Fluid Fertilizer Foundation Sponsored Cotton Trials 2013

Improving Cotton Production Efficiency with Phosphorus and Potassium Placement at Multiple Depths in Strip Tillage Systems

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Executive Summary

The study conducted during the 2013 growing season evaluated the placement and application rate of phosphorus (P) and potassium (K) in upland cotton production systems. The trial was implemented at two locations, one at the Tidewater Agricultural Research and Extension Center in Suffolk, VA (TAREC) and the other at the North Carolina Department of Agriculture's Peanut Belt Research Station in Lewiston, NC (Lewiston). The objectives were to 1) determine the impact on early season development of upland cotton (*Gossypium hirsutum)* through first square, nutrient status during the first and fourth week of bloom, and lint yield and quality of placing a fluid P & K fertilizer at multiple depths below the seed during strip-till cultivation and 2) evaluate selected combinations of P and K placed at multiple depths in the strip-till process in combination with 2X2 banding of P and K solutions at planting on crop establishment, growth through first square, nutrient status during the first and fourth week of bloom, and lint yield and quality. Thirteen treatments were replicated four times at each location and included an unfertilized control, broadcast fertilizer control, and liquid P starter control with broadcast K to compare against two new nutrient management strategies. The first new strategy involve applying a P and K liquid fertilizer blend in a 2 inch by 2 inch band (2X2) and the second strategy utilized strip-tillage to place a liquid P and K fertilizer at 6, 9, and 12 inches below the row (deep placement). Each new strategy was test at 50, 100, and 150% of the soil test recommendations. Combinations of the 2X2 and deep placement were also tested at the 100% P and K soil test recommendations. Early in the growing season a wind storm resulted in sand-burn damage on the cotton at Lewiston. This injury resulted in highly variable plant measurement, tissue nutrient concentrations, and yield data. At the TAREC location, the 2X2 band increased early season plant height compared to standard nutrient management systems. At TAREC the unfertilized control had the highest P concentrations throughout the bloom period. The high petiole P concentrations may be related to N deficiency and if this proves to be true then N status will have to be evaluated before making in-season management decisions based on petiole P concentrations. When comparing the 2X2 band and deep placement across multiple application rates, the 2X2 band produced 144 lbs lint/acre more than the deep placement of P and K. More data is needed to solidify the findings, but the 2X2 band containing N-P-K-S significantly increased early season vigor of cotton and increased lint yields over the deep placement strategy alone.

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Project Name:

Improving Cotton Production Efficiency with Phosphorus and Potassium Placement at Multiple Depths in Strip Tillage Systems

Term of Project:

January 1, 2013- Dec. 31, 2015

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Locations:

Tidewater Agricultural Research and Extension Center (TAREC)

North Carolina Department of Agriculture and Consumer Services Research Station (Lewiston)

Project Objectives**:**

1. Determine the impact on early season development of upland cotton (*Gossypium hirsutum)* through first square, nutrient status during the first and fourth week of bloom, and lint yield and quality of placing a fluid P & K fertilizer at multiple depths below the seed during strip-till cultivation.

2. Evaluate selected combinations of P and K placed at multiple depths in the strip-till process in combination with 2x2 banding of P and K solutions at planting on crop establishment, growth through first square, nutrient status during the first and fourth week of bloom, and lint yield and quality.

Materials and Methods

Site Characteristics

The trials were conducted at two locations during 2013: the Tidewater Agricultural Research and Extension Center (TAREC) of Holland, Virginia (36^{o} 39’ 46.2” N, 76^{o} 44’ 3.9” W), and the North Carolina Department of Agriculture and Consumer Services Peanut Belt Research Station located in Lewiston, North Carolina (36^{o} 8’ 5.4” N, 77^{o} 10’ 43.5” W). The soil type at the TAREC location was a Eunola loamy sand (fine-loamy, siliceous, semiactive, thermic Aquic Hapludults). The soil type at Lewiston was a Rains sandy loam (fine-loamy, siliceous, semiactive, thermic Typic Paleaquults). Soil samples were taken from both locations to a total depth of 12 inches (30 cm) and split into depths of 0-3, 3-6, 6-9, and 9-12 inches. The Mehlich I soil test levels for each location can be found in Table 1. The base (100%) preplant phosphorus and potassium fertilizer rates were 40 lbs P_2O_5 /acre and 40 lbs K_2O /acre and based on Mehlich I soil test levels. All other agronomic practices were conducted according to Virginia extension recommendations. Planting, treatment application, and harvest dates can be found in Table 2.

Experimental Design

The study was conducted using four row plots measuring 12 feet wide by 40 feet long at two locations. Each treatment was replicated four times in a randomized complete block design. The cotton variety grown was Phytogen 499 WRF, an early to mid- maturing variety with a high yield potential. Thirteen treatments evaluated placement of phosphorus (P) and potassium (K) fluid fertilizers (Table 2). Treatment 1 was an unfertilized P and K control, however at TAREC unfertilized plots did not receive nitrogen (N) or sulfur (S); while the unfertilized check

Table 1: Mehlich I extractable phosphorus and potassium at 0-3, 3-6, 6-9, 9-12 inch depths at TAREC and Lewiston

Depth	TAREC		Lewiston	
inches	P	K	P	K
	ppm			
0-3	49 (H+)¶	99 (H-)	30 (H)	126 (H)
3-6	31 (H)	86 (M+)	18 (H-)	59 (M)
6-9	20 (H-)	73 (M)	13 (M)	37 (L+)
6-12	19 (H-)	68 (M)	7 (M-)	33 (L+)

¶ Indicates the soil test level based on Virginia's soil test calibration

Table 2: Strip-tillage, planting, and harvesting dates for all locations during the 2013 growing season

Location	Strip-tillage	Planted	Harvested
TAREC	5/7	5/10	10/21
Lewiston	5/16	5/30	11/19

at Lewiston received 80 lbs N per acre in a sidedress application. Two agronomic control treatments were implemented to simulate the current nutrient management systems in Virginia: 1) all of the required P and K broadcast prior to planting; and 2) 100 lbs starter material (10-34-0) per acre applied in a 2X2 band at planting with the remainder of the P and K broadcast prior to planting (Table 2). Treatments 4-9 evaluated the response to P and K fluid fertilizer applied in the 2X2 band at planting and deep placement during strip-tillage at 50, 100, and 150% of the recommended rates based on soil tests. The remaining treatment combinations evaluated a series of combinations of the 2X2 band and deep placement, all totaling the 100% of the recommended P and K fertilization rates (Table 2).

Table 3: Treatment List for 2013 Locations

Trt	Placement	Description
1	Unfertilized Control	No P or K Fertilization
2	Broadcast Agronomic Control	P + K Broadcast – Soil test recommendation‡
3	Starter Agronomic Control	100 lbs /acre† of 10-34-0 in 2X2 band + Remaining P+K broadcast
4	2X2 Band	50%P + 50%K¶
5	2X2 Band	100%P + 100%K
6	2X2 Band	150%P + 150%K
7	Deep Placement	50%P + 50%K
8	Deep Placement	100%P + 100%K
9	Deep Placement	150%P + 150%K
10	2X2 + Deep Placement	(80%P + 80% K) + (20%P + 20%K)
11	2X2 + Deep Placement	(60%P + 60% K) + (40%P + 40%K)
12	2X2 + Deep Placement	(40%P + 40% K) + (60%P + 60%K)
13	2X2 + Deep Placement	(20%P + 20% K) + (80%P + 80%K)

† 100 lbs/acre of 10-34-0 is the recommended rate for cotton placed in a 2X2 band at planting in by North Carolina State University Cooperative Extension.

‡ Recommended nutrient application rates applied based on Mehlich 1 extractable phosphorus and potassium and Virginia Cooperative Extension Recommendations

¶ Percentages represent the proportion of recommended nutrient application rates applied based on Mehlich 1 extractable phosphorus and potassium and Virginia Cooperative Extension Recommendations.

