Zinc and Sulfur Fertilization for High Yield Corn Production

2010 AFREC (R2008-01) Annual Report and 2008–2010 Summary

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Introduction

High corn yields obtained in recent years have raised questions about the need for secondary and micro-nutrients on medium and fine-textured soils in Minnesota. Researchers in Southern Minnesota and Northeast Iowa have reported corn yield responses to sulfur (S) fertilization on medium and fine-textured soils. Historically, S fertilization has been limited to coarse-textured low organic matter soils in this region. Significant reductions in atmospheric S deposition in recent years could partially explain the increased incidence of corn yield responses to S on these soils. Meanwhile on some of these same soils, grid soil samples have shown areas that test low or marginal for Zn. Current University of Minnesota fertilizer recommendations do not recommend Zn fertilizer on corn when the DTPA soil test is greater than 0.75 ppm. However, increased reports of corn responses to Zn fertilization have been occurring and some of these anecdotal reports have shown certain corn hybrids to be more responsive to Zn fertilization than others. The objectives of these studies were: 1) to determine the effects of starter-band and broadcast applications of zinc (Zn) and sulfur (S) on high-yielding corn in Southern Minnesota and 2) to determine if corn hybrids respond differently to band and broadcast-applied Zn.

The original project was funded for two cropping seasons with 3 sites in 2008 and 4 sites in 2009 for objective 1, plus one site in each year for objective 2. The same experimental design was used in the 2008 and 2009 cropping seasons. An extension was funded by AFREC to include 3 sites in 2010 which focused on objective 1. This report will highlight the 2010 research sites (objective 1) and a 3-year summary of data across all sites. For site specific summaries of 2008 and 2009 sites (Objective 1) and information on the hybrid study (Objective 2), please see the 2008 and 2009 annual reports. A link to those reports can be found on page 10 of this report.

Materials and Methods

Objective 1: Effects of Starter-band and Broadcast Applications of Sulfur and Zinc

Experiments were conducted at three sites [Mower Co. (43.87° N, 92.68° W), Goodhue Co. (44.27° N, 93.66° W), and the Southwest Research and Outreach Center (Lamberton)] in 2010. Nine treatments were replicated four times in a randomized, complete-block design (Table 1). Plots measured 10 ft. wide (four, 30-inch rows) and a minimum of 40 ft. in length. Treatments included: 1) a control; 2) 5 gal/A of ammonium poly phosphate (APP, 10-34-0); 3) 5 gal/A of APP + 1 qt/A of a 10% chelated Zn (0.25 lb Zn/A); 4) 5 gal/A of APP + 2 qt/A of chelated Zn (0.50 lb Zn/A); 5) 15.1 lb/A of $ZnSO_4$ (5 lb Zn/A + 2.7 lb S/A); 6) 30.3 lb/A of $ZnSO_4$ (10 lb Zn/A + 5.5 lb S/A); 7) 5 gal/A of APP + 2 gal/A of ammonium thiosulfate (ATS, 12-0-0-26, 5.75 lb S/A); 8) 5 gal/A of APP + 2 gal/A of ATS + 1 qt/A of chelated Zn (5.75 lb S/A + 0.25 lb Zn/A); 9) (added in 2010) 5 gal/A of APP applied in-furrow + 2 gal/A of ATS applied as a surface band one inch from the row. The rates of APP, chelated Zn, and ATS used in this study are typical application rates for these products on southern Minnesota soils. The rates of $ZnSO_4$ used in this study match current Univ. of Minnesota broadcast Zn recommendations for low Zn testing soils. The APP and APP + chelated Zn treatments (#'s 2, 3, and 4) were applied in the seed furrow (pop-up) at planting, while the $ZnSO_4$ treatments (#'s 5 and 6) were broadcast-applied and incorporated with tillage. Treatment #'s 7 and 8 were applied as a surface band one inch away from the row at planting. The completion dates for each experimental procedure are listed in Table 2. Corn (DeKalb 48-37VT3) was planted at 35,000 seeds/A. Weeds were controlled with a combination of pre- and post-emergence herbicides at labeled rates.

Experimental measurements included soil, plant, and grain samples. One soil sample (16 cores, 0-6 inch depth) was taken to characterize each experimental area prior to establishing the site. It was air dried, ground, and analyzed for organic matter, pH, Bray P_1, exchangeable K, and DTPA Zn. Additional soil samples were taken (8 cores/plot, 0-6 inch depth) from each control plot prior to treatment application and from each control plot and all $ZnSO_4$ plots after harvest. These samples were air dried, ground, and analyzed for DTPA and Mehlich III Zn. Small corn plants (8 plants/plot in 2010) were harvested at V7. These samples were dried at 150° F, weighed when dry, ground, and submitted for elemental analysis. Total dry matter yields from the small plants were calculated along with nutrient uptake (N, P, K, S, and Zn) in the whole plants. Emerged plant stands were determined by counting plants in the center two rows (full length) of each plot. Plots were thinned to a uniform stand at each site. Corn grain yield and grain moisture were determined by combine harvesting the center two rows. Grain samples were saved for all sites. However, only samples from sites that showed a significant yield response to treatments were submitted for nutrient (N, P, Zn, and S) concentration in the grain. Economic return was calculated based on the following costs: $0.15 per bu. for grain handling, $0.04 per bu. per one percent for grain drying, $2.00 per gal of 10-34-0, $3.75 per qt. of chelated Zn, $0.80 per lb of $ZnSO_4$, $1.65 per gal of ATS, and a price of $4 per bushel for corn. All other input costs were assumed to be similar and were not included in the calculation.

Analysis of variance was used to statistically interpret the data. Least significant differences (LSD) were calculated at a 0.10 level of significance for individual site crop production data and for all soil data; whereas, a 0.05 level of significance was used for the multi-site analysis of crop production data.

Results and Discussion

Climatic conditions varied among experiment locations during the 2010 growing season (Table 3). A slightly warmer-than-normal growing season was observed throughout Southern Minnesota. Temperatures in August were 3 to 4 degrees above normal, while September was cool. Monthly precipitation was less than normal in May at all sites and in August at Mower Co., whereas significantly greater than normal precipitation was recorded at all sites in June, July and September. Growing season precipitation was 132, 165 and 160% of normal at the Mower Co., Goodhue, Co., and Lamberton sites, respectively. The excess rainfall, which resulted in flooding and N loss in many farm fields across southern Minnesota, did not adversely affect this research in 2010.

Site characteristics and background soil test information are presented in Table 4. The Kasson silt loam at the Mower Co. site (# 8) had 3.7% organic matter, 32 ppm Bray P_1 (very high), 154 ppm exchangeable K (high) and 0.4 ppm DTPA Zn, which is significantly less than the 0.76 ppm critical value (1). The Goodhue Co. site (# 9) (also a Kasson silt loam) had 4.7% organic matter, 47 ppm Bray P_1 (very high), 196 ppm exchangeable K (very high) and 0.7 ppm DTPA Zn. The Ves loam soil at Lamberton (site 10) had 4.6% organic matter, 16 ppm Bray P_1 (high), 136 ppm exchangeable K (high) and 0.7 DTPA Zn. Preliminary samples from sites 9 and 10 showed slightly lower DTPA Zn values than were found with our preplant samples, which are reported here.

