Fluid Fertilizer Foundation

Fluid nitrogen-sulfur fertilizer formulations to mitigate sulfur deficiencies and maximize cotton yields in the upper-southeast coastal plain. 2016 Report

Project Objectives:

1. Evaluate granular and fluid N sources with varying S application rates on in-season NDVI measurements, petiole and leaf S status during the first week of bloom, and lint yield of cotton in the upper southeast coastal plain.

2. Determine the effect of high N:S ratios in side-dress fluid N sources at varying N application rates on NDVI, petiole and leaf N:S ratios, and lint yield in the upper southeast coastal plain.

Materials and Methods:

Experimental Design

Three trials were implemented across the upper southeast coastal plain cotton production region in 2016. The trial locations were Tidewater Agricultural Research Center in Suffolk, VA (Suffolk), Everett Farms in Southampton County, VA (SHC) and the Peanut Belt Research Station in Lewiston, NC (LEW). The study was a randomized complete block design with four replications of each treatment. Treatments were applied to four row plots measuring 35 ft. in length and 12 ft. wide. Prior to planting a composite soil sample was taken at 0-6, 6-12, 12-24, and 24-36 inch depths and analyzed for soil ammonium and nitrate concentrations using a 2M potassium chloride (KCl) extraction procedure. All other nutrients, except N and S, were applied based on soil test recommendations and/or extension recommendations for North Carolina and Virginia cotton production.

There were at total of seventeen fertilizer treatments (Table 1). The primary fluid N sources were urea ammonium nitrate solutions (28-32% UAN) and granular urea. A bulk blend of granular urea and ammonium sulfate (AMS) was applied at 100 pounds of N per acre with S rates ranging from 0 to 30 pounds S per acre (Treatments 2-5). The granular fertilizers were spread uniformly over the plot area by hand. The total N application rates for the fluid N-S sources were 60, 100, and 140 lbs N per acre (Treatments 6-17). Nitrogen was applied in split applications with 20 pounds N per acre applied at planting and the remaining N applied at the 1st square stage of development. To achieve the varying ratios of N:S solutions, UAN was mixed with ammonium thiosulfate (ATS) (12-0-0-26S). Ammonium thiosulfate was chosen for its high S concentration over AMS solutions (8-0-0-9S). The four ratios were no applied S, 8:1, 4:1, and 2.66:1. The analyses of each fluid N-S side-dress fertilizer material were 32-0-0, 24-0-0-3S, 24-0-0-6S, and 24-0-0-9S, representing fluid fertilizer formulations currently feasible using UAN and ATS solutions (Tom Fairweather, personal communication). The fluid fertilizers were applied using pressurized carbon dioxide system mounted on a four (36 inch) row applicator outfitted with coulters/fertilizer injection knives approximately 6 inches to the side of the row. All N sources were treated with the urease inhibitor N-(n-butyl) thiophosphoic triamide (NBPT), to minimize any ammonia volatilization from surface applied urea based fertilizers.

Table 1: Total N, side-dress N, and S application rates for differing fluid N-S formulations.

Trt	N-S Formulations	Total N	Side-dress N	Sulfur	Total N:S	Fluid Fertilizer N:S
		------------- lb acre^{-1} -------------				
1	No Applied N or S Control	-	-	-	-	-
2ǂ	Urea	100	80	0	100:0	-
3ǂ	Urea + AMS†	100	80	10	10:1	-
4ǂ	Urea + AMS	100	80	20	5:1	-
5ǂ	Urea + AMS	100	80	30	3:1	-
6	32-0-0	60	40	0	60:0	32:0
7ǂ	32-0-0	100	80	0	100:0	32:0
8	32-0-0	140	120	0	140:0	32:0
9	24-0-0-3S	60	40	5	12:1	8:1
10ǂ	24-0-0-3S	100	80	10	10:1	8:1
11	24-0-0-3S	140	120	15	9.33:1	8:1
12	24-0-0-6S	60	40	10	6:1	4:1
13ǂ	24-0-0-6S	100	80	20	5:1	4:1
14	24-0-0-6S	140	120	30	4.67:1	4:1
15	24-0-0-9S	60	40	15	4:1	2.66:1
16ǂ	24-0-0-9S	100	80	30	3:1	2.66:1
17	24-0-0-9S	140	120	45	3.11:1	2.66:1

†AMS = granular ammonium sulfate (21-0-0-24S)

ǂ Treatments to be compared to evaluate sulfur application rates and granular vs fluid N-S sources.

Pre-plant Soil Nitrate and Ammonium Sampling

Prior to planting, soil samples were taken from each site. Six to ten cores were taken per location. Samples were taken at 0-6, 6-12, 12-24, and 24-36 inch increments to be analyzed for ammonium and nitrate. The soils were air-dried and extracted with 2M KCl. Ammonium and nitrate concentrations from each sampling depth were determined using colorimetric analysis using a Lachat Quickchem 8500 (Lachat Instrument, Denver, CO).

Normalized Difference Vegetative Index Measurements

Remote sensing measurements was initiated one week after side-dress N applications using a Greenseeker® handheld crop sensor (Trimble Navigation Limited, Sunnyvale, CA). The Greenseeker® measures the normalized difference vegetative index (NDVI), a measurement of the reflected near infrared and red light from the crop canopy. Greenseeker® measurements were taken for 5 weeks after N application. Normalized difference vegetative index measurements were taken on the second row of the plot and the sensor height was 36 inches above the canopy. Reflectance measurements, like NDVI, have been correlated to chlorophyll content and N status in multiple crops. Given that S deficiencies occur in the upper crop canopy, NDVI may also be sensitive to variations in S status in crops.

Tissue and Petiole Sampling during Bloom

During the first week of bloom twenty-four cotton petioles and leaves were sampled from the first and fourth rows of each plot. Research in Virginia has shown that petiole and leaf nutrient concentrations have a higher correlation to yield during the 1st week of bloom than later sampling intervals. The petiole and leaf was sampled from the fourth mature leaf below the apical meristem (bud) down the main stem. Cotton petioles and leaves were separated immediately to ensure accuracy of nutrient concentrations. Petioles and leaves were dried at 65 ^{o}C and ground to pass 1 mm and 0.5 mm sieve sizes for petioles and leaves, respectively. The petioles were analyzed for nitrate-N, phosphorus (P), potassium (K), and sulfur (S) and leaf tissue underwent a complete nutrient analysis at Water's Agricultural Laboratory (Camilla, GA).

