UPTAKE AND LEACHING POTENTIAL OF POTASSIUM AND SULFUR WHEN SPLIT APPLIED FOR CORN ON IRRIGATED SOIL

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Abstract

Coarse textured soils used in irrigated agriculture often face nutrient losses through the soil profile due to low cation exchange capacity (CEC). Split fertilizer application on sandy soils has been recommended for the corn crops in MN to avoid the leaching of fertilizers nutrients. Our study aimed to look at the potential for potassium and sulfur to be taken up or leached out in corn production. Two K and two S fertilizers studies were set up in Minnesota on coarse irrigated soils. Each site had a split plot fertilizer rates with main pre-plant plots and side-dress sub-plots. Early and mid-season plant samples were taken to assess nutrient uptake in the corn plants. Lysimeters were installed in 0-0,m 0-high, high-0, and high-high pre-plant-side-dress application rates to look at general leaching trends in the soil over the growing season. No evidence was found of sub-plot effect with our early plant samples, but mid-season samples showed some significant differences in plant nutrient uptake with both main and sub plot fertilizer rates. Lysimeters data showed more nutrient movement with sulfur fertilizer than potassium especially in sandier soils versus sandy loams. After our first year we did not find any significant results in yield differences but found that corn was able to uptake nutrients from side-dress fertilizer applications. Sulfur movement suggests there may be some carryover benefits on heavier textured soils with split applications. More research will be conducted during the next growing season to increase the number of locations considered and to increase the data in our dataset.

Introduction

Corn (*Zea mays* L.) grown on irrigated soils has high grain yield potential because supplemental water can be applied when needed. In most cases, irrigated soils in Minnesota are sandy or gravelly in texture and do not have a high water holding capacity. These irrigated sandy soils can present problems for nutrient management. Coarse textured soils have a low cation exchange capacity (CEC). Because of this lower CEC, the amount of basic cations held in the soil is less than finer textured soils in Minnesota that may not be irrigated. The basic cation required in the highest quantity for corn production is potassium. Because of the reduced ability of sandy soils to hold cations, supplemental potassium has to be added on an annual basis to satisfy that needed for crops. In most fine textured soils, if the crop needs more K than is applied, the plant can access the soil for more. Also if the application of K fertilizer is greater than the plant needs, then the soil K will be attached to the soil CEC and it will be immobile and not lost. However in sandy soils, the capacity to retain the K is small and it is subject to leaching. Almost all of the K is taken up by corn between the V6 and R2 growth stages (Abendroth et al., 2011). Heavy rainfall early in the season may have the potential to leach K below the root zone. Since K is critical in plant moisture relations, it can affect the plant's ability to handle dry conditions.

Because of the leaching potential of K, irrigated corn growers have been questioning whether a single application of K pre-plant is enough for optimum growth of their crops or if split applications should be considered. There are also questions related to timing of pre-plant K. Many growers apply K in the fall when it is convenient, but there have been no studies on what the K leaching potential is over the winter. Recommendations for a split application have not been previously established; therefore, research should be conducted to look at single versus split application of K rates on irrigated soils. Another complicating factor is the large fluctuations in potash price over the last few years. In fact, prices have dropped for this input, but still are high relative to what they were only 10 years ago. In most cases farmers would prefer to put a greater amount of potash on than is needed by corn if the potential for loss is high, but with high K prices, this approach can severely limit the profitability for corn. Therefore, it would be beneficial to corn growers to know what kind of leaching potential could be expected from K and the potential economic benefits from single versus split applications of K for corn.

Sulfur is another input that has been recommended on sandy soils for corn (Rehm, 1993). Sulfur differs from potassium in that the available form in the soil is negatively charged (SO_4^{2-}) and therefore is not held in the soil. Leaching potential is great for sulfur in most soils, but that potential increases when corn is grown on coarser textures. Our current recommendations are 28 kg per hectare of sulfur broadcast prior to planting as a single rate (Kaiser et al., 2011). Along with potassium, irrigators are also questioning split versus single applications of sulfur for corn. We are currently focusing on an update to the sulfur recommendations for corn therefore it would be a very opportune time to look at split applications of sulfur to determine if timing should be considered for farmers growing corn under irrigation. Current work with sulfur has shown high potential yield increases from this nutrient, upwards from 20 to 40 bushels in loam soils (Kaiser, unpublished data). For sands, this yield increase could be potentially greater. With the greater potential for movement the importance of split applications could be greater than for K. Therefore with the dollar value of the fertilizer at stake, a project studying the effects of sulfur and potassium would be beneficial to make sure the high yield and profit potential is protected in irrigated systems.