Mower Co. (Site 8)

Treatment effects on dry matter yield, nutrient concentration and nutrient uptake in V7 corn plants at Mower Co. are presented in Table 5. Dry matter yield, S concentration and Zn and S uptake were increased with both rates of $ZnSO_4$, compared with the control. An in-furrow application of 5 gal/A of APP alone or in combination with chelated Zn did not increase dry matter yield, nutrient concentration and nutrient uptake in V7 corn plants. These findings are quite different than previous site-years of this study. An increase in early growth associated with in-furrow applications of starter fertilizers containing APP has been common in this multi-site study, while an increase in early growth with $ZnSO_4$ has rarely occurred. When 2 gal/A of ATS was applied as a surface band with 5 gal/A of APP in-furrow (treatment # 9), dry matter yield and N and S uptake in small plants were increased compared with 5 gal/A of APP in-furrow. However, the dual placement treatment (# 9) was not significantly greater than the 5 gal/A of APP + 2 gal/A of ATS applied as a surface band treatment (# 7). Zinc concentration and uptake in V7 corn plants was not affected by the chelated Zn treatments in this study on a low testing (0.4 ppm DTPA Zn) soil. Zinc concentration in treatment means of small corn plants was greater than the established critical level (20 ppm) only with the $ZnSO_4$ fertilized plots.

Treatment effects on corn production parameters and economic return are presented in Table 6. Corn yield was 10 bu/A greater than the control with the 5 gal/A of APP applied in-furrow treatment; however, economic return was not significantly greater at $4/bu corn and $2/gal APP. Adding 2 qt/A (0.5 lb Zn) of chelated Zn to 5 gal/A of APP applied in-furrow reduced grain yield and economic return significantly. Generally, the rate of chelated Zn has had little to no effect on corn production at other sites during this study. The 10 lb Zn/A as $ZnSO_4$ treatment (# 6) increased yield and return above the control on this low Zn testing soil. However, the yields and returns from treatment # 6 were not greater than the 5 gal/A of APP treatment (# 2) or the APP + ATS treatments (#'s 7 and 8). These data do not clearly determine which nutrient(s) (P, S, or Zn) contributed to the yield increase at this site. The application of 10 lb Zn/A as $ZnSO_4$ did affect soil test Zn (see soil test discussion later in report), which may affect corn yield and profitability for years to come. This site was about 0.5 miles north of last year's Mower Co. site, which also had a DTPA Zn soil test of 0.4 ppm and did not respond to Zn fertilization. Grain moisture at harvest, stand counts, and final plant populations were not affected by treatments.

Goodhue Co. (Site 9)

Treatment effects on dry matter yield, nutrient concentration and nutrient uptake in V7 corn plants at the Goodhue Co. site are presented in Table 7. Total dry matter yield in V7 corn plants was increased above the control with 5 gal/A of APP applied in-furrow; however, adding ATS or chelated Zn to APP did not further increase dry matter yield above the 5 gal/A of APP treatment. Phosphorus and S concentrations varied among treatments and were significantly greater than the critical levels for V7 corn plants. Zinc concentrations were related to dry matter yields (dilution effect) and were greatest with the 10 lb Zn/A rate of $ZnSO_4$ treatment (# 6). Adding chelated Zn to APP starter had no effect on Zn concentration in small plants. Generally, nutrient uptakes were affected more by dry matter yield differences than by differences in nutrient concentrations.

Corn production parameters and economic returns were not affected by treatments at this site (Table 8). Corn yields ranged from 199 bu/A in the control to 208 bu/A with the 5 lb Zn/A as $ZnSO_4$ treatment (# 5) and the 5 gal/A of APP + 2 gal/A of ATS treatment (# 7). The lack of a yield response to APP and ATS at this site would be expected because of the very high P (47 ppm Bray P_1) soil test and adequate S concentration in small plants (> 0.25%). The 0.7 ppm DTPA Zn soil test at this site was marginal and Zn concentration in small plants was increased with $ZnSO_4$ fertilization, but no yield response was observed.

Lamberton (Site 10)

Treatment effects on dry matter yield, nutrient concentration and nutrient uptake in V7 corn plants at the Lamberton site are presented in Table 9. Generally, dry matter yield, P concentration and P uptake of V7 corn plants were increased above the control with in-furrow application of APP alone, APP + chelated Zn, and APP applied in-furrow + ATS applied as a surface dribble band (treatment # 9). Potassium concentrations in small plants on this high K testing soil (136 ppm exchangeable K): were marginally deficient (less than the 2.5% critical level), varied among treatments, and could not be completely explained by the dilution effect (greater early growth = lower concentration of nutrients in tissue). Moreover, no differences in K uptake were found. Sulfur concentrations were near the 0.20% critical level in all non S containing treatments and generally were increased slightly by S containing fertilizer applications ($ZnSO_4$ and ATS). Zinc concentration in small plants was not affected by the treatments. Nitrogen, S and Zn uptake differences primarily resulted from differences in dry matter yield, not differences in nutrient concentration

Corn production parameters and economic returns were not affected by the treatments at this site based on the analysis of variance *F* tests for each parameter (Table 10). However, contrast statistics (P=0.024 and 0.058, data not shown) showed grain yields and economic returns were 8 bu/A and $29/A greater, respectively, with 5 gal/A of APP + 2 gal/A of ATS applied as a surface dribble band (treatment # 7) compared with 5 gal/A of APP alone (# 2). These positive yield and economic return responses to S were small and were not consistent across other ATS (S) containing treatments (#'s 8 and 9). Corn yields were excellent at this site and ranged from 204 to 212 bu/A. Moreover, it's unlikely the marginal K concentrations in small corn plants reduced yield potential at this site.

<u>Results and discussion across nine sites from 2008 through 2010 (the low yielding and highly variable site at Lamberton in 2008 was removed).</u>

Total dry matter yield, nutrient concentration, and nutrient uptake were affected by the main effects of site and treatment, and there were many significant site × treatment interactions (Table 11). Averaged across treatments, N and P concentrations in small corn plants varied among sites; however, N and P concentrations were never below recognized critical levels (2). Whereas, K, S and Zn concentrations were below critical levels at 1, 2, and 2 of 9 sites, respectively. Averaged across sites, dry matter yields were increased 28% above the control with 5 gal/A of APP applied in-furrow. Dry matter yields were further increased when 0.25 lb/A of chelated Zn was added to the APP compared with APP alone. While significant N and P concentration differences were found the differences were very small and not agronomically important. Potassium concentration decreased with the APP + chelated Zn treatments, compared with APP alone or in combination with ATS. This response could not be explained by the dilution effect, because on sites where it occurred dry matter yields were not different between APP and APP + chelated Zn. Sulfur concentrations in whole plants were increased significantly above the control by sulfur containing treatments ($ZnSO_4$ and ATS), averaged across sites. In-furrow application of starter fertilizer decreased S and Zn concentrations in small plants compared with the control. This response can be explained by the dilution effect as a subsequent increase in dry matter was found in those treatments and sites. Sulfur concentrations with in-furrow starter treatments were slightly greater than the 0.20% critical value for S in small corn plants, when averaged across sites. A significant site × treatment interaction showed that enhanced early growth of corn, a common plant response to in-furrow application of starter fertilizers, resulted in S concentration in small plants < 0.20% and the onset of S deficiency at 2 of 9 sites (data not shown). Generally, nutrient uptake differences among treatments primarily resulted from increased dry matter with in-furrow application of starter fertilizers and partially from differences in nutrient concentration due to treatments.