Defoliation and Lint Yield

Defoliation timing of cotton varies depending on the growing season and development of the crop. The cotton during this trial was defoliated when 40-60% of the bolls were opened. This timing were based upon treatments with a total N application rate of 100 pounds N per acre. High N application rates can delay maturity in cotton; however given that the upper southeast coastal plain falls within the northern latitudes of the U.S. cotton production region any delay in maturity can be detrimental to crop yield. This range in percentage of open bolls will allow for some adjustment based on the development of the crop during the study, but falls within the recommendations for defoliating cotton in Virginia and North Carolina (Edmisten, 2012; Wilson, 2015).

The cotton from the center two rows was harvested with a Case International two row cotton picker. Seed cotton was weighed from each plot then a one pound subsample was taken and ginned to determine lint turnout. Lint yield will be calculated from the percent turn out from the ginning process and seed cotton weights from the harvested rows. The ginned lint was sent to the USDA cotton quality lab in South Carolina for lint quality analysis. The lint was analyzed using a High Volume Instrument (HVI) where length (staple), strength, micronaire, color and leaf (trash) grade was determined.

Statistical Analysis

The statistical analysis of the experiment included a regression analysis and analysis of variance (ANOVA) conducted using SAS 9.2 (SAS Institute, 2009). The dataset was separated in order conduct the appropriate statistical analyses for based on treatment design to determine the effect of S fertility on NDVI, petiole and tissue S concentrations, and lint yield and quality. The first dataset compared granular N/S fertilizers to fluid N/S fertilizers with varying S application rates at a fixed N rate of 100 pounds N per acre. The treatment design for the first dataset was a 2X4 factorial design with two N/S fertilizer sources and four S rates. The N/S fertilizer sources were blends/formulations of granular urea+AMS and fluid UAN+ATS solutions. The S rates were 0, 10, 20, and 30 pounds S per acre for each fertilizer source. Fisher's LSD mean separation procedure was used to detect treatment differences at $\alpha = 0.05$ level of significance. Regression analysis were used to describe the response of each dependent variable to increasing S application rates.

The second dataset compared the interaction of N rate and S rate using N-S fluid fertilizers with varying N:S ratios. The treatment design for the second dataset was a 3X4 factorial design with three total N rates and four N:S fluid fertilizers. The three total N application rates were 60, 100, and 140 pounds N per acre and the four N:S fluid ratios were 32:0, 8:1, 4:1, and 2.66:1. Fisher LSD mean separation procedure was used to detect treatment differences at $\alpha = 0.05$ level of significance.

Results and Discussion

General Comments

Overall the 2016 growing season was marked by challenging weather events which limited the productivity of cotton in Virginia and North Carolina. The cotton yields were the lowest for the region in the last five year with Virginia's average yield being 673 lb lint per acre in 2016. This was due to a cool weather May, followed by a dry August, and then two to three weeks of rainy cloudy weather from two tropical systems in late September and early October. Yields at two of the three locations were low and responses in yield to N/S formulations were limited at these locations. One location, Suffolk, was high yielding and responsive to N/S formulations. All sites were responsive to N/S formulations during the growing season in terms of NDVI and tissue N and S concentrations. Background soil ammonium-N and nitrate-N concentrations were low at each location with a total available N ranging from 10.1 – 15.6 ppm N (20 – 31 lb N per acre) in the top 36 inches of soil. Though lint yields were limited by environmental conditions at each location there were common responses across locations which allowed for inference into the role of S in cotton production on low CEC, low organic matter, and low water holding capacity soils commonly found in the coastal plain regions.

Table 2: Soil ammonium and nitrate-N concentrations prior to planting at depths of 0-6, 6-12, 12-24, and 24-36 inches at each location in 2016.

Sampling Depth	**TAREC**		**Southampton**		**Lewiston**	
in.	NH_4^+-N	NO_3^--N	NH_4^+-N	NO_3^--N	NH_4^+-N	NO_3^--N
	ppm					
0-6	2.03	2.55	1.15	1.81	0.79	1.26
6-12	1.85	0.99	0.96	1.59	0.83	1.13
12-24	2.11	1.14	1.08	1.16	0.60	1.93
24-36	2.65	2.25	5.31	1.08	1.37	2.21
Total	8.63	6.93	8.50	5.63	3.59	6.52

Normalized Difference Vegetative Index (NDVI)

Remote sensing has gained popularity as a means of detecting nutrient deficiencies, especially N, across cropping systems. In this study NDVI was measured the five weeks following N/S application in cotton. Significant differences in NDVI were found in at least one sampling interval for every location in 2016 (Table 2). The two most responsive NDVI locations were Suffolk and LEW with 4 out of 5 sampling intervals having NDVI differences among treatments at each location (Table 2). At all locations NDVI increased with time and this would be expected as the cotton becomes larger there is more leaf area resulting in a higher percentage of light reflectance in the red and near infrared spectrums. For the last three sampling intervals at each location the NDVI values for plots receiving N and S were 0.84-0.89, values that indicate the reflectance was almost saturated. This raises concerns on how sensitive the index will be in terms of making in season decisions once cotton is a certain size. Differences in NDVI can be attributed to both N and S deficiencies at each location with the lowest NDVI values occurring for the no N/S controls in approximately half of the sampling intervals. There were sampling intervals at Suffolk when the 32-0-0 treatments had lower NDVI values than the no N/S controls indicating that S deficiency was severe (Table 2). The 32-0-0 treatments did have lower NDVI values in sampling intervals where NDVI differed from treatments receiving both N and S at sidedress. Visual S deficiencies occurred at Suffolk during the study (Fig. 1A and B) and symptoms could be distinguished from the no N/S control treatments. This raises the concern that NDVI can detect S deficiencies when compared to healthy cotton, but is limited in distinguishing between N or S deficiencies. An analysis of a broader array of visible and infrared spectrums may allow for indices to be developed that could differentiate certain nutrient deficiencies in a field setting without the need for ground trothing. To test this theory a multispectral imager will be used in 2017 to query different visible and infrared spectrums to

Table 3: Normalized difference vegetative index during the five weeks following sidedress N/S application at all locations in 2016.