Objectives

1. Evaluate timing and rate of sulfur and potassium application early season nutrient uptake and ear leaf concentration.
2. Determine the potential for sulfur and potassium leaching in coarse-textured irrigated soils.

Methods and Materials

Each study (either K or S) was comprised of two locations for a total of four studies (Table 1). Trials were arranges in a split plot design with main plots consisting of either four K or S fertilizer applied before (K) or at planting (S). At the V3 growth stage (Abendroth et al., 2011) each main plot was split into four subplots and the same fertilizer rates applied to each main plot were applied within each sub-plot giving four separate fertilizer rates applied over each pre- or at planting fertilizer rate. Rates used for the K studies were 0, 80, 160, and 240 lbs K_2O per acre while rates were 0, 12.5, 25, and 37.5 lbs of S for the sulfur studies. All fertilizer was hand applied and the pre-plant K fertilizer was incorporated prior to planting. Fertilizer sources used were potassium chloride (0-0-60) and ammonium sulfate (21-0-0-24). All other nutrients were maintained at non-limiting rates according to current university recommendations (Kaiser et al., 2011).

Soil samples were taken before treatment application. Individual sub plots were sampled at the 0-6" level and either analyzed for K or S following recommended procedures for the North Central Region (Brown, 1998). Additional samples were collected from the 6-12" and 12-24" depths. Soil test data are summarized in Tables 2 and 3. Plant samples were taken from two timings for both studies. Early plant samples were collected at the V5 to V8 growth stage. The above ground portion of six plants was sampled at random from each sub plot. At the R2 growth stage 15 ear leaves (leaf opposite and below the ear) were sampled from each sub plot. All samples were dried at 65^oC and ground to pass through a 2 mm sieve. Tissue K concentration was determined with ICP following wet digestion. Tissue S concentration was determined through a combustion procedure using a Variomax CNS analyzer. Early plant uptake was calculated by multiplying average plant dry weight by nutrient concentration.

Suction lysimeters were constructed using PVC tubing and ceramic cups at one end and installed to a depth of 2 feet. Four treatment combinations received lysimeters for soil water sampling. Lysimeters were installed in plots that had the zero rate pre plant and side-dress, zero rate pre plant and high rate side-dress, high rate pre plant and zero rate side-dress, and high rate pre plant and side-dress . Samples were taken weekly at each location. Nutrient concentration was determined with and ICP for K studies and with ion chromatography for S studies. Flow was not measured so all reported variables are in concentration only.

Statistical analysis was conducted using PROC MIXED in SAS. Plant sampling measurements were analyzed assuming fixed main effects of pre-plant and side-dress fertilizer rates and random block effects. When the analysis indicated a significant ($P<0.10$) main effect then treatment means were separated using least significant differences (LSD). For water samples a repeated measures procedure was used. If the analysis indicated a significant interaction between main effects the interactions were sliced for individual main effects using the SLICE option in the LSMEANS statement.

Results and Discussion

Early Plant Growth and K and S Uptake

Tables 4 and 5 summarize early plant growth and nutrient uptake for the sulfur and potassium studies, respectively. Analysis was completed factoring in both main (application at or before planting) and sub-plot treatments (application in-season) but there was no evidence of a sub plot effect with the early samplings at any locations. Data are only summarized for the main plot treatments. The only significant differences in early plant growth were seen at the sulfur site near Hastings. For this location there was a significant difference between the no sulfur control and all treatments receiving sulfur. Plants were 26% larger with sulfur, produced more biomass, and the plots showed less plant to plant variation (as indicated by the lower standard deviation of the mean for the NDVI values at this site). Plants were overall larger at the Randolph location, but there were no significant effects from sulfur. Plants were sampled later at this location which was reflected in the larger plant size. There were no significant differences at the K locations for early plant growth which is not surprising since K seldom effects early plant growth.

