EVALUATION OF SECONDARY AND MICRONUTRIENTS FOR SOYBEAN AND WHEAT PRODUCTION

by

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ABSTRACT

The application of micronutrients to increase yields has become more popular with increased commodity prices and higher yielding crops. Two studies were completed evaluating secondary and micronutrient for soybean *(Glycine max* [L.] Merr.) and wheat (*Triticum aestivum*).The objective of the first study was to evaluate the response of soybean, under a double crop system after wheat, to soil-and foliar-applied macro and micronutrients. Macronutrients (N, P, K) were applied at 22 kg ha^{-1}, micronutrients (Fe, Mn, Zn) were soil applied at 11 kg ha^{-1}and S was applied at 22 kg ha^{-1}. Plant response parameters were evaluated including changes in nutrient concentration, and seed yield response. Tissue samples were collected at the respective R1 growth stage. Samples were analyzed for the nutrients applied with the fertilizer treatments. Soybean seed yield slightly responded to soil-applied S, Mn, and Zn. When micronutrients were foliar-applied, seed yield was significantly decreased. The second study evaluated the application of S and micronutrients to winter wheat. The objectives were to evaluate the wheat response to sulfur and micronutrient fertilization and evaluate soil testing and tissue analysis as diagnostic tools. Fertilizer treatments consisted of sulfur, iron, manganese, zinc, boron, copper. All of the micronutrients were sulfate-based products and the sulfur treatments were applied as gypsum. Fertilizer treatments were applied as topdress in early spring. Soil samples were collected before fertilizer application and after harvest. Flag leaf samples were collected and analyzed for the nutrients applied with the fertilizer treatments. Significant increases in tissue concentration were observed when Zn, B, and S were applied. Significant increases in soil test Zn, Cu, B, and S were observed compared to the control treatment. Despite the increases in soil test concentration across locations, no significant increases in yield by any of the nutrients or combination of nutrients were observed.

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CHAPTER 1 - INTRODUCTION

Soybean and wheat yields can be affected by several factors. One of the key factors that can be controlled by producers is nutrient management. Proper nutrient management is imperative for optimizing yields. In Kansas soybean and wheat are two of the major crops produced. With increasing commodity prices producers have posed questions about the utilization of micronutrients along with the macronutrients they are already applying.

Throughout Kansas double cropping soybean into wheat stubble after the wheat harvest has become a more common farming practice. By double cropping soybean, producers are able to harvest two crops in one year. Double cropping soybean behind wheat can be risky due to environmental conditions for late planted soybean. Heat, drought, and possible frost injury late in the growing season can limit seed formation. In addition, limited residual moisture in the soil after wheat harvest can effect early soybean establishment and growth. A successful double cropping system can increase gross returns per unit area relative to small production cost increases. Spreading fixed costs such as land, taxes and machinery over two crops with coupled with relatively few inputs, make double-crop soybean a viable option compared to letting the wheat field sit fallow after harvest (Massey, 2010).

In soybean production the most likely response from micronutrients can be with Fe, Mn, and Zn (Mueller, 2012). Typically, Fe deficiencies are found on alkaline soils with free $CaCO_3$ in the profile (Marschner, 1995). Mn deficiencies have become a hot topic due to glyphosate induced Mn deficiencies (Loecker, 2010). Zn deficiencies are not overly common but have been found in locations where topsoil has been removed (Whitney, 1997)

Genetic advances in wheat have significantly improved yields, generating an increased demand for nutrients. Increased yields have spurred questions about the application of micronutrients to further increase yield potential. Some questions have arisen about yield responses from the addition of micronutrients, optimum application timing, tissue nutrient concentration sampling, and soil test analysis for these micronutrients. The application of additional fertilizer to meet the demands from more intensive cropping practices coupled with the high yield potential may require additional micronutrients to obtain maximum yields. Thesis organization

Thesis organization

This thesis is divided into four chapters. The first chapter is an introduction to provide an overview of the material covered in the thesis. The second chapter "Evaluation of macro and micronutrients for soybean after wheat" evaluates at the use of macro and micronutrients on double crop soybean. The study was conducted at 8 locations throughout Central and Eastern Kansas. The focus of this study was on seven nutrients that have been found to be limiting throughout Kansas: N,P,K,S,Fe,Mn,and Zn. The third chapter "Sulfur and micronutrient fertilization for wheat production in Kansas" evaluated the effect of S and micronutrients Zn, Mn, Cu, B, and Fe on wheat. Four locations were established through North Central and North East Kansas in the 2011-2012 growing season to determine the influence the nutrients have on wheat tissue, soil test and yield. Chapter four is a conclusion that summarizes the results of the research.

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CHAPTER 2 - EVALUATION OF MACRO AND MICRONUTRIENTS FOR DOUBLE-CROP SOYBEAN AFTER WHEAT

ABSTRACT

With double crop soybean [*Glycine max* (L.) Merr.], fertilizer is typically applied prior to planting wheat (*Triticum aestivum*) and intended for both crops. When wheat nutrient removal is higher than expected this may limit nutrient supply for the following soybean crop. The objective of this study was to evaluate the response of soybean under a double crop system to soil and foliar-applied macro and micronutrients. The study was established at 8 locations with four of the locations data not presented because of crop failure due to extreme drought conditions. Of the four remaining locations three were rain fed and one was irrigated. All locations were no-till fields planted immediately after wheat harvest. Macronutrients (N, P, K) were applied at 22 kg ha^{-1}, micronutrients (Fe, Mn, Zn) were applied at 11 kg $ha^{-1}$and S was applied at 22 kg ha^{-1}. Fertilizer treatments were band-applied over the row at planting. Foliar Fe, Mn, and Zn fertilizer treatments were applied at the R1 growth stage. Plant response parameters were evaluated including changes in tissue nutrient concentration, and seed yield response. Tissue samples were collected prior to foliar fertilization at R1 growth stage. Pre-plant and post-harvest soil sample were collected and analyzed for the nutrients applied with the fertilizer treatments. Soybean seed yield showed little response to soil-applied S, Mn, and Zn. No yield responses were obtained from N,P, and K. However when micronutrients were foliar-applied, seed yield was significantly decreased. This response was likely due to some leaf damage caused by foliar fertilizer application. During the two years of the study severe drought limited the potential yield response and possibly nutrient uptake. Results across

location indicated that tissue nutrient concentration and soil test for micronutrients was a poor indicator of potential yield response because no responses from any treatments were observed in this study.

Abbreviations: DTPA, diethylene triamine pentaacetic acid; EDTA, ethylenediamine tetraacetic acid; HEDTA, N-hydroxyethyl-ethylenediamine triacetic acid.

INTRODUCTION

Commodity prices have increased the economic feasibility of double-cropping soybean after wheat in some regions of the U.S. Fertilizer programs for this system traditionally include application prior to wheat planting and the nutrients are intended for both wheat and soybean crops. However, when wheat nutrient removal is higher than expected this may limit the amount of nutrients available for double crop soybean. Therefore fertility management options for this system, and the possible need of micronutrients and direct fertilization prior to planting soybean are unknown.

Double cropping soybean behind wheat can be risky due to environmental conditions for late planted soybean. Heat, drought, and possible frost injury late in the growing season can limit seed formation. In addition, limited residual moisture in the soil after wheat harvest can affect early soybean establishment and growth. Although there are risks associated with this system, double crop soybean can be a productive and profitable option considering the recent market prices (Shapiro, 1992). Based on recent costs and commodity prices, the wheat-soybean double cropping system has produced significantly higher net returns over a system with wheat or soybean only (Danehower, 2012). A successful double cropping system can increase gross returns per unit area relative to small production cost increases. According to a 2010 cost-return budget in central and eastern Kansas double-crop soybean can generate return to annual costs in the range of 11-150% (Dumler, 2011). Spreading fixed costs such as land, taxes, and machinery over two crops coupled with limited inputs makes double-crop soybean a viable option versus fields remaining fallow after wheat harvest. In addition this system can help reduce soil erosion because of continuous vegetative cover (Massey, 2010).

Fertilization of double crop soybean can be completed by several different application methods including broadcast, but, application timing should also be considered to ensure optimum yield potential (Rhoton, 1998). A common practice used in a double-crop system is the application of additional to meet the needs of the wheat crop as well as providing additional nutrients for the soybean crop (Minor, 1998). Determining the amount of fertilizer applied is done through yield goals and soil samples. Double crop soybean are usually planted immediately after the wheat harvest, therefore collecting soil samples may be difficult due to reduced time to collect and analyze samples. Another option for producers is to collect soil samples prior to wheat planting and estimate the amount of fertilizer needed by both crops.

Several plant and environmental factors influence the effectiveness of foliar-applied nutrients including age of the leaf, growth stage, leaf surface moisture, temperature, light, wind, humidity, time of day, application rate and pH (Eibner, 1986). In addition, foliar-applied nutrients may burn the leaf which can result in decrease yields if damage is substantial (Mortvedt, 1972).

Application of mobile nutrients such as nitrogen and sulfur may be broadcast applied prior to soybean planting. Nutrients such as phosphorous, manganese, iron, and zinc with limited mobility in the soil may benefit from band application. When applying non-mobile nutrients, placement and application depth could be critical (Minor, 1998). A study evaluating yield response of banded versus broadcast N, P, and K found higher yields when banded compared to broadcasted (Farst, 1998).