Trt	Nitrogen Rate	Sulfur Rate	Normalized Difference Vegetative Index (NDVI)														
	lb N ac^{-1}	lb S ac^{-1}	Suffolk					SHC					LEW				
			Jun-29	Jul-6	Jul-12	July-18	Jul-25	Jul-1	Jul-12	Jul-19	Jul-26	Aug-3	Jul-7	Jul-15	Jul-21	Jul-29	Aug-2
1	0	0	0.55 e*	0.80	0.79 cde	0.82 d	0.84 bcd	0.68	0.63	0.77	0.78 e	0.83	0.64	0.75 d	0.75 d	0.78 d	0.78 d
2	100	0	0.69 a	0.82	0.80 bcde	0.86 abc	0.86 abc	0.72	0.61	0.80	0.80 cde	0.85	0.74	0.81 abc	0.85 ab	0.85 ab	0.86 abc
3	100	10	0.60 bcde	0.81	0.84 abc	0.87 a	0.87 a	0.75	0.70	0.82	0.85 abcd	0.86	0.73	0.81 abc	0.85 ab	0.85 ab	0.86 abc
4	100	20	0.67 ab	0.84	0.87 a	0.88 a	0.88 a	0.74	0.72	0.83	0.81 cde	0.86	0.72	0.80 abc	0.86 a	0.86 a	0.86 abc
5	100	30	0.64 abcd	0.81	0.83 abc	0.88 a	0.87 a	0.72	0.66	0.83	0.85 abcd	0.87	0.71	0.79 c	0.85 ab	0.87 a	0.86 abc
6	60	0	0.58 cde	0.74	0.76 ef	0.83 bcd	0.82 d	0.75	0.69	0.83	0.81 cde	0.85	0.72	0.81 abc	0.84 abc	0.83 bc	0.85 abc
7	100	0	0.63 abcde	0.77	0.77 def	0.87 a	0.83 cd	0.71	0.65	0.82	0.81 cde	0.86	0.67	0.81 abc	0.84 abc	0.86 a	0.83 c
8	140	0	0.57 de	0.78	0.74 f	0.83 bcd	0.84 bcd	0.77	0.67	0.80	0.79 de	0.82	0.73	0.81 abc	0.82 bc	0.81 c	0.84 bc
9	60	5	0.62 abcde	0.79	0.81 bcd	0.87 a	0.88 a	0.72	0.66	0.77	0.82 abcde	0.85	0.73	0.80 bc	0.85 ab	0.86 a	0.86 abc
10	100	10	0.63 abcde	0.79	0.84 abc	0.87 a	0.89 a	0.74	0.69	0.85	0.86 abc	0.88	0.72	0.82 abc	0.85 ab	0.87 a	0.86 abc
11	140	15	0.66 abc	0.80	0.82 abc	0.88 a	0.88 a	0.81	0.73	0.86	0.88 a	0.87	0.70	0.84 a	0.84 abc	0.86 a	0.87 ab
12	60	10	0.64 abcd	0.81	0.83 abc	0.88 a	0.88 a	0.79	0.70	0.85	0.86 abc	0.88	0.70	0.81 abc	0.84 abc	0.86 a	0.86 abc
13	100	20	0.57 de	0.82	0.84 abc	0.87 a	0.88 a	0.81	0.71	0.87	0.88 a	0.88	0.72	0.83 ab	0.85 ab	0.87 a	0.88 a
14	140	30	0.65 abcd	0.77	0.84 abc	0.87 a	0.88 a	0.81	0.76	0.87	0.87 a	0.87	0.70	0.81 bc	0.84 abc	0.86 a	0.85 abc
15	60	15	0.63 abcde	0.77	0.82 abc	0.88 a	0.87 a	0.80	0.77	0.85	0.87 a	0.88	0.72	0.79 c	0.83 abc	0.85 ab	0.87 ab
16	100	30	0.64 abcd	0.81	0.84 abc	0.87 a	0.89 a	0.82	0.77	0.86	0.88 a	0.87	0.71	0.82 abc	0.85 ab	0.87 a	0.85 abc
17	140	45	0.68 ab	0.80	0.84 abc	0.88 a	0.86 abc	0.80	0.73	0.87	0.88 a	0.88	0.67	0.80 bc	0.85 ab	0.87 a	0.88 a
ANOVA Pr > F			**0.0353**	**NS**	**0.0003**	**0.0163**	**0.0008**	**NS**	**NS**	**NS**	**0.0073**	**NS**	**NS**	**0.0101**	**< 0.0001**	**< 0.0001**	**< 0.0001**

***** Values with the same letters are not significantly different within location and date at α = 0.05.

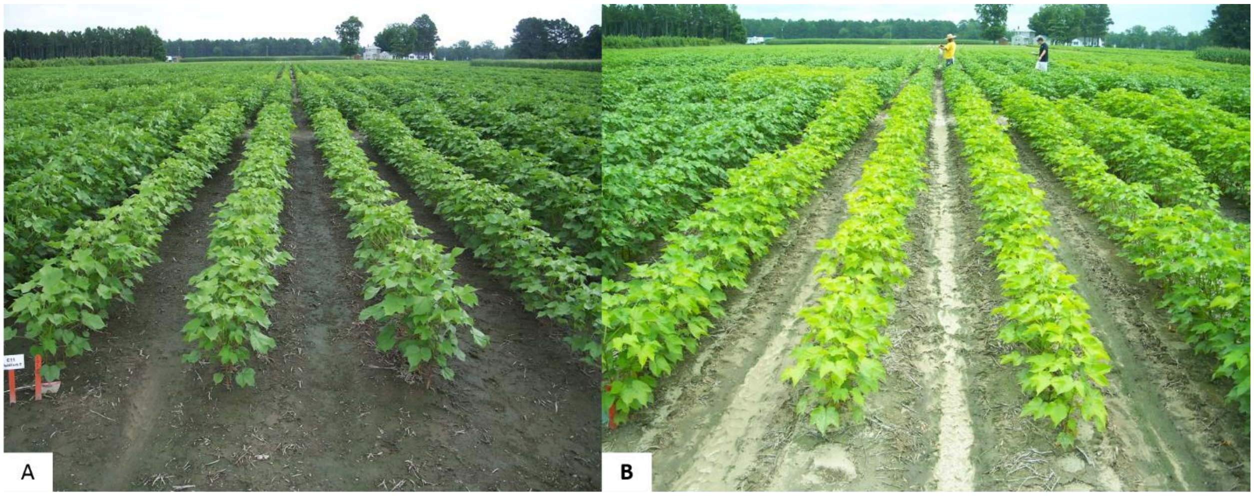

Fig. 1: Cotton treated with no N/S (A) and 140 lb N acre^{-1} with no S applied as 32-0-0 injected at Suffolk in 2016.

identify a unique spectrum for N and S deficiencies in cotton.