Treatment Application

Treatments were applied with a two strip-tillage implement three days prior to planting at TAREC and 14 days prior to planting at Lewiston. Fertilizer placement with strip tillage was accomplished with an apparatus depicted in Fig. 1. To dispense fluid fertilizers at 6, 9, and 12 inches below the soil surface, holes drilled 90^{o} to the direction of travel allowed the fluid fertilizer to exit each down spout and maximize contact with the soil at the targeted depths. The 2X2 banded fertilizer was applied at planting using a double disk opener mounted on the toolbar of a two row Monosem planter. The application rate for the liquid P and K sources was controlled by a carbon dioxide pressurized system and the application rates were controlled using inline orifices (Fig. 1).

The broadcast P and K was applied on the same day as the strip tillage cultivation and deep placement of P and K for both locations. Diammonium phosphate (DAP) (18-46-0) and muriate of potash (0- 0-60) were used as the P and K sources for the broadcast agronomic control treatment. The liquid phosphorus source applied was ammonium polyphosphate (10-34-0) (APP) and the liquid potassium source was potassium thiosulfate (0-0-25-17S).

The potassium thiosulfate supplied 40.8 lbs sulfur (S)/acre when applied at the 150% rate, which is greater than the recommended agronomic S rates in cotton. Ammonium thiosulphate (12-0-0-26S) (ATS) was used to balance the S rate among treatments. In the treatments where a combination of placement techniques were implemented, the added sulfur was applied using deep placement to prevent any potential injury to cotton seedlings. Preplant nitrogen (N) was balanced at the same level as the broadcast agronomic control plus additional N from ATS. The preplant N rate for the P and K fertilized treatments was 35 lbs N per acre. The N was balanced using urea-ammonium nitrate solutions (30-0-0). The total N application rate was set at 115 lbs N/ acre, with the remaining 80 lbs N being applied in a sidedress application using a 24- 0-0-3S at TAREC and UAN30 at Lewiston applied at matchhead square. At TAREC, the

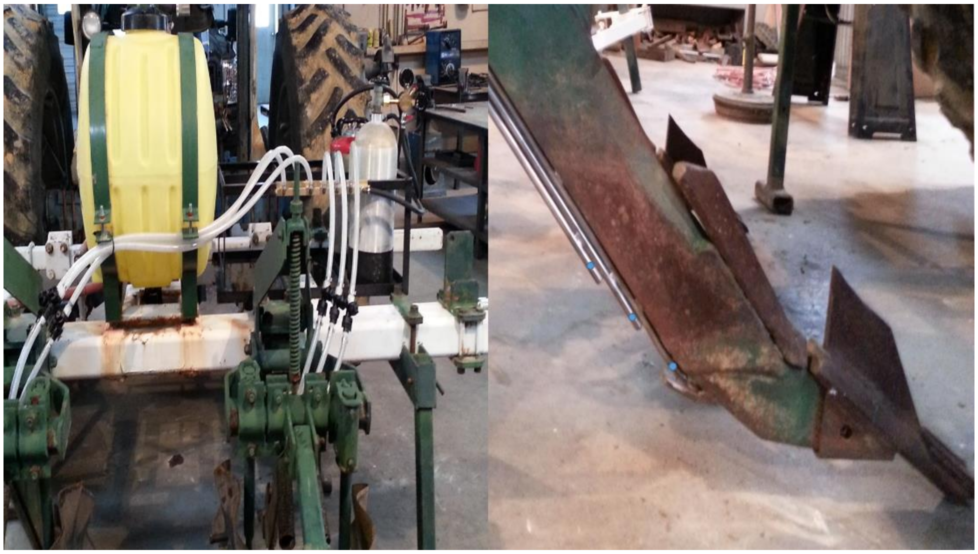

Fig. 1: Picture of the strip-tillage fertilizer systems and shank to place fluid phosphorus and potassium fertilizers at 6, 9, and 12 inches below the soil surface during strip tillage.

unfertilized control treatment received no sidedress N or S, while at Lewiston the unfertilized plots received the full 80 lbs N/acre sidedress application rate. Other nutrients will be applied based on the soil test recommendations.

In-Season Development and Tissue Sampling

Plant population was measured by counting the number of emerged seedlings in two ten foot sections of row. Plant population counts were taken at 7, 10, 14, and 21 days after planting. Plant heights were measured weekly beginning with the appearance of the second true leaf and measured from the ground to the apical meristem on five randomly selected cotton plants per plot. At the appearance of the first square, the total number of nodes were counted weekly on five randomly selected plants per plot. Plant height and total node measurements ceased with the appearance of the first white flower at each location. During the bloom period nodes above white flower (NAWF) were counted on five randomly selected plants per plot until NAWF ≤ 3.

Beginning during the first week of bloom, twenty-four cotton petioles were sampled from the first and fourth rows of each plot. The fourth leaf and petiole down the main stem of the cotton plant were sampled and separated immediately. Petioles were sampled weekly for the first nine weeks of bloom. Petioles sampled during the seventh through ninth weeks of bloom were taken from the third leaf down the main stem as there were not enough leaves in the fourth position for a complete sample. The maturity level of the leaves was thought to be similar as vegetative growth had ceased prior to this stage of development. The plant tissue samples were sent to Water's Agricultural Laboratories (Camilla, GA) for analysis. The petioles were analyzed for nitrate-N, phosphorus, potassium, and sulfur. Nutrient concentrations in petioles were plotted against time. Leaf samples collected during the first and fifth weeks of bloom only, and a complete nutrient analysis was conducted on the leaf tissue.

Defoliation, Lint yield, and Lint Quality

Defoliation timing of cotton varies depending on the growing season and development of the crop. The trial was defoliated when 50-60% of the bolls were opened. Seed cotton was harvest using two row commercial cotton pickers modified for small plot harvest. The center two rows of each plot were harvested and plot weights recorded. A one pound subsample of seed cotton was ginned on a 10-saw micro-gin to determine lint percentage. Seed cotton weights were multiplied by the lint percentage to calculate lint yields. Cotton lint was sent to the USDA cotton quality lab in Florence, SC for lint quality analysis. The lint was analyzed using a High Volume Instrument (HVI) to determine fiber length (staple), strength, micronaire, color and leaf (trash) grade.

Statistical Analysis

The data set was separated into three separate datasets and analysis of variance (ANOVA) using PROC MIXED in SAS. 9.3 was used to determine differences among treatments (SAS Institute, 2012). The first data set consisted of the different nutrient management systems tested at the 100% P and K rate based on soil test recommendations. The nutrient management systems were analyzed as single treatment factors in a randomized complete block design. The second data set was to determine the effect of P and K rate and placement on each of the measured dependent variables. The data set was analyzed as a 3x2 factorial treatment design in a randomized complete block design using ANOVA. The last data set evaluated the different proportions of P and K applied in the 2X2 band and deep placement at the 100% application rate. Combinations were tested as single treatment factors using ANOVA. Differences in among treatments in each analysis were determine using the Tukey-Kramer HSD at $\alpha = 0.1$ level of significance.

Results

General Comments

The 2013 growing season was very unique in the upper southeast coastal plain of the United States. A cool wet May delayed cotton planting for up to two weeks and cooler than normal temperatures prevailed for much of the growing season (See Appendix for weather data). The shortened cotton season seemed to have little impact on yield in Virginia as the two study locations produced exceptional yields. The Lewiston location was planted later than was expected and suffered sand-burn damage very early in the growing season (Fig.2). The decision was made not to abandon the location since treatments had been applied. Luckily the first sampling for plant population had been conducted before the damage and another plant population count was conducted after the damage. With the two plant population sampling intervals it was found that on average the injury reduced plant populations by 2 plants per 10 ft of row. This is not insignificant loss of stand and represents a decrease in the plant population of 2,904 plants per acre. The cotton was slow to recover from the damage and in-season plant measurements were affected by the variation introduced by the sand-burn damage at Lewiston.

