0.139	0.016
ATS (12-0-0-26) applied as a surface dribble band								
None				17.9	218.8	34.4	34.0	98.3
2 gal/ac				18.1	211.4	34.4	34.1	96.9
4 gal/ac				18.0	218.7	34.4	34.1	97.7
P > F:				0.089	0.071	0.396	0.098	0.007
Average LSD (0.10):				0.2	5.9	NS	0.2	0.9
Interactions (P > F)								
APP×UAN				0.190	0.171	0.562	0.433	0.777
APP×ATS				0.029	0.367	0.485	0.535	0.586
UAN×ATS				0.771	0.029	0.452	0.222	0.029
APP×UAN×ATS				0.803	0.553	0.374	0.229	0.754

* 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	1.11	0.24	0.31	0.089	111	23.5	30.6	8.89
2	0	0	2	1.07	0.26	0.33	0.089	105	25.7	32.1	8.67
3	0	0	4	1.19	0.24	0.31	0.090	126	25.5	32.5	9.54
4	0	8	0	1.12	0.25	0.32	0.089	112	25.3	31.7	8.89
5	0	8	2	1.05	0.27	0.34	0.089	113	28.9	36.1	9.54
6	0	8	4	1.14	0.25	0.31	0.090	118	26.1	32.4	9.27
7	4	0	0	1.14	0.27	0.33	0.090	115	26.8	33.4	9.07
8	4	0	2	1.21	0.24	0.31	0.092	126	25.3	32.5	9.52
9	4	0	4	1.13	0.26	0.32	0.089	118	27.0	33.4	9.28
10	4	8	0	1.16	0.26	0.33	0.091	115	25.5	32.3	8.99
11	4	8	2	1.13	0.27	0.34	0.090	120	28.8	35.6	9.54
12	4	8	4	1.23	0.25	0.31	0.092	123	25.0	31.5	9.28
13	4	0	1*	1.16	0.23	0.30	0.085	116	23.4	30.3	8.52
14	4	8	1*	1.13	0.28	0.34	0.091	110	27.3	33.6	8.89
Stats for RCB design (all 14 treatments)											
P > F:				0.479	0.183	0.201	0.258	0.086	0.115	0.147	0.161
Average LSD (0.10):				NS	NS	NS	NS	11	NS	NS	NS
Stats for a Factorial Design (Treatments 1-12)											
APP (10-34-0) applied in-furrow											
None				1.14	0.25	0.32	0.090	118	26.3	33.1	9.31
4 gal/ac				1.16	0.26	0.32	0.090	117	26.2	32.8	9.08
P > F:				0.092	0.407	0.396	0.114	0.059	0.425	0.454	0.364
UAN (28-0-0) applied as a surface dribble band											
None				1.13	0.26	0.32	0.090	117	26.8	33.6	9.30
8 gal/ac				1.17	0.25	0.32	0.090	118	25.6	32.3	9.09
P > F:				0.880	0.273	0.301	0.589	0.965	0.195	0.242	0.591
ATS (12-0-0-26) applied as a surface dribble band											
None				1.17	0.25	0.31	0.090	121	25.9	32.4	9.34
2 gal/ac				1.14	0.25	0.32	0.089	114	25.2	31.9	8.87
4 gal/ac				1.13	0.27	0.33	0.091	117	27.6	34.4	9.37
P > F:				0.287	0.262	0.103	0.796	0.071	0.099	0.064	0.109
Average LSD (0.10):				NS	NS	NS	NS	6	1.5	1.5	NS
Interactions (P > F)											
APP×UAN				0.546	0.554	0.776	0.500	0.936	0.216	0.280	0.491
APP×ATS				0.382	0.266	0.228	0.834	0.094	0.490	0.538	0.381
UAN×ATS				0.571	0.550	0.547	0.559	0.914	0.067	0.042	0.292
APP×UAN×ATS				0.367	0.270	0.484	0.464	0.162	0.615	0.937	0.350