Corn grain moisture, grain yield, and economic return were affected by the main effects of site and treatment and there were significant site × treatment interactions (Table 12). Corn grain yields varied by site and ranged from 187 to 207, when averaged across treatments. Excellent yields were obtained across sites except for the 2008 Lamberton site, which was excluded from this combined analysis. Significant treatment effects were found for grain moisture, grain yield, and economic return, when averaged across sites. Grain moisture was 0.6 and 0.4 percentage points less than the control and 5 gal/A of APP treatments, respectively, when 5 gal/A of APP + 2 gal/A of ATS were applied as a surface band. Drier grain at harvest is a typical S response. A significant site × treatment interaction for grain moisture showed at 2 of 9 sites grain moisture was 2 percentage points drier with the APP + ATS treatment compared with the control or APP alone (date not shown). Five gal/A of APP increased grain yield 4 bu/A (about 2%) compared with the control, averaged across sites (7 of 9 sites had Bray P_1 > 25 ppm). However no difference in economic return was found between the control and the 5 gal/A of APP treatments. Five gal/A of APP + 2 gal/A of ATS applied as a surface band treatment increased yield 5 bu/A and economic return $16/A compared with 5 gal/A of APP applied in-furrow, averaged across sites. Yields and economic returns were increased 6 bu/A and $13/A above the control with the 15 lb/A rate of $ZnSO_4$ (5 lb/A of Zn), when averaged across sites. Some of the yield response to $ZnSO_4$ was attributed to S at some sites, even with this very low rate (2.7 lb/A of S) of broadcast S. Yields and economic returns were reduced with the 5 gal/A of APP + 2 qt/A of chelated Zn (0.5 lb Zn/A) treatment compared with APP alone. Initial plant stands and final plant populations varied among sites; however, stands and populations were not affected by treatments, and there were no significant site × treatment interactions.

Significant site × treatment interactions for grain yield and economic return were found (Table 12). Corn grain yields were increased above the control with 5 gal/A of APP at 3 of 9 sites in 2008-10 and for the nine site average (Figure 1). Five gal/A of APP increased economic return at 1 of 9 sites, but also decreased return at one site (data not shown). The addition of 1 qt/A of chelated Zn (0.25 lb Zn/A) to 5 gal/A of APP increased corn yield and economic return at 2 of 9 sites (when compared with 5 gal/A of APP alone) and reduced yield and return at 2 of 9 sites (Figure 2). Moreover at the Waseca site (# 1) where yields were increased with the APP + 0.25 lb Zn/A treatment compared with APP alone, yields with APP + 0.25 lb Zn/A were not greater than the control and the site had a 1.8 ppm DTPA Zn soil test (much greater than the 0.75 ppm critical value). Applying 5 gal/A of APP + 2 gal/A of ATS in a surface band increased corn yield (Figure 3) and economic return at 3 of 9 sites and for the 9-site average, when compared with 5 gal/A of APP applied in-furrow.

<u>Soil data (all 10 sites)</u>

Soil test results from control plots showed very similar DTPA-Zn when comparing spring and fall sampling times (Table 13); whereas, Mehlich III-Zn varied between sampling times in 2008, but was repeatable in 2009 and 2010. Except for the high rate at the Mower Co. site in 2009 (site # 5), soil test Zn in the post harvest (fall) samples increased with increasing rate of $ZnSO_4$ for both the DTPA and Mehlich III extractants. Averaged across sites, DTPA Zn from post-harvest samples was lowest (0.95 ppm) with the control, intermediate (2.80 ppm) with the 5 lb Zn/A treatment, and greatest (4.31 ppm) with the 10 lb Zn/A treatment. Based on these data and the literature, a broadcast application of 5–10 lb/A of Zn will provide adequate Zn for 3–5 years. When amortized across years, applications of $ZnSO_4$ have the greatest potential for economic return on Zn deficient soils.

Summary (2008–2010)

Five gal/A of APP applied in-furrow (pop-up) increased grain yields at 3 of 9 sites and averaged 4 bu/A across sites on these high and very high P testing soils. Five gal/A of APP + 2 gal/A of ATS applied as a surface band increased yield and economic return at 3 of 9 sites, compared with 5 gal/A of APP applied in-furrow. Averaged across sites, yields were increased 5 bu/A and economic return $16/A. The addition of 1 qt/A of chelated Zn (0.25 lb Zn/A) to 5 gal/A of APP increased corn yield and economic return at 2 of 9 sites (when compared with 10-34-0 alone)

and reduced yield and return at 2 of 9 sites. However in only of 1 of 9 sites did the addition of chelated Zn to APP increase yields above the control. A response to chelated Zn was found in 1 of 3 sites that had a soil test DTPA-Zn of 0.4 ppm (in the responsive range which is < 0.76 ppm, based on current Univ. of Minnesota recommendations). Yields and economic returns were increased 6 bu/A and $13/A above the control with the 15 lb/A rate of $ZnSO_4$, when averaged across sites. However, some of the response to this treatment was attributed to S. In this research study corn yield responses to Zn fertilization were rare and small when they did occur.

Recommendation

In-furrow (pop-up) starter fertilizer on very high P testing soils

Applying 5 gal/A of APP (10-34-0) to Bray P>25 ppm soils may occasionally increase corn grain yield and usually increases early growth. Obtaining an economic return to APP will depend on the price of corn and APP.

Zinc fertilization

In fields with some marginally deficient grid cells (DTPA-Zn = 0.5–1.0 ppm), obtaining an economic return to Zn seems unlikely, especially if the whole field is fertilized with Zn. On deficient areas of fields (DTPA-Zn < 0.5 ppm), a site specific application of 5-10 lb/A of Zn as $ZnSO_4$ has the best chance for an economic return to Zn. Fields (grids) that received broadcast applications of 5-10 lb/A of Zn should be soil tested again in 3 to 5 years. Routine or prophylactic additions of chelated Zn to APP would not be recommended based on these data. These data showed no advantage for using a 0.5 lb Zn/A rate as chelated Zn compared with the 0.25 lb Zn/A rate. University of Minnesota recommendations for Zn fertilization were validated and are correct.

Sulfur fertilization

Corn yield response to S was found at 1/3 of the sites, all of which had greater than 3% organic matter. A corn yield response to S appears less likely in corn after soybean compared with corn after corn, based on these and other recent data from the authors. On medium and fine-textured soils with > 3.5% organic matter a broadcast rate of 10–15 lb/A or a surface band of 4-8 lb/A of sulfate-S seems appropriate.