Average plant uptake of sulfur is summarized for the two locations in Table 6. Nutrient uptake is a function of both plant concentration and early growth. Typically early growth is a major factor influencing the total uptake of nutrients. The data in table 6 is summarized for individual plants and not on a per acre basis. Early in the season the total uptake per acre tends to be very small therefore the data per acre is not as relevant as uptake per plant. Early uptake of sulfur was increased at both locations. At Hastings, the pre-plant application of S increased uptake early in the season. Similar to early plant growth, uptake was increased by the first increment of S and there was no difference between the 12.5, 25, and 37.5 lb S rates. There was no effect of side-dress application on early uptake. No effect was expected since this location was sampled the same day prior to side-dress S application. The plants were sampled later at Randolph and there was an effect of side dress S on S uptake. At this site the high application rate of S (37.5 lbs S/ac) increased uptake more than the lower rates which did not differ from 0 lbs applied side-dress. Early plant S concentration, while not shown, was influenced by S application at planting and side-dress. The 37.5 lb S rate at planting and side-dress resulted in a higher S concentration than all other rates. The 12.5 and 25 lb S rates only differed from the control for side-dress applied S at Randolph. This data indicates that application did result in higher uptake of S early in the season and that the fertilizer applied was available. However, these types of increases seldom result in higher yields unless they indicate a deficiency.

Early plant K uptake is summarized in Table 7. Early plant K uptake was only affected by main treatment effects at Becker. In this case the 160 and 240 lb rates resulted in more K uptake while the 80 lb rate was no different from either of the two higher rates or than the control. There was no effect of main treatments at the Randolph locations even though there were effects of K rate on early plant K concentration for both the pre-plant and side-dress application (not shown). For the pre-plant rates the K concentration was the highest for the 160 and 240 lb application rates (neither were significantly different from each other). The 80 lb rate was less than the higher two rates but greater than the control. There was no difference between K application rates (80, 160, and 240 lbs K_2O/ac), but all three were higher than the control (0 lbs K_2O) for the side-dress treatments. While an increase would have been expected for the pre-plant incorporated treatment it is surprising to find effect from the side-dress treatments since there was not a long period of time between application and sampling (about 1-2 weeks) and K is not very mobile in soils. It appears that some of the side-dress K can be taken up even if it is surface applied. However, it still probably is not as efficient as K applied and incorporated prior to

Mid-Season K and S Availability

Ear leaf samples were taken at the R2 stage at all locations. Table 8 summarizes the data for the Becker and Randolph K locations. Results from the statistical analysis showed that both the pre-plant and side-dress potassium applications affected ear leaf K concentration. In addition, there was a significant interaction indicated at both locations. A significant interaction means that there were likely differences in the response to the side-dress K treatments depending on the pre-plant rate. This means that the increase in K concentration in the ear leaves changed based on the amount of K applied pre-plant. For both locations it appeared that increases in ear leaf K from the side-dress application were larger when no K was applied pre-plant. In fact there was little to no response for the 80, 160, and 240 lb rates. What is interesting is the fact that there was a fairly large increase in ear leaf K concentration from the side-dress application of an immobile nutrient. This provides evidence that K can be side-dress applied and be taken up by the plant on the irrigated soils even when the soil texture was loamy at the Randolph site. However, when the values were compared to current critical ranges most pre- and side-dress applications fell within the optimal range. The only treatment that would be considered low was the treatment where no K was applied at the Becker location. It is likely that a yield response would only occur at this location.

At planting and side-dress sulfur application effects on ear leaf sulfur concentration for the two locations in 2011 are given in Table 9. There were no significant effects on ear leaf sulfur at the Hastings location. Even though deficiency symptoms were seen in some areas of the research plot there did not appear to be any clear trends in the data showing responses to the different rates or application timing at that location. At Randolph, there were effects of ear leaf S concentration for the side-dress S rates. There were no difference between the 0 and 12.5 lb rates and ear leaf S concentration were higher for the 25 and 37.5 lb rates with the latter producing the highest concentration of all of the treatments. For the ear leaf sample, a S concentration between 0.1 to 0.3% is considered optimum. For this study there did not appear to be any mid to late season deficiencies based on the tissue data.