The delay in development of the cotton at Lewiston allowed the first initial petiole results to come in for TAREC. The petiole results indicate elevated P concentrations in petiole for the unfertilized checks as well as N deficiency. The decision was made to apply sidedress N at

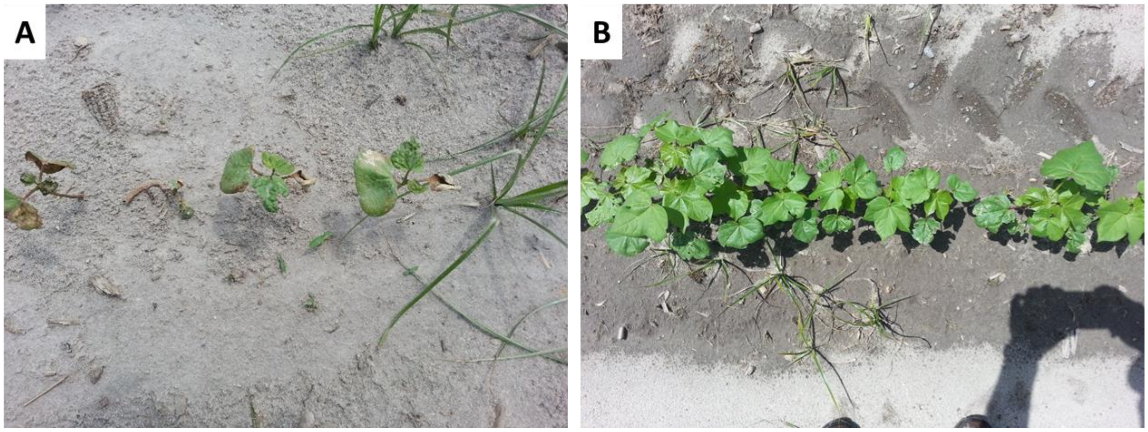

Fig. 2: Sand-burn injury at Lewiston, NC on 6/17/2013 (A) and 7/2/2013 (B)

Lewiston and test the hypothesis that N deficiency produces elevated P concentrations in cotton petioles. If this hypothesis is proven to be true then decisions about P management in cotton cannot be made off petiole concentrations is there is a known N deficiency. For growers looking to improve nutrient use efficiencies with petiole testing this knowledge will increase the efficacy of their in-season nutrient management decsions.

Nutrient Management Systems

In-season Plant Growth Measurements

In-season plant growth measurements were initiated seven days after planting with plant population counts. There were no differences among the nutrient management systems in plant population at any sampling intervals (data not shown). Emergence was 50-60% of the final plant population seven days after planting at TAREC and was nearly 100% of the final plant population 10 days after planting at TAREC (Data not shown). Emergence was similar at Lewiston up to the sand-burn injury which reduced plant populations by 2 plants per 10 row feet representing (data not shown).

Plants heights were very responsive to nutrient management systems as every sampling interval but one produced significantly different plant heights at TAREC (Table

4). The plant heights at TAREC were not significantly different on the first sampling interval, however by the second sampling interval all fertilized treatments produced taller plants than the unfertilized check (Table 4). Plant heights were significantly taller using the 2X2 band (100%) program (12.1 in.) than the unfertilized check (9.4 in.) and broadcast program (10.5 in.) on Jun 20th (Table 4). Plants heights were significantly taller using the broadcast program than the unfertilized control on June 20th. The 2X2 band (100%) program produced the tallest plants in each of the remaining sampling intervals. The 2X2 band (100%) program produced significantly taller plant than deep placement (100%), broadcast control, and unfertilized check on the June 26th and July 3rd sampling intervals (Table 4). Both the deep placement (100%) and broadcast control resulted in taller plants than the unfertilized control on June 26th and July 3rd. The data indicates that the 2X2 placement of nutrients promotes early season growth compared to other placement strategies at the TAREC location. Sidedress N was applied at TAREC on June 27th and plant growth regulators were applied to the test on June 28th and helps explain why observed differences in plant heights at TAREC on fertilized plots were reduced after the June 26th sampling date. No plant height differences were observed among nutrient management systems at the Lewiston location and was most likely due to the early sand-burn injury (data not shown).

The total number of nodes and nodes above white flower (NAWF) counts were significantly different among nutrient management systems at TAREC for all sampling intervals (Table 5). The unfertilized control at TAREC had significantly fewer total nodes than the fertilized treatment, except for the broadcast control on July 3rd (Table 5). Nodes above white flower followed a similar trend as the unfertilized control had fewer NAWF than the fertilized treatments. The overall effect observed in the number of nodes and NAWF is a response to

Table 4: Early season plant height of cotton grown under different nutrient management systems at TAREC

Treatment	Plant Height (in.)					
	4-Jun	13-Jun	20-Jun	26-Jun	3-Jul	10-Jul
Unfertilized Check	4.8	7.4 c¶	9.4 c	13.2 d	18.0 c	22.0 b
Broadcast Control	4.8	8.5 ab	10.5 bc	15.4 c	22.4 b	29.6 a
Starter Control	5.0	9.6 a	11.1 ab	17.8 ab	24.1 ab	31.4 a
2 x 2 Band (100%)	5.2	9.4 ab	12.1 a	18.6 a	25.9 a	32.0 a
Deep Placement (100%)	4.9	8.7 ab	11.3 ab	16.9 bc	23.9 b	30.9 a
ANOVA (Pr > F)	NS*	0.0033	0.011	< 0.0001	< 0.0001	< 0.0001

* The overall ANOVA was not significant at α =0.1

¶ Values with the same letter are not significantly different at α =0.1

Table 5: Total nodes and NAWF for cotton grown under different nutrient management systems at TAREC

Treatment	Total Nodes		Nodes Above White Flower (NAWF)			
	3-Jul	11-Jul	17-Jul	23-Jul	30-Jul	7-Aug
Unfertilized Check	9.8 b¶	10.1 b	6.6 b	4.8 b	3.2 b	1.8 b
Broadcast Control	10.5 ab	11.7 a	7.7 a	6.3 a	4.5 a	2.6 ab
Starter Control	11.1 a	11.9 a	7.3 a	5.8 a	4.0 ab	2.3 ab
2 x 2 Band (100%)	11.5 a	11.6 a	7.4 a	5.8 a	4.2 ab	2.8 a
Deep Placement (100%)	11.2 a	11.4 a	7.9 a	6.0 a	4.1 ab	3.0 a
ANOVA (Pr > F)	0.0059	0.0084	0.0025	0.0039	0.0555	0.0215

¶ Values with the same letter are not significantly different at α =0.1

fertilization; as no differences among fertilized treatments were observed in the total nodes and NAWF at TAREC (Table 5). Regardless of the nutrient management system, applying fertilizer increases the total number of nodes and NAWF which are indicators of the potential number of harvestable boll sites. No differences were observed in the total number of nodes and NAWF during any sampling interval at the Lewiston location (Data not shown).

Petiole and Tissue Analysis

Petiole and tissue testing allow producers and consultants to gain insight into the nutrient status of cotton during the growing season. A critical time period in the growth and development of cotton is during the bloom period. The bloom period is when cotton is actively fruiting and establishing bolls which determines the amount of harvestable lint at season's end. Petiole and leaf tissue were monitored during the bloom period with petiole tested weekly for the first nine weeks of bloom and leaf tissue sampled during the 1st and 5th weeks of bloom. At TAREC, all nutrients monitored in cotton petioles decreased throughout the bloom period (Fig. 3). Petiole K at TAREC did not different during any other the first nine weeks of bloom (Fig. 3A). The overall ANOVA p-value was significant for petiole P among nutrient management systems at during every week except the second week of bloom at TAREC (Fig. 3B). The unfertilized check had the highest petiole P concentrations of the nutrient management systems which was surprising as no fertilizer P was applied. Nitrate-N concentrations in cotton petioles differed in four out of the first five weeks of bloom, the unfertilized control had the lowest nitrate-N values during this time period (Fig. 3C). Sulfur concentrations in cotton petioles increased from the first to the second week of bloom and then decreased for the remaining bloom period sampling intervals (Fig. 3D). Sulfur petiole concentrations were lowest in the unfertilized control to begin the bloom period, however late in the bloom period the unfertilized control had the highest sulfur concentrations (Fig. 3D).