Acknowledgement

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Outreach Activities

These data have been presented at several meetings in Minnesota with a total of 1250 in attendance from the study's inception in 2008 to March 10, 2011. The 2010 final report will be posted on our website, the 2008 report is online at:
http://sroc.cfans.umn.edu/prod/groups/cfans/@pub/@cfans/@sroc/@research/documents/asset/cfans_asset_113665.pdf
If interested in Zn response to hybrids see the 2009 report online at:
http://sroc.cfans.umn.edu/prod/groups/cfans/@pub/@cfans/@sroc/@research/documents/asset/cfans_asset_180638.pdf

References

1) Rehm, G., G. Randall, J. Lamb, and R. Eliason. 2006. Fertilizing Corn in Minnesota. University of Minnesota Extension Service. Bulletin FO-3790-C. Available online at http://www.extension.umn.edu/distribution/cropsystems/DC3790.html
2) AESL Plant Analysis Handbook – Agronomic Crops – Corn. Univ. of Georgia, College of Agriculture and Environmental Sciences, Cooperative Extension Service. [available online] http://aesl.ces.uga.edu/publications/plant/CornWhole.htm

Table 1. Zinc and sulfur fertilizer treatments (treatment 9 applied only in 2010).

	Fertilizer Treatments		
Trt	Products	Rate	Placement
#		per acre	
1	None	None	None
2	10-34-0	5 gal	In-furrow
3	10-34-0 + Zn chelate	5 gal + 1 qt (0.25 lb Zn)	In-furrow
4	10-34-0 + Zn chelate	5 gal + 2 qt (0.50 lb Zn)	In-furrow
5	ZnSO4	15.1 lb (5 lb Zn+2.7 lb S)	PPI
6	ZnSO4	30.3 lb (10 lb Zn+5.5 lb S)	PPI
7	10-34-0 + ATS	5 gal + 2 gal (5.8 lb S)	Surf. band
8	10-34-0 + ATS + Zn chelate	5 gal + 2 gal + 1 qt	Surf. band
9	10-34-0 In-furrow + ATS Surface band	5 gal + 2 gal (5.8 lb S)	Dual

Table 2. Inputs and dates of experimental procedures were performed at each site in 2010.

Experimental Procedures and inputs	Site 8 Mower Co.	Site 9 Rice Co.	Site 10 Lamberton
Preplant soil samples	9-Apr	12-Apr	29-Apr
ZnSO4 application	9-Apr	12-Apr	29-Apr
Nitrogen application date	14-Apr	Nov-09	Nov-09
Nitrogen source	Urea	AA+N-Serve	AA+N-Serve
Previous crop	Soybean	Soybean	Soybean
Total nitrogen rate (lb N/A)	140-lb	140-lb	135-lb
Field cultivation	16-Apr	24-Apr	29-Apr
Corn planting	27-Apr	28-Apr	29-Apr
Residue counts	27-Apr	28-Apr	28-Apr
Stand counts	26-May	27-May	27-May
Thin to uniform stand	26-May	27-May	27-May
Glyphosate application	16-Jun	ND	10-Jun
V6-7 whole plant samples	16-Jun	16-Jun	18-Jun
Corn harvest	8-Oct	18-Oct	12-Oct
Post harvest soil samples	8-Oct	18-Oct	12-Oct

ND = no data or not reported by farmer cooperator.

Table 3. Monthly air temperature and precipitation in 2010 as compared to (30-yr normal).			
Month	Mower Co.	Goodhue Co.	Lamberton
	----------- temperature, degree F. ------------		
May	56.3 (56.3)	58.4 (57.8)	58.3 (58.9)
June	65.3 (66.6)	67.1 (67.5)	68.1 (68.7)
July	70.3 (70.1)	73.1 (71.6)	73.2 (72.1)
Aug.	70.7 (67.7)	73.0 (69.1)	73.9 (69.3)
Sept.	59.6 (59.0)	57.2 (60.1)	59.1 (60.2)
Average	64.4 (63.9)	65.7 (65.2)	66.5 (65.4)
	------------ precipitation, inches ------------		
May	2.7 (4.3)	3.4 (3.7)	2.0 (3.3)
June	6.9 (4.4)	6.0 (4.2)	6.3 (3.9)
July	8.8 (4.8)	6.1 (4.3)	3.8 (3.8)
Aug.	1.9 (5.1)	5.7 (4.4)	4.8 (3.2)
Sept.	8.8 (3.5)	11.7 (3.2)	10.6 (3.0)
Total	29.1 (22.0)	32.9 (19.9)	27.5 (17.2)

Table 4. Site information and soil test parameters for each study.								
	Previous	Tillage	Soil	Organic			Exch.	DTPA
Site	Crop	System	Type	Matter	pH	Bray P	K	Zn
				%		--------- ppm ----------		
1-Waseca	Soybean	SFC*	Webser cl	6.8	5.5	38	188	1.9
2-Rochester	Corn	Chisel	Port Byron sil	5.4	5.8	33	235	0.9
3-Lamberton	Soybean	SFC	Ves-Revere l	4.6	5.2	16	119	1.3
4-Waseca	Soybean	SFC	Nicollet cl	5.3	5.4	28	169	0.8
5-Mower Co.	Soybean	Chisel	Oran sil	4.8	7.2	26	136	0.4
6-Rice Co.	Soybean	SFC	Hayden, l	3.0	6.2	29	136	0.8
7-Lamberton	Soybean	SFC	Ves, loam	4.0	5.5	29	130	0.4
8-Mower Co.	Soybean	Chisel	Kasson, sil	3.7	7.3	32	154	0.4
9-Goodhue Co.	Soybean	Chisel	Kasson, sil	4.7	6.3	47	196	0.8
10-Lamberton	Soybean	SFC	Ves, loam	4.6	5.4	16	136	0.7
* SFC = Spring field cultivate.								

Table 5. Total dry matter yield, nutrient concentration, and nutrient uptake of whole corn plants at V7 as affected by fertilizer treatments at site 8 (Mower Co.).

Treatments		Whole Plant Samples at V7 (June 16)										
			Concentration					Uptake				
Product/Rate	Placement	Yield	N	P	K	S	Zn	N	P	K	S	Zn
per acre		TDM/A	%				ppm	lb/ac				
None	None	0.178	4.31	0.443	4.27	0.204	19.8	15.3	1.58	15.2	0.73	0.007
5 gal APP	In-furrow	0.190	4.17	0.461	4.02	0.217	19.6	15.7	1.74	15.3	0.82	0.007
APP+¼-lb Zn	In-furrow	0.208	4.23	0.466	4.09	0.213	19.6	17.7	1.94	17.2	0.89	0.008
APP+½-lb Zn	In-furrow	0.201	4.27	0.463	4.25	0.211	18.5	17.2	1.87	17.1	0.86	0.007
15.1-lb ZnSO4	PPI	0.232	4.41	0.433	4.08	0.241	21.1	20.5	2.01	19.0	1.12	0.010
30.3-lb ZnSO4	PPI	0.267	4.33	0.414	3.88	0.245	22.8	23.1	2.21	20.7	1.31	0.012
APP+2 gal ATS	Surf. band	0.204	4.40	0.447	3.80	0.251	18.8	17.9	1.82	15.5	1.02	0.008
APP+ATS+¼Zn	Surf. band	0.232	4.27	0.454	4.11	0.242	19.0	19.7	2.10	18.9	1.12	0.009
APP+2 gal ATS	Dual	0.236	4.33	0.436	3.77	0.224	19.0	20.5	2.06	17.9	1.06	0.009
Statistical analysis of treatment effects												
P > F:		0.020	0.696	0.143	0.494	<0.001	0.195	0.011	0.190	0.184	0.003	0.011
LSD (0.05):		0.047	NS	NS	NS	0.017	NS	4.0	NS	NS	0.26	0.003
LSD (0.10):		0.039	NS	NS	NS	0.014	NS	3.4	NS	NS	0.21	0.002
CV (%):		14.9	4.2	5.7	9.2	5.0	11.1	14.9	16.4	17.4	17.7	20.3

Table 6. Corn production parameters as affected by fertilizer. treatments at site 8 (Mower Co.).