Soil Solution K and S Concentration

Soil solutions K and S concentrations were measured on weekly intervals starting May 23rd 2011. Water samples were taken until the end of September before harvest. Sulfur studies at Randolph and Hastings are given in Figures 1 and 2. All figures summarize the concentration of sulfur or potassium and the daily recorded precipitation from the closest reporting weather station. Also included is the standard error associated with each measurement (line extending from each point on the graph). Since we did not measure the total amount of water moving through the profile we cannot measure the amount of S or K lost during a rainfall event. What we are looking for are peaks in concentration to see when it is likely that the fertilizer applied may be moving through the profile.

Sulfur leaching was more evident at the Hastings location than the Randolph site. Both locations had similar heavy rainfall events but the sandier site at Hastings appeared to show increases in sulfur concentrations at 2’ more quickly than at Randolph. In fact, there were no differences between treatments at the Randolph site until around day 200 (July 18) when the highest application rate (37.5 lbs S at planting + 37.5 lbs of S side-dress) started to separate out from the other treatments. There were no detectable differences between no sulfur applied and 37.5 lbs applied at planting or as a early side dress. All concentrations trended higher towards the end of the season as a result of less rainfall. At Hastings, the concentration of S at 2’ increased starting about day 160 (June 8) and peaked around day 200. This was likely a large concentration of S moving as a mass through the soil profile from the application at planting. The 37.5 side dress rate was no different from the control. The plots where S was applied as a side dress appeared to show higher concentrations at 2’ at the end of the season, but there was no statistical evidence of a difference at that time. This shows that at this site much of the sulfur applied at planting was likely below the 2’ depth by the end of the season while the loamy surface texture at the Randolph site appeared to hold the sulfur for longer as concentrations remained constant throughout most of the season. The implication for this are that even under irrigation the site with the loamy surface texture can have some sulfur carryover from one year to the next, but annual applications on the sandy locations should be used since carryover cannot be counted on. On the sandy soils, the split application appeared to hold sulfur in the upper profile longer. However, there was no effect on yield so we could not see if having sulfur in the upper profile longer would be give a large enough yield benefit to warrant split applications.

Potassium studies at Randolph and Becker (Figures 3 and 4) showed a generally constant concentration of K in soil water throughout the season with some notable leaching events following heavy periods of precipitation. This was evident at the Becker location (Figure 4) where there was a large spike in concentration around day 190 (July 8). However, there was no clear response in concentration from the potassium rates. At Randolph there was a significant difference between the 240 lb rate early in the season. For most of the season there was no difference between treatments. Soil samples were collected to determine if there was movement, but showed no clear evidence of an increase in soil K concentration below 6” (data not shown). While the movement of K is possible it appears unlikely that a significant amount moved through the profile as to cause issues with availability during the growing season.

Conclusions

Sulfur fertilizer applied as a side-dress increased uptake early in the growing season and ear leaf S concentration. Potassium uptake was increased by potassium application pre-plant. However, ear leaf potassium concentration was increased by both pre-plant and side-dress K application at both locations. The lysimeter data provided no evidence of significant movement of K to a two foot depth. Sulfur leaching potential was much higher and varied by location. For the sandy location movement was more rapid than a site with a loam surface soil. The previous work is the first year of a multi-year study. More data will be collected to evaluate split applications of K and S on irrigated soil. In addition yield data will be analyzed in order to determine if split applications pay for themselves in terms of increased grain yield on irrigated soils.

References

Abendroth, L.J., R.W. Elmore, M.J. Boyer, and S.K. Marlay. 2011. Corn growth and development, Ext. Publ. PM 1009. Iowa State Univ. Ext., Ames, IA.

Brown, J.R. 1998. Recommended Chemical Soil Test Procedures for the North Central Region. North Central Reg. Res. Publ. No. 221 (revised). Univ. of Mo. Columbia.

Kaiser, D.E., J.A. Lamb, and R. Eliason, 2011. Fertilizer guidelines for agronomic crops in Minnesota. Ext. Publ. BU-06240-S (Rev.), Univ. of MN Ext., Saint Paul.

Rehm, G.W. 1993. Timing sulfur applications for corn (*Zea Mays*. L.) production on irrigated sandy soils. Commun. Soil Sci. Plant Anal. 24:285-294.