At the Lewiston location the unfertilized control received a N application at side-dress whereas the unfertilized control at TAREC received no in-season N application. Petiole nutrient concentrations at Lewiston were affected by the early season sand-burn damage, however certain trends are apparent in the data. At Lewiston, the unfertilized control had lower numerical K, P, and S concentrations in cotton petioles than the fertilized treatments (Fig. 4A-D). The variability introduced from the early season injury most likely masked any effect of nutrient management on petiole K, P, and S. Fertilizing with N at Lewiston lowered the K, P, and S concentrations compared to the fertilized treatments. Also the damage suffered early in the season seem to delay the peak nutrient content of N and K for a week and peak P levels were delayed 4-6 weeks (Fig. 4A-C). Nitrate-N among nutrient management systems did not differ during any of the first nine weeks of bloom. The nitrate-N concentrations had less variability among nutrient

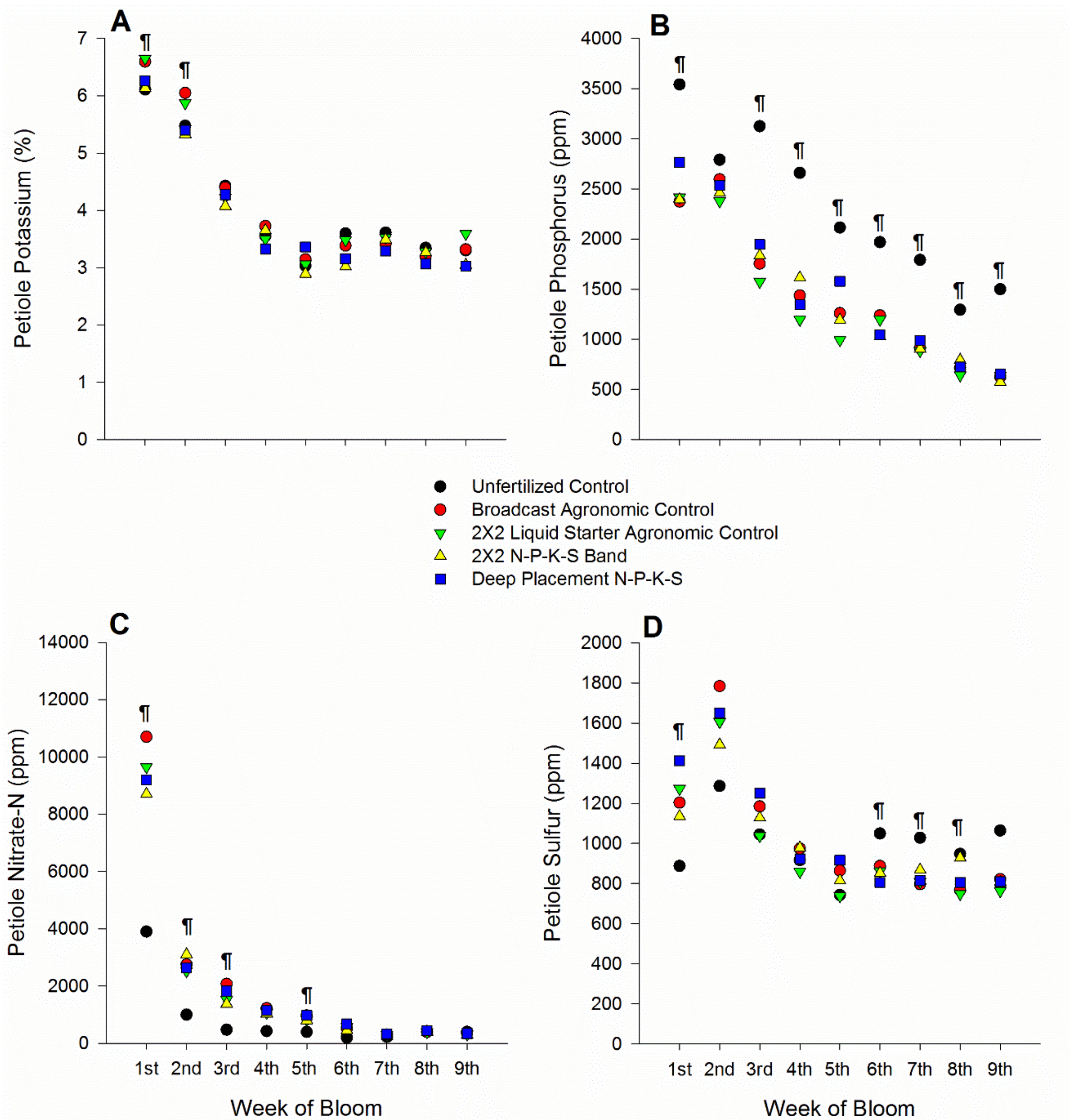

Fig. 3: Potassium (A), phosphorus (B), nitrate-N (C), and sulfur (D) concentrations in cotton petioles using different nutrient application management systems during the 1st nine weeks of bloom at TAREC (¶ ANOVA was significant at $\alpha = 0.1$ for that sampling interval).

