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SULFUR AND TENNESSEE ROW CROPS

Sulfur (S) deficiencies have become more common in recent years. This publication outlines the importance and role of S in higher plants, summarizes recent research, and defines the University of Tennessee's current S recommendations for row crops.

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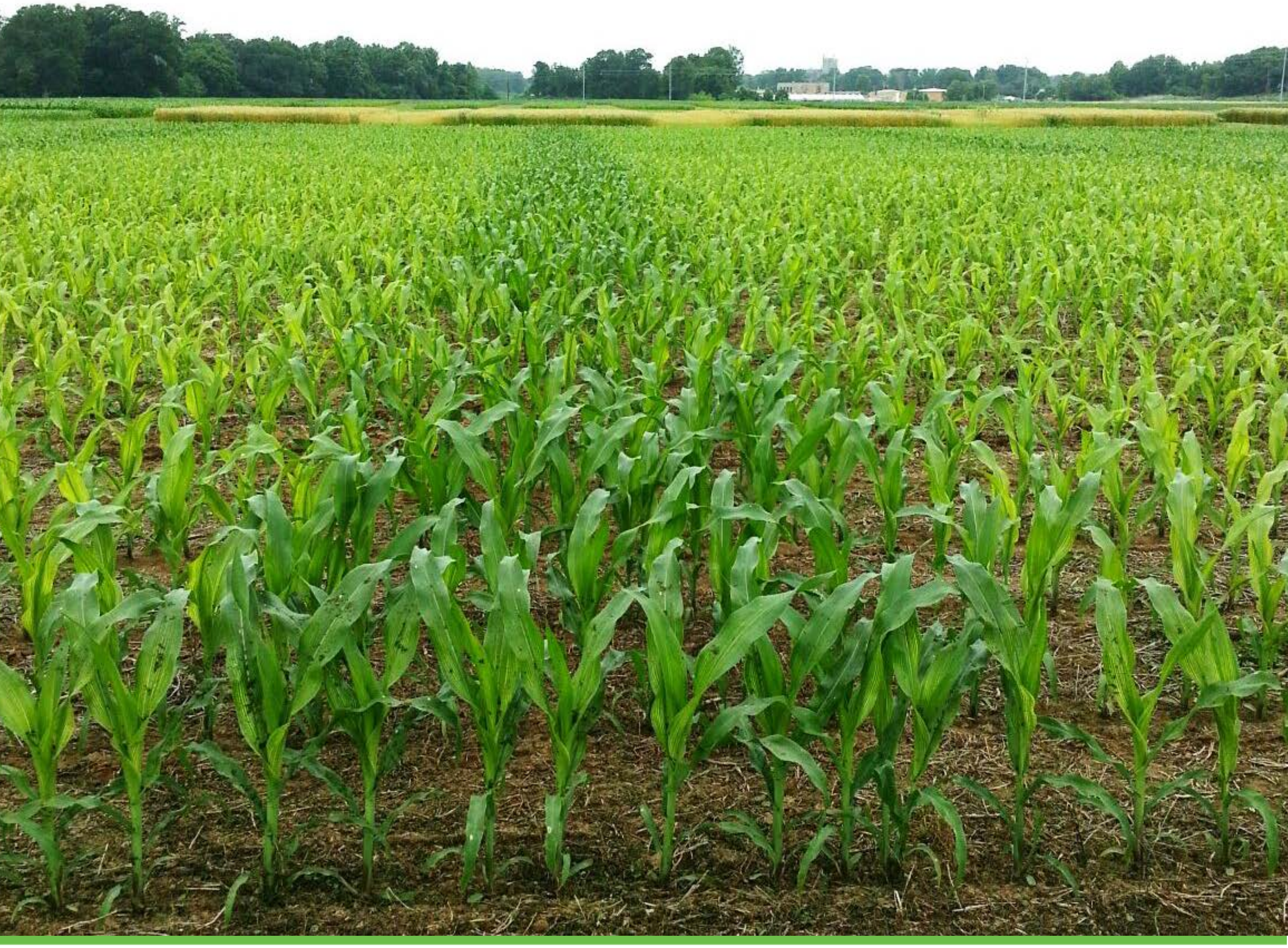