Table 1. Plot locations and soil types in 2011.

Study	Location	Soil Type	Texture	Location
Potassium	Becker	Hubbard	Loamy Sand	Experiment Station
	Randolph	Estherville	Sandy Loam	Farmer Field
Sulfur	Hastings	Sparta	Loamy Fine Sand	Farmer Field
	Randolph	Estherville	Sandy Loam	Farmer Field

Table 2. Initial soil test summary for sulfur studies in 2011 for samples collected prior to sulfur treatment application in spring.

		Sample	Soil Test†				S‡	
Location	Soil Type	Depth	P	K	pH	OM	Avg	StDev
			------ppm-----			-%-	----ppm-----	
Hastings	Sparta	0-6"	44	172	6.5	1.3	4.0	0.0
		6-12"	--	--	--	--	5.5	--
		12-24"	--	--	--	--	4.8	--
Randolph	Esterville	0-6"	31	83	5.3	2.8	3.3	0.4
		6-12"	--	--	--	--	3.5	--
		12-24"	--	--	--	--	2.5	--

† P, Bray-P1 phosphorus; K, ammonium acetate K; pH, soil pH; OM, organic matter.
‡ Average (AVG) and standard deviation (StDev) for the monocalcium phosphate S extraction.

Table 3. Initial soil test summary for potassium studies in 2011 for samples collected prior to sulfur treatment application in spring.

		Sample	Soil Test†				K‡	
Location	Soil Type	Depth	P	Zn	pH	OM	Avg	StDev
			------ppm-----			-%-	----ppm-----	
Becker	Hubbard	0-6"	15	0.8	5.4	1.1	42	8.7
		6-12"	--	--	--	--	41	--
		12-24"	--	--	--	--	35	--
Randolph	Estherville	0-6"	37	2.0	5.5	3.9	90	14.7
		6-12"	--	--	--	--	56	--
		12-24"	--	--	--	--	55	--

† P, Bray-P1 phosphorus; Zn, DTPA extractable zinc; pH, soil pH; OM, organic matter.
‡ Average (AVG) and standard deviation (StDev) for the ammonium acetate K extraction.

Table 4. Early plant growth at the V4 to V8 growth stage and plot average NDVI readings taken with the crop circle and the standard deviation of NDVI readings.

Location	Sulfur Rate	Early Growth†	NDVI† Average	NDVI† StdDev
	-lb S/ac-	----g/plant---		
Hastings	0	2.8b	0.74b	0.084a
	12.5	3.4a	0.79a	0.056b
	25	3.6a	0.78a	0.064b
	37.5	3.6a	0.78a	0.063.b
Randolph	0	11.2	0.83	0.027
	12.5	11.3	0.84	0.025
	25	11.4	0.83	0.025
	37.5	11.5	0.83	0.021

† Means with different letters are significantly different at $P \leq 0.10$.

Table 5. Early plant growth at the V4 to V8 growth stage and plot average NDVI readings taken with the greenseeker and the standard deviation of NDVI readings.

Location	Potassium Rate	Early Growth†	NDVI† Average	NDVI† StdDev
	-lb K_2O/ac-	----g/plant---		
Becker	0	1.8	0.704	0.044
	80	2.1	0.738	0.029
	160	2.3	0.765	0.027
	240	2.0	0.731	0.026
Randolph	0	10.6	0.813	0.011
	80	10.5	0.810	0.017
	160	10.3	0.812	0.016
	240	11.2	0.818	0.012

† Means with different letters are significantly different at $P \leq 0.10$.

Table 6. Summary of early plant uptake of sulfur for pre-plant and sulfur side-dress treatments at two locations in 2011. Uptake values are the average amount of S taken up by individual plants.