	Treatments		Grain	Grain	2010 Econ.	Initial Plant	Final Plant
#	Product/Rate	Placement	H_2O	Yield	Return	Stand	Pop.
	per acre		%	bu/A	$/A	plants×10^3/A	
1	None	None	14.9	200	767	33.7	33.5
2	5 gal APP	In-furrow	14.9	210	793	32.8	32.8
3	APP+¼-lb Zn	In-furrow	14.7	204	769	33.3	33.2
4	APP+½-lb Zn	In-furrow	14.7	194	727	32.2	32.2
5	15.1-lb ZnSO4	PPI	14.4	208	791	33.2	32.8
6	30.3-lb ZnSO4	PPI	14.6	216	808	33.7	33.4
7	APP+2 gal ATS	Surf. band	14.5	215	815	34.6	34.0
8	APP+ATS+¼Zn	Surf. band	14.6	211	792	33.1	33.1
9	APP+2 gal ATS	Dual	14.4	205	778	33.9	33.5
Statistical analysis of treatment effects							
P > F:			0.365	0.010	0.024	0.113	0.164
LSD (0.05):			NS	10	42	NS	NS
LSD (0.10):			NS	8	35	NS	NS
CV (%):			2.2	3.4	3.7	2.7	2.2

Table 7. Total dry matter yield, nutrient concentration, and nutrient uptake of whole corn plants at V7 as affected by fertilizer treatments at site 9 (Goodhue Co.).

Treatments		Whole Plant Samples at V7 (June 16)										
			Concentration					Uptake				
Product/Rate	Placement	Yield	N	P	K	S	Zn	N	P	K	S	Zn
per acre		TDM/A	-------------- %			--------------	ppm	------------------ lb/ac				------------------
None	None	0.150	4.32	0.424	4.26	0.269	23.5	13.0	1.28	13.0	0.81	0.007
5 gal APP	In-furrow	0.191	4.22	0.432	4.29	0.250	21.4	16.2	1.65	16.5	0.96	0.008
APP+¼-lb Zn	In-furrow	0.205	4.31	0.445	4.20	0.251	21.3	17.7	1.83	17.2	1.03	0.009
APP+½-lb Zn	In-furrow	0.221	4.28	0.466	4.32	0.272	21.2	18.9	2.06	19.1	1.21	0.009
15.1-lb ZnSO4	PPI	0.191	4.41	0.431	4.43	0.275	25.6	16.9	1.65	16.9	1.05	0.010
30.3-lb ZnSO4	PPI	0.138	4.35	0.404	4.25	0.270	28.7	12.0	1.13	11.9	0.75	0.008
APP+2 gal ATS	Surf. band	0.225	4.39	0.504	4.93	0.275	24.6	19.8	2.28	22.3	1.24	0.011
APP+ATS+¼Zn	Surf. band	0.161	4.32	0.458	4.43	0.271	23.0	14.0	1.48	14.3	0.87	0.007
APP+2 gal ATS	Dual	0.203	4.30	0.469	4.63	0.273	21.2	17.4	1.90	18.9	1.11	0.009
Statistical analysis of treatment effects												
P > F:		0.001	0.332	<0.001	0.329	0.016	0.002	0.002	<0.001	0.009	0.005	0.017
LSD (0.05):		0.041	NS	0.035	NS	0.016	3.5	3.7	0.43	5.2	0.25	0.002
LSD (0.10):		0.034	NS	0.029	NS	0.014	2.9	3.1	0.36	4.3	0.21	0.002
CV (%):		15.2	2.4	5.4	9.5	4.2	10.2	15.7	17.4	21.2	17.0	16.9

Table 8. Corn production parameters as affected by fertilizer treatments at site 9 (Goodhue Co.).

Treatments			Grain	Grain	2010 Econ.	Initial Plant	Final Plant
#	Product/Rate	Placement	H_2O	Yield	Return	Stand	Pop.
	per acre		%	bu/A	$/A	plants×10^3/A	
1	None	None	17.0	199	742	33.3	33.1
2	5 gal APP	In-furrow	16.5	205	761	33.5	33.2
3	APP+¼-lb Zn	In-furrow	16.5	202	746	33.5	33.1
4	APP+½-lb Zn	In-furrow	16.3	203	748	33.4	33.2
5	15.1-lb ZnSO4	PPI	16.8	208	766	33.5	33.3
6	30.3-lb ZnSO4	PPI	16.5	200	726	33.1	32.9
7	APP+2 gal ATS	Surf. band	17.0	208	762	33.2	33.1
8	APP+ATS+¼Zn	Surf. band	16.0	205	758	33.2	33.1
9	APP+2 gal ATS	Dual	16.1	206	766	32.9	32.8
Statistical analysis of treatment effects							
P > F:			0.232	0.607	0.603	0.865	0.850
LSD (0.05):			NS	NS	NS	NS	NS
LSD (0.10):			NS	NS	NS	NS	NS
CV (%):			3.6	3.6	3.9	1.8	1.2

Table 9. Total dry matter yield, nutrient concentration, and nutrient uptake of whole corn plants at V7 as affected by fertilizer treatments at site 10 (Lamberton).

Treatments		Whole Plant Samples at V7 (June 18)										
			Concentration					Uptake				
Product/Rate	Placement	Yield	N	P	K	S	Zn	N	P	K	S	Zn
per acre		TDM/A	------------- % -------------				ppm	----------------- lb/ac -----------------				
None	None	0.246	3.84	0.296	2.18	0.200	31.3	18.8	1.44	10.9	0.97	0.016
5 gal APP	In-furrow	0.325	3.69	0.316	1.81	0.202	29.3	24.0	2.06	11.8	1.31	0.019
APP+¼-lb Zn	In-furrow	0.325	3.76	0.326	2.00	0.200	32.2	24.5	2.13	13.3	1.29	0.021
APP+½-lb Zn	In-furrow	0.326	3.82	0.326	2.00	0.200	29.9	25.0	2.12	13.5	1.29	0.020
15.1-lb ZnSO4	PPI	0.255	3.77	0.285	2.23	0.210	32.5	19.2	1.47	11.5	1.08	0.017
30.3-lb ZnSO4	PPI	0.268	3.89	0.292	1.99	0.220	33.5	20.8	1.56	10.7	1.17	0.018
APP+2 gal ATS	Surf. band	0.257	3.85	0.306	2.17	0.214	31.0	19.7	1.61	11.3	1.10	0.016
APP+ATS+¼Zn	Surf. band	0.284	3.72	0.316	2.26	0.218	30.8	21.1	1.80	13.0	1.23	0.017
APP+2 gal ATS	Dual	0.358	3.90	0.334	2.07	0.215	31.3	27.9	2.40	15.0	1.53	0.022
Statistical analysis of treatment effects												
P > F:		0.004	0.565	0.070	0.085	0.053	0.680	0.006	0.001	0.193	0.005	0.124
LSD (0.05):		0.059	NS	NS	NS	NS	NS	4.8	0.45	NS	0.24	NS
LSD (0.10):		0.049	NS	0.028	0.24	0.013	NS	3.9	0.38	NS	0.20	NS
CV (%):		13.7	4.1	7.6	9.6	5.3	9.9	14.6	16.9	18.9	13.7	18.9

Table 10. Corn production parameters as affected by fertilizer treatments at site 10 (Lamberton).