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INTRODUCTION

Sulfur (S) deficiencies have become more common in recent years due to a reduction in S deposition. Research at the University of Tennessee has begun to answer several key questions on crop response to applications of this nutrient. **The objective of this publication is to outline the importance of S and the role it plays within higher plants, describe why the deficiencies are becoming more common, summarize recent research and define the University of Tennessee's current S recommendations for Tennessee row crops.**

THE ROLE AND IMPORTANCE OF SULFUR IN HIGHER PLANTS

Sulfur is an important nutrient in living systems; it is contained within four common amino acids that assist in the synthesis, structure and function of proteins (Brosnan & Brosnan, 2006). In plant nutrition, S is classified as a macronutrient since it is required in quantities much larger than most micronutrients. Within the macronutrient classification, S falls within the secondary nutrient subclassification along with calcium and magnesium. Although S isn't a primary macronutrient, it is occasionally referred to as the fourth major nutrient (Stewart, 2010), and if contained within a fertilizer, the S percentage is commonly listed as the fourth number in the fertilizer analysis or grade (**Figure 1**). Generally, crops require S as a ratio of N; larger N applications typically require larger S applications to maximize response to fertilizers. This ratio generally falls between 12 and 15 parts of N per one part S.

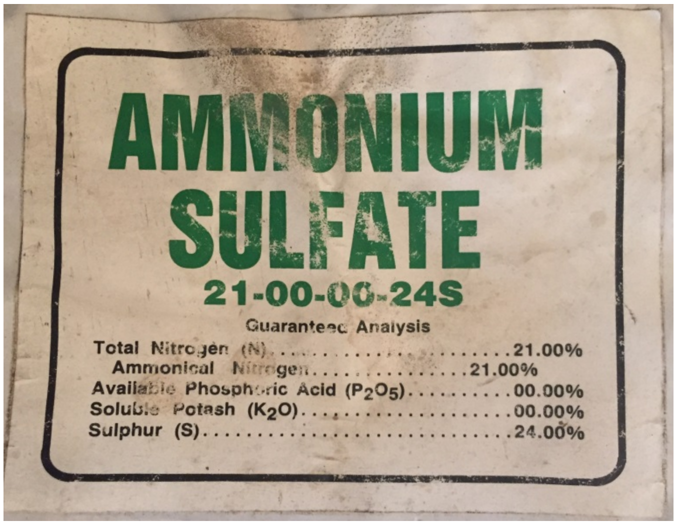

Figure 1: *Most S containing fertilizers have four numbers reported in the analysis or grade, with the first three representing N, P2O5, K20 and the fourth representing S. This bag of ammonium sulfate has an analysis of 21-0-0-24, indicating 21 percent N, 0 percent P2O5, 0 percent K2O, and 24 percent S.*

SULFUR UPTAKE, MOBILITY AND DEFICIENCY CHARACTERISTICS

Sulfur is taken up by plant roots in the anionic sulfate form (SO_4^{2-}). As a result, applications of elemental-S must convert to sulfate-S before they will become available to plant roots. Due to the time it takes to convert elemental-S to sulfate-S, it is commonly recommended to apply during the fall prior to the growing season, incorporate elemental S, or to use a sulfate source of S such as ammonium sulfate if deficits are expected (Schulte and Kelling, 1992). Unfortunately, sulfate is very mobile in soils with pH values greater than 5. The mobile nature of sulfate in soils causes temporal and spatial variability of the nutrient and, because of this variability, a soil test in humid environments may not be a reliable measure of the S nutritional status of cropping systems (Bloem et al., 2001).