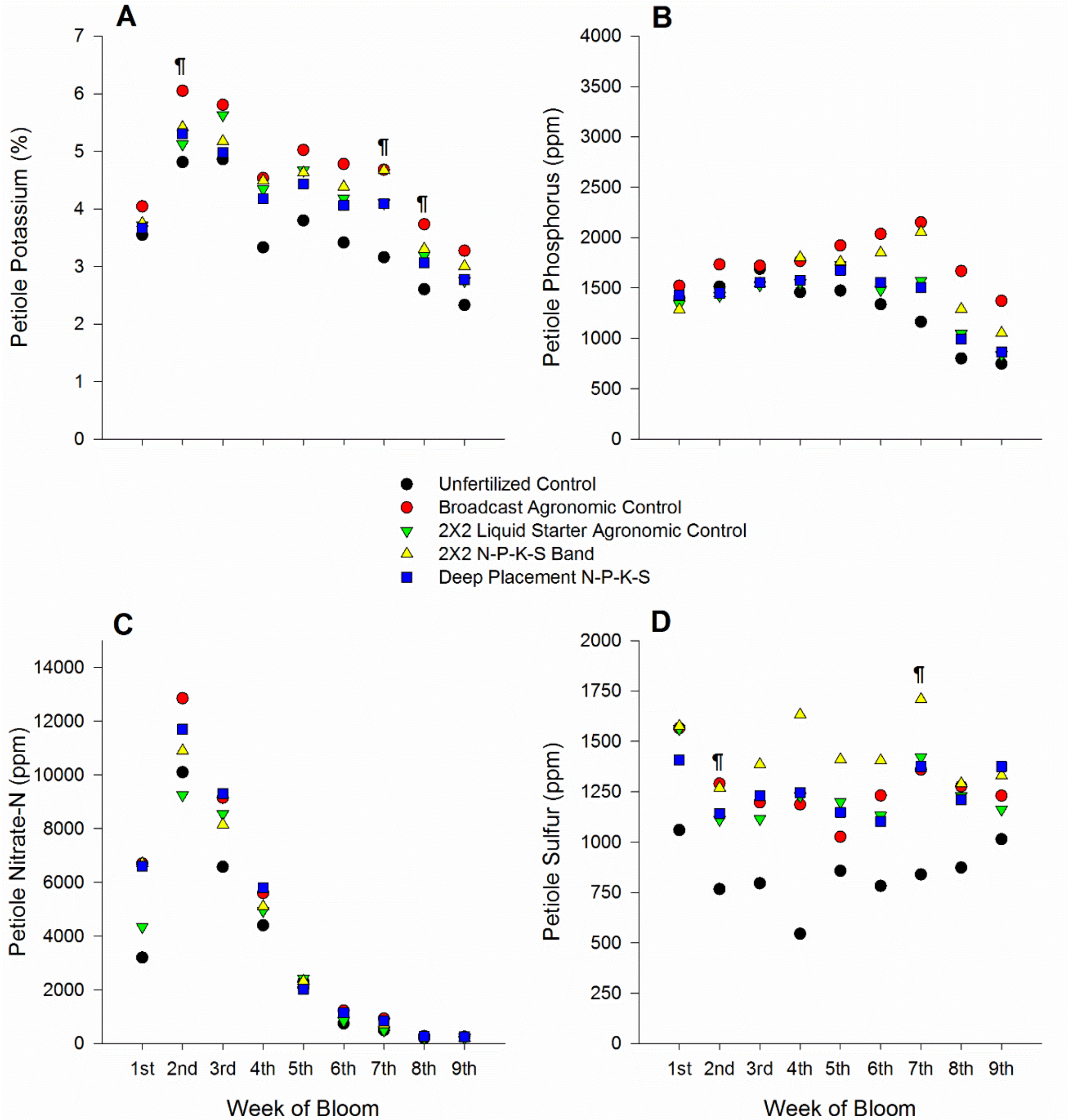

Fig. 4: Potassium (A), phosphorus (B), nitrate-N (C), and sulfur (D) concentrations in cotton petioles using different nutrient application management systems during the 1st nine weeks of bloom at Lewiston, NC (¶ ANOVA was significant at α = 0.1 for that sampling interval).

management systems than the other petiole nutrients tested at Lewiston.

The results from both locations during the 2013 growing season indicate that the N status of the cotton plant will influence petiole K, P, and S concentrations. If this hypothesis is true then in-season decisions based on petiole nutrient concentrations must start with the N status of the crop. If N is deficient, then accurate inferences about K, P, and S status of the cotton crop cannot be made due elevated nutrient levels resulting from N deficiency, this seems to be especially true for petiole P concentrations. Also, the early season injury at Lewiston seemed to delay the time of peak nutrient concentrations which is also helpful if using this strategy to manage in-season nutrient applications. If a producer knows the crop was severely stressed early then testing petioles during the first week of bloom may produce a false negative (a nutrient deficiency/low concentration) nutrient concentration as the plant is still recovering physiologically from the injury. That producer may want to wait and test during the 2nd or 3rd week of bloom before making a management decision as the petiole nutrient concentrations may increase.

Results from the leaf tissue analyses reinforced the petiole tissue sampling program. Nitrogen concentrations in leaf tissue were highest in the 2X2 band (100%) and significantly higher than the deep placement (100%) and unfertilized control (Table 6). The deep placement (100%) program did produce significantly higher leaf N than the unfertilized control (Table 6). Differences in leaf N between nutrient management systems during the 1st week of bloom indicate that deep placement of preplant N with strip-tillage significantly limits the availability of N up to the 1st week of bloom. Differences in leaf phosphorus were only observed during the 5th week of bloom at TAREC and reinforce the petiole results as the unfertilized control had significantly higher leaf phosphorus than the broadcast and starter agronomic control treatments. (Table 6). The overall ANOVA was significant for leaf potassium at $\alpha = 0.1$ level, however the Tukey-Kramer HSD procedure did not separate the nutrient management systems as being significantly different (Table 6). Leaf S concentrations differed at TAREC during the 1st

Table 6: Nitrogen, phosphorus, potassium, sulfur, and boron concentrations in cotton leaf tissue during the 1st and 5th weeks of bloom at TAREC

Placement	Nitrogen		Phosphorus		Potassium		Sulfur		Boron	
	Week of Bloom									
	1st	5th	1st	5th	1st	5th	1st	5th	1st	5th
	%								ppm	
Unfertilized Check	3.34 c¶	3.15 b	0.35	0.27 a	1.62 a	1.40	0.47 b	0.65	29.8	46.1
Broadcast Control	4.14 a	3.81 a	0.35	0.23 b	1.81 a	1.32	0.69 a	0.67	30.2	42.7
Starter Control	4.16 ab	3.71 a	0.34	0.22 b	1.68 a	1.38	0.67 a	0.64	31.0	45.5
2 x 2 Band (100%)	4.2 a	3.79 a	0.33	0.24 ab	1.79 a	1.37	0.70 a	0.68	32.0	46.5
Deep Placement (100%)	3.91 b	3.84 a	0.34	0.24 ab	1.66 a	1.38	0.65 a	0.62	27.8	43.2
ANOVA (Pr > F)	<.0001	<.0001	NS*	0.0101	0.0905	NS	0.0005	NS	NS	NS

* The overall ANOVA was not significant at α =0.1

¶ Values followed by the same letter are not significantly different at α =0.1

Table 7: Nitrogen, phosphorus, potassium, sulfur, and boron concentrations in cotton leaf tissue during the 1st and 5th weeks of bloom at Lewiston, NC

Placement	Nitrogen		Phosphorus		Potassium		Sulfur		Boron	
	Week of Bloom									
	1st	5th	1st	5th	1st	5th	1st	5th	1st	5th
	%								ppm	
Unfertilized Check	4.23	4.24	0.27	0.27	1.07 ab¶	1.21	0.56 b	0.52 b	28.2	47.6
Broadcast Control	4.22	3.99	0.28	0.30	1.09 ab	1.24	0.77 ab	0.66 ab	28.1	48.6
Starter Control	4.00	3.99	0.25	0.29	0.97 b	1.26	0.72 ab	0.72 ab	26.8	52.1
2 x 2 Band (100%)	4.29	3.71	0.27	0.30	1.25 a	1.26	0.98 a	0.80 a	25.1	50.1
Deep Placement (100%)	4.13	3.91	0.28	0.29	1.13 ab	1.22	0.79 ab	0.70 ab	26.1	50.2
ANOVA (Pr > F)	NS*	NS	NS	NS	0.0264	NS	0.0311	0.041	NS	NS

* The overall ANOVA was not significant at α =0.1

¶ Values followed by the same letter are not significantly different at α =0.1

week of bloom with the unfertilized control having significantly lower sulfur concentrations than the fertilized treatments.

There were no leaf N or P differences between nutrient management systems at the Lewiston location (Table 7). The unfertilized control received 80 lbs N at sidedress to provide a location where N was not limiting. Leaf potassium levels at Lewiston differed during the 1st week of bloom, however there was no clear trend in the differences. The unfertilized control did have the lowest leaf potassium levels (1.09%) and the 2X2 band (100%) (1.25%) produced the highest leaf potassium levels during the 1st week of bloom at Lewiston (Table 7). The only other leaf tissue differences observed at Lewiston were for sulfurconcentrations during the 1st and 5th weeks of bloom (Table 7). The unfertilized control was significantly lower in leaf sulfur concentrations than the 2X2 band (100%) treatment during both sampling intervals (Table 7).

Lint Yield and Fiber Quality

The lint yields at both locations were exceptional considering the 2013 growing season and the planting date at the Lewiston, NC in conjunction with the early season injury. Yields at TAREC ranged from 1,184 lbs to 2,024 lint per acre and Lewiston yields ranged from 1,100 to 1469 lbs lint per acre. The yield data for individual nutrient management systems can be found in Figs. 5 and 6 for TAREC and Lewiston, respectively. The only yield differences observed between nutrient management systems tested at the 100% P and K application rates occurred at TAREC (Fig. 5). The unfertilized control produced significantly less lint per acre than the fertilized systems. There were no differences in fiber quality characteristics at either location during the 2013 growing (Data not shown).