Treatments			Grain	Grain	2010 Econ.	Initial Plant	Final Plant
#	Product/Rate	Placement	H_2O	Yield	Return	Stand	Pop.
	per acre		%	bu/A	$/A	plants×10^3/A	
1	None	None	15.0	207	790	34.7	34.0
2	5 gal APP	In-furrow	14.7	204	772	34.7	34.0
3	APP+¼-lb Zn	In-furrow	14.5	208	788	34.1	33.9
4	APP+½-lb Zn	In-furrow	14.5	207	780	34.2	33.9
5	15.1-lb ZnSO4	PPI	14.7	203	769	34.6	33.9
6	30.3-lb ZnSO4	PPI	14.6	205	766	34.5	33.9
7	APP+2 gal ATS	Surf. band	14.8	212	801	34.4	33.9
8	APP+ATS+¼Zn	Surf. band	14.8	208	781	34.6	33.9
9	APP+2 gal ATS	Dual	14.8	207	781	33.8	33.5
Statistical analysis of treatment effects							
P > F:			0.300	0.374	0.351	0.176	0.114
LSD (0.05):			NS	NS	NS	NS	NS
LSD (0.10):			NS	NS	NS	NS	NS
CV (%):			1.8	2.4	2.6	1.4	0.6

Table 11. Total dry matter yield, nutrient concentration, and nutrient uptake of whole corn plants at V7 as affected by fertilizer treatments across 9 sites.												
		Whole Plant Samples at V7										
Treatments			Concentration					Uptake				
Product/Rate	Placement	Yield	N	P	K	S	Zn	N	P	K	S	Zn
per acre		TDM/A	---------------	%	--------------		ppm	-----------------	lb/ac	---------------		
Stats for RCB Design (All Treatments across sites)												
Site												
1 Waseca		0.363	3.84	0.414	3.41	0.178	34.2	27.8	3.00	24.7	1.30	0.025
2 Rochester		0.427	4.01	0.450	3.64	0.185	25.2	34.2	3.84	31.3	1.58	0.021
4 Waseca		0.138	4.38	0.413	3.43	0.256	34.2	12.0	1.14	9.4	0.70	0.009
5 Mower Co.		0.254	3.67	0.453	2.82	0.215	17.6	18.6	2.30	14.4	1.09	0.009
6 Rice Co.		0.429	3.54	0.403	3.56	0.206	29.7	30.4	3.44	30.3	1.76	0.025
7 Lamberton		0.190	4.07	0.345	2.86	0.222	30.3	15.3	1.33	10.7	0.82	0.011
8 Mower Co.		0.214	4.30	0.447	4.06	0.228	19.9	18.4	1.91	17.4	0.98	0.009
9 Goodhue Co.		0.185	4.32	0.445	4.39	0.267	23.6	16.0	1.67	16.4	0.99	0.009
10 Lamberton		0.286	3.79	0.308	2.08	0.208	31.3	21.7	1.77	12.0	1.18	0.018
P > F:		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
LSD (0.05):		0.036	0.10	0.018	0.43	0.008	2.2	2.8	0.30	3.4	0.14	0.003
Treatment												
None	None	0.232	4.04	0.413	3.41	0.212	28.4	18.4	1.94	15.9	0.94	0.013
5 gal APP	In-furrow	0.297	3.92	0.406	3.40	0.204	25.4	22.8	2.39	20.0	1.17	0.015
APP+¼-lb Zn	In-furrow	0.321	3.88	0.411	3.13	0.203	25.9	24.5	2.62	19.8	1.25	0.017
APP+½-lb Zn	In-furrow	0.301	3.94	0.412	3.22	0.207	26.2	23.3	2.45	18.9	1.20	0.016
15.1-lb ZnSO4	PPI	0.260	4.04	0.402	3.48	0.227	28.2	20.6	2.13	18.4	1.13	0.014
30.3-lb ZnSO4	PPI	0.261	4.06	0.399	3.30	0.236	30.4	20.7	2.10	17.2	1.19	0.016
APP+2 gal ATS	Surf. band	0.273	4.02	0.414	3.50	0.228	27.2	21.6	2.31	19.5	1.20	0.015
APP+ATS+¼Zn	Surf. band	0.266	4.04	0.413	3.45	0.230	27.1	21.1	2.19	18.4	1.18	0.015
P > F:		<0.001	<0.001	0.047	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
LSD (0.05):		0.019	0.08	0.011	0.18	0.005	1.3	1.5	0.17	1.8	0.08	0.001
Interactions												
Site by treatment (P > *F*):		<0.001	0.292	<0.001	0.077	0.001	0.089	<0.001	<0.001	0.001	<0.001	<0.001
CV (%):		14.7	4.3	5.9	11.8	5.3	9.9	15.0	15.7	21.2	15.1	19.3

Table 12. Corn production parameters as affected by fertilizer treatments across 9 sites.						
				2010	Initial	Final
Treatments		Grain	Grain	Econ	Plant	Plant
Product/Rate	Placement	H_2O	Yield	Return	Stand	Pop.
per acre		%	bu/A	$/A	plants×10^3/A	
Stats for RCB Design (All Treatments across sites)						
Site						
1 Waseca		22.8	187	636	36.6	34.2
2 Rochester		22.7	192	654	33.2	32.3
4 Waseca		28.3	200	628	36.3	34.1
5 Mower Co.		23.6	205	690	37.8	35.3
6 Rice Co.		31.7	203	604	36.7	34.8
7 Lamberton		22.7	194	659	36.7	34.6
8 Mower Co.		14.6	207	783	33.3	33.1
9 Goodhue Co.		16.6	204	751	33.3	33.1
10 Lamberton		14.7	207	781	34.5	33.9
P > F:		<0.001	<0.001	<0.001	<0.001	<0.001
LSD (0.05):		0.6	7	22	0.4	0.2
Treatment						
None	None	22.3	196	682	35.5	34.0
5 gal APP	In-furrow	22.1	200	690	35.4	33.9
APP+¼-lb Zn	In-furrow	21.8	199	685	35.3	33.9
APP+½-lb Zn	In-furrow	21.9	197	673	35.1	33.8
15.1-lb ZnSO4	PPI	22.0	202	695	35.5	33.9
30.3-lb ZnSO4	PPI	21.9	201	680	35.6	34.0
APP+2 gal ATS	Surf. band	21.7	205	706	35.6	34.0
APP+ATS+¼Zn	Surf. band	21.9	201	687	35.3	33.9
P > F:		0.006	<0.001	<0.001	0.054	0.140
LSD (0.05):		0.3	3	12	NS	NS
Interactions						
Site by treatment (P > *F*):		0.004	0.001	<0.001	0.161	0.070
CV (%):		2.9	3.7	3.9	1.9	0.9

Table 13. DTPA and Mehlich III zinc soil test as affected by broadcast zinc fertilizer rate.