Research evaluating direct fertilization of double crop soybean and including micronutrients is limited. For this study we focused on seven nutrients which may be limiting, including N, P, K, S, Fe, Mn, and Zn. The objective of this study was to evaluate double crop soybean seed yield response, tissue nutrient concentration and soil test values as affected by macro and micronutrients.

MATERIALS AND METHODS

Field experiments were conducted at 8 locations from 2011 to 2012; however, only data from 4 locations are presented here (Table 2-1). Soybean were planted on 76 cm rows for locations 1, 3, and 4 and drilled at location 2 on 19 cm row spacing. Locations 1, 2, and 3 were rain fed while location 4 was irrigated. At all locations fertilizer was applied surface band at planting. Nitrogen was applied as urea (22 kg N ha^{-1}), P_2O_5 as mono-ammonium phosphate (MAP) (22 kg ha^{-1}), K_2O as potassium chloride (22 kg ha^{-1}), sulfur as elemental sulfur (22 kg ha^{-1}) at locations 1, 2, and 3 and gypsum (22 kg S ha^{-1}) at location 4, iron as iron sulfate (11 kg Fe ha^{-1}), and zinc as zinc sulfate (11 kg Zn ha^{-1}) and manganese as manganese sulfate (11 kg Mn ha^{-1}).

Foliar micronutrients iron, manganese, and zinc were applied at a rate of 0.2 kg ha^{-1} at the R1growth (Pedersen, 2007). Mn and Zn were applied as EDTA and Fe was applied as HEDTA chelates.

Experimental Design

Experimental design was a randomized compete block with four replications. Nine treatments were evaluated an omission plot approach, wherefore one treatment consisted of all nutrients: N-P-K, S, Mn, Zn, Fe, and foliar micronutrients, and one nutrient or set of nutrients omitted for subsequent treatments. In addition a treatment with S only and a control treatment with all nutrients omitted was included. Fertilizer treatments were applied surface band over the rows immediately after planting.

Foliar micronutrient fertilizer treatments consisted of Fe, Mn, and Zn at the R1-R2 growth stage. Foliar micronutrients were applied with a pressurized CO^2 backpack sprayer set to 0.14 Mpa. The boom used was two rows 2.3 meter wide with nozzle spacing of 76 cm and two passes were made per plot to cover all four rows. The spray tips were 80° flat fan nozzles. Application speed was 4.0 km hr^{-1}.

Soil and plant Samples

Soil samples were collected prior to fertilizer application and after harvest. Ten to twelve cores were taken from 0-15 cm depth from each plot (Carter, 2006). After sampling soil was oven dried at 40°C for at least 4 days and then ground to pass through a 2 mm sieve. Soil samples were analyzed for pH by 1:1 (soil:water), P by Mehlich-3 colormetric method (Frank, 1988) K by ammonium acetate ICP Spectrometer (Warncke and Brown, 1998), organic matter by Walkley-Black method (Combs and Nathan, 1998), Fe, Mn, and Zn were analyzed by DTPA ICP Spectrometer (Whitney, 1998).

Tissue samples were collected at the R-1 growth stage from the uppermost fully developed trifolialate omitting the petiole. Thirty trifoliate leaves were collected from each plot and dried at 65°C for 5-7 days. Samples were ground to pass through a 2 mm screen then analyzed for nutrient concentration. Phosphorus, potassium, sulfur, iron, manganese, and zinc were digested with HNO_3, and nutrient concentrations were then determined by ICP-AES (Grande, 1981). Total nitrogen was determined by dry combustion using a LECO FP-528 nitrogen analyzer (LECO Co., St Joseph, MI) (McGill, 1993). Seed yield was determined by harvesting the middle two rows with a plot combine and adjusted to 130 g kg^{-1}moisture.

Statistical analysis was completed using the GLIMMIX procedure in SAS (SAS Institute, 2010). When analyzed across locations, the location and block within location were considered as random factors in the model (SAS Institute, 2010). Statistical significance was set at the alpha level of 0.10. The PROC REG procedure was used for regression analysis.

RESULTS AND DISCUSSION

Soil pH was adequate at all locations except for location 1 where the soil pH was low at 5.3 (Table 2-1). Remaining locations had pH values ranging from 6.4 to 7.0. Soil test P varied across locations ranging from 13-42 mg kg^{-1}. Soil test K also varied greatly across locations ranging from 74-630 mg kg^{-1}.

Tissue Nutrient Concentrations

Results from tissue analysis showed significant treatment effect on tissue nutrient concentrations for P, K, and Zn at location 2 (Table 2-2). At locations 1, 3, 4, and across all locations there were no statistically significant differences in tissue nutrient concentrations (Table 2-2). Soil test P value at location 2 was above the critical level of 20 mg kg^{-1} while soil test K values were below the critical level of 130 mg kg^{-1} (Leikam, 2003). At location 2 tissue P concentrations were significantly higher with P applied compared to treatments with P omitted

(Table 2-3). Tissue K concentrations at location 2 were also significantly higher on treatments where no nutrients were omitted than the treatments with K omitted. None of the other locations showed significant tissue K increase, but they tended to follow the same trend as location 2. All locations except for location 2 were above the critical level (Jones, 1967) and the tissue K concentration showed sufficient tissue K concentrations being greater than the 15-55 g kg^{-1}at all locations (Mills, 1996). On high soil test K soils, uptake responses to additional fertilizer are not typically found (Mallarino, 2011). At location 2 the analysis of variance showed a significant increase in Zn tissue concentrations (Table 2-2). The tissue Zn concentrations ranged from 24.1-28.9 mg kg^{-1} which are all above the sufficiency range of 20-100 mg kg^{-1} in the plant and yield responses would not be expected from additional Zn (Mills, 1996).

Tissue N concentrations were above the critical value of 40 g kg^{-1}, suggesting there were sufficient N levels in the plant (Mills, 1996). The treatment with N, P, K omitted had the same tissue N concentration as the treatments with all nutrients omitted and all nutrients but S omitted (Table 2-3). The treatment with N omitted tended to have a lower N concentration than the treatments with no nutrients omitted (Table 2-3). These results are similar to what Parker and Harris (1977) found when they evaluated yield and tissue N response from applications of N and Mo (Parker and Harris, 1977). They found that the application of early season N tended to increase the soybean tissue N concentration. Location 4 was irrigated and locations 1 had more typical and uniform rainfall than locations 2 and 3. Tissue N concentrations at locations 1 and 4 were higher with no nutrients omitted than with N, P, K omitted (Table 2-3). Results were not similar at locations 2 and 3, which may suggest that greater rainfall amounts could have had an affected on the N concentration at R1-R2. At location 2, tissue P and K concentrations were significantly higher on treatments with no nutrients omitted than on treatment with P and K omitted (Table 2-3). Other locations tended to follow the same pattern with the omission of N,P,K decreasing tissue P and K concentrations. Tissue P and K levels on all treatments were above the critical value and yield responses on the treatment with greater P and K concentrations were not expected (Mills, 1996). A study conducted in the northeast United States on soils with high soil test P levels found similar results with increases in tissue P concentration from starter P even though soil tests are above the critical level (Roth, 2006).

Tissue concentrations showed no responses from S application (Table 2-3). Sulfur was applied as elemental S at locations 1, 2, and 3, and gypsum at location 4. The S source did not have an effect on tissue uptake. Across locations and within location no response between treatments with pre plant S applied were observed(Table 2-3). No differences were observed in tissue concentration between treatments with only S applied and the control suggesting adequate levels of S in the soil or S not available to the plant at the time of the tissue sampling may have been the reason no S response was observed.

Based on Mills (1996) plant analysis handbook, locations 1 and 3 had average tissue Zn concentrations below the critical level of 20 mg kg^{-1} (Table 2-3). Leikam’s (2003) soil test interpretation suggests adequate levels of Zn in the soil at both locations. The lower tissue concentration with Zn omitted was not predicted by the soil test Zn.

Application of Mn had no effect on the tissue Mn concentration. Across locations treatments with Mn applied showed no statistical difference in Mn concentration compared to the other treatments (Table 2-3). The tissue Mn concentrations were all above the critical level (Mills, 1996). Although not statistically significant locations 1, 2, and 3 treatments with Mn applied decreased tissue Mn concentration on average by 0.81 mg kg^{-1} versus treatments without Mn (Table 2-3).

Pre plant application of Fe did not have an effect on the tissue Fe concentration (Table 2-3). Across locations, all treatments showed sufficient amounts of Fe in the plant and responses from additional Fe was not likely (Mills, 1996). There was no response between treatments with soil-applied Fe versus treatments without Fe. Other studies have found significant increases in tissue Fe concentration from applications of Fe in locations with low soil test levels, but there have been limited studies looking at Fe responses on soils with adequate amounts of Fe (Ai-Quin, 2011). A study looking at Fe in locations with iron chlorosis found that seed applied Fe increased plant height, chlorophyll meter readings at V3 and V6 and grain yield (Liesch, 2011). Typically, Fe deficiencies are found on alkaline soils with free $CaCO_3$ in the profile (Marschner, 1995). This suggests that soil test Fe is not the best was to determine plant availability of Fe.