* 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	CV of	Whole Plant Samples at V7 (July 1)								
	Fertilizer rate			Plant	Plant		Concentration				Uptake			
Trt	APP	UAN	ATS	height	height	Yield	N	P	K	S	N	P	K	S
#	----	gal/ac	-----	inch	%	lb/ac	-------------	%	-------------		----------	lb/ac	-----------	
1	0	0	0	32.5	5.5	404	3.83	0.367	3.24	0.187	15.3	1.50	13.2	0.75
2	0	0	2	34.2	6.3	489	3.89	0.347	3.10	0.181	19.1	1.71	15.3	0.89
3	0	0	4	33.9	6.8	432	3.92	0.349	3.26	0.187	16.8	1.50	14.1	0.80
4	0	8	0	35.6	5.6	632	3.86	0.344	3.12	0.182	24.4	2.18	19.7	1.15
5	0	8	2	35.4	7.6	682	3.89	0.346	3.21	0.180	26.7	2.31	21.7	1.21
6	0	8	4	36.7	5.7	579	3.79	0.347	3.15	0.183	21.8	1.97	17.8	1.06
7	4	0	0	36.2	6.1	603	3.91	0.361	3.10	0.179	23.6	2.19	18.8	1.08
8	4	0	2	34.9	6.3	522	3.66	0.337	2.84	0.181	19.0	1.75	14.8	0.94
9	4	0	4	35.7	5.3	575	3.82	0.360	3.40	0.183	21.9	2.07	19.6	1.05
10	4	8	0	36.5	4.9	627	3.77	0.359	3.13	0.186	23.6	2.25	19.6	1.17
11	4	8	2	36.5	4.0	651	3.85	0.361	3.15	0.185	25.0	2.36	20.6	1.20
12	4	8	4	35.3	5.5	582	3.75	0.351	3.00	0.191	21.7	2.04	17.6	1.09
13	4	0	1*	35.9	6.3	613	3.75	0.342	3.00	0.184	22.9	2.09	18.4	1.13
14	4	8	1*	35.7	6.0	636	3.73	0.339	2.75	0.185	23.7	2.16	17.5	1.18
Stats for RCB design (all 14 treatments)														
P > F:				<0.001	0.559	<0.001	0.787	0.779	0.551	0.807	<0.001	<0.001	<0.001	<0.001
Average LSD(0.10):				1.2	NS	79	NS	NS	NS	NS	2.9	0.31	2.9	0.14
Stats for a Factorial Design (Treatments 1-12)														
APP (10-34-0) applied in-furrow														
None				34.7	6.3	536	3.86	0.350	3.18	0.183	20.7	1.86	17.0	0.98
4 gal/ac				35.8	5.3	593	3.79	0.355	3.10	0.184	22.5	2.11	18.5	1.09
P > F:				<0.001	0.079	0.006	0.230	0.437	0.422	0.725	0.017	0.003	0.029	0.003
UAN (28-0-0) applied as a surface dribble band														
None				34.6	6.0	504	3.84	0.353	3.16	0.183	19.3	1.79	16.0	0.92
8 gal/ac				36.0	5.6	625	3.82	0.351	3.12	0.184	23.9	2.19	19.5	1.15
P > F:				<0.001	0.348	<0.001	0.729	0.721	0.714	0.551	<0.001	<0.001	<0.001	<0.001
ATS (12-0-0-26) applied as a surface dribble band														
None				35.2	5.5	566	3.84	0.358	3.14	0.184	21.7	2.03	17.8	1.04
2 gal/ac				35.2	6.0	586	3.82	0.348	3.07	0.182	22.5	2.03	18.1	1.06
4 gal/ac				35.4	5.8	542	3.82	0.352	3.20	0.186	20.5	1.90	17.3	1.00
P > F:				0.821	0.744	0.178	0.936	0.421	0.534	0.316	0.077	0.235	0.560	0.361
Average LSD (0.10):				NS	NS	NS	NS	NS	NS	NS	1.4	NS	NS	NS
Interactions (P > F)														
APP×UAN				0.002	0.243	0.001	0.806	0.325	0.922	0.055	0.001	0.017	0.004	0.007
APP×ATS				0.018	0.376	0.116	0.653	0.948	0.788	0.700	0.029	0.173	0.056	0.185
UAN×ATS				0.746	0.994	0.209	0.367	0.284	0.139	0.994	0.042	0.123	0.010	0.219
APP×UAN×ATS				0.025	0.162	0.372	0.408	0.512	0.507	0.747	0.118	0.235	0.236	0.395

* 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.

Trt	Fertilizer rate APP	Fertilizer rate UAN	Fertilizer rate ATS	Grain H_2O	Grain Yield	Initial Plant Stand	Final Plant Pop.	VT-R1 Leaf Chloro
#	-------	gal/ac	-------	%	bu/ac	plants×10^3/ac		%
1	0	0	0	22.3	228	34.2	33.7	98.3
2	0	0	2	21.7	231	34.3	33.4	97.3
3	0	0	4	21.5	223	33.8	33.4	98.2
4	0	8	0	20.8	235	34.7	33.9	96.7
5	0	8	2	21.1	238	33.0	32.7	97.8
6	0	8	4	20.7	238	33.3	33.2	98.9
7	4	0	0	21.9	231	33.3	33.2	97.6
8	4	0	2	20.8	223	34.3	33.7	97.3
9	4	0	4	21.5	231	34.2	33.5	98.4
10	4	8	0	21.1	239	34.0	33.3	98.2
11	4	8	2	20.0	235	33.3	33.0	97.5
12	4	8	4	20.8	234	33.7	33.3	98.2
13	4	0	1*	20.8	233	33.5	33.3	98.8
14	4	8	1*	21.1	234	33.4	33.1	97.6
Stats for RCB design (all 14 treatments)								
P > F:				0.051	0.055	0.352	0.302	0.276
Average LSD (0.10):				1.0	8	NS	NS	NS
Stats for a Factorial Design (Treatments 1-12)								
APP (10-34-0) applied in-furrow								
None				21.3	232	33.9	33.4	97.9
4 gal/ac				21.0	232	33.8	33.3	97.9
P > F:				0.217	0.511	0.795	0.802	0.969
UAN (28-0-0) applied as a surface dribble band								
None				21.6	228	34.0	33.5	97.8
8 gal/ac				20.7	237	33.6	33.3	97.9
P > F:				0.001	<0.001	0.161	0.152	0.909
ATS (12-0-0-26) applied as a surface dribble band								
None				21.5	233	34.0	33.5	97.7
2 gal/ac				20.9	232	33.7	33.2	97.5
4 gal/ac				21.1	232	33.7	33.3	98.4
P > F:				0.109	0.289	0.556	0.310	0.049
Average LSD (0.10):				NS	NS	NS	NS	0.7
Interactions (P > F)								
APP×UAN				0.720	0.207	0.748	0.960	0.619
APP×ATS				0.150	0.143	0.203	0.083	0.668
UAN×ATS				0.701	0.637	0.043	0.067	0.540
APP×UAN×ATS				0.816	0.018	0.974	0.982	0.143