	Zinc	DTPA Zn			Mehlich III Zn	
Site	rate	Spring	Fall		Spring	Fall
	lb/A	------------------		ppm	------------------	
1-Waseca	0	1.76	1.93		2.22	3.31
1-Waseca	5		3.59			5.32
1-Waseca	10		6.04			8.46
2-Rochester	0	0.96	1.10		2.90	1.78
2-Rochester	5		4.00			5.60
2-Rochester	10		5.30			7.54
3-Lamberton	0	1.37	1.50		1.76	2.11
3-Lamberton	5		1.80			2.57
3-Lamberton	10		4.00			5.56
4-Waseca	0	0.78	1.00		1.51	1.53
4-Waseca	5		2.00			2.76
4-Waseca	10		4.93			6.37
5-Mower Co.	0	0.38	0.40		1.10	1.02
5-Mower Co.	5		1.80			3.33
5-Mower Co.	10		1.60			2.71
6-Rice Co.	0	0.77	1.00		1.51	1.76
6-Rice Co.	5		3.55			4.33
6-Rice Co.	10		4.08			3.65
7-Lamberton	0	0.44	0.50		0.85	0.93
7-Lamberton	5		1.03			1.45
7-Lamberton	10		5.47			6.10
8-Mower Co.	0	0.43	0.48		0.98	0.99
8-Mower Co.	5		2.18			3.29
8-Mower Co.	10		2.35			4.06
9-Goodhue Co.	0	0.78	0.80		1.58	1.53
9-Goodhue Co.	5		5.08			6.65
9-Goodhue Co.	10		5.19			7.44
10-Lamberton	0	0.68	0.83		0.98	1.29
10-Lamberton	5		3.00			3.86
10-Lamberton	10		4.20			5.40
All site average	0	0.83	0.95c		1.54	1.62c
All site average	5		2.80b			3.92b
All site average	10		4.31a			5.73a

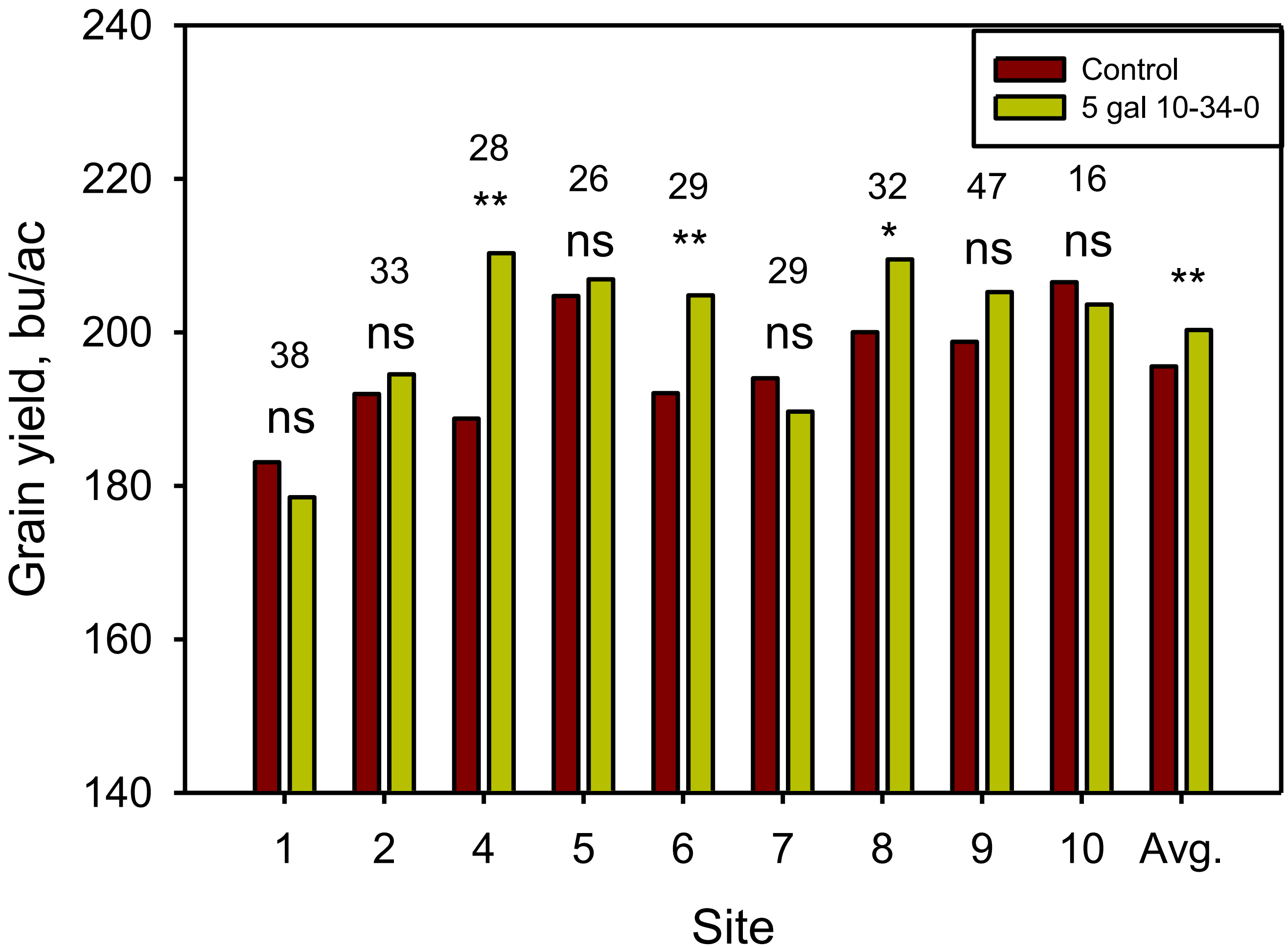

Figure 1. Corn grain yield at 9 sites as affected by rate of 10-34-0 (APP) starter fertilizer applied in-furrow (ns = not significant, * = significant at 0.10, ** = significant at 0.05, and the number "38" = site average Bray P1 soil test.