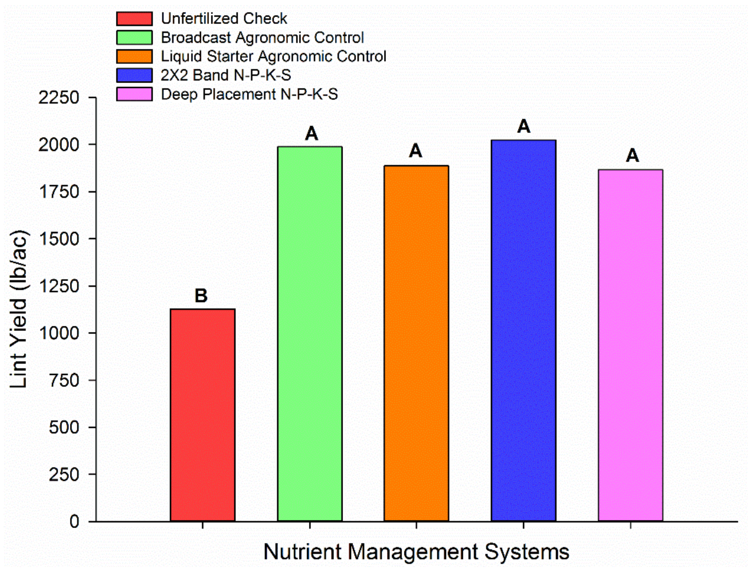

Fig. 5: Lint yield and nutrient management systems at TAREC

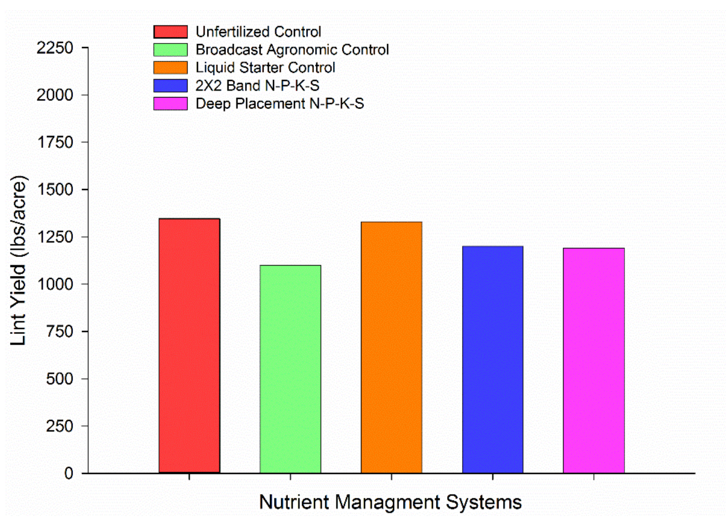

Fig. 6: Lint yield and nutrient management systems at Lewiston, NC

Phosphorus and Potassium Placement and Rate

In-season Plant Growth Measurements

In-season plant measurements were less responsive to preplant P and K application rates than placement during the study. Plant populations were are affected by P and K rate at 10 days after planting (May 21st) at TAREC (Table 8). Plant population was significantly impacted by placement in three out the four sampling interval. The 2X2 band placement produced significantly higher plant populations 7, 14, and 21 days after planting (Table 8). On average the 2x2 placement produced 2 more plants per row foot than deep placement. Faster emergence rates would be beneficial in Virginia cotton production as weather patterns in May can be highly variable. A key question is if there is enough root growth present at time of emergence to take advantage of the 2X2 band placement and can this effect be replicated over multiple locations and years.

No differences in plant heights were observed between P and K rates and placement methods until Jun 26th (Table 8). On June 26th, the plant heights for the 150% P and K rates were significantly higher than the 50% P and K rate at TAREC (Table 8). This was the only sampling interval where plant heights differed among P and K rates. The 2X2 band placement produced taller plants from June 26th through July 10th at TAREC (Table 8). Plants grown using the 2X2 band placement at TAREC consistently showed to have increase early season vigor throughout the 2013 study.

In addition to increased early season vigor the 2X2 banded application produced more total nodes than deep placement of P and K on July 3rd (Table 9). The maturity rate, measured by NAWF, seemed to be influenced more by P and K rate than placement (Table 9). Significant differences in in NAWF were found in two out of the four sampling intervals. On July 17th the 50% and 100% rates had more NAWF than the 150% rate. Typically, as nutrients become

Table 8: Phosphorus (P) and potassium (K) application rate and placement on stand establishment and early season plant height at TAREC

Placement	P and K Rate†	Plant Population (plants / 10 ft row)				Plant Height (in.)					
	%	17-May	21-May	24-May	31-May	4-Jun	13-Jun	20-Jun	26-Jun	3-Jul	10-Jul
-	50	16.87	28.8 b¶	29.8	29.7	5.0	8.7	11.0	16.5 b	24.1	31.2
-	100	18.25	31.1 a	30.9	31.3	5.1	9.1	11.7	17.7 ab	24.9	31.5
-	150	17.43	29.6 ab	29.9	31.1	5.1	9.3	11.6	18.1 a	25.0	31.9
2X2 Band	-	18.5 a	30.3	30.8 a	31.3 a	5.1	9.2	11.5	17.9 a	25.5 a	32.0 a
Deep Placement	-	16.5 b	29.4	29.6 b	30.1 b	5.0	8.8	11.4	17.0 b	23.9 b	30.9 b
2X2 Band	50	18.0	29.3	31.1 ab	31.1	4.9	8.7	10.6	16.4	24.8	31.3
2X2 Band	100	20.0	31.4	30.4 ab	31.8	5.2	9.4	12.1	18.6	25.9	32.0
2X2 Band	150	17.5	30.3	30.8 ab	30.9	5.2	9.5	11.7	18.7	25.8	32.8
Deep Placement	50	15.8	28.3	28.4 b	28.3	5.1	8.7	11.3	16.7	23.5	31.0
Deep Placement	100	16.5	30.9	31.4 a	30.9	4.9	8.7	11.3	16.9	23.9	30.9
Deep Placement	150	17.4	29.0	29.1 ab	31.3	5.0	9.1	11.6	17.4	24.2	30.9
					ANOVA (Pr > F)						
P and K Rate		NS*	0.0303	NS	NS	NS	NS	NS	0.0591	NS	NS
Placement		0.0545	NS	0.0675	0.0942	NS	NS	NS	0.0919	0.0009	0.0214
Rate*Placement		NS	NS	0.0466	NS	NS	NS	NS	NS	NS	NS

¶ Values with the same letter are not significantly different at α =0.1
* The ANOVA for that fixed effect in the model was not significant at α =0.1
† 100% of the recommended rate is equal to 40 lbs P_2O_5 and 40 lbs K_2O per acre

Table 9: Phosphorus (P) and potassium (K) application rate and placement on the total number of nodes and nodes above white flower (NAWF) at TAREC

Placement	P and K Rate†	Total Nodes		Nodes Above White Flower (NAWF)			
	%	**3-Jul**	**11-Jul**	**17-Jul**	**23-Jul**	**30-Jul**	**7-Aug**
-	**50**	11.1	11.9	7.6 a	6.1	4.7 a	3.1
-	**100**	11.3	11.5	7.6 a	5.9	4.1 ab	2.9
-	**150**	11.0	11.9	7.2 b	5.8	3.9 b	2.5
2X2 Band	-	11.3 a¶	11.7	7.3	5.7 b	4.3	2.7
Deep Placement	-	10.9 b	11.8	7.6	6.2 a	4.2	2.9
2X2 Band	**50**	11.3	11.6	7.5	5.6	4.5	2.7
2X2 Band	**100**	10.8	12.3	7.7	6.6	4.9	3.5
2X2 Band	**150**	11.5	11.6	7.4	5.8	4.2	2.8
Deep Placement	**50**	11.2	11.4	7.9	6.0	4.1	3.0
Deep Placement	**100**	11.2	12.1	7.2	5.6	4.3	2.6
Deep Placement	**150**	10.8	11.7	7.2	6.0	3.6	2.3
		ANOVA (Pr > F)					
P and K Rate		NS*	NS	0.0786	NS	0.0656	NS
Placement		0.0552	NS	NS	0.0327	NS	NS
Rate*Placement		NS	NS	NS	NS	NS	NS

¶ Values with the same letter are not significantly different at α =0.1
* The ANOVA for that fixed effect in the model was not significant at α =0.1
† 100% of the recommended rate is equal to 40 lbs P_2O_5 and 40 lbs K_2O per acre

limiting, the NAWF decrease as the plant cannot support any additional bolls or fruiting sites. On July 30th the NAWF were again greater at the lower nutrient application rates (Table 9). A possible reason for the fewer NAWF at higher P and K rates would be that the plants were more advanced in terms of flowering and boll production prior to the initial NAWF counts in the higher fertility treatments. Placement was only significant on the July 23rd sampling interval and the 2X2 band had fewer NAWF than the deep placement (Table 9).