	Pre-plant S	Side Dress S Rate (lb S/ac) 0	12.5	25	37.5	Mean	Statistics† Pre	SD	Pre x SD
	-lbs S/ac-	----------------mg S/plant-------------------					---------P>F----------		
Hastings	0	8.7	8.7	7.5	8.2	***8.3b***	0.04	0.77	0.96
	12.5	10.5	11.0	9.7	11.0	***10.5a***			
	25	11.2	11.6	11.8	12.3	***11.7a***			
	37.5	11.4	11.5	11.3	10.9	***11.3a***			
	Mean	10.4	10.7	10.1	10.6				
Randolph	0	31.6	31.7	32.7	39.1	33.8	0.23	<0.01	0.36
	12.5	32.1	35.0	33.7	36.6	34.3			
	25	32.8	39.3	35.2	35.6	35.7			
	37.5	35.8	35.1	36.3	42.8	37.5			
	Mean	***33.1b***	***35.3b***	***34.5b***	***38.5a***				

† Statistical significance for Pre, pre plant S; SD, side-dress S; Pre x SD, interaction between timings.

Table 7. Summary of early plant uptake of potassium for pre-plant and sulfur side-dress treatments at two locations in 2011. Uptake values are the average amount of K taken up by individual plants.

	Pre-plant K	Side Dress K Rate (lb K_2O/ac) 0	80	160	240	Mean	Statistics† Pre	SD	Pre x SD
	-lbs K_2O/ac-	----------------mg K/plant--------------------					----------P>F-----------		
Becker	0	45	45	47	52	***47b***	0.06	0.89	0.08
	80	65	62	63	67	***64ab***			
	160	90	89	76	94	***87a***			
	240	78	79	102	71	***82a***			
	Mean	70	69	72	71				
Randolph	0	456	469	464	484	468	0.24	0.43	0.11
	80	503	617	448	585	538			
	160	531	532	580	646	572			
	240	570	642	683	532	607			
	Mean	515	565	544	562				

† Statistical significance for Pre, pre plant S; SD, side-dress S; Pre x SD, interaction between timings.

Table 8. Summary of pre-plant and in-season sulfur application rate effects on ear leaf K concentration at 50% silk at two irrigated locations in 2011.

	Pre-plant S	Side Dress S Rate (lb S/ac) 0	12.5	25	37.5	Mean	Statistics† Pre	SD	Pre x SD
	-lbs S/ac-	---------------------%------------------------					----------P>F-----------		
Hastings	0	1.50	1.73	1.76	1.97	***1.74a***	<.001	<.001	0.10
	12.5	1.87	2.02	2.11	2.12	***2.03b***			
	25	2.04	2.13	2.10	2.11	***2.1bc***			
	37.5	2.07	2.13	2.18	2.25	***2.16c***			
	Mean	***1.87a***	***2.00b***	***2.04bc***	***2.11c***				
Randolph	0	1.92	2.23	2.37	2.45	**2.24a**	<.001	<.001	0.02
	12.5	2.30	2.39	2.36	2.50	**2.39b**			
	25	2.43	2.45	2.60	2.69	**2.54c**			
	37.5	2.51	2.64	2.67	2.60	**2.6c**			
	Mean	***2.29a***	***2.42b***	***2.5bc***	***2.56c***				

† Statistical significance for Pre, pre plant S; SD, side-dress S; Pre x SD, interaction between timings.

Table 9. Summary of pre-plant and in-season sulfur application rate effects on ear leaf S concentration at 50% silk at two irrigated locations in 2011.

	Pre-plant S	Side Dress S Rate (lb S/ac) 0	12.5	25	37.5	Mean	Statistics† Pre	SD	Pre x SD
	-lbs S/ac-	---------------------%------------------------					----------P>F-----------		
Hastings	0	0.30	0.27	0.27	0.28	0.28	0.65	0.24	0.90
	12.5	0.30	0.29	0.29	0.30	0.30			
	25	0.30	0.29	0.29	0.29	0.29			
	37.5	0.28	0.29	0.28	0.28	0.28			
	Mean	0.30	0.29	0.28	0.29				
Randolph	0	0.26	0.25	0.26	0.27	0.26	0.43	0.001	0.25
	12.5	0.24	0.25	0.26	0.28	0.26			
	25	0.25	0.25	0.27	0.31	0.27			
	37.5	0.25	0.28	0.30	0.30	0.28			
	Mean	***0.25c***	***0.26c***	***0.27b***	***0.29a***				

† Statistical significance for Pre, pre plant S; SD, side-dress S; Pre x SD, interaction between timings.