* 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	1.09	0.24	0.31	0.087	117	25.6	33.4	9.4
2	0	0	2	1.09	0.26	0.33	0.090	119	28.8	36.0	9.8
3	0	0	4	1.17	0.24	0.31	0.089	123	25.6	32.4	9.3
4	0	8	0	1.10	0.25	0.32	0.088	122	28.1	35.0	9.8
5	0	8	2	1.07	0.27	0.34	0.089	120	30.3	37.9	10.0
6	0	8	4	1.15	0.26	0.32	0.091	130	28.8	36.1	10.2
7	4	0	0	1.16	0.27	0.33	0.089	126	29.1	36.1	9.8
8	4	0	2	1.21	0.24	0.31	0.090	126	25.3	32.7	9.6
9	4	0	4	1.15	0.25	0.32	0.089	125	27.7	34.7	9.8
10	4	8	0	1.16	0.26	0.33	0.090	131	29.3	37.1	10.2
11	4	8	2	1.13	0.26	0.32	0.088	126	28.8	35.9	9.8
12	4	8	4	1.14	0.25	0.32	0.093	126	27.7	34.8	10.2
13	4	0	1*	1.15	0.25	0.32	0.087	127	27.8	35.3	9.6
14	4	8	1*	1.16	0.27	0.34	0.090	128	28.6	36.0	9.9
Stats for RCB design (all 14 treatments)											
P > F:				0.286	0.649	0.584	0.513	0.467	0.118	0.086	0.101
Average LSD (0.10):				NS	NS	NS	NS	NS	NS	2.8	NS
Stats for a Factorial Design (Treatments 1-12)											
APP (10-34-0) applied in-furrow											
None				1.11	0.25	0.32	0.089	122	27.9	35.1	9.8
4 gal/ac				1.16	0.26	0.32	0.090	127	28.0	35.2	9.9
P > F:				0.028	0.878	0.867	0.217	0.050	0.775	0.891	0.292
UAN (28-0-0) applied as a surface dribble band											
None				1.14	0.25	0.32	0.089	123	27.0	34.2	9.6
8 gal/ac				1.12	0.26	0.32	0.090	126	28.8	36.1	10.0
P > F:				0.389	0.029	0.317	0.352	0.230	0.004	0.003	0.001
ATS (12-0-0-26) applied as a surface dribble band											
None				1.12	0.25	0.32	0.089	124	28.0	35.4	9.8
2 gal/ac				1.12	0.26	0.33	0.089	122	28.3	35.6	9.8
4 gal/ac				1.15	0.25	0.32	0.090	126	27.5	34.5	9.9
P > F:				0.456	0.469	0.226	0.256	0.476	0.459	0.250	0.704
Average LSD (0.10):				NS	NS	NS	NS	NS	NS	NS	NS
Interactions (P > F)											
APP×UAN				0.732	0.539	0.503	0.835	0.693	0.313	0.416	0.587
APP×ATS				0.097	0.060	0.037	0.654	0.251	0.007	0.006	0.166
UAN×ATS				0.541	0.747	0.825	0.137	0.768	0.708	0.690	0.315
APP×UAN×ATS				0.796	0.413	0.768	0.812	0.862	0.190	0.246	0.716

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

Table 8. Early growth, yield, nutrient concentration and uptake of V6-7 corn plants as affected by starter fertilizer treatments at Waseca (four-year average, 2010-2013).