Seed Yield

Analysis of variance showed a significant yield response at location 1 (Table 2-2) with the foliar micronutrients significantly decreasing yield. At the other locations, 2, 3, 4, and across all locations, treatments with foliar micronutrients omitted had the highest yield; however this trend was not statistically significant (Table 2-5). Some leaf burn was noticed on treatments where the foliar micronutrients were applied. According to a previous study, leaf damage from foliar fertilizers in soybean is common and can generate decrease in yield (Haq, 2000). In addition Mallarino (2001) found that foliar fertilization on soybean showed non-significant and infrequent yield increases. Suggesting an economic yield response may be obtained if micronutrients were tankmixed with post emergence herbicides to minimize the application cost. At location 1 Soybean yield was significantly reduced when S, Mn, Zn, or Fe was omitted versus no nutrients omitted. These results were not found at any of the other locations and were not expected since all locations showed adequate levels of all nutrients in the soil. Location 2 did not show any significant yield response, but tended to show similar results as location 1, with the foliar micronutrient treatment decreasing yield. Treatments with foliar micronutrients omitted out-yielded treatments with no nutrients omitted, Fe omitted, all nutrients but S omitted, and all nutrients omitted (Table 2-5). Location 3 showed a non-significant trend but overall the omission of foliar micronutrients out yielded the treatments with N,P,K omitted, S omitted, Fe omitted, all nutrients but S omitted, and all nutrients omitted (Table 2-5). Visual leaf burn symptoms were similar at locations 1, 2, and 3, and this was likely the cause of the decreased yield on the treatments that received foliar nutrients.

Location 4 did not follow the same trend as the other locations, and showed no statistical yield differences between the omission of the foliar treatment compared the other treatments (Table 2-5). This varying trend may be explained by the fact that Location 4 was the only irrigated field. Even though this location was irrigated the leaf burn was still present and may have caused some yield loss. Having less plant stress from water limitation could have lessened the effect of the foliar burn.

Across all locations there were no statistical yield differences between treatments, but application of foliar micronutrient tended to decreased yield (Table 2-5). These results are similar to those from other studies that found no increase in yield with foliar application of micronutrients and some level of leaf burn (Mallarino, 2001b). Foliar fertilizer application generated lower yields and contributed to variability. However, when foliar fertilization was omitted, the combination of all soil-applied macro and micronutrients was the most beneficial.

Post-Harvest Soil Test Nutrients

Fertilizer treatments showed statistically significant effects on soil nutrient concentration for P, K, Mn, and Zn across locations (Table 2-6). None of the locations showed a significant effect on post-harvest soil test Fe concentrations (Table 2-6). Across locations when comparing the treatment with no nutrients omitted to the treatments with N, P, K and Mn omitted, soil test P, K, and Mn accurately showed omission of the nutrients (Table 2-7). A similar relationship was not observed with Zn and Fe.

At locations 2, 3, and across all locations a significant decrease in soil test P values on treatments with N, P, K omitted compared to the treatment with no nutrients omitted was observed (Table 2-7). Change in soil test P at location 1 and 4 was not significant but had a similar trend as locations 2 and with N, P, K omitted lowering soil test P levels (Table 2-7). Results evaluating the changes in soil test P over time suggests that the soil test P levels will decrease until it comes to equilibrium with the soil solution P (Pedersen, 2007). This equilibrium may require a longer period; however an increased soil test P level is also expected. The application of 22 kg ha^{-1} of P_2O_5 increased post-harvest soil test P values by 0.76 mg kg^{-1}(Figure 2.1). According to the University of Minnesota it takes 22 kg of P_2O_5 to increase soil test P by 1 mg kg^{-1} (Rehm 2009). Soil test P increases in this study were very similar. In addition, fertilizer treatments in this study were surface banded over the rows and not over the entire plot, which could lead to greater increases than predicted.

Across all locations soil test K values were lower on the treatment with N, P, K omitted than the treatment with no nutrients omitted (Table 2-7). Across locations the treatment with no nutrients omitted had higher soil test K values than all other treatments but it was significantly higher than the treatments with foliar omitted and N, P, K omitted (Table 2-7). At each location a similar trend was observed with no differences in soil test K between the treatments with no nutrients omitted, all but S omitted, and all omitted. Rehm (2009) estimated that it takes 11 kg ha^{-1} of K_2O to increase soil test K by 1 mg kg^{-1}. An increase in soil test of 0.79 mg kg^{-1} with the addition of 22 kg ha^{-1} was observed(Figure 2.1). A statistical differences was not found at locations 1, 2, and 3 between the treatment with no nutrients omitted and N, P, K omitted but a similar trend was observed with no nutrients omitted having higher soil test K levels than the treatment with N, P, and K omitted (Table 2-7).

Applications of Zn did not significantly change post-harvest soil test Zn when comparing treatment with no nutrients omitted and only Zn omitted (Table 2-7). At each location and across locations no differences in soil test Zn when comparing the treatments with no nutrients omitted and Zn omitted was observed. Treatments with all nutrients but S omitted, all nutrients omitted, and Fe omitted were statistically lower in soil test Zn than the treatments with no nutrients omitted and Zn omitted (Table 2-7). There was no relationship between pre-plant and post-harvest soil test Zn (Figure 2-1). Other studies have found that soil test Zn usually works well so it was surprising to not observe a relationship between pre-fertilization and post-harvest soil test Zn (Leggett, 1983).

Across locations soil-applied Mn significantly increased post-harvest soil test Mn levels (Table 2-6 and 2-7). Soil test Mn trended lower on the treatments with pre-plant Mn omitted than treatments with Mn applied. In addition, no differences in soil test Mn were observed with Mn omitted and all nutrients but S omitted and all nutrients omitted (Table 2-7). There was a strong relationship between pre-plant and post-harvest soil test Mn (Figure 2-1). Across locations, a significant Mn soil test increase with no nutrients omitted compared to the treatment with Mn omitted was observed (Table 2-7).

No significant soil test differences were observed when no nutrients omitted and Fe was omitted (Table 2-7). At each location and across locations the results were the same with no change in soil test Fe with the application of fertilizer Fe (Table 2-7).

CONCLUSION

All rain-fed locations experienced significantly lower rainfall and yields were well below historical county averages. Results from this study indicate that band-applied macro and micronutrients tended to increased yield, and foliar micronutrients tended to decreased yield. Band-applied P and K tended to increase the tissue nutrient concentration of P and K at R1-R2. Pre plant application of micronutrients Mn, Zn, and Fe did not have a significant effect on tissue leaf concentration. The application of S had no impact on tissue S concentration or yield. Application of foliar EDTA chelated micronutrients Fe, Mn, and Zn tended to decrease yield.

Individual nutrients had no significant effect on soybean yield. Combination of soil-applied macro and micronutrients without foliar micronutrients tended to increase yield over the control but was not significant. Therefore the application of micro and macronutrients was not significantly contributing to increased yield in this study, but it is possible that under more favorable environmental conditions some nutrients may have contributed to a yield increase.

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TABLES AND FIGURES

Table 2-1. Location information, predominant soil type, planting date and mean pre-plant soil chemical analysis.

			Planting	Foliar	Soil		Annual	Soil chemical analysis§							
Location	County	Year	date	application	Series†	Subgroup	precipitation‡	CEC	pH	OM	P	K	Zn	Fe	Mn
							mm	Meq $100g^{-1}$		g kg^{-1}	- - - - - - - - - - mg kg^{-1} - - - - - - - -				
1	Republic	2011	12 July	22 Aug.	Crete sil	P. Argiustolls	690	19.23	5.3	21.6	42	630	1.7	113	83.4
2	Montgomery	2011	26 May	15 Aug.	Bates sil	T. Argiudolls	1010	17.52	6.4	16.2	24	74	1.8	44.9	35.3
3	Franklin	2011	27 May	16 Aug.	Woodson sil	O.Haplustalfs	990	23.10	6.9	22.3	13	125	1.4	30.6	35.2
4	Shawnee	2012	14 May	30 July	Eudora sil	F. Hapludolls	920	22.30	7.0	15.1	28	211	1.3	12.7	13.2

† Soil Series: sil, silt loam.
‡ Mean rainfall from 30-yr norm from weather station within 20 km of each study location.
§ P Mehlich-3 test; K, Ammonium-acetate; Zn, Fe, and Mn analyzed with DTPA extraction

Table 2-2. Significance of F values for the fixed effects of fertilizer treatments on tissue nutrient concentration and seed yield.

Location	Tissue Nutrient							Yield
	N	P	K	S	Fe	Mn	Zn	
	- -			- P > F -			- -	
1	0.293	0.496	0.672	0.672	0.697	0.633	0.195	0.035
2	0.605	0.036	0.003	0.625	0.519	0.636	0.018	0.114
3	0.263	0.411	0.191	0.191	0.316	0.364	0.864	0.344
4	0.482	0.871	0.456	0.456	0.732	0.471	0.208	0.373
All locations	0.191	0.495	0.849	0.498	0.392	0.695	0.261	0.117

Table 2-3. Mean nutrient concentration in the uppermost fully-expanded soybean trifoliate at the R1-R2 growth stage.