Granular vs. Fluid N/S Formulations

When S fertilizer source was evaluated over four S applications, S source was significant at two of three locations (Fig. 2). At the SHC location the UAN32 + ATS produced significantly higher petiole S concentrations than the broadcast granular urea + AMS, whereas at the LEW location the granular N/S formulations produced significantly higher petiole S concentrations (Fig. 2). At the LEW location there was a significant interaction between S source and application rate with the broadcast N/S formulation having significantly higher petiole S concentrations with only 10 lb S per acre (1,448 ppm S) than all S application rates for the UAN32 + ATS from 10 – 30 lb S per acre which were 690, 977, and 842 for 10, 20, and 30 lb S per acre. This was the only location in 2016 where an interaction between N/S formulation and S application rate was observed for petiole S concentrations. This interaction was not present in

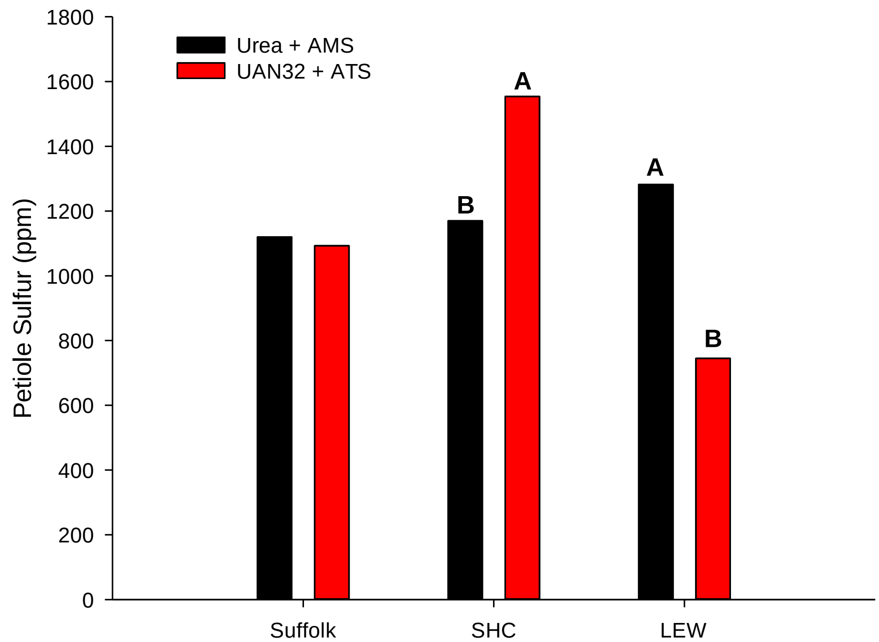

Fig. 2: Petiole S concentrations for the main effect of S source for each location in 2016.

leaf S concentrations at LEW (data not shown). No N/S formulation differences were found for leaf S for any location in 2016 (data not shown).

Sulfur application rate was highly correlated with petiole S concentrations during the first week of bloom at all locations (Fig. 3). The SHC location had the highest petiole S concentrations when S was applied and were maximized with 10 lb S per acre application rate. At the other two locations petiole S was significantly increased up to 20 lb S per acre at Suffolk and 30 lb S per acre at LEW. All three locations had a quadratic response to S application rate when 100 lb N per acre was applied.

An interesting finding was that even at 0 lb S per acre no treatments were below the current leaf S critical concentrations of 0.25% (Mitchell and Baker, 2009) (Fig. 4). The lowest S concentration found when N was applied, regardless of formulation was 0.35% S in leaf tissue. As S application rate increased leaf S content also increased in a similar manner to petiole S

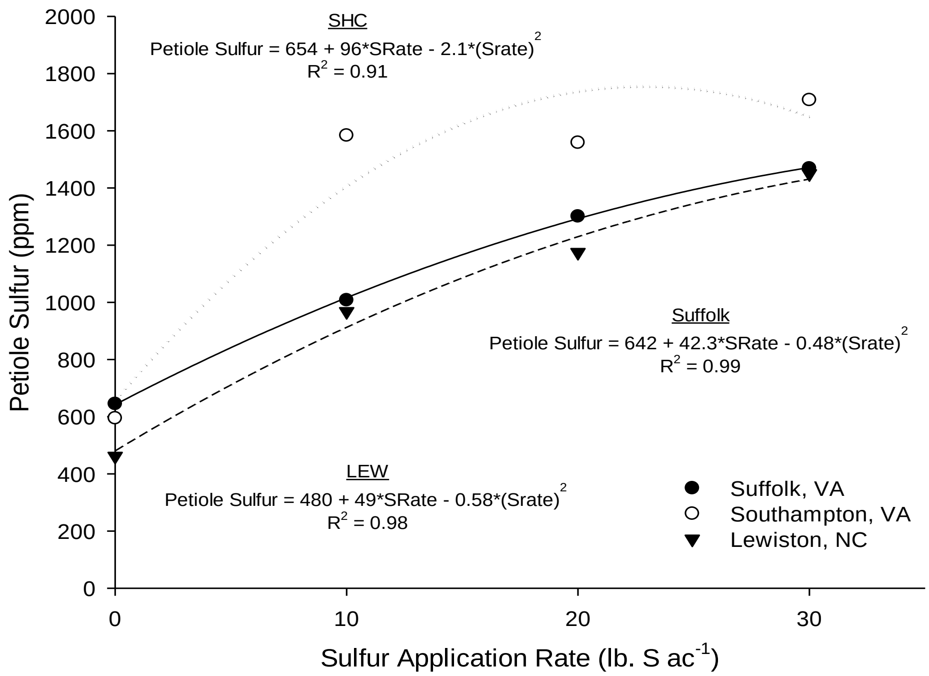

Fig. 3: Petiole S concentrations and S application rate for cotton receiving l00 lb N per acre at all locations in 2016.

concentrations (data not shown). There is a moderate correlation between petiole S and leaf S, with leaf S increasing at a decreasing rate as petiole S concentrations increase (Fig. 4). This indicates that petiole S is more sensitive to S application rates than leaf S during the first week of bloom, as there is a greater range of petiole S per unit of S applied. It is concerning that the 0 lb S per acre application rate did not produced leaf S concentrations triggering a deficient tissue test when visible S deficiency symptoms were present for at least one location.

In addition to S, petiole nitrate-N and leaf N was also measured to evaluate the impact of N/S formulation and S application rate. The N/S formulations were different at 100 lb N per acre at each location during 2016 (Fig. 5). Petiole nitrate-N concentrations for the UAN32 + ATS were over 2X higher than the urea + AMS formulations during the first week of bloom at the