				V6-8	CV of	Whole Plant Samples at V6-8								
	Fertilizer rate			Plant	Plant		Concentration				Uptake			
Trt	APP	UAN	ATS	height	height	Yield	N	P	K	S	N	P	K	S
#	---- gal/ac -----			inch	%	lb/ac	-------------- % --------------				---------- lb/ac -----------			
1	0	0	0	27.8	9.4	428	3.71	0.390	4.18	0.198	15.9	1.68	18.4	0.83
2	0	0	2	28.6	10.4	510	3.59	0.384	4.26	0.190	18.5	1.99	22.5	0.96
3	0	0	4	31.5	8.2	575	3.55	0.403	4.36	0.196	20.7	2.37	26.5	1.12
4	0	8	0	33.0	6.0	651	3.65	0.394	4.24	0.184	23.9	2.56	28.1	1.18
5	0	8	2	33.7	6.6	713	3.53	0.390	4.12	0.184	25.8	2.80	29.9	1.32
6	0	8	4	33.8	6.8	709	3.28	0.383	4.31	0.181	23.7	2.72	31.0	1.30
7	4	0	0	32.7	6.7	598	3.42	0.390	4.25	0.178	20.8	2.31	25.7	1.05
8	4	0	2	33.5	7.0	684	3.50	0.402	4.30	0.183	24.3	2.76	29.9	1.24
9	4	0	4	33.7	7.7	669	3.48	0.391	4.22	0.188	23.6	2.61	28.8	1.25
10	4	8	0	34.1	7.4	733	3.41	0.376	4.33	0.167	25.2	2.80	32.7	1.23
11	4	8	2	34.7	6.4	773	3.44	0.383	4.19	0.181	26.8	2.99	32.9	1.40
12	4	8	4	35.4	5.3	792	3.38	0.373	4.21	0.186	27.0	2.95	33.4	1.46
13	4	0	1*	33.6	6.8	668	3.52	0.392	4.21	0.182	23.8	2.63	28.6	1.21
14	4	8	1*	33.6	7.1	704	3.27	0.388	4.29	0.169	23.1	2.73	30.8	1.18
Stats for RCB design (all 14 treatments)														
P > F:				<0.001	<0.001	<0.001	0.011	0.390	0.731	0.003	<0.001	<0.001	<0.001	<0.001
Average LSD(0.10):				1.3	1.5	64	0.19	NS	NS	0.011	3.2	0.34	3.3	0.15
Stats for a Factorial Design (Treatments 1-12)														
APP (10-34-0) applied in-furrow														
None				31.4	7.9	598	3.55	0.391	4.25	0.189	21.4	2.35	26.1	1.12
4 gal/ac				34.0	6.8	708	3.44	0.386	4.25	0.181	24.6	2.74	30.6	1.27
P > F:				<0.001	0.002	0.007	0.072	0.232	0.952	0.044	0.029	0.001	0.007	0.004
UAN (28-0-0) applied as a surface dribble band														
None				31.3	8.3	577	3.54	0.393	4.26	0.189	20.7	2.29	25.3	1.07
8 gal/ac				34.1	6.4	728	3.45	0.383	4.23	0.181	25.4	2.80	31.3	1.31
P > F:				0.013	0.069	0.028	0.347	0.389	0.511	0.028	0.089	0.102	0.041	0.076
ATS (12-0-0-26) applied as a surface dribble band														
None				31.9	7.4	602	3.55	0.387	4.25	0.182	21.5	2.34	26.2	1.07
2 gal/ac				32.7	7.6	670	3.51	0.390	4.22	0.184	23.9	2.63	28.8	1.23
4 gal/ac				33.6	7.0	686	3.42	0.387	4.27	0.188	23.8	2.66	29.9	1.28
P > F:				0.004	0.361	<0.001	0.040	0.898	0.818	0.573	0.029	0.013	0.009	0.023
Average LSD (0.10)				0.5	NS	28	0.08	NS	NS	NS	1.5	0.16	1.8	0.11
Interactions (P > F)														
APP×UAN				<0.001	0.004	0.109	0.492	0.098	0.735	0.321	0.137	0.040	0.085	0.130
APP×ATS				0.174	0.357	0.441	0.019	0.199	0.146	0.050	0.974	0.173	0.069	0.795
UAN×ATS				0.298	0.584	0.265	0.248	0.276	0.128	0.220	0.195	0.156	0.178	0.471
APP×UAN×ATS				0.020	0.009	0.227	0.642	0.360	0.994	0.574	0.139	0.135	0.338	0.153

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

Table 9. Grain moisture and yield, plant stand, final plant population, and relative leaf chlorophyll at Waseca (four-year average, 2010-2013).