Location	Nutrient(s) omitted †								
	None	N,P,K	S	Mn	Zn	Fe	Foliar	All but S	All
	- -N Concentration g kg^{-1}- -								
1	49.3	43.4	49.6	47.3	41.7	48.2	48.4	47.1	47.8
2	37.4	36.2	36.9	39.3	36.1	35.9	36.5	35.7	34.7
3	31.2	31.9	29.2	32.5	30.6	30.9	31.2	30.6	30.6
4	53.9	51.0	53.6	52.9	51.7	54.3	52.0	53.1	51.9
All locations	42.9	40.4	42.1	43.0	39.7	42.2	41.9	41.6	41.6
	- P Concentration g kg^{-1}- -								
1	3.8	3.2	3.3	3.2	3.7	3.9	3.8	3.4	3.4
2	3.6 a	3.1 bc	2.9 c	3.4 ab	2.8 c	2.8 c	3.1 bc	2.8 c	3.0 bc
3	2.8	2.9	2.9	2.9	3.0	2.8	2.9	2.8	3.0
4	3.6	3.7	3.7	3.7	3.8	3.7	3.7	3.8	3.7
All locations	3.4	3.2	3.2	3.3	3.3	3.3	3.4	3.2	3.3
	- K Concentration g kg^{-1}- -								
1	47.3	41.7	39.5	42.6	42.9	47.1	42.9	44.0	43.4
2	50.3 a	42.9 c	46.2 bc	50.9 a	44.8 bc	42.7 c	47.4 ab	43.0 c	44.7 bc
3	24.1	22.9	24.1	23.5	23.9	25.2	23.0	25.0	24.2
4	19.5	19.5	20.5	20.6	20.8	20.5	18.1	19.8	21.1
All locations	31.0	30.0	29.3	30.7	31.1	29.8	29.1	29.1	29.4
	- S Concentration g kg^{-1}- -								
1	1.9	1.7	1.6	1.9	1.8	1.9	1.7	1.7	1.6
2	2.1 bc	2.1 bc	2.0 ab	2.2 a	2.0 ab	1.9 b	2.1 ab	1.9 b	2.1 ab
3	1.9	2.0	1.9	2.0	2.0	1.9	1.9	1.9	1.9
4	3.4 ab	3.5 ab	3.3 b	3.4 ab	3.4 ab	3.3 b	3.6 a	3.4 ab	3.5 ab
All locations	2.5 a	2.4 ab	2.4 ab	2.5 a	2.4 b	2.5 a	2.5 a	2.5 a	2.5 a
	- Zn Concentration mg kg^{-1}- -								
1	18.4	19.2	20.9	24.0	16.3	18.4	17.8	17.1	17.7
2	20.2 bc	19.8 bc	24.9 a	22.7 ab	19.8 bc	24.4 a	20.7 bc	18.3 c	18.9 c
3	15.8	17.8	16.5	16.2	17	16	17.3	16.2	15.9
4	35.6	36.7	32.9	38.2	35.3	32.4	36.0	34.5	35.7
All locations	26.3	25.6	27.9	28.9	24.1	27.6	26.4	26.9	26.6
	- Mn Concentration mg kg^{-1}- -								
1	74.1	90.2	108.8	79.8	68.7	76.5	80.6	91.2	72.4
2	69.7	75.2	74.2	80.9	71.5	60.3	66.1	76.2	64.8
3	107	98.7	105	113	105	118	93.6	107	114
4	56.7	56.1	50.4	54.5	56.1	50.7	60.7	56.1	55.2
All locations	74.6	78.2	77.5	80.5	74.1	73.7	71.8	78.5	74.4
	- Fe Concentration mg kg^{-1}- -								
1	118	112	107	100	125	110	112	113	104
2	127	136	115	124	144	114	128	149	144
3	99	104	98	101	107	97.6	99.8	93.1	100
4	118	114	110	118	111	113	119	110	106
All locations	115	117	108	111	122	109	115	116	114

† Treatment means within location for each nutrient followed by a different letter are significantly different at the 0.10 probability level.

Table 2-4. Change in tissue nutrient concentration across 4 locations with the addition of starter fertilizer.

Nutrient	Increase in concentration	Significance
	mg kg^{-1}	*P* > *F*
N	0.20†	0.122
P	0.02	0.119
K	0.33	0.004
S	0.01	0.154
Fe	5.66	0.393
Mn	-0.81	0.893
Zn	-1.41	0.154

† Change in tissue nutrient concentration with the addition of fertilizer treatment.

Table 2-5. Average yield of each fertilizer treatment by location and across location.

	Location				
Nutrient omitted	1	2	3	4	All locations
	- - - - - - - - - - - - -	- - - - - - - -	kg ha^{-1}	- - - - - - - - - - - -	- - - - - - - - - -
None	2254 ab†	1257	1160	2408	1770
N,P,K	2195 ab	1428	1035	2067	1681
S	1801 c	1308	1080	2525	1679
Mn	1818 c	1395	1133	2194	1635
Zn	1797 c	1333	1131	2710	1743
Fe	1701 c	1157	1118	2583	1640
Foliar	2355 a	1551	1256	2470	1908
All but S	1981 bc	1099	1116	2275	1618
All	2026 abc	1120	1111	2405	1665

† Treatment means within location for each nutrient followed by a different letter are significantly different at the 0.10 probability level.

Table 2-6. Significance of F values for the fixed effects of fertilizer treatments on post-harvest soil nutrient.

Location	Post-harvest soil nutrient				
	P	K	Fe	Mn	Zn
	- - - - - - - - - - - - - P > F- - - - - - - - - - - - - - -				
1	0.500	0.349	0.463	0.056	0.006
2	0.053	0.265	0.979	0.680	0.005
3	0.003	0.005	0.683	0.005	0.001
4	0.535	0.250	0.451	0.349	0.002
All locations	0.001	0.086	0.228	<0.001	<0.001

Table 2-7. Mean soil test values from 0-15 cm after harvest by location and across locations.

	Nutrient(s) omitted								
Location	None	N,P,K	S	Mn	Zn	Fe	Foliar	All but S	All
	P Concentration mg kg^{-1}								
1	81.2	50.3	74.2	66.0	75.1	76.3	66.8	67.2	61.6
2	15.7cd	14.3d	24.8ab	29.6a	23.5abc	18.9bcd	20.8bcd	18.4bcd	14.3d
3	42.6a	9.6c	18.5dc	25.7b	21.3bc	27.8b	24.2b	10.6c	9.3c
4	25.4	20.1	21.9	21.9	25.1	24.0	29.7	20.1	18.0
All locations	41.2a	23.6c	34.8ab	35.8ab	36.3a	36.7a	35.4ab	29.1c	25.8c
	K Concentration mg kg^{-1}								
1	862	755	817	760	832	855	742	837	850
2	112	106	122	117	124	120	123	116	101
3	169	153	162	190	164b	167b	161	156	142
4	229ab	187c	219abc	210bc	228ab	249a	202bc	207bc	205bc
All locations	343ab	300d	330ab	319bcd	337ab	348a	307cd	329abc	324abcd
	Zn Concentration mg kg^{-1}								
1	15.66a	17.83a	17.74a	17.14a	15.91a	3.33b	18.93a	2.08b	1.98b
2	11.09bc	13.11ab	16.18ab	20.30a	11.94b	4.65c	15.09ab	3.95c	4.28c
3	26.05ab	26.71a	17.09ab	25.89ab	15.44b	4.29c	21.79ab	1.49c	1.36c
4	9.23a	7.73ab	5.09bc	8.01ab	5.39bc	1.84ab	7.68ab	1.04d	1.05d
All locations	15.51ab	16.34a	14.03ab	17.83a	12.17b	3.53c	15.87ab	2.14c	2.17c
	Mn Concentration mg kg^{-1}								
1	71.1ab	66.8abc	71.9a	64.1bc	70.0ab	72.3a	72.5a	61.8c	60.9c
2	57.0	55.0	60.5	53.4	58.2	59.3	63.8	53.9	52.3
3	47.2	34.0	34.8	30.2	34.3	32.5	39.3	24.0	22.1
4	6.82a	6.41abc	6.28abc	6.52abc	6.74ab	6.92a	6.67abc	6.03bc	5.95c
All locations	45.5a	40.6bc	43.4ab	38.6cd	42.3abc	42.7ab	45.6a	36.4d	35.3d
	Fe Concentration mg kg^{-1}								
1	106	103	106	97.6	110	108	104	103	98.1
2	53.0	47.7	53.0	47.4	47.3	52.6	54.0	49.9	49.4
3	32.2	25.7	28.6	28.1	26.3	29.8	28.8	28.3	23.7
4	16.2	15.3	13.7	14.6	14.8	17.7	14.8	15.9	13.0
All locations	52.0	48.2	50.4	46.8	49.6	52.0	50.5	49.4	46.2

† Treatment means within location for each nutrient followed by a different letter are significantly different at the 0.10 probability level.