Petiole and Tissue Analysis

The N and S concentrations in petioles are not reported for the rate by placement analyses as the N and S rates di not differ across treatments. There were very few differences in P and K concentrations in the petiole analyses for placement and rate (Fig. 7A-F). As with the nutrient management systems analysis, P concentrations decrease linearly throughout the bloom period while potassium decreases linearly from weeks one to five then remains relatively constant for week six through nine (Figs. 7). Petiole concentrations at Lewiston did not differ (data not shown).

Leaf tissue analysis was more sensitive to differences among placement and application rates of P and K at Lewiston than petiole nutrient concentrations (data not shown). Phosphorus concentrations in leaf tissue differed during the 1st week of bloom with the deep placement having higher P concentrations than the 2X2 band at Lewiston (Table 10). This difference in P concentration was not observed during the 5th week of bloom at Lewiston. Potassium concentrations in cotton leaves differed among application rates and placement during the 1st and 5th week of bloom (Table 10). Lewiston had the lowest soil test levels of K out of the two locations and is why Lewiston was more responsive to K rate. Leaf potassium concentrations increased as application rate increase during both sampling intervals at Lewiston (Table 10). The 2X2 band also increased leaf potassium concentrations during both sampling intervals (Table 10). These findings suggest that leaf tissue analysis may be more sensitive to changes in plant K status

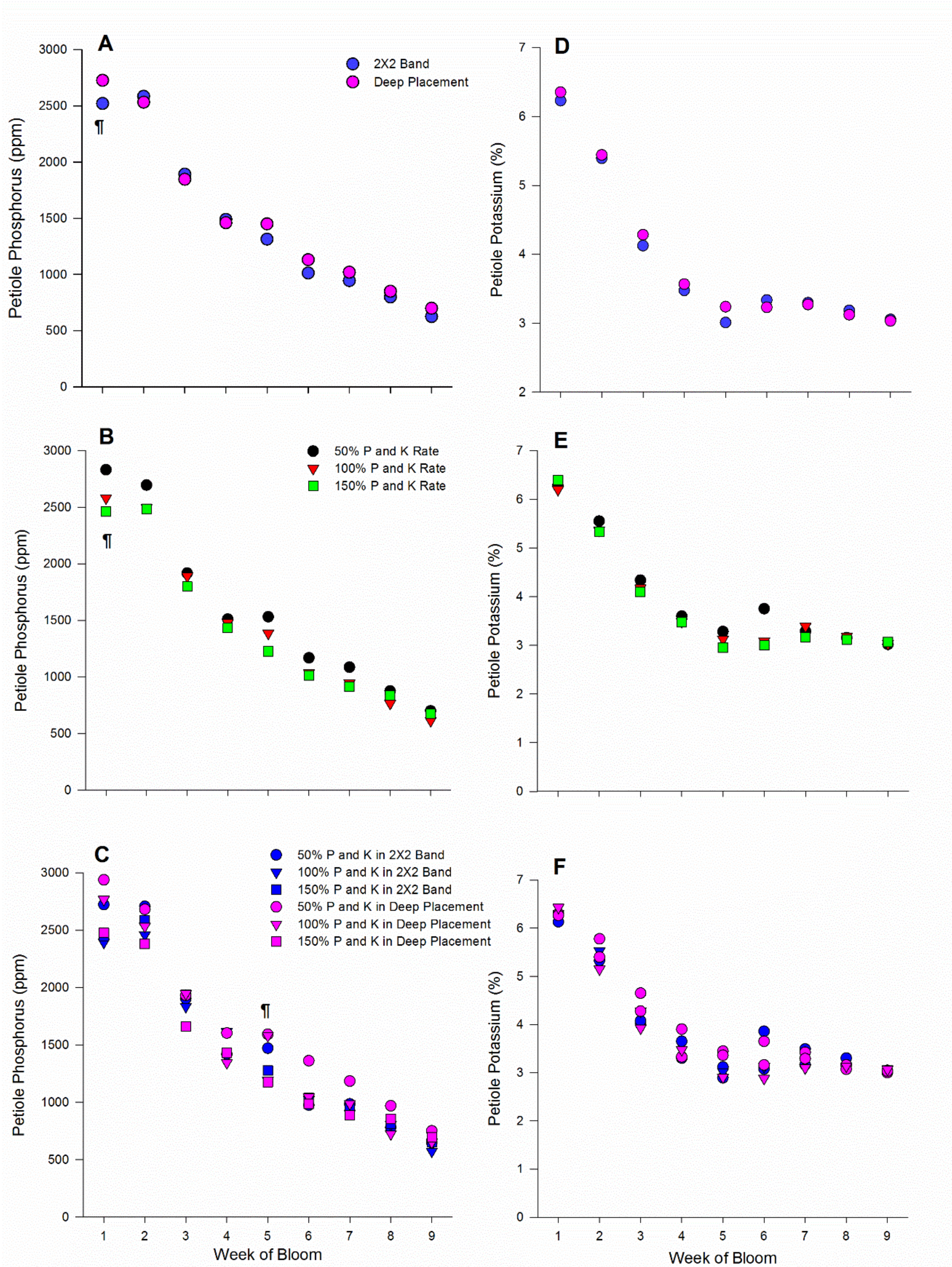

Fig. 7: Cotton petiole phosphorus (A-C) and potassium (D-F) concentrations during the bloom period as affected by rate (A and D), placement (B and E), and their interaction (C and F) at TAREC (¶ ANOVA was significant for that model effect at α = 0.1 for that sampling interval).

Table 10: Cotton leaf nutrient concentrations during the 1st and 5th week of bloom as affected by application rate and placement at Lewiston, NC

Placement	P and K Rate†	Nitrogen		Phosphorus		Potassium		Sulfur		Boron	
	%	Week of Bloom									
		1st	5th	1st	5th	1st	5th	1st	5th	1st	5th
		%								ppm	
-	**50**	4.12	4.07	0.27	0.28	1.10 b¶	1.18 b	0.86	0.73	25.0	46.6
-	**100**	4.21	3.81	0.27	0.29	1.19 b	1.24 ab	0.88	0.75	25.6	50.1
-	**150**	3.93	3.87	0.25	0.26	1.32 a	1.31 a	0.89	0.73	25.2	51.4
2X2 Band	-	4.08	3.99	0.25 b	0.28	1.26 a	1.29 a	0.95 a	0.76	25.1	49.8
Deep Placement	-	4.10	3.85	0.28 a	0.27	1.15 b	1.19 b	0.81 b	0.72	25.4	48.9
2X2 Band	**50**	3.98	4.39 a¶	0.26	0.27	1.15	1.24	0.86	0.69 a	24.3	48.0
2X2 Band	**100**	4.29	3.71 b	0.26	0.30	1.25	1.26	0.98	0.80 a	25.1	50.1
2X2 Band	**150**	3.98	3.87 ab	0.24	0.27	1.40	1.37	1.00	0.79 a	25.9	51.3
Deep Placement	**50**	4.27	3.75 b	0.23	0.28	1.07	1.12	0.85	0.78 a	25.8	45.1
Deep Placement	**100**	4.13	3.92 ab	0.28	0.28	1.13	1.22	0.79	0.70 a	26.1	50.2
Deep Placement	**150**	3.89	3.88 ab	0.27	0.25	1.24	1.25	0.79	0.67 a	24.4	51.4
		ANOVA (Pr > F)									
	P and K Rate	NS*	NS	NS	NS	0.0003	0.0337	NS	NS	NS	0.0276
	Placement	NS	NS	0.0331	NS	0.002	0.0186	0.0289	NS	NS	NS
	Rate*Placement	NS	0.0367	NS	NS	NS	NS	NS	0.0943	NS	NS

* The overall ANOVA was not significant at $\alpha = 0.1$

¶ Values followed by the same letter are not significantly different at $\alpha = 0.1$

† 100% of the recommended rate is equal to 40 lbs P_2O_5 and 40 lbs K_2O per acre

than petiole testing. Also K concentrations in leaf tissue are more stable than petiole K concentrations throughout the bloom period in cotton. Leaf K concentrations are may be more indicative of K status of cotton during the bloom period than petiole K.