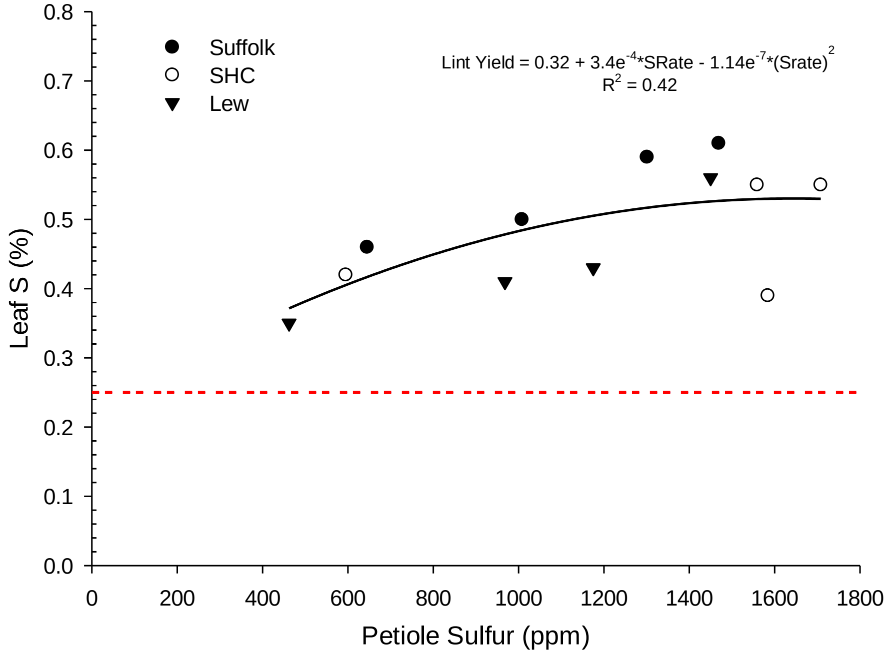

Fig.4: Correlation between petiole S concentrations and leaf S concentrations for all S application rates and locations in 2016.

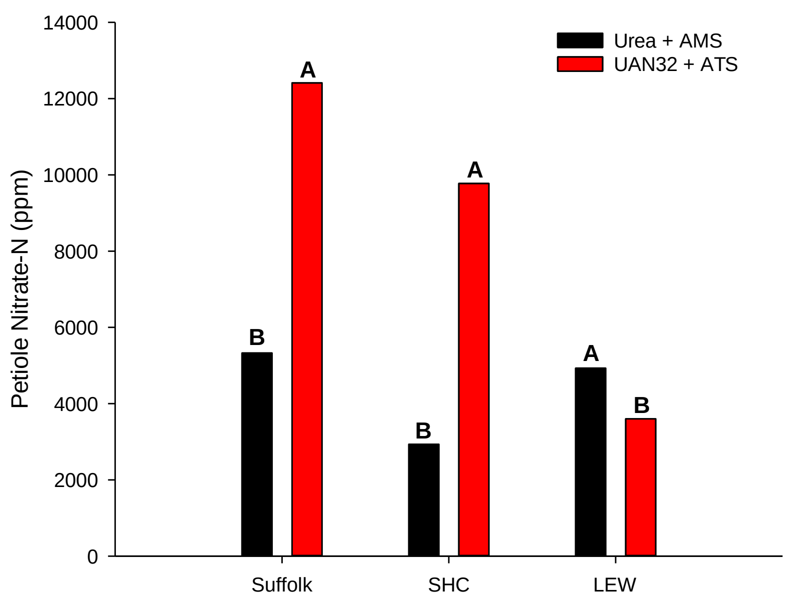

Fig. 5: Petiole nitrate-N concentration with different N/S formulations across S application rates at all locations in 2016.

Suffolk and SHC locations (Fig. 5). However, at the LEW location the broadcast N/S formulations produced significantly higher petiole nitrate-N than the injected fluid N/S formulation at 100 lb N per acre. At the LEW location the average leaf N content for broadcast N/S formulations was 4.45% N whereas for the fluid N/S formulations was 4.78% N which was significantly higher than the latter. Leaf N was also significantly greater for SHC with fluid N/S formulations compared to broadcast formulations at 100 lb N per acre with 4.72% N and 4.19% N, respectively. At the Suffolk location, leaf N was numerically higher with fluid N/S sources compared to broadcast sources, though not statistically significant.

Increasing S application rates did impact petiole nitrate-N concentrations at all locations the petiole nitrate-N concentrations decreased with increasing S application rates (Fig. 6). Only the SHC location had a significant decrease with the highest two S application rates having significantly less petiole nitrate-N than 0 lb S per acre when 100 lb N per acre was

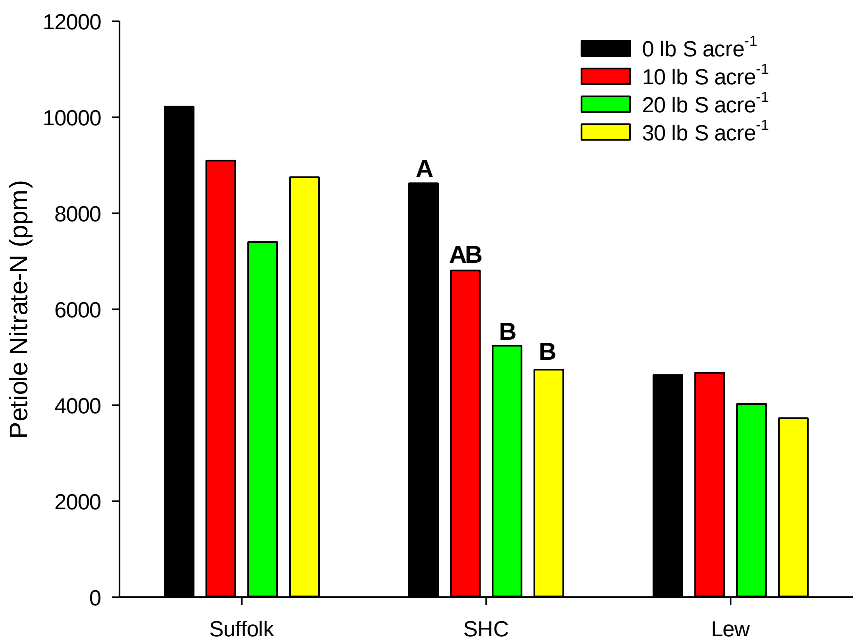

Fig. 6: Petiole nitrate-N concentrations with varying S application rates at all locations in 2016.

applied. This is significant as increasing S rates decreased petiole nitrate-N concentrations, which may impact in-season nutrient management decisions when evaluating cotton nutrient status. More data are needed to ascertain the relationship between S application rate and nitrogen nutrition in cotton.