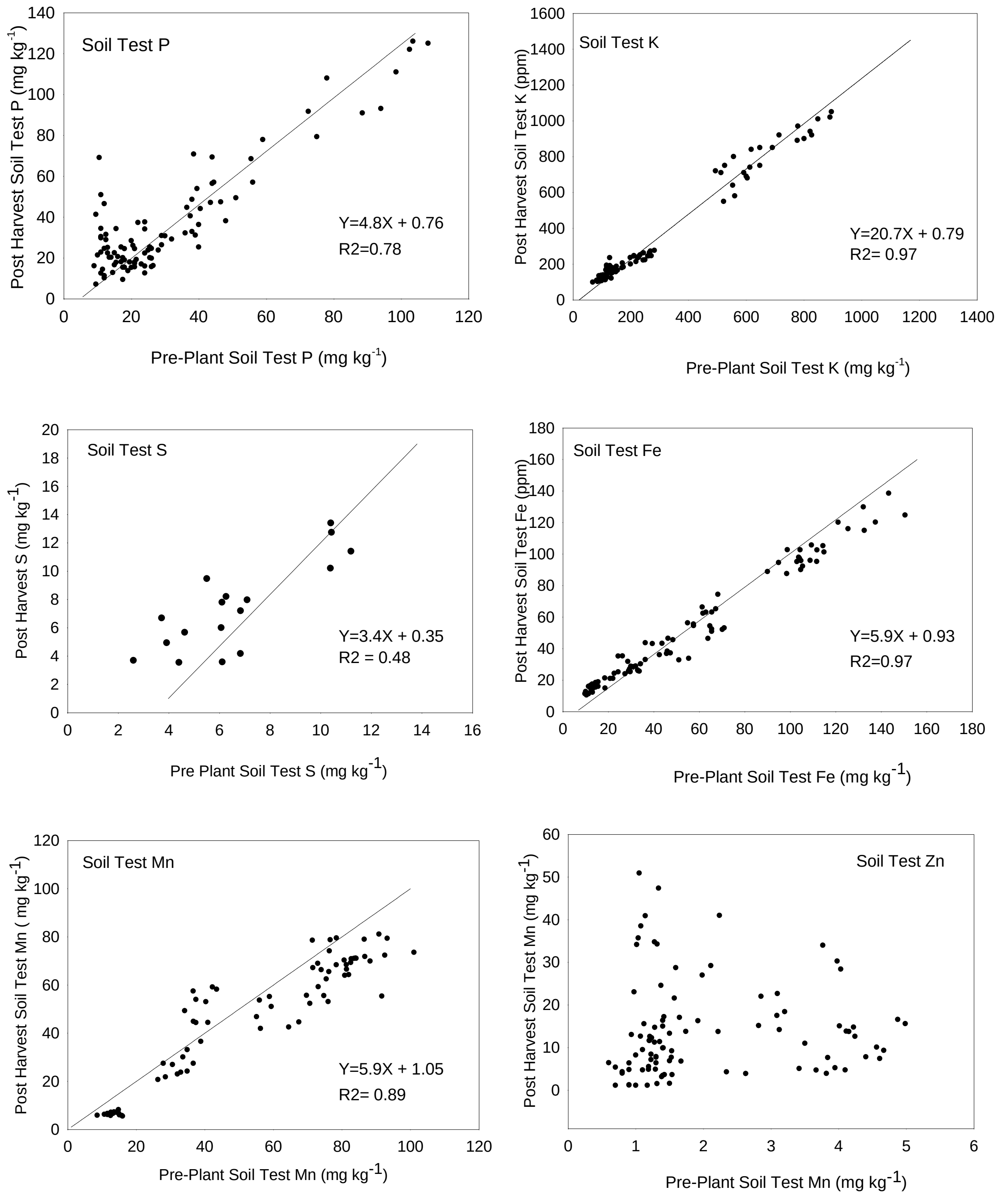

Figure 2-1. Pre-plant and post-harvest soil test values for each nutrient. Samples shown for each nutrient were analyzed from plots where the specified nutrient was applied. The purpose of these figures was to show how much the concentration varied from the application of each nutrient. Proc Reg was used to calculate the regression model and coefficient of determination.

CHAPTER 3 - SULFUR AND MICRONUTRIENT FERTILIZATION FOR WHEAT PRODUCTION IN KANSAS

ABSTRACT

Genetic advances in wheat (*Triticum aestivum*) and increased yield potential may require the need for secondary and micronutrient fertilization. The objectives of this study were to evaluate the wheat response to sulfur and micronutrient fertilization and evaluate soil testing and tissue analysis as a diagnostic tool for secondary and micronutrient management. Four locations were established in 2012, all locations were established in under dryland conditions under conventional tillage system. Fertilizer treatments consisted of topdress sulfur, iron, manganese, zinc, boron, copper and a mixture of all nutrients. Micronutrients Fe, Mn, and Zn were sulfate based, Cu was an oxy-sulfate, and B was boric acid products and sulfur treatments were applied as gypsum. Fertilizer treatments were applied topdress in the early spring. Soil samples were collected form each plot before fertilizer application and after harvest, and analyzed for micronutrients. Tissue samples were collected at feekes 8 by collecting the flag leaf and analyzed for the nutrients applied with the fertilizer treatments. Results across locations indicated application of micronutrients resulted in significantly higher soil test Zn and S for the treatment with the mix of all nutrients compared to the other treatments. Results showed that the Zn treatment had significantly greater soil test Zn concentrations than the control. Results showed no increase in yield by any of the nutrients or combination of nutrients. The soil test results showed significant increases in soil test Zn, Cu, B, and S with the application of these nutrients individually or in combination.

INTRODUCTION

Genetic advances in wheat have significantly improved current wheat yields, generating an increased demand for nutrients. The increased yields have spurred questions about the application of micronutrients to further increase yield potential. Many of these questions pertain to yield responses from the application of micronutrients, optimum application timing for micronutrients, and the value of tissue analysis and soil test for these micronutrients. Recent increases in sulfur deficiencies in wheat also require research for sulfur management. In Kansas and throughout the Midwest there has been an increased utilization of reduced tillage operations. One of the main concerns producers have with decreased tillage and higher yielding wheat is meeting the increased fertility demands due to the increases yield potential and lack of incorporation of immobile nutrients. The application of additional fertilizer to meet the demands from more intensive cropping practices coupled with the high yield potential may require additional micronutrients to obtain optimum yields.

The application of sulfur and micronutrients has been evaluated with some positive results on wheat in the eastern and southeastern United States (Sing, 2004). Jones (2012) found that S applications have increased yields when deficiencies are found. Studies conducted in regions of Asia and India where micronutrient deficiencies can be common, found significant responses from the application of Cu and Mn, and moderate responses to Zn (Sing, 2004). Other nutrients such as B and Fe have had limited responses (Sing, 2004). It is typically suggested that micronutrients are not a limiting factor for wheat in Kansas. Kansas State University Wheat Production Handbook states that in Kansas B, Mn, Fe, Cu and Zn have had inconsistent responses generally did not affect optimum wheat yields (Whitney, 1997). One micronutrient that has resulted in significant yield increase is Cl (Duncan, 1995). A study evaluating at wheat's response to chloride found that both tissue and grain yield significantly increased with Cl application at topdress (Ruiz Diaz, 2012).

Sulfur deficiencies have become more common in recent years with the implementation of the Clear Skies Act, which was implemented to cut sulfur dioxide emissions (EPA, 2003). Prior to the Clear Skies Act atmospheric S deposits were substantial enough to meet crop demands (Camberato, 2010). Sulfur deficiencies have been found in south central and north central Kansas on soils in recent years (Shroyer, 2011). A study conducted by Mortensen (1994) found that even though yield increases were not always significent, increases in grain quality and protein content were significent.

Soil pH and organic matter influence the availability and solubility of micronutrients in the soil. As pH increases the availability of Mn, Fe, Cu, Zn, and B tend to decrease (Essington 2004). Soil organic matter is a major source of micronutrients, and over time most agricultural soils have shown a decline in soil organic matter caused primarily by erosion. Decline in soil organic matter may lead to a lower availability of micronutrients in the soil. In Kansas, micronutrient deficiencies are not common in wheat (Mengel, 2011), but it is possible to see a response from having an additional nutrients available to the plant.

Tissue nutrient analysis can often be a better indicator of secondary and micronutrients than soil testing because it provides information about the nutrients content of the plant at a given point in time (Ritchey, 2011). A general for a wheat nutrient sufficiency ranges for flag leaf samples collected between boot to heading stages are: Fe 30-200 mg kg^{-1}, Mn 20-150 mg kg^{-1}, Zn 15-70 mg kg^{-1}, Cu 5-25 mg kg^{-1}, and B 1.5-4.0 mg kg^{-1} (Jones, 1967). Based on nutrient sufficiency ranges established by Jones (1967) for flag leaf samples, and studies conducted by

(Murdock, 2000) and (Ritchey, 2011), when the nutrient concentrations were above the sufficiency range additional nutrients were not needed to obtain maximum yields.

The purpose of this study was to evaluate the response of wheat to sulfur and micronutrients (Zn, Cu, B, Mn, and Fe) on an individual basis and as a mixture of all nutrients on winter wheat throughout Kansas. The study was primarily focused on identifying the effects of individual nutrients and combination of nutrients on tissue concentration, yield, and soil test changes.