Trt	Fertilizer rate APP	Fertilizer rate UAN	Fertilizer rate ATS	Grain H_2O	Grain Yield	Initial Plant Stand	Final Plant Pop.	VT-R1 Leaf Chloro
#	--------	gal/ac	---------	%	bu/ac	plants×10^3/ac		%
1	0	0	0	18.4	203	33.8	33.5	95.5
2	0	0	2	18.0	207	33.8	33.2	95.8
3	0	0	4	17.6	214	33.1	32.7	98.6
4	0	8	0	17.7	210	33.9	33.5	95.1
5	0	8	2	17.4	215	33.5	33.1	97.4
6	0	8	4	17.6	209	33.3	32.9	97.8
7	4	0	0	17.6	207	33.3	33.1	95.5
8	4	0	2	17.4	212	33.6	33.3	96.5
9	4	0	4	17.2	213	33.6	33.4	97.9
10	4	8	0	17.5	206	33.4	33.3	95.8
11	4	8	2	16.9	211	33.1	32.7	98.7
12	4	8	4	17.0	210	33.1	33.0	97.4
13	4	0	1*	17.5	209	33.0	32.9	97.2
14	4	8	1*	17.3	202	32.5	32.4	96.0
Stats for RCB design (all 14 treatments)								
P > F:				0.388	0.064	0.092	0.171	0.032
Average LSD (0.10):				NS	7	0.7	NS	2.0
Stats for a Factorial Design (Treatments 1-12)								
APP (10-34-0) applied in-furrow								
None				17.8	209	33.6	33.2	96.7
4 gal/ac				17.3	210	33.4	33.1	96.9
P > F:				0.032	0.836	0.271	0.853	0.329
UAN (28-0-0) applied as a surface dribble band								
None				17.7	209	33.5	33.2	96.6
8 gal/ac				17.3	210	33.4	33.1	97.0
P > F:				0.132	0.777	0.343	0.493	0.365
ATS (12-0-0-26) applied as a surface dribble band								
None				17.8	207	33.6	33.3	95.5
2 gal/ac				17.4	211	33.5	33.1	97.1
4 gal/ac				17.4	211	33.3	33.0	97.9
P > F:				0.757	0.079	0.529	0.415	0.212
Average LSD (0.10):				NS	4	NS	NS	NS
Interactions (P > F)								
APP×UAN				0.580	0.120	0.363	0.274	0.371
APP×ATS				0.989	0.977	0.327	0.254	0.031
UAN×ATS				0.317	0.199	0.503	0.488	<0.001
APP×UAN×ATS				0.378	0.323	0.664	0.426	0.902

Table 10. Nutrient concentration and uptake in the corn grain as affected by starter fertilizer treatments at Waseca (four-year average, 2010-2013).

	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	1.21	0.25	0.35	0.084	116	24.1	33.2	8.1
2	0	0	2	1.19	0.26	0.36	0.086	116	25.8	34.9	8.5
3	0	0	4	1.25	0.27	0.36	0.092	126	27.0	36.4	9.3
4	0	8	0	1.19	0.26	0.36	0.083	119	25.8	35.6	8.3
5	0	8	2	1.19	0.27	0.37	0.085	121	27.9	37.8	8.7
6	0	8	4	1.18	0.27	0.37	0.090	117	26.2	36.1	8.9
7	4	0	0	1.22	0.27	0.37	0.083	120	26.2	36.4	8.2
8	4	0	2	1.24	0.27	0.36	0.085	125	26.9	36.2	8.6
9	4	0	4	1.22	0.27	0.36	0.089	123	26.9	36.2	8.9
10	4	8	0	1.21	0.28	0.37	0.084	118	27.0	36.1	8.2
11	4	8	2	1.22	0.26	0.36	0.087	121	26.1	35.6	8.7
12	4	8	4	1.23	0.26	0.37	0.090	122	25.9	36.5	9.0
13	4	0	1*	1.21	0.26	0.35	0.084	120	25.9	35.1	8.4
14	4	8	1*	1.20	0.27	0.36	0.085	115	26.1	34.4	8.2
Stats for RCB design (all 14 treatments)											
P > F:				0.115	0.553	0.454	0.000	0.017	0.320	0.084	<0.001
Average LSD (0.10)				NS	NS	NS	0.003	5	NS	1.9	0.4
Stats for a Factorial Design (Treatments 1-12)											
APP (10-34-0) applied in-furrow											
None				1.20	0.26	0.36	0.087	119	26.1	35.7	8.6
4 gal/ac				1.22	0.27	0.36	0.086	121	26.5	36.2	8.6
P > F:				0.187	0.629	0.462	0.784	0.274	0.507	0.258	0.842
UAN (28-0-0) applied as a surface dribble band											
None				1.22	0.26	0.36	0.086	121	26.1	35.5	8.6
8 gal/ac				1.20	0.27	0.37	0.087	120	26.5	36.3	8.6
P > F:				0.114	0.428	0.089	0.744	0.332	0.508	0.103	0.612
ATS (12-0-0-26) applied as a surface dribble band											
None				1.21	0.26	0.36	0.084	118	25.8	35.3	8.2
2 gal/ac				1.21	0.27	0.36	0.086	121	26.7	36.1	8.6
4 gal/ac				1.22	0.27	0.36	0.090	122	26.5	36.3	9.0
P > F:				0.583	0.808	0.828	0.024	0.225	0.221	0.166	0.009
Average LSD (0.10)				NS	NS	NS	0.003	NS	NS	NS	0.3
Interactions (P > F)											
APP×UAN				0.334	0.352	0.236	0.049	0.665	0.143	0.048	0.688
APP×ATS				0.362	0.035	0.032	0.457	0.574	0.141	0.106	0.660
UAN×ATS				0.726	0.421	0.938	0.893	0.160	0.136	0.527	0.225
APP×UAN×ATS				0.087	0.543	0.468	0.788	0.041	0.419	0.149	0.362

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

Table 11. Early growth, yield, nutrient concentration and uptake of V6-7 corn plants as affected by starter fertilizer treatments at Rochester (four-year average, 2010-2013).

