SULFUR AND MICRONUTRIENT FERTILIZATION FOR WHEAT PRODUCTION IN KANSAS

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Abstract

Genetic advances in wheat (Triticum aestivum) and increased yield potential may require changes in fertilization programs including the addition of secondary and micronutrients. The objective of this study was to evaluate wheat response to sulfur and micronutrient fertilization and evaluate soil testing and tissue analysis as a diagnostic tool. Seven locations were established in 2012 and 201, all locations were established in under dryland conditions (four locations presented in this paper). Fertilizer treatments consisted of topdress sulfur, iron, manganese, zinc, boron, copper. The micronutrients Fe, Mn, and Zn were sulfate based, Cu was an oxy-sulfate, B was based on boric acid, and the sulfur treatments were applied as calcium sulfate. Fertilizer treatments were applied topdress in 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 that the application of micronutrients resulted in significantly higher post-harvest soil test for Zn, Cu, B, and S. Flag leaf tissue nutrient concentration was affected for Zn, B, and S. Wheat grain yield was not affected by any nutrients or combination of nutrients across locations.

Introduction

Increased in crop yields have spurred questions about the need for micronutrient application to maintain and increase yield levels. Some questions include optimum application timing for micronutrients, as well as the value of tissue analysis and soil test for these micronutrients. Recent increase in sulfur deficiencies in wheat also requires research for sulfur management. In Kansas and throughout the Midwest there has been an increased utilization of reduced tillage systems. One of the main concerns producers have with decreased tillage and higher yielding crops is meeting the nutrient demands due to the increased yield and lack of incorporation of immobile nutrients.

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 small responses to Zn (Sing, 2004). Other nutrients such as B and Fe show very limited responses (Sing, 2004). Typically is considered that micronutrients are not a limiting factor for wheat in Kansas. However, one micronutrient that has resulted in significant yield increase is Cl (Duncan, 1995). A study looking 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 and deficiencies have been found in south central and north central Kansas in recent years (Shroyer, 2011). A study conducted by Mortensen (1994) found that even though yield increases were not always significant, increases in grain quality and protein content can be significant.

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. This 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 still possible to see a response from having an additional nutrients available to the plant particularly in soils with high pH and low OM. Tissue nutrient analysis may be a better indicator of secondary and micronutrients than soil testing because. However, research is needed for interpretation of results.

In Kansas soybean can show significant yield response to Fe fertilizer application in soils prone to develop Fe chlorosis. Micronutrient deficiencies in soybean can be found in several regions of the US with individual soil characteristics that can affect plant nutrient availability.

The purpose of this study was to evaluate the response of wheat and soybean to sulfur and micronutrients (Zn, Cu, B, Mn, and Fe) as individual nutrients as well as a mixture of all nutrients.

Materials and Methods

Seven locations were established in the 2011-2012 and 2012-2013 growing season for wheat (four locations are presented in this paper) (Table 1). Soils were conventional tillage and pre-plant N-P-K fertilizer was applied based on soil test and current guidelines. Fertilizer treatments were applied topdress at a rate of 11 kg ha-1 for S, Zn, Cu, B, Mn, and Fe. All treatments were broadcast prior to feekes 4 (Miller, 1999) with a handheld broadcast spreader.

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 centimeter rows. Plot size was 3 meters by 9.1 meters.

Composite soil samples were collected, 10-15 cores, at the 0-to 15-cm depth 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 (Frank K, 1988). Soil pH was measured on 1:1 (soil:water). Iron, 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.

Results and Discussion

Results showed a significant increase in tissue nutrient concentration across locations from the topdress application of Zn, B, and S (Table 2). At location 1 we found significant increases in tissue Zn, Cu, B, and S. Location 2 showed significant increase in tissue Cu, B, and S. Location 3 showed significant increases in Mn concentration, and location 4 showed significant increase in tissue Zn concentration.

Across locations tissue Zn concentrations were significantly higher in the mix treatment than all other treatments (Table 3). We found a similar trend at all locations with the mix treatment tending to have the highest tissue Zn concentrations than the other treatments. Across locations the Zn only treatment did not show an increase in tissue concentration. The Zn treatment at each location and across locations showed no significant response when compared to control, and it tended to have lower concentrations than the mix treatment. These findings are different from those of Zeindan (2010), where they found that the application of Zn increased the tissue concentration over the control (Zeidan, 2010). The difference between their study and ours was that the soil test Zn levels in their study averaged 0.13 mg kg-1, which is below the critical range of 0.2-2.0 (Jones, 1981). Soil test Zn in our study ranged from 0.5 to 2.8 mg kg-1.

Across all locations we found no increase in tissue concentration for Cu (Table 2). At locations 1 and 2 we saw a significant increase in tissue Cu, (Table 2) where the mix and Cu treatments had significantly greater Cu concentrations than the control treatment (Table 3). Previous studies indicated that plant response to Cu fertilizer was unlikely with soil Cu levels above 0.6 mg kg-1 (Franzen, 1998). The average Cu soil test across locations ranged from 1.79-4.07 mg kg-1. 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).