Lint yields for N/S formulation and S application rate were not as responsive as petiole and leaf tissue N and S concentrations. Regression analyses revealed that lint yields at the Suffolk location increased with increasing S application, but only slightly (Fig. 7). The fluid N/S sources had lower lint yields at the 0 and 30 lb S per acre rates compared to the granular sources. The lower yield at the 0 lb S per acre rate was most likely due to an increased efficiency with

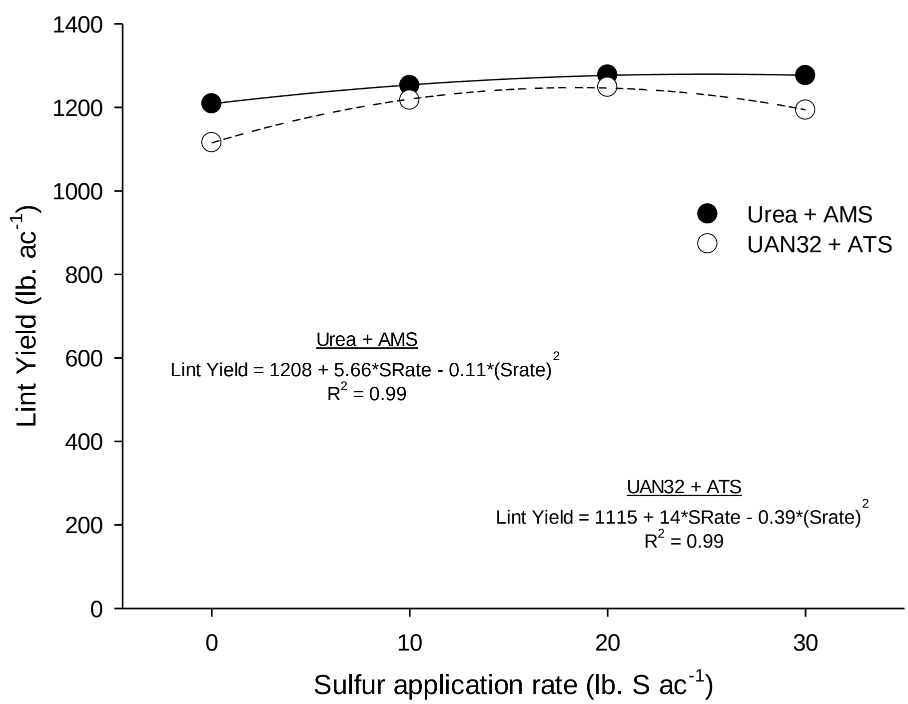

Fig. 7: Lint yield for cotton produced using granular and fluid N/S formulations with varying S application rates at a fixed N rate of 100 lb N per acre at the Suffolk location in 2016.

fluid sources which exacerbated the N:S ratio in the plant resulting S deficiency occurring similar to Fig. 1B. The decrease at the 30 lb S per acre rate can be explained by delayed maturity due to rank growth thus resulting in hard lock and decreased yields. The other location where significant yield responses were observed was at SHC, where granular N/S formulations produced significantly higher lint yield than fluid sources with 663 and 569 lb per acre, respectively. There was also a S application rate response with the 10 lb S per acre having significantly higher yields than all other treatments at SHC. Sulfur application rates exceeding 20 lb S per acre decreased lint yields at all sites for the fluid sources and this trend for S rate needs to be examined further. The high S rates may contribute to rank growth and delayed maturity resulting in decreased yields. There also was increased utilization of fluid sources at two of three locations which may indicate a greater N and S use efficiency for fluid sources.

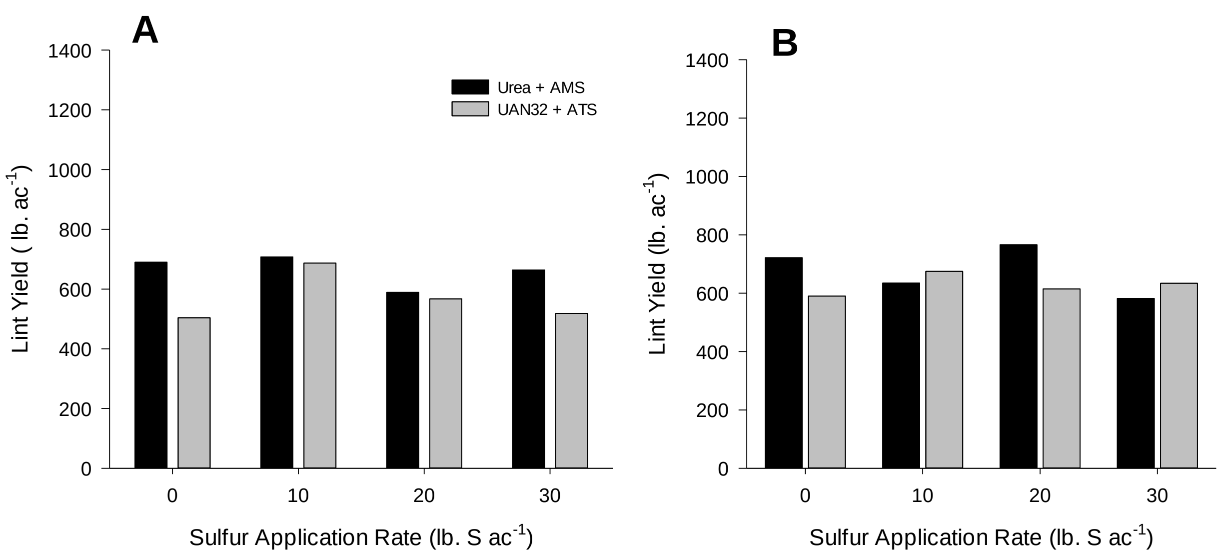

Fig. 8: Lint yield for cotton produced using granular and fluid N/S formulations with varying S application rates at a fixed N rate of 100 lb N per acre at the SHC (A) and LEW (B) locations in 2016.

Fluid N/S Combinations at Various N Application Rates

A key component of this study was to determine the impact of varying N application rates on the need to increase the S content of current N/S formulations to meet S demands by cotton. Four formulations were evaluated over three total N application rates, and N/S formulations were applied at sidedress during the study. Petiole S concentrations increased with N/S formulations at all locations with the high S content blends having high petiole S concentrations (Fig. 9). The 24-0-0-6S blend produced similar petiole S concentrations to 24-0-0-9S at all locations. The range of petiole S concentrations was different depending on location during 2016. At the SHC location, the 24-0-0-3S blend produced similar petiole S concentrations as the other N/S blends, however at Suffolk and LEW this blend produced significantly lower petiole S than the other high S content blends (Fig. 9).