	Fertilizer rate			V6-8 Plant height	CV of Plant height	Whole Plant Samples at V6-8								
							Concentration				Uptake			
Trt	APP	UAN	ATS	height	height	Yield	N	P	K	S	N	P	K	S
#	----	gal/ac	-----	inch	%	lb/ac	-------------	%		--------------	----------	lb/ac		-----------
1	0	0	0	29.9	7.3	623	3.66	0.352	2.99	0.207	22.5	2.41	22.7	1.26
2	0	0	2	30.3	6.2	624	3.69	0.355	2.67	0.213	22.8	2.32	18.3	1.29
3	0	0	4	30.6	6.8	636	3.68	0.349	2.74	0.220	23.2	2.36	18.8	1.38
4	0	8	0	31.2	6.7	743	3.69	0.345	2.87	0.209	26.8	2.73	24.9	1.51
5	0	8	2	32.2	6.7	781	3.65	0.349	2.64	0.210	28.1	2.79	22.6	1.61
6	0	8	4	32.3	5.8	727	3.71	0.348	2.59	0.220	26.6	2.63	20.4	1.61
7	4	0	0	33.0	6.1	864	3.65	0.354	2.70	0.205	30.4	3.15	27.0	1.70
8	4	0	2	33.1	6.5	826	3.58	0.358	2.80	0.210	28.3	3.12	29.5	1.66
9	4	0	4	33.6	6.2	885	3.62	0.357	2.78	0.213	31.5	3.27	27.4	1.83
10	4	8	0	33.5	6.7	842	3.62	0.359	2.70	0.206	29.5	3.10	25.7	1.67
11	4	8	2	33.7	5.4	919	3.69	0.352	2.50	0.211	33.0	3.34	26.1	1.91
12	4	8	4	33.5	6.1	923	3.71	0.361	2.76	0.221	33.1	3.47	33.2	1.97
13	4	0	1*	33.3	6.4	860	3.58	0.354	2.69	0.206	30.0	3.17	28.3	1.67
14	4	8	1*	33.4	6.5	908	3.65	0.355	2.46	0.210	31.7	3.36	28.4	1.83
Stats for RCB design (all 14 treatments)														
P > F:				<0.001	0.460	0.001	0.514	0.949	0.624	0.011	<0.001	0.003	0.307	<0.001
Average LSD(0.10):				1.4	NS	136	NS	NS	NS	0.008	4.0	0.53	NS	0.24
Stats for a Factorial Design (Treatments 1-12)														
APP (10-34-0) applied in-furrow														
None				31.1	6.6	689	3.68	0.350	2.75	0.213	25.0	2.54	21.3	1.44
4 gal/ac				33.4	6.2	877	3.64	0.357	2.71	0.211	31.0	3.24	28.1	1.79
P > F:				0.087	0.208	0.143	0.539	0.307	0.735	0.563	0.112	0.145	0.269	0.110
UAN (28-0-0) applied as a surface dribble band														
None				31.7	6.5	743	3.65	0.354	2.78	0.211	26.4	2.77	23.9	1.52
8 gal/ac				32.7	6.2	823	3.68	0.352	2.68	0.213	29.5	3.01	25.5	1.71
P > F:				0.019	0.414	<0.001	0.345	0.817	0.230	0.635	<0.001	0.006	0.363	0.042
ATS (12-0-0-26) applied as a surface dribble band														
None				31.9	6.7	768	3.65	0.353	2.81	0.207	27.3	2.85	25.1	1.53
2 gal/ac				32.3	6.2	788	3.65	0.354	2.65	0.211	28.0	2.89	24.1	1.62
4 gal/ac				32.5	6.2	793	3.68	0.354	2.72	0.218	28.6	2.93	24.9	1.69
P > F:				0.193	0.232	0.637	0.523	0.951	0.442	0.014	0.475	0.803	0.916	0.077
Average LSD (0.10)				NS	NS	NS	NS	NS	NS	0.005	NS	NS	NS	0.11
Interactions (P > F)														
APP×UAN				0.002	0.725	0.037	0.243	0.361	0.957	0.214	0.070	0.175	0.488	0.074
APP×ATS				0.580	0.755	0.549	0.975	0.653	0.390	0.800	0.489	0.486	0.285	0.715
UAN×ATS				0.613	0.714	0.278	0.650	0.653	0.879	0.344	0.142	0.600	0.657	0.231
APP×UAN×ATS				0.570	0.046	0.626	0.128	0.714	0.533	0.467	0.380	0.785	0.347	0.506

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

Table 12. Grain moisture and yield, plant stand, final plant population, and relative leaf chlorophyll at Rochester (four-year average, 2010-2013).