All locations showed significant increases in tissue B concentration from the application of B (Table 2). All locations showed that the mix treatment and the B treatment had significantly greater B concentrations in the flag leaf samples than other treatments (Table 3). At locations 1, 3, and 4 we found the mix and B treatments had significantly greater B concentrations (Table 3). Mellbye and Gingrich (1999) evaluated the effect of B on soil and plant tissue and found similar results.

Location 3 was the only location with significant increases in tissue Mn concentration. At this location we found that the Mn treatment and mix treatments had significantly lower tissue Mn concentrations than the control treatment (Table 3). This trend was not found at any of the other locations and overall we found inconsistent results across locations. Tissue Fe concentrations did not show any responses to our treatments (Table 3).

We found that at locations 1, 2, and across all locations that tissue S analysis showed significant increases in concentration on the mix treatment (Table 2). Both location 1 and 2 had significantly greater S tissue concentrations in the mix treatment than all of the other treatments (Table 3). At locations 3 and 4 we found the same trend, but it was non-significant (Table 3). Since all of the micronutrients were sulfate based the tissue response to S could be caused by the higher total S rate of 28 kg ha-1for that treatment.

Grain yields (Table 4) response showed a significant increase for the treatment with the mix, and the S treatments at location 4 over the control (Table 2 and 4). A general trend was that the mix nutrient treatment showed higher yield than the control treatment (Table 4). Although not significant, at locations 1, 2, and 3 we found the mix treatment to have the highest yields of all treatments (Table 4). Overall, these results are similar to those of other studies looking at micronutrients in wheat showing no grain yield response when adequate amounts of each micronutrient were in the soil and tissue samples (Jones, 2012). A study looking at the effect of micronutrients on wheat yields found that soils where micronutrient levels were not limiting, yield responses were not likely (Habib, 2009).

Post-harvest soil test analysis showed significant changes in concentration across locations for the Zn, Cu, B, and S treatments when comparing the treatments to the control (Table 5). Across locations we found a significant increase in soil test Zn on the mix treatment over the Zn treatments and a significantly higher level than the control (Table 6). Across all locations the soils samples showed significant increases in soil test Cu in the mix treatment over the Cu and control treatments (Table 6). Locations 1, 3 and 4 showed significant increases from the Cu application when compared to the control. Locations 1, 3, and across all locations the mix treatment showed significantly greater Cu concentrations than the Cu treatment and control (Table 6). Soil test B showed increases in post-harvest soil test B concentrations at all locations (Table 6). We found that post-harvest soil test B significantly increased compared to the control for B that was applied either in the mix or as B alone (Table 6). The application of S had a significant increase in soil test S across locations (Table 5). Locations 1, 2 and across all locations had significantly greater S concentrations in the mix than the S and control treatments (Table 6). The greater increase in S concentration on the mix treatment is expected as higher total S was applied with the mix nutrient treatment.

Conclusion

No significant yield responses were attributed to the application of micronutrients across all locations. At location 4 we found significantly higher yield with the mix treatment. Tissue Zn, B, and S concentrations were significantly increases by the application of fertilizer. Post-harvest soil analysis showed significant increases in Zn, Cu, B, and S when compared to the pre plant analysis. Wheat response to micronutrients was inconsistent, and specific soil conditions should be evaluated before fertilization with micronutrients to increase the probability of yield response. Tissue and soil analysis can be valuable to as diagnostic tool for some micronutrients, however the performance of tissue and soil analysis are better for some micronutrients. Tissue and soil analysis for Mn and Fe showed no effect of fertilizer application.

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

Location	County	Soil Type‡	Soil Subgroup	Soil Chemical Analysis†								
				CEC	pH	OM	Zn	Fe	Mn	S	Cu	B
				meq/100g		g kg^{-1}	------------------------ mg kg^{-1} ----------------------					
1	Republic	Crete sil	P. Argiustolls	19.2	4.9	2.5	1.3	106	78.2	6.9	1.3	0.74
2	Republic	Crete sil	P. Argiudolls	17.5	4.9	2.1	0.5	87.2	63.3	5.5	1.1	0.61
3	Riley	Smolan sil	P. Argiudolls	23.1	7.8	1.3	0.6	10.3	16.6	15.5	0.7	1.20
4	Riley	Belvue sil	T. Udifluvents	22.3	7.5	2.3	2.8	10.1	11.1	2.1	4.3	0.70

† Zn, Fe, Mn, S and Cu analyzed with DTPA extraction. Soil Type: sil, silt loam.
‡ Soil Type: sil, silt loam.
§ Mean rainfall from 30-yr average from weather station within 20 km of each study location.

Table 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. Mean nutrient concentration in the flag leaf collected at feekes 8.

Location(s)	Mix	Zn	Cu	B	Mn	Fe	S	Control
	Treatment ¶							
				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 4. Average yield of each 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	2973a	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 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 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	6.77a	5.36ab	3.17ab
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.

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