MATERIALS AND METHODS

Four locations were established in the 2011-2012 growing season (Table 3-1). Locations were in Belleville, Scandia, Manhattan, and at Ashland Bottoms. Soils were conventional tillage and pre-plant N-P-K fertilizer was applied by the research stations at rates typical for their areas. Average rates for all locations were 111 kg ha^{-1} N, 56 kg ha^{-1} P_2O_5, and no K_2O was needed at any locations in 2011-2012 due to adequate amounts in the soil. Soil types were silt loams at all locations and fertilizer treatments were applied topdress at a rate of 11 kg ha^{-1} for S, Zn, Cu, B, Mn, and Fe. All of the micronutrients were Agrium Advanced Technology's Ultra Yield granular sulfate based fertilizer products. Analyses of the nutrient were as follows: Manganese was applied as Manganese sulfate and was composed of 20% Mn, 12% S, and 6% Zn; Zinc was applied as zinc sulfate which contained 20% Zn, 14% S, and 2.0% N. Copper was applied at copper oxy-sulfate and was made up of 12% Cu, 13% S, and 6% Zn; Boron was applied as boric acid and was composed of 10% B, 10% Ca, 5% Mg, and 1.5% S; Iron was applied as iron sulfate which was composed of 50% Fe, and 3% S; Sulfur was applied as gypsum ($CaSO_4$) with 17% S, and 21% Ca (Agrium, 2012). All treatments were broadcast evenly over the plots prior to feekes 4 (Miller, 1999) with a handheld broadcast spreader.

Experimental Design and Field Measurements

The experimental design was a randomized complete block design with four replications. Treatments included a control, Zn, Cu, B, Mn, Fe, S, and a mix containing all nutrients. The application rate for each nutrient was 11 kg ha^{-1}. All locations were drilled on 19 cm rows. Plot sizes were 3 m by 9.1 m.

Composite soil samples of, 10-15 cores at the 0-to 15-cm depth were collected before treatment application from each plot. Soil samples were then dried at 40°C for 3-5 days and ground to pass through a 2 mm sieve. Soil analysis included soil organic matter by Walkley-Black method (Combs and Nathan, 1998), soil test phosphorus and potassium by Mehlich-3 Inductively Coupled Plasma (ICP) Spectrometer, with a Model 720-ES ICP Optical Emission Spectrometer, manufactured by Varian Austrailia Pty Ltd, Mulgrave, Vic Australia (Frank K, 1988). Soil pH was measured on 1:1 (soil:water). Additionally, Fe, Zn, Cu, and Mn we analyzed by DTPA (Warncke, 1998) B by hot water (Watson, 1998), and S by Calcium Phosphate Extaction (Watson, 1998).

A total of 50 flag leaf samples were collected from each plot at feekes 8 (Miller, 1999). Samples were dried at 65°C for 5-7, days ground to pass through a 2 mm screen, then analyzed for Fe, Zn, Cu, Mn, B, and S. All nutrients were analyzed using the Nitric-Perchloric digest method and Inductively Coupled Plasma Spectrometer (ICP) (Donohue, 1992).

Statistical analysis was completed using the GLIMMIX procedure in SAS (SAS Institute, 2010). Analysis was completed by location and across locations. Location and block within location were considered as random factors in the model for analysis across locations (SAS Institute, 2010). Statistical significance was set at alpha of 0.10. Regression analysis was completed on pre-plant and post-harvest soil samples using the PROC REG procedure.

RESULTS AND DISCUSSION

Soil analysis indicated relatively low pH levels at locations 1 and 2 (Table 3-1). Locations 3 and 4 were slightly above the neutral pH range (6.6-7.3). All locations had very high soil test P, greater than 50 mg kg^{-1}, and K, greater than160 mg kg^{-1}, values. Based on each location's pre-plant soil test information the nutrient concentration varied greatly across locations. Across all four locations the soil test P and K values were above the critical value of 20 mg kg^{-1} P and 130 mg kg^{-1} K , respectively (Leikam, 2003). Critical range for each micronutrient is: Zn 0.2-2.0 mg kg^{-1} (Jones, 1981), Fe 2.5-5.0 mg kg^{-1} (Jones, 1981), Mn 1.0-5.0 mg kg^{-1} (Jones, 1981) Cu 0.53 mg kg^{-1} (Westerman, 1989) B 0.1-2.0 mg kg^{-1} (Jones, 1981). All locations had soil test levels above these critical ranges.

Flag Leaf Tissue Samples

Analysis of variance indicated significant increases in tissue nutrient concentration across locations from the topdress application of Zn, B, and S (Table 3-2). At location 1 significant increases in tissue Zn, Cu, B, and S. Location 2 showed significant increase in tissue Cu, B, and S. Location 3 indicated significant increases in Mn and B concentration, while location 4 had a significant increase in tissue B concentration.

Across locations tissue Zn concentrations were significantly higher in the mix treatment than all other treatments (Table 3-3). Similar trends at individual locations with the mix treatment increasing tissue Zn concentrations were observed. However, Zn treatments at each location and across locations showed no significant response when compared to control, and tended to have lower concentrations than the mix treatment. These findings are contrary to another study by Zeindan (2010), where they found applications of Zn increased the tissue concentration over the control. The difference between the two studies was that the soil test Zn levels. The Zeindan study averaged 0.13 mg kg^{-1}, which is below the critical range of 0.2-2.0 (Jones, 1981), while the soil test Zn in this study ranged from 0.5 to 2.8 mg kg^{-1}, thus the lack of increase in concentration. The across locations and treatments Zn concentration ranged from 18.56-22.68 mg kg^{-1}. According to the sufficiency range for flagleaf tissue Zn at boot to heading is 5-25 mg kg^{-1} (Jones, 1967). Based on the tissue Zn concentration plants had an adequate amount Zn and yield responses from additional Zn would not be expected.

Across all locations, no increase in tissue concentration for Cu was observed (Table 3-2). At location 2 a significant increase in tissue Cu was observed in the mix and Cu treatments had significantly greater Cu concentrations than the control treatment (Table 3-3). At location 1, a significantly greater tissue Cu concentration in the mix treatment over the S, Zn and control treatments was observed. A previous study indicated that plant response to Cu fertilizer was unlikely with soil Cu levels above 0.6 mg kg^{-1} (Franzen, 1998). This study found the average Cu soil test across locations ranged from 1.79-4.07 mg kg^{-1} which is well above the 0.6 mg kg^{-1} level. With the adequate amounts of Cu in the soil, sufficient amounts of Cu in the plant occured at all locations. With adequate amounts of Cu in the soil and tissue, yield responses would not be expected with additional Cu (Campbell, 2000). Across all locations the average tissue Cu concentration ranged from 4.79-5.54 mg kg^{-1}. According to Jones (1967) the sufficiency range for Cu from boot to heading is 5-25 mg kg^{-1} (Jones, 1967).

Significant increases in tissue B from the application of B were observed at all locations (Table 3-2). The greatest increases were observed with the mix treatment and the B treatment at all locations except location 2 with the mixed treatment (Table 3-3). Mellbye and Gingrich (1999) evaluated the effect of B on soil and plant tissue and found similar results showing that flag leaf concentrations of B were significantly increased over the control when B was applied

(Mellbye, 1999). The tissue concentration ranged from 18-70 mg kg^{-1} which is well above the sufficiency range of 1.5-4.0 mg kg^{-1} (Jones, 1967).

Location 3 was the only location to show significant differences in tissue Mn concentration (Table 3-3). The Mn treatment and mix treatments had significantly lower tissue Mn concentrations than the control treatment. However, Mn concentrations in the plant were sufficient according to Jones's (1967) sufficiency range of 20-150 mg kg^{-1} Mn concentration across treatments and locations ranged from 97.3-104 mg kg^{-1}.

Tissue Fe concentrations across all locations were above the critical range of 2.5-5.0 mg kg^{-1} (Jones, 1981) (Table 3-3). Tissue Fe concentration across all locations and treatments ranged from 90.68-101.6 mg kg^{-1}. The sufficiency range outlined by Jones (1967) from boot-heading is 30-200 mg kg^{-1}. No significant differences were observed for Fe tissue concentrations. Adequate amounts of Fe were in the plant when the samples were collected.

The greatest concentration in tissue S was observed in the mix treatment at location 1, 2 and across locations (Table 3-3). All of the micronutrients were sulfate based therefore the tissue response to S may be from the mix treatment recieving 28 kg ha^{-1} of S from the sulfate in the Zn, Mn, Cu, B, Fe, and gypsum versus 11 kg ha^{-1} in the S only treatment. The sufficiency range for leaf samples at boot to heading is 0.15-0.55 mg kg^{-1} (Jones, 1967). Across all locations and treatments the tissue S concentration ranged from 0.30-0.34 mg kg^{-1} putting it well within the sufficiency range.

Grain Yield

Grain yields across locations were very good and were well above the county averages for each location (USDA, 2012) (Table 3-4). a significant yield increase for the treatment with the mix, and the S treatments at location 4 over the control (Table 3-2 and 3-4). Although not significant, at locations 1 and 2 the mix treatment tended to have the highest yields of all treatments (Table 3-4). At location 3 we found the opposite results with the mix treatment tended to be the lowest yielding treatment (Table 3-4). In general results are similar to those of other studies evaluating micronutrients in wheat where adequate amounts of micronutrients were present in soil and tissue samples and no yield increases occurred (Jones, 2012) (Habib, 2009).

Post-Harvest Soil Nutrient Concentration

Post-harvest soil test analysis indicated significant changes in concentration across locations for Zn, Cu, B, and S treatments when comparing the treatments to the control (Table 3-5). Manganese and Fe did result in significant soil test changes across locations (Table 3-5).