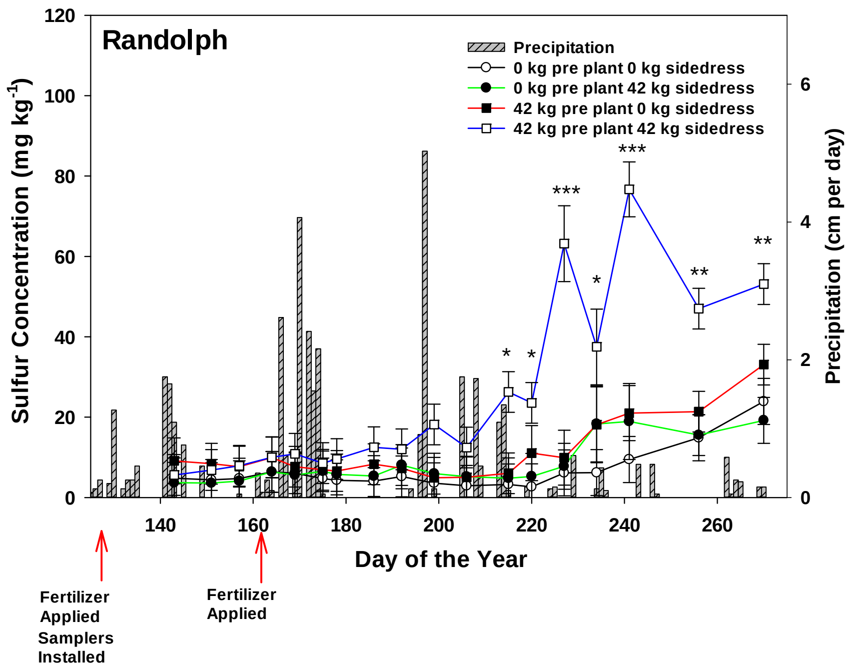

Figure 1. Summary of weekly water collection data the Randolph sulfur location in 2011. Vertical bars represent daily precipitation totals at each location. Asterisks indicate fertilizer treatment significance within each sampling date (*, $P \leq 0.05$; **, $P \leq 0.01$, ***$P \leq 0.001$).

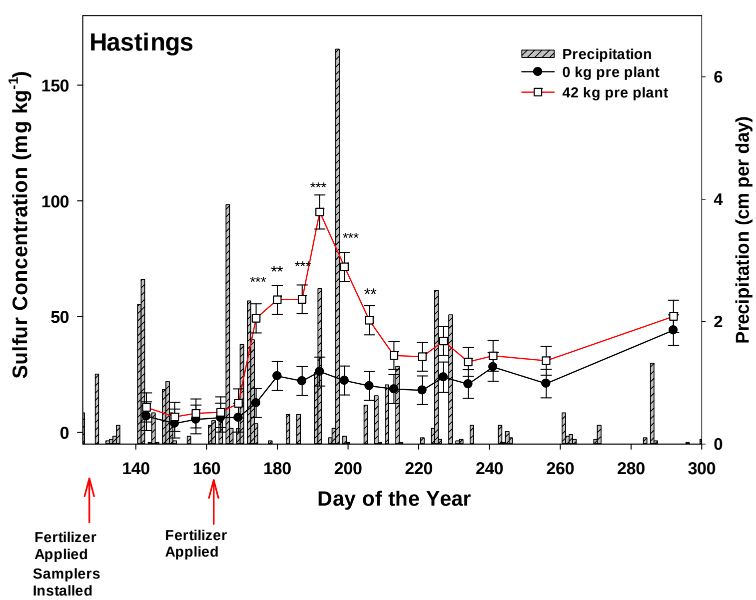

Figure 2. Summary of weekly water collection data the Hastings sulfur location in 2011. Vertical bars represent daily precipitation totals at each location. Asterisks indicate fertilizer treatment significance within each sampling date (*, $P \leq 0.05$; **, $P \leq 0.01$, ***$P \leq 0.001$).