	Fertilizer rate			Grain	Grain	Initial Plant	Final Plant	VT-R1 Leaf
Trt	APP	UAN	ATS	H_2O	Yield	Stand	Pop.	Chloro
#	------	gal/ac	-------	%	bu/ac	plants×10^3/ac		%
1	0	0	0	19.8	217	34.8	34.3	97.5
2	0	0	2	19.3	217	35.1	34.3	98.1
3	0	0	4	19.1	217	34.9	34.2	98.0
4	0	8	0	19.2	217	35.0	34.2	96.1
5	0	8	2	18.7	220	34.5	33.9	98.0
6	0	8	4	18.7	222	34.1	33.9	98.4
7	4	0	0	18.6	218	34.1	33.9	97.5
8	4	0	2	18.9	216	34.7	34.1	97.3
9	4	0	4	18.3	219	34.5	34.1	98.2
10	4	8	0	18.5	219	34.5	34.0	97.7
11	4	8	2	18.0	220	34.4	34.0	98.3
12	4	8	4	18.7	220	34.2	33.9	98.4
13	4	0	1*	18.6	218	34.2	33.9	98.5
14	4	8	1*	18.6	218	33.8	33.5	97.9
Stats for RCB design (all 14 treatments)								
P > F:				0.001	0.847	0.002	0.012	0.007
Average LSD (0.10)				0.6	NS	0.5	0.3	0.9
Stats for a Factorial Design (Treatments 1-12)								
APP (10-34-0) applied in-furrow								
None				19.1	219	34.8	34.1	97.7
4 gal/ac				18.5	219	34.4	34.0	97.9
P > F:				0.126	0.890	0.080	0.092	0.317
UAN (28-0-0) applied as a surface dribble band								
None				19.0	218	34.7	34.1	97.8
8 gal/ac				18.6	220	34.5	34.0	97.8
P > F:				0.118	0.387	0.156	0.151	0.912
ATS (12-0-0-26) applied as a surface dribble band								
None				19.0	218	34.6	34.1	97.2
2 gal/ac				18.7	219	34.7	34.1	97.9
4 gal/ac				18.7	220	34.4	34.0	98.2
P > F:				0.077	0.594	0.460	0.788	0.031
Average LSD (0.10)				0.3	NS	NS	NS	0.6
Interactions (P > F)								
APP×UAN				0.089	0.804	0.123	0.092	0.053
APP×ATS				0.192	0.700	0.219	0.201	0.153
UAN×ATS				0.013	0.506	0.072	0.532	0.110
APP×UAN×ATS				0.106	0.417	0.792	0.901	0.230

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

Table 13. Nutrient concentration and uptake in the corn grain as affected by starter fertilizer treatments at Rochester (four-year average, 2010-2013).

	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	1.17	0.25	0.35	0.085	120	25.3	36.4	8.8
2	0	0	2	1.15	0.26	0.37	0.087	118	26.8	37.8	9.0
3	0	0	4	1.17	0.24	0.34	0.087	120	24.8	35.1	9.0
4	0	8	0	1.18	0.26	0.36	0.086	121	26.3	37.4	8.9
5	0	8	2	1.16	0.27	0.37	0.088	120	27.9	38.9	9.2
6	0	8	4	1.16	0.26	0.35	0.089	122	26.9	37.2	9.4
7	4	0	0	1.16	0.27	0.38	0.088	120	27.8	38.8	9.1
8	4	0	2	1.18	0.25	0.35	0.087	120	25.9	36.6	9.0
9	4	0	4	1.16	0.26	0.36	0.089	120	26.6	37.0	9.3
10	4	8	0	1.18	0.26	0.36	0.086	122	26.6	37.7	9.0
11	4	8	2	1.18	0.25	0.35	0.088	123	26.3	36.9	9.2
12	4	8	4	1.17	0.25	0.35	0.092	122	25.7	36.5	9.6
13	4	0	1*	1.17	0.26	0.37	0.086	121	27.2	38.1	9.0
14	4	8	1*	1.17	0.26	0.36	0.087	120	26.5	36.6	9.0
Stats for RCB design (all 14 treatments)											
P > F:				0.979	0.142	0.085	0.076	0.894	0.282	0.317	0.097
Average LSD (0.10)				NS	NS	0.0176	0.003	NS	NS	NS	0.4
Stats for a Factorial Design (Treatments 1-12)											
APP (10-34-0) applied in-furrow											
None				1.17	0.25	0.36	0.087	120	26.3	37.1	9.1
4 gal/ac				1.17	0.26	0.36	0.088	121	26.5	37.2	9.2
P > F:				0.687	0.919	0.926	0.032	0.619	0.812	0.894	0.227
UAN (28-0-0) applied as a surface dribble band											
None				1.17	0.25	0.36	0.087	120	26.2	37.0	9.0
8 gal/ac				1.17	0.26	0.36	0.088	121	26.6	37.4	9.2
P > F:				0.636	0.565	0.597	0.333	0.084	0.435	0.356	0.214
ATS (12-0-0-26) applied as a surface dribble band											
None				1.17	0.26	0.36	0.086	121	26.5	37.6	8.9
2 gal/ac				1.17	0.26	0.36	0.087	120	26.7	37.6	9.1
4 gal/ac				1.17	0.25	0.35	0.089	121	26.0	36.4	9.3
P > F:				0.793	0.380	0.112	0.203	0.772	0.572	0.362	0.253
Average LSD (0.10)				NS	NS	NS	NS	NS	NS	NS	NS
Interactions (P > F)											
APP×UAN				0.699	0.029	0.050	0.420	0.773	0.078	0.097	0.474
APP×ATS				0.446	0.075	0.094	0.242	0.587	0.103	0.042	0.304
UAN×ATS				0.965	0.692	0.785	0.053	0.871	0.745	0.737	0.078
APP×UAN×ATS				0.843	0.466	0.689	0.450	0.883	0.521	0.733	0.883