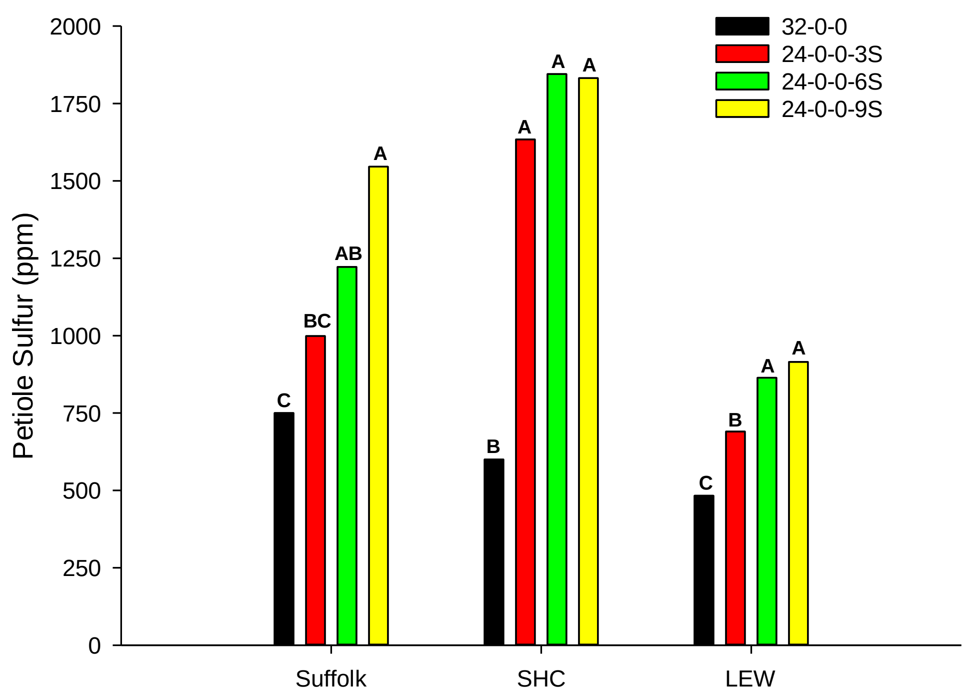

Fig. 9: Petiole S concentrations for varying N/S fluid formulations with varying N:S ratios averaged over three N application rates at all locations in 2016.

Leaf S content followed the same trends as the petiole S concentrations with two out of three locations having differences among fluid N/S sources. Across all locations the leaf S concentrations ranged from 0.37 – 0.69 % S for fluid N/S sources (data not shown). These levels were still above current thresholds documented by Mitchell and Baker (2009) even when UAN 32 was used alone, regardless of N application rate. There was an interaction for leaf S at LEW for N application rate and fluid N/S formulations (data not shown). In general at LEW when N application rate increased, leaf S concentrations decreased.

Petiole nitrate-N concentrations were responsive to N application rate at every location during 2016 (Fig. 10). At Suffolk and LEW, petiole nitrate-N increased with increasing N application rates, whereas at SHC the 100 lb N per acre rate maximized petiole nitrate-N concentrations and was significantly higher than the 60 and 140 lb N per acre rates. The LEW

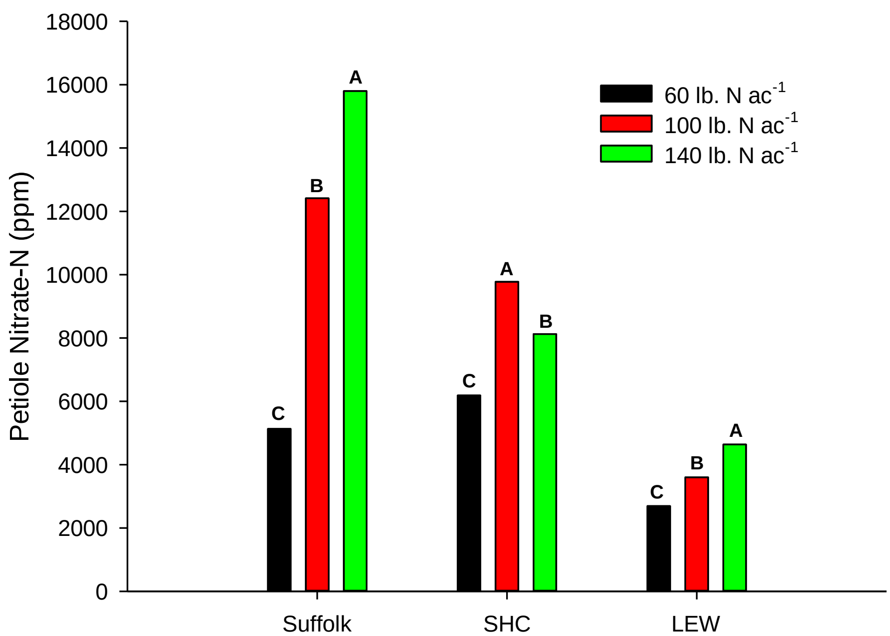

Fig. 10: Petiole nitrate-N concentrations for varying N application rates at all locations in 2016.

location had the lowest concentrations of petiole nitrate-N of any location (Fig. 10). Petiole nitrate-N concentrations at SHC again decreased as the percentage of S in the fertilizer formulation increased. This was the only location when fluid source was evaluated that showed a significant decrease in petiole nitrate-N concentrations as S application rate increased.

Lint yield during 2016 varied depending on location with Suffolk having the highest lint yields followed by LEW and SHC. Lint yield was significant at the Suffolk location only for N/S formulation with yields maximized with the 24-0-0-3S (Fig. 11, top). This was the only location where lint yields were significantly different for fluid N/S formulations. However, every location had a numeric increase in lint yield when 24-0-0-3S was used instead of 32-0-0 (Fig. 11, top). Two out of the three locations during 2016 had significant lint yield differences among N application rates (Fig. 11, bottom). At Suffolk, lint yields increased from 60 to 100 lb N per acre, whereas at SHC lint yield decreased significantly from 60 to 100 lb N per acre (Fig. 11, bottom). The N application rate of 140 lb N per acre did not significantly increase lint yields above the 100 lb N per acre rate at any location. Both SHC and LEW showed a decreasing yield trend with N rate, and this was most likely due to dry conditions in August (boll fill period) at both locations followed a period in late September/October of cloudy rainy weather. This combination of weather events and N application rates delayed maturity of the cotton resulting in high vegetative growth and low lint yields.