Across locations, a significant increase in soil test Zn with the mix treatment over the Zn treatments and a significantly higher level than the control (Table 3-6). At location 4 and no difference in soil test Zn was observed between the Zn treatment and the control. The mix treatment at locations 1, 2, and 3 increased Zn over the control.

Across all locations, significant increases in soil test Cu occured in the mix treatment over the Cu and control treatments (Table 3-6). Cu soil test values significantly increased at locations 1, 3 and 4 with the mix treatment when compared to the control. A 0.02 mg kg^{-1} increase in soil test Cu occurred for each kg ha^{-1} of Cu applied.

Post-harvest soil test B significantly increased in the mix treatment and B alone compared to the control (Table 3-6). Soil test B concentration increased by 0.14 mg kg^{-1} for each kg ha^{-1} of B applied. No differences in soil test B were observed between the mix and B treatment at locations 1 and 4. The B only treatment at location 2 was nearly twice the B concentration as the mix treatment (Table 3-6). Since these results occurred at only one location, samples could have been collected from spots were B concentrations were higher and results were skewed.

The soil test Mn significantly increased in concentration with the Mn treatment versus the control and mix treatments at locations 2 and 4 (Table 3-6). The control treatment at location 3 was significantly greater than the Mn treatment. These results do not follow the same trend of the other 2 locations (Table 3-1), however, the soil pH at location 3 was 7.8. At pH's of 7.5 and higher the relative availability of Mn declines substantially (Brett, 2008). The high pH at this location is a possible explanation for the lack of soil test increase from the application of Mn.

Location 2 was the only location with a significant difference in Fe soil test (Table 3-1). Fe treatment had significantly greater soil test concentrations than the mix and control treatments (Table 3-6).

Applications of S significantly increased soil test S at location 1 and 2 across locations (Table 3-5). Locations 1, 2 and across all locations had significantly greater S concentrations in the mix than the S and control treatments (Table 3-6). The greater increase in S concentration with the mix treatment is most likely caused by the fact that there was a total of 28 kg ha^{-1} S applied on the mix versus 11 kg ha^{-1} with S only.

A regression analysis comparing the pre plant soil tests versus the post-harvest for each nutrient can be found on Figure 3-1. A regression model could only be fit for Mn and Fe due to the lack of a linear relationship for the other micronutrients (Figure 3-1). These data points were from only one year of data and a linear relationship was not found for Zn, Cu, B, and S. Improved regression models may occur with additional data points collected over a wider range of environments.

CONCLUSION

The overall yields at locations ranged from 2900-6700 kg ha^{-1} (Table 3-4), which was well above the county averages for all locations (USDA-NASS, 2012). At location 4 the mix treatment yielded significantly greater than Fe, S, and control treatments. Tissue Zn, B, and S concentrations were significantly increases with the application of the mixture of the Zn, Cu, B, Mn, Fe, and S over the other treatments (Table 3-3). Soil and tissue analysis were adequate for all nutrients suggesting yields was not limited by the any of the nutrients. Post-harvest soil analysis indicated significant increases in Zn, Cu, B, and S when compared to the pre plant analysis (Table 3-5)

Overall, the application of mixtures of micronutrients increased the tissue Zn and S concentrations as well as the post-harvest soil test Zn, Cu, B, and S. Treatments with individual micronutrient on Zn and B significantly increased soil test levels over the control. In conclusion, we found that the application of S and micronutrients (Zn, Cu, B, Mn, Fe, and S) on wheat in Kansas had mixed results with an increased yield at loction 4 but no significant responses at locations 1, 2, and 3. More site years would be needed to accurately determine the effects of S and micronutrients fertilization for wheat

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TABLES AND FIGURES

Table 3-1 Location information, predominant soil type, planting date, and mean pre-plant soil chemical analysis.

						Soil Chemical Analysis ‡										
Location	County	Location	Year	Soil type†	Soil subgroup	CEC	pH	OM	P	K	Zn	Fe	Mn	S	Cu	B
						Meq100g^{-1}		g kg^{-1}	------------------------------- mg kg^{-1}---------------------------							
1	Republic	Belleville	2012	Crete sil	P. Argiustolls	19.2	4.9	2.5	71.3	405	1.3	106	78.2	6.9	1.3	0.74
2	Republic	Scandia	2012	Crete sil	P. Argiudolls	17.5	4.9	2.1	66.4	665	0.5	87.2	63.3	5.5	1.1	0.61
3	Riley	Manhattan	2012	Smolan sil	P. Argiudolls	23.1	7.8	1.3	54.1	173	0.6	10.3	16.6	15.5	0.7	1.20
4	Riley	Ashland	2012	Belvue sil	T. Udifluvents	22.3	7.5	2.3	179	367	2.8	10.1	11.1	2.1	4.3	0.70

† Soil Type: sil, silt loam.
‡ P Mehlich-3 test; K, Ammonium-acetate; Zn, Fe, Mn, S and Cu analyzed with DTPA extraction.

Table 3-2. Significance of F values for the fixed effects of fertilizer treatments on tissue nutrient concentration and grain yield.

Location	Tissue nutrient						Yield
	Zn	Cu	B	Mn	Fe	S	
	- -	- - -	P > F	- - -	- - -	- -	
1	0.020	0.124	<0.001	0.618	0.169	<0.001	0.876
2	0.163	0.026	<0.001	0.341	0.253	0.003	0.266
3	0.995	0.336	<0.001	0.070	0.956	0.811	0.176
4	0.154	0.805	<0.001	0.573	0.255	0.803	0.059
All locations	0.024	0.174	<0.001	0.694	0.554	0.001	0.270

Table 3-3. Mean nutrient concentration in the flag leaf collected at feekes 8 growth stage.

Location(s)	Treatment							
	Mix	Zn	Cu	B	Mn	Fe	S	Control
				Zn Concentration mg kg^{-1}				
1	26.72ab	24.39bc	27.63a	21.76c	22.11c	23.88c	23.78c	24.46bc
2	20.75	18.89	15.19	15.22	14.22	23.02	15.41	14.61
3	19.57	19.12	18.53	18.59	18.84	18.79	18.64	19.76
4	23.69a	18.62b	20.53b	18.51b	21.01ab	20.44b	19.12b	20.49b
All	22.68a	20.25bc	20.47bc	18.56c	19.05c	21.53ab	19.24c	20.10bc
				Cu Concentration mg kg^{-1}				
1	6.26a	5.03b	5.54ab	5.47ab	4.84b	5.41ab	4.73b	5.11b
2	4.93a	4.86a	4.56ab	4.52abc	3.96d	4.27bc	3.98cd	4.02bcd
3	5.14	5.41	6.45	5.71	4.82	5.21	6.25	5.69
4	5.60	6.28	5.59	5.89	5.56	5.69	5.77	5.87
All	5.48	5.39	5.54	5.40	4.79	5.15	5.18	5.24
				B Concentration mg kg^{-1}				
1	59.87a	23.77c	21.87c	70.43a	24.45c	25.10c	21.80c	24.30c
2	50.85b	21.78c	19.75c	62.43a	24.05c	21.02c	20.00c	20.60c
3	84.50a	33.07b	33.70b	70.08a	31.00b	70.08b	30.40b	37.20b
4	69.80a	19.30b	19.92b	61.08a	18.78b	17.85b	17.85b	17.85b
All	66.25a	24.48b	23.31b	65.66a	24.49b	25.48b	22.51b	25.83b
				Mn Concentration mg kg^{-1}				
1	191	213	196	196	217	192	203	188
2	114	106	104	111	106	112	97.2	99.3
3	42.73d	46.91bcd	58.73a	54.62abc	42.15d	46.12cd	57.06ab	48.71bc
4	47.12	52.06	54.93	46.36	49.37	45.96	45.84	47.71
All	98.8	104	103	102	103	99.3	100	97.3
				Fe Concentration mg kg^{-1}				
1	108.1	111.5	112.1	113.5	110.7	113.3	114.3	115.0
2	84.91	82.87	77.66	89.08	128.5	87.23	79.89	82.41
3	88.49	87.43	89.99	88.32	83.88	85.30	86.91	89.76
4	89.14	84.15	88.17	85.04	83.39	83.09	81.57	84.80
All	92.66	91.51	91.99	93.90	101.6	92.25	90.68	93.39
				S Concentration mg kg^{-1}				
1	0.46a	0.38bc	0.39bc	0.36cd	0.37cd	0.35d	0.40b	0.35d
2	0.23a	0.21cd	0.21bcd	0.21b	0.20cd	0.21bc	0.19d	0.20bc
3	0.42	0.39	0.39	0.39	0.36	0.36	0.37	0.38
4	0.26	0.25	0.26	0.24	0.25	0.25	0.24	0.25
All	0.34a	0.31b	0.31b	0.30b	0.29b	0.29b	0.30b	0.30b

† Numbers within each row followed by a different letter are significantly different at the 0.10 probability level.

Table 3-4. Average yield of each fertilizer treatment by location and across locations.

Location	Treatment							
	Mix	Zn	Cu	B	Mn	Fe	S	Control
	- - - - - - - - - - - - - - - - kg ha^{-1} - - - - - - - - - - - - - - - -							
1	6723	6217	6467	6299	6527	6521	6237	6543
2	5409	4531	3975	4104	4714	4662	4455	4259
3	4096	4732	4552	4435	4561	4288	5004	4549
4	3890a†	3420abc	3660ab	3477abc	3750ab	3137bc	2973bc	2961bc
All locations	5030	4725	4664	4444	4888	4652	4667	4304

† Treatment means within location for each nutrient followed by a different letter are significantly different at the 0.10 probability level.