Further complicating soil testing for S is the large percentage of total S within the soil's organic matter. As organic matter breaks down, S is released into the soil solution where it is converted to the sulfate form. Since organic matter breakdown is driven by a number of environmental factors, including water content and temperature, S deficiencies in row crops are commonly noted during cool, moderately wet periods often in the months of April, May or June where processes of root growth and organic matter breakdown are occurring very slowly. These deficiencies occasionally disappear after environmental conditions shift to support root growth and organic matter breakdown.

The mobile nature of sulfate in soils greatly contrasts the immobile nature of the nutrient within plant tissues. After sulfate is taken up by the plant, it is broken down to elemental-S before being incorporated in amino acids. After this conversion, S is not readily remobilized. The immobility of S within the plant and the integral role the nutrient plays in the formation of chlorophyll results in very specific, identifiable deficiency characteristics. First, the youngest leaves near the top and outside of the plant begin to turn yellow, or become “chlorotic” S (**Figure 2**). This change in color occurs uniformly across the leaf in soybeans and cotton (yellowing across the leaf through leaf edges and veins) but may appear as interveinal chlorosis in corn. If S is not available for plant uptake, the deficiency may progress until even the lower leaves of the plant become chlorotic.

Figure 2: *New growth of S deficient plants will appear chlorotic, as evident in the row to the right, in contrast to S sufficient plants, pictured left.*

Figure 3: *(LEFT) Sulfur deficiencies are characterized by uniform chlorosis of the upper growth in soybeans and cotton and are not easily confused with other nutrient deficiencies in these crops. (RIGHT) Sulfur deficiencies in corn may be characterized by interveinal chlorosis. Since several nutrients can cause interveinal chlorosis in corn, a tissue test may be necessary to properly diagnose the deficiency.*

WHY ARE S DEFICIENCIES APPEARING MORE OFTEN?

In 1966, Russell Coleman, president of the Sulfur Institute, wrote an article covering the importance of S as a plant nutrient in crop production. According to Coleman, by 1966 S deficiencies had become more common due to “(a) the increased use of S-free fertilizers, (b) the decreased use of S as a fungicide and insecticide, and (c) increased crop yields” (Coleman, 1966). Trends of reduced deposition and increases in crop yields have continued at an exponential rate in the 50 years since Coleman made that statement (**Figure 4**), with additional legislation reducing S emissions passed within the past 10 years and additional regulations planned for implementation within the next 15 years (EPA, 2016). These trends have directly contributed to a reduction in the amount of sulfate available to row crops and thereby increased the frequencies of S deficiencies.