In order to better understand the relationship between N and S physiology of cotton ratios of petiole nitrate-N to petiole S (PN:PS) and leaf N to leaf S (LN:LS) were analyzed and correlated to yield. This anlaysis was only conducted for the data from Suffolk as it was the only statistically responsive site during 2016. The result of this analysis is a response surface

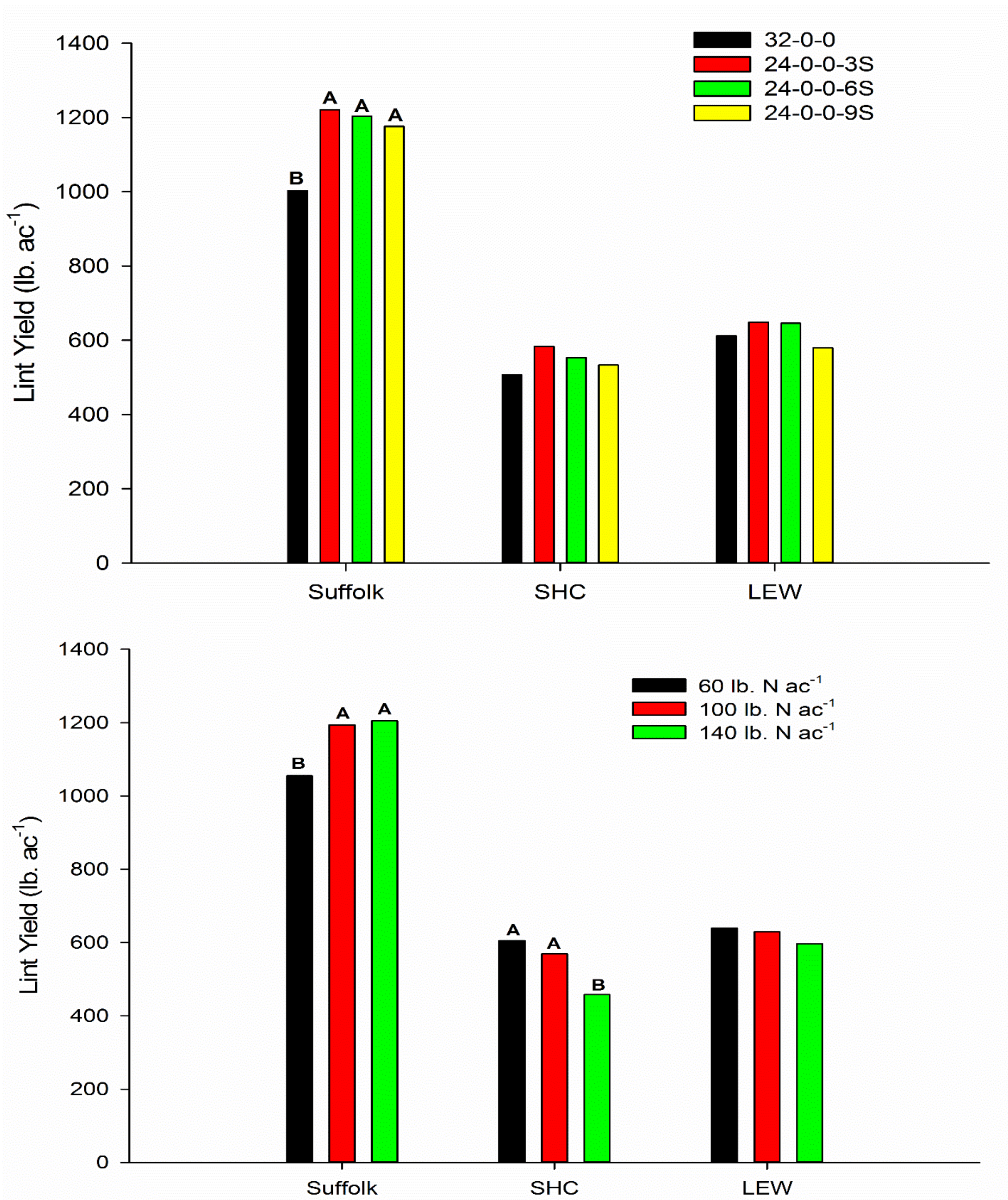

Fig. 11: Lint yield for varying N:S ratios in fluid fertilizers (top) and varying N application rates (bottom) at all locations in 2016.

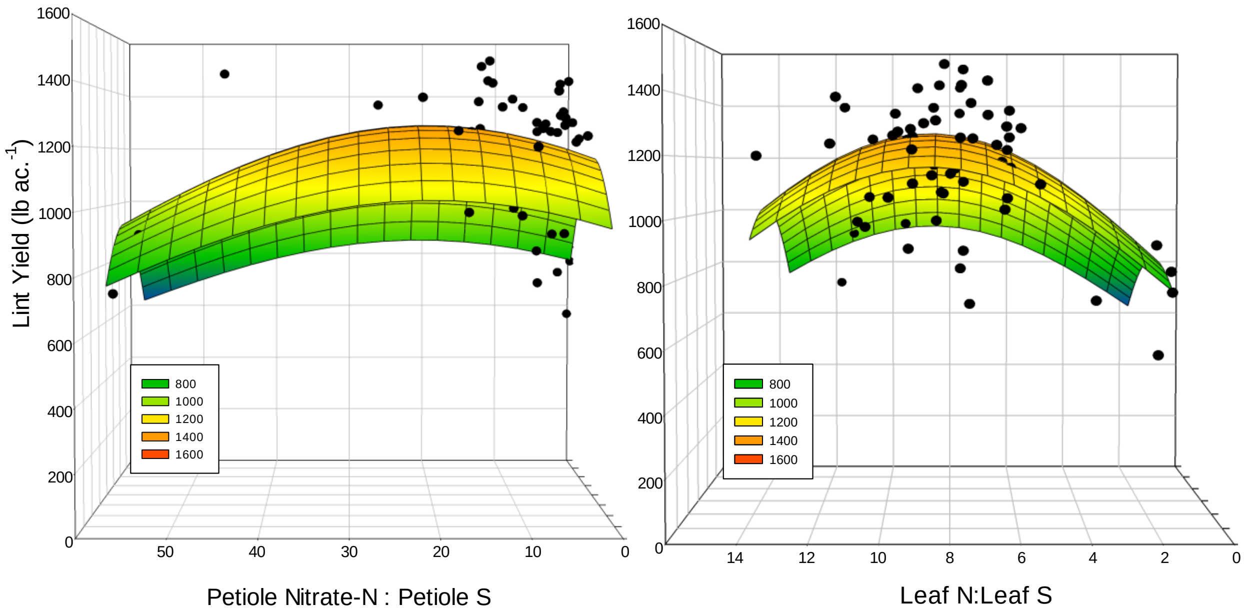

Fig. 12: Evaluating the optimum petiole nitrate-N to petiole sulfur and leaf N to leaf sulfur ratios to predict lint yield response at Suffolk, VA in 2016.

regression found in Fig. 12. Overall when PN:PS ratios are above 20 lint yields decreased at the Suffolk location and when the PN:PS ratio fell below 10 lint yields also decreased (Fig. 12, left). When evaluating LN:LS there was a similar trend in that when LN:LS ratios were greater than 10 and less than 7 lint yields declined (Fig. 12, right). More data are needed to validate and build upon this one responsive site, however these ratios may be a likely way to evaluate the N and S status of cotton during the first week of bloom.

Lint quality characteristics were tested and significant responses to N and S treatments were sparse during the study. This will be another area where N and S fertility may impact cotton moving forward, but the data set is small on impacts of N and S fertility on lint quality in Virginia.