Table 3-5. Significance of F values for the fixed effects of fertilizer treatments on post-harvest soil nutrient.

Location	Post-harvest soil nutrient					
	Zn	Cu	B	Mn	Fe	S
	- - - - - - - - - - - - - - -	- - - - - - - - - - - - - - -	P > F	- - - - - - - - - - - - - - -	- - - - - - - - - - - - - - -	- - - - - - - - - - - - - - -
1	0.007	0.005	0.008	0.317	0.523	0.001
2	0.025	0.115	0.002	0.067	0.084	0.001
3	0.028	<0.001	0.004	0.100	0.431	0.221
4	0.063	0.004	0.001	0.064	0.774	0.510
All locations	<0.001	<0.001	<0.001	0.315	0.905	<0.001

Table 3-6. Mean soil test values from 0-15 cm after harvest by location and across locations.

Location	Treatment		
	Mix	Zn	Control
	Zn Concentration mg kg^{-1}		
1	5.70a	4.11a	1.13b
2	4.25a	3.99a	0.71b
3	4.08a	2.62ab	0.75b
4	6.77	5.36	3.17
All locations	5.20a	4.02b	1.54c
	Mix	Cu	Control
	Cu Concentration mg kg^{-1}		
1	4.78a	1.30b	1.47b
2	3.49	1.07	1.02
3	4.45a	0.70b	1.09b
4	3.58a	4.16a	1.46b
All locations	4.07a	1.79b	1.24b
	Mix	B	Control
	B Concentration mg kg^{-1}		
1	3.71a	3.29a	0.77b
2	2.19b	4.00a	0.72c
3	5.26a	3.27b	1.38c
4	5.45a	4.64a	1.02b
All locations	4.15a	3.80a	0.95b
	Mix	Mn	Control
	Mn Concentration mg kg^{-1}		
1	82.86	91.00	78.85
2	70.28b	77.74a	71.69b
3	26.62ab	16.97b	27.92a
4	16.54b	26.56a	16.85b
All locations	49.07	53.07	49.37
	Mix	Fe	Control
	Fe Concentration mg kg^{-1}		
1	104.8	90.80	98.38
2	76.69b	85.49a	77.32b
3	14.96	12.45	16.90
4	14.83	16.92	14.78
All locations	52.84	51.41	52.07
	Mix	S	Control
	S Concentration mg kg^{-1}		
1	17.28a	12.03b	11.65b
2	12.52a	9.65b	10.18b
3	10.86	7.29	8.74
4	5.38	4.68	4.81
All locations	11.51a	8.41b	9.00b

† Treatment means within location for each nutrient followed by a different letter are significantly different at the 0.10 probability level.

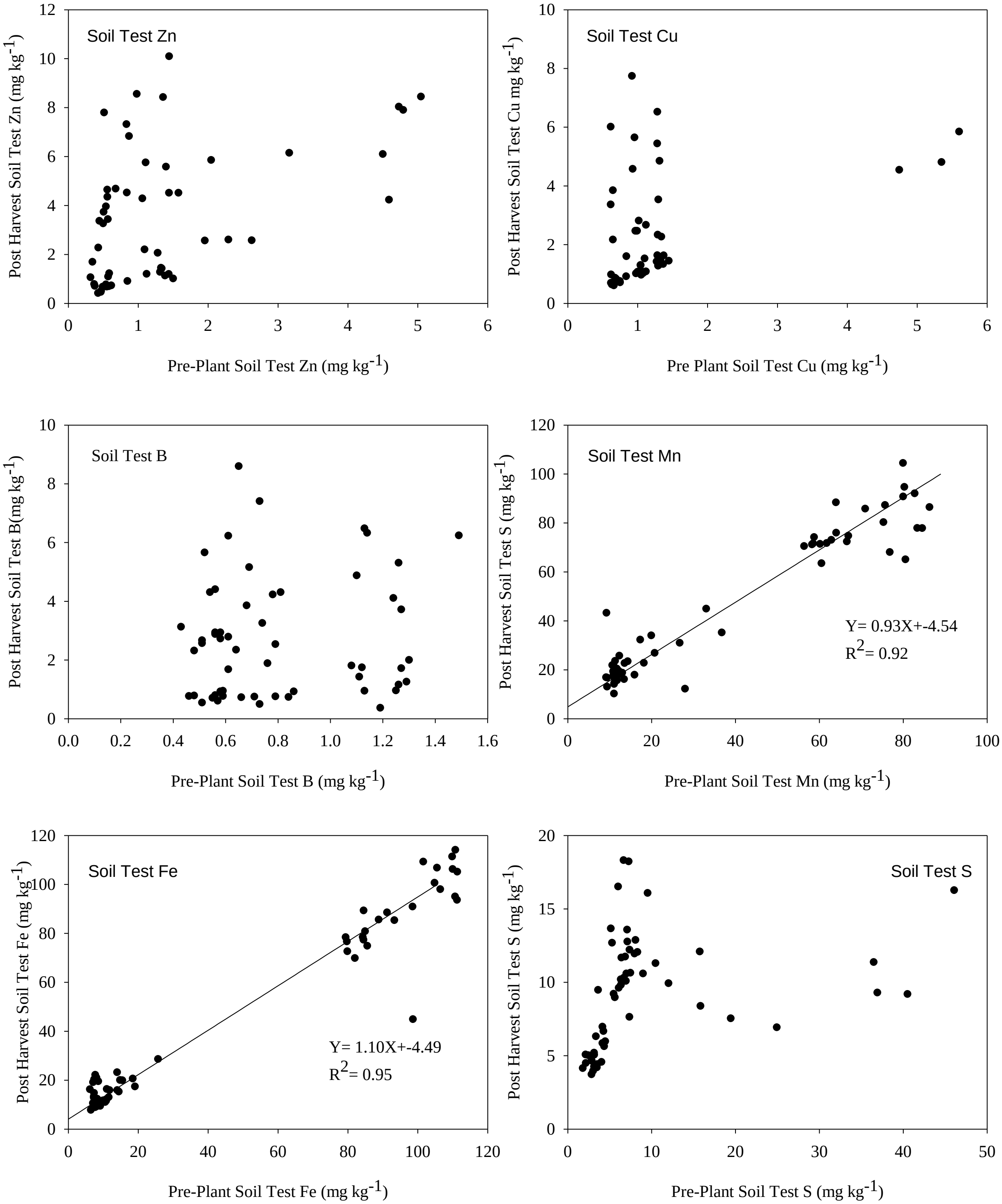

Figure 3-1. Pre-plant and post-harvest soil test values for each nutrient. Pre-plant and post-harvest samples shown for each nutrient were analyzed from plots where the specified nutrient was applied. The purpose of these figures is to show the response varied for each nutrient. Proc Reg was used to calculate the regression model and coefficient of determination.

CHAPTER 4 - CONCLUSIONS

A study of double crop soybean following wheat was conducted to analyze the effects of starter macro and micronutrients as well as foliar micronutrients. Four locations of data are presented from 2011-2012 throughout eastern Kansas. In both years growing conditions were very poor with above normal temperatures, and below normal rainfall experienced in all locations. Results from this study indicate that the band-applied application of macro and micronutrients tended to increased yield, and foliar micronutrients tended to decreased yield. Band-applied N, P, and K was beneficial for increasing tissue nutrient concentration of P and K at R1-R2. Pre plant application micronutrients Mn, Zn, and Fe did not have a significant effect on tissue leaf concentration. Application of S had no impact on tissue S concentration or yield. Application of foliar EDTA chelated micronutrients Mn, and Zn and HEDTA Fe tended to decrease yield. These results are similar to what was found by Mueller (2012) showing that foliar Fe, Mn, and Zn decreased yield.

Individual nutrient(s) had no significant effect on soybean response. Foliar application of EDTA chelated micronutrients resulted in benefit for double crop soybean. Combination of soil-applied macro and micronutrients without foliar micronutrients tended to increased yield over the control but it was non-significant. Therefore the application of macro and micronutrients are not necessary under environmental conditions evaluated in our study.

A study evaluating at the effects of sulfur and micronutrients Zn, Cu, B, Mn, and Fe on wheat found no significant yield responses occured from the application of these nutrients at 3 locations. However, one location resulted in a significant yield response to the mix treatment over the control. Overall yields ranged from 2900-6700 kg ha^{-1}, which was well above the county averages for all locations ((USDA-NASS). Tissue Zn and S concentrations were significantly increases by the application of the mixture of the Zn, Cu, B, Mn, Fe, and S over the other treatments. Soil and tissue analysis indicated adequate levels of all nutrients suggesting yields would not be limited by micronutrients. Post-harvest soil analysis indicated significant increases in Zn, Cu, B, and S when compared to the pre plant analysis.

Overall, the application of mixtures of micronutrients increased the tissue Zn and S concentrations as well as the post-harvest soil test Zn, Cu, B, and S. Treatments with individual micronutrient on Zn and B showed significant increases in soil test levels over the control. Application of S and micronutrients (Zn, Cu, B, Mn, Fe, and S) on wheat did not significantly increase yield and would not be a profitable investment based solely on yield gains.

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