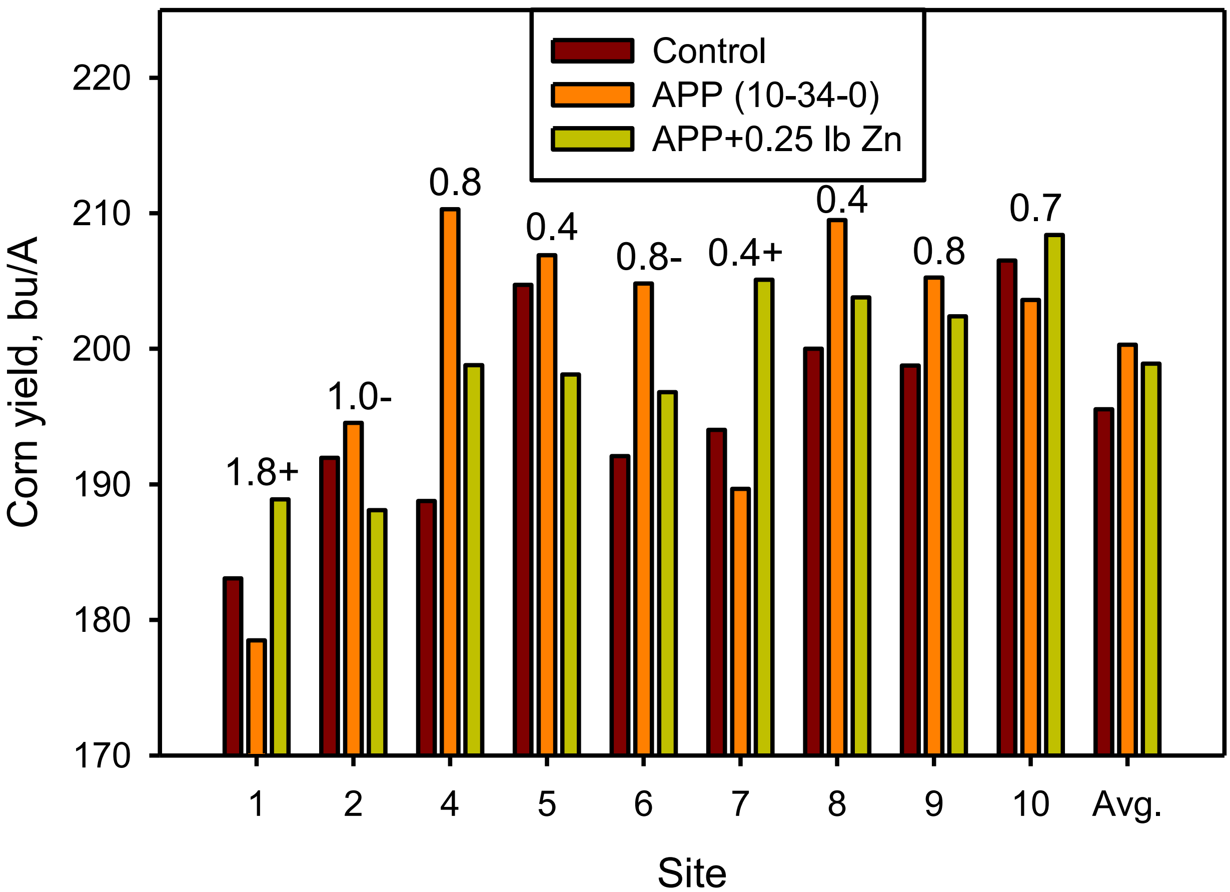

Figure 2. Corn grain yield at 9 sites as affected by APP (10-34-0) application and the addition of 0.25 lb chelated Zn to the starter fertilizer applied in-furrow (the number “1.8” = DTPA Zn soil test at site, + = yield with APP+0.25 lb Zn > yield with APP alone, and – = yield with APP+0.25 lb Zn < yield with APP alone).

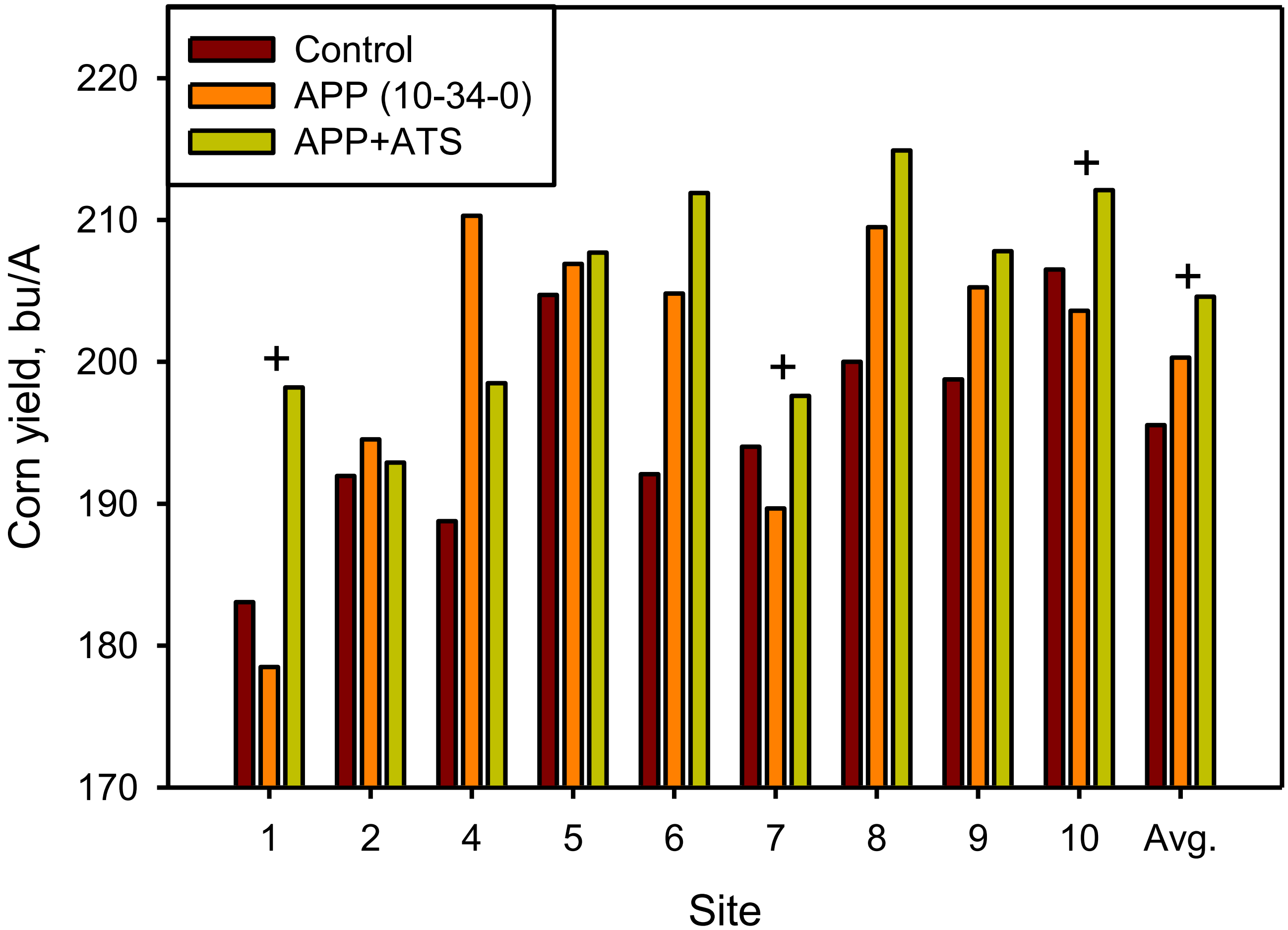

Figure 3. Corn grain yield at 9 sites as affected by the addition of 2 gal/A of ATS to a starter fertilizer containing 5 gal/A of APP (+ = yield with APP+ATS > yield with APP alone).