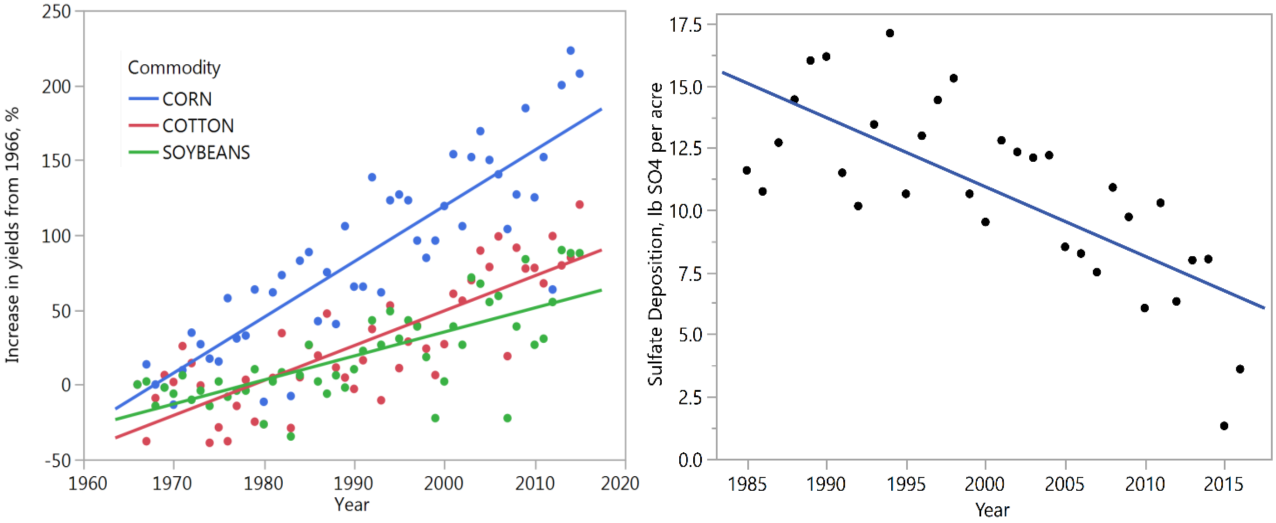

Figure 4: *(LEFT) Substantial increases in yields have been noted in corn, cotton and soybeans since 1966. These increases in yields require an increase in available nutrients to meet plant demands. Reported data represents Tennessee state average yields (USDA-NASS, 2016). (RIGHT) A decrease in sulfate deposition has been occurring over the same timeframe. Deposition data was collected by the National Atmospheric Deposition Program in the Hatchie National Wildlife Refuge (NADP/NTN, 2016).*

UNIVERSITY OF TENNESSEE RESEARCH ON SULFUR

Responses of corn, cotton and soybeans to S applications have been evaluated at the AgResearch and Education Center at Milan since 2013. Treatments of 0, 10, 20 and 30 pounds S per acre, applied as ammonium sulfate, were applied each year at planting to replicated plots. Data from these trials are summarized in **Table 1** and **Figure 5**. Significant yield responses of corn and cotton to applications of S contrast the insignificant response of soybeans. These trials are ongoing and recommendations will be updated as necessary.

Frank Yin, associate professor in the Department of Plant Sciences, has evaluated the response of cotton to S applications throughout West Tennessee since 2007. His data includes over 15 site-years. Many of these site-years have been published elsewhere (Yin et al., 2007; Yin et al., 2011), but a summary of the 2014 and 2015 data can be found in **Table 2**. During 2014, a significant increase in lint yield to applications of S was not noted. In contrast, a very strong response was noted during the 2015 season. Differences in responses across these two seasons can be partially explained by differences in soil textures at some of the included locations and very different growing environments.

Table 1: Yield and net return related to S cost and yield return from S trials conducted at the AgResearch and Education Center in Milan. Sulfur source was ammonium sulfate. Net return was calculated as price times yield minus sulfur fertilizer cost. Soil types at location were Collins and Falaya Silt Loams.

		Corn		**Cotton**		**Soybeans**	
Treatment (lb S/ac)	S cost* ($/ac)	2013-2015 Yield (bu/ac)	Net Return at $3.40/bu	2014-2015 Lint Yield (lb/ac)	Net Return at $0.72/lb	2013-2015 Yield (bu/ac)	Net Return at $9/bu
0	$0.00	173.8 b¥	$590.92	944.2 b	$679.82	47.52	$427.68
10	$7.50	198.5 a	$667.40	973.7 ab	$693.56	48.51	$429.09
20	$15.00	207.3 a	$689.82	1042.1 a	$735.31	47.51	$412.59
30	$22.50	199.3 a	$655.12	1054.6 a	$736.81	47.17	$401.76

*Note: S cost equaled $0.75 per lb and included no application cost since it is commonly spread with P and K fertilizers.
¥Values followed by the same letter are not significantly different (p=0.05).