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

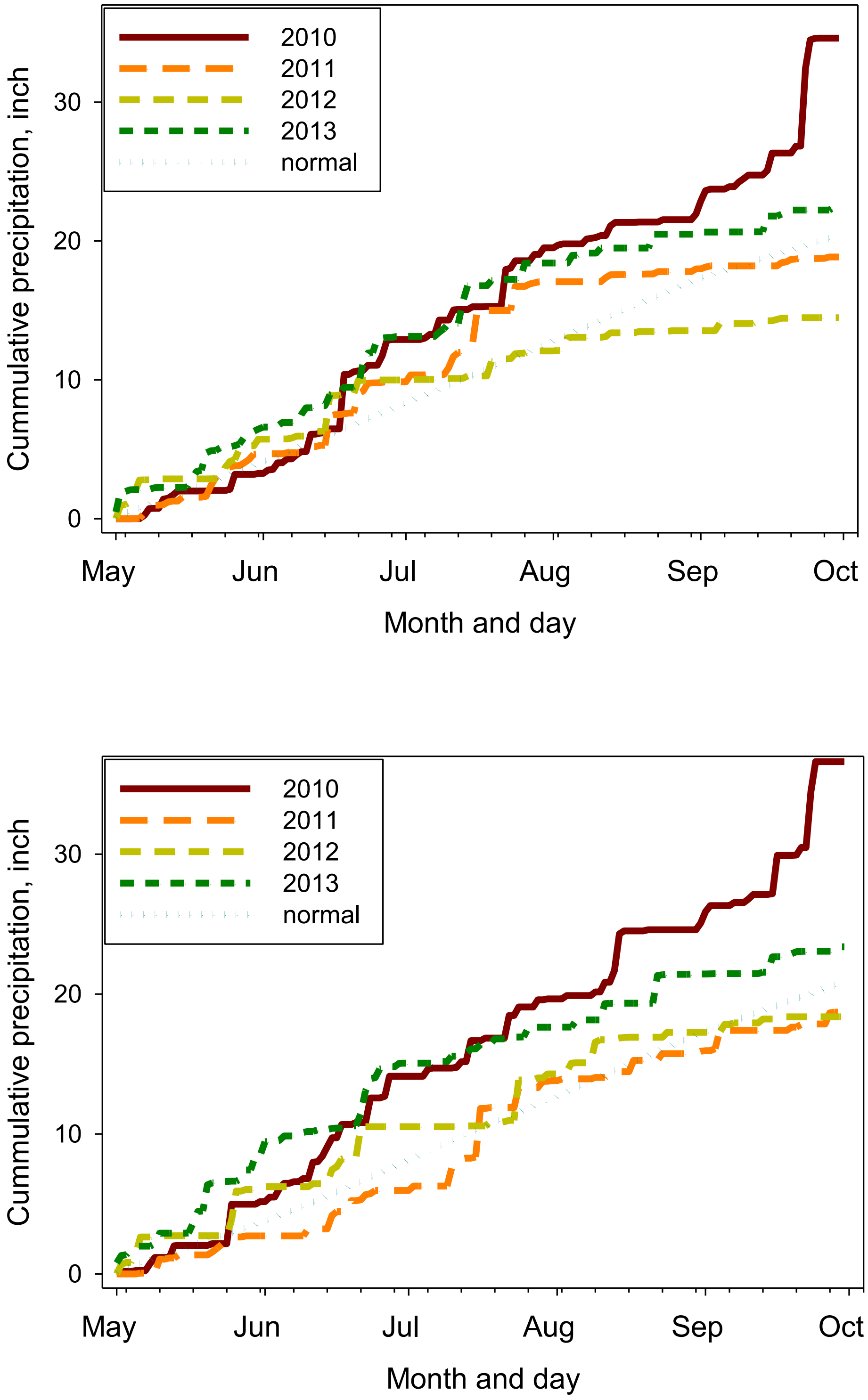

Figure 1. Cumulative growing season precipitation at Waseca (top) and Rochester (bottom).