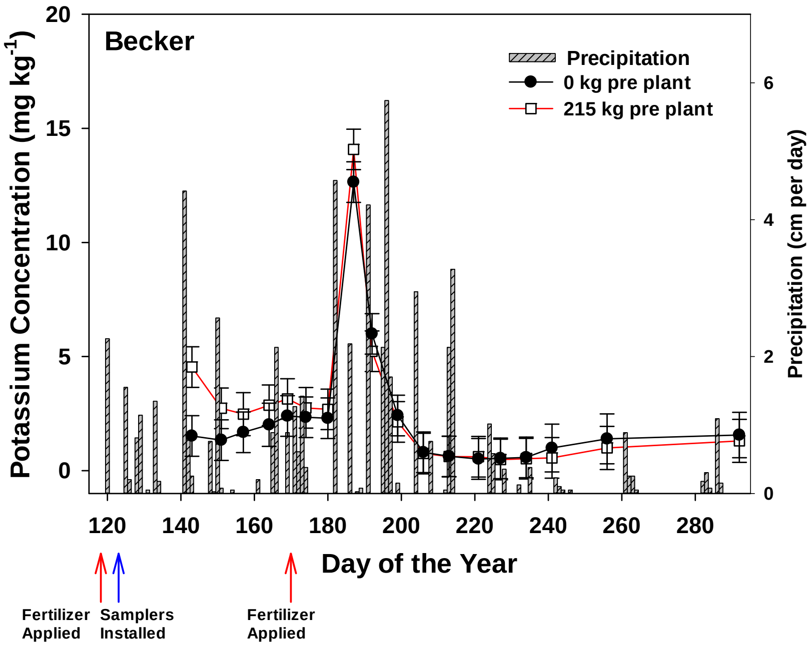

Figure 3. Summary of weekly water collection data the Becker potassium location in 2011. Vertical bars represent daily precipitation totals at each location. Asterisks indicate fertilizer treatment significance within each sampling date (*, $P\leq$0.05; **, $P\leq$0.01, ***$P\leq$0.001).

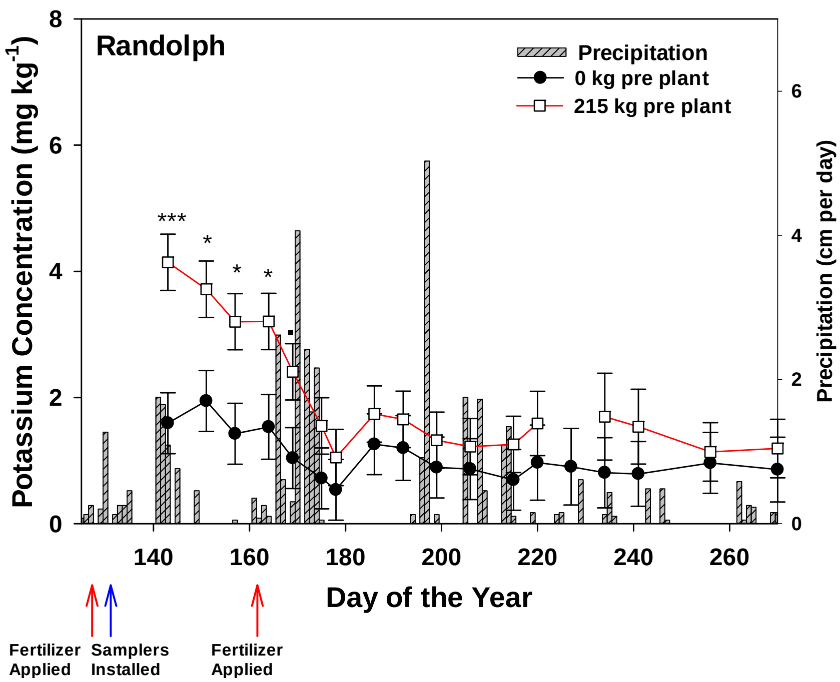

Figure 4. Summary of weekly water collection data the Randolph potassium location in 2011. Vertical bars represent daily precipitation totals at each location. Asterisks indicate fertilizer treatment significance within each sampling date (*, $P\leq$0.05; **, $P\leq$0.01, ***$P\leq$0.001).

PROCEEDINGS OF THE

42nd

NORTH CENTRAL EXTENSION-INDUSTRY SOIL FERTILITY CONFERENCE

Volume 28

November 14-15, 2012
Holiday Inn Airport
Des Moines, IA

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Published by:

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