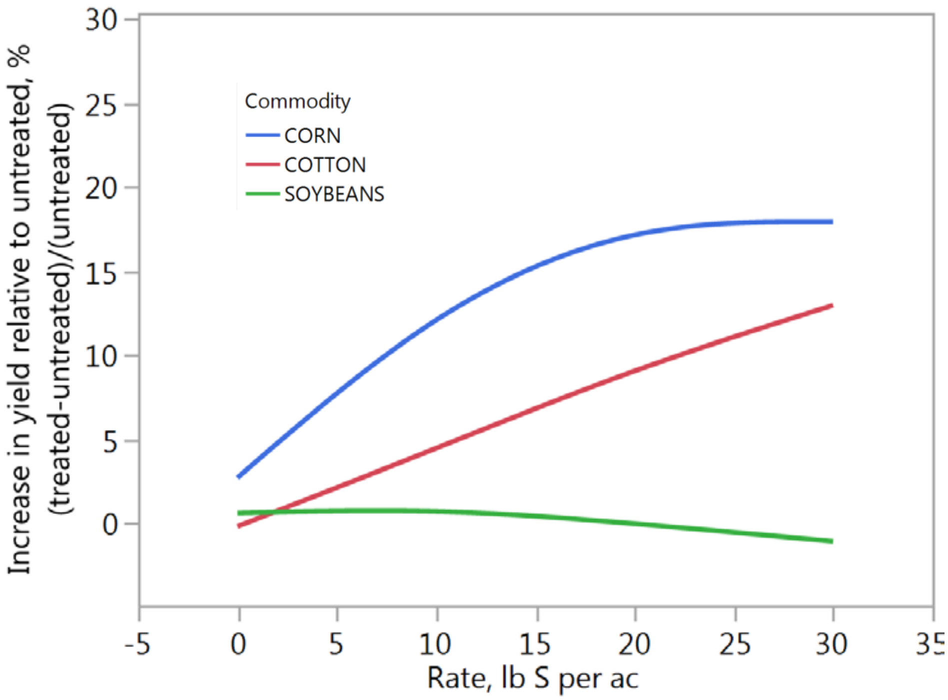

Figure 5: Increase in yield relative to untreated treatments in corn, cotton and soybeans to applications of S in the form of ammonium sulfate at the AgResearch and Education Center in Milan, Tennessee. Response curves for corn and soybeans represent averages across 2013-2015, while response to cotton represents an average of the 2014 and 2015 seasons. Although the relationship between cotton yield and rate of S appears to be linear, a statistically significant increase in yield has not been observed at rates exceeding 10 pounds S per acre.

Table 2: Cotton lint yield response to sulfur rate averaged across five locations during the 2014 and 2015 seasons. Lack of response during the 2014 season greatly contrasts the strong response noted in 2015 and highlights variability in response dependent upon soil texture and environment.

Sulfur Rate, lb S per acre	2014 Average Lint Yield, lb per acre	2015 Average Lint Yield, lb per acre
0	1341.7	1303.5b¥
10	1357.7	1385.3a
20	1303.8	1394.9a
30	1322.4	1376.1a
40	1303.4	1434.0a
P-value	0.8188	0.0027

¥Values followed by the same letter are not significantly different (p=0.05).

AREAS AND CROPS LIKELY TO RESPOND TO S FERTILIZERS

Soil Type and Environment

Due to the inability to accurately and precisely determine the likelihood of a crop response from a soil test, other information about the field should be used to determine if an application of a S containing fertilizer is warranted. From work within and outside the state of Tennessee, fields with coarse-textured soils, well drained and low in organic matter are most likely to respond favorably to an application. Deficiency characteristics are more common on conservation-tillage or no-tillage fields due to the lower soil temperatures, especially early in the season. Exceptionally cool and/or wet springs may also slow organic matter breakdown and result in an increase in deficiencies.

Crop

Based on data generated within the University of Tennessee Institute of Agriculture, in deficient soils, corn and cotton are more likely to respond to added S than soybeans. Preliminary data on small grains suggests applications may increase yields, but consistent, significant yield increases to applications of S have not yet been noted within Tennessee.

CURRENT RECOMMENDATIONS

Canola/Rape, Corn, Cotton, Small Grains, Grain Sorghum and Sunflower

On soils having a coarse-textured subsoil, 10 pounds of sulfur per acre as part of the fertilizer blend may benefit yield, especially where deficiency symptoms have been observed in the past or where plant tissue tests have suggested sulfur deficiency.

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