Lint Yield and Fiber Quality

Lint yield was not affected by P and K application rates at either location during 2013. At TAREC, lint yields were increased with the 2X2 band placement compared to the deep placement of P and K (Fig. 8A). The 2X2 band produced 2,002 lbs of lint at TAREC while the deep placement of nutrients yielded 1,858 lbs of lint at TAREC. At Lewiston lint yields with the 2X2 band were not significantly different from the deep placement system, however there was a 79 lbs lint difference between the two treatments, with 1,333 lbs lint/acre and 1,254 lint per acre, respectively. No differences in fiber quality were observed between the 2X2 band and deep placement at either location (data not shown).

Placement Combinations

In-Season Plant Measurements

Plant populations differed at two of the four locations for the differing ratios of 2X2 band and deep placement of P and K at TAREC (Table 11). The differences occurred at 7 and 21 days after planting, however there are no clear trends or similarities between the two sampling intervals in the treatment differences. Plant populations effectively reached the maximum levels at 10 days after planting. No differences in plant populations were observed at the Lewiston location when differing ratios of the placement methods were used. There was no clear advantage in population establishment using a combination of the 2X2 band and deep placement of P and K.

Plant height responses to differing ratios of placement were delayed compared to responses observed in the nutrient management systems analysis, this is most likely due to the absence of an unfertilized control treatment. Plant height differences were measured on June 26th and July 3rd at TAREC (Table 11). The 2X2 band alone produced the tallest plants during both

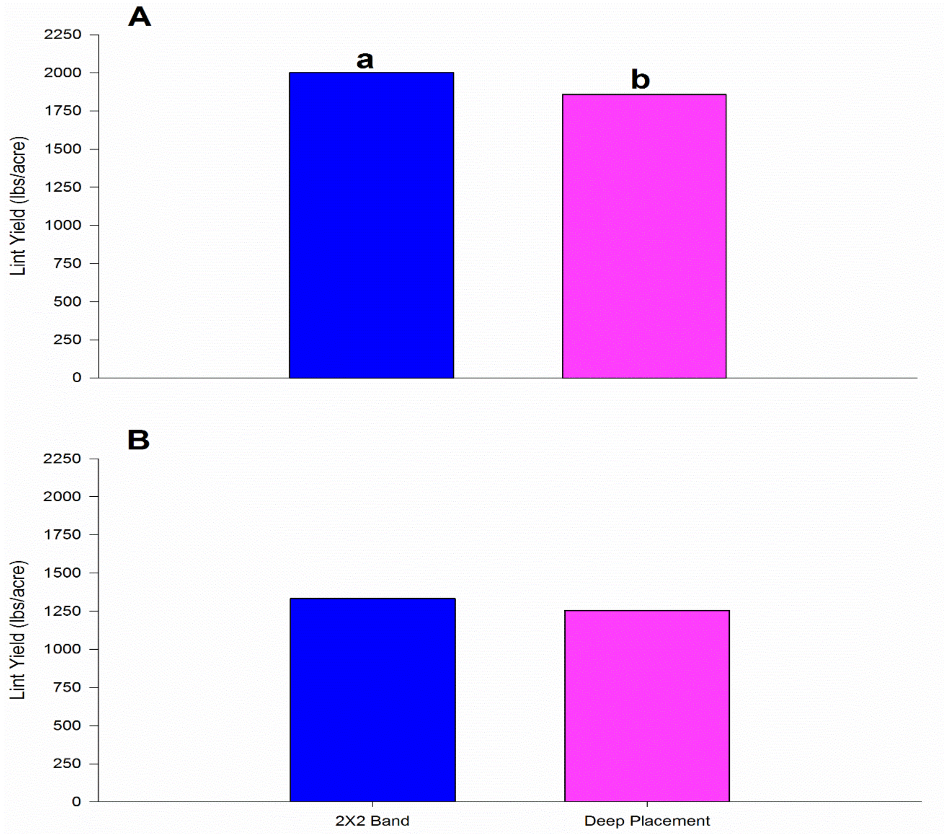

Fig. 8: Lint yield of cotton when phosphorus and potassium are placed in a 2X2 band and deep placement under the row at TAREC (A) and Lewiston, NC (B)

sampling intervals and the plants were significantly taller than the deep placement alone. On July 3rd the acombination of 80% of the P and K applied in a 2X2 band with 20% applied in the deep placement bands produced taller cotton plants than the deep placement alone (Table 11). At both sampling intervals plant heights decreased as the percentage of P and K applied in deep placement bands increased. No differences in plant height were observed at the Lewiston location among differing ratios of 2X2 band and deep placement of P and K. There were no differences between nodes and NAWF among differing ratios the 2X2 band and deep placement of P and K at either location during 2013. (Table 12, Lewiston data not shown).

Table 11: Plant population and early season plant height of cotton fertilized using varying ratios of the 2X2 band and deep placement to apply P and K at TAREC

Placement Combinations†	Plant Population (plants / 10 ft. row)				Plant Height (in)					
% / %	17-May	21-May	24-May	31-May	4-Jun	13-Jun	20-Jun	26-Jun	3-Jul	11-Jul
100 / 0	20.0 a¶	31.4	30.4	31.80 ab	5.2	9.4	12.1	18.6 a	25.9 a	32.0
80 / 20	15.9 ab	29.9	30.9	30.3 ab	5.2	9.3	12.1	18.3 ab	25.6 a	31.7
60 / 40	15.8 ab	30.9	31.9	31.4 ab	5.0	9.0	11.8	17.7 ab	24.9 ab	30.0
40 / 60	14.6 b	29.8	30.4	30.0 b	5.0	8.8	11.8	17.4 ab	24.7 ab	31.0
20 / 80	14.1 b	31.5	31.6	33.1 a	5.1	9.1	11.5	17.5 ab	24.6 ab	31.4
0 / 100	16.5 ab	30.9	31.4	30.9 ab	4.9	8.7	11.3	16.9 b	23.9 b	30.9
ANOVA (Pr > F)	0.0772	NS*	NS	0.0887	NS	NS	NS	0.0457	0.0172	NS

* The overall ANOVA was not significant at α =0.1

¶ Values followed by the same letter are not significantly different at α =0.1

† Combinations of deep placement and 2x2 band of the P and K applied at the 100% (40lbs /acre) rate

Table 12: Total nodes and nodes above white flowers of cotton fertilized using varying ratios of the 2X2 band and deep placement to apply P and K at TAREC

Placement Combinations†	Nodes		Nodes Above White Flower (NAWF)			
% / %	3-Jul	11-Jul	17-Jul	23-Jul	30-Jul	7-Aug
100 / 0	11.5	11.6	7.4	5.8	4.2	2.8
80 / 20	11.2	11.7	7.4	6.0	3.9	2.6
60 / 40	11.3	12.0	7.6	5.9	4.6	3.0
40 / 60	11.1	12.0	7.7	5.8	4.3	2.7
20 / 80	11.2	11.6	7.9	6.2	5.1	3.3
0 / 100	11.2	11.4	7.9	6.0	4.1	3.0
ANOVA (P > F)	NS*	NS	NS	NS	NS	NS

* The overall ANOVA was not significant at α =0.1

† Combinations of deep placement and 2x2 band of the P and K applied at the 100% (40lbs /acre) rate

Petiole and Tissue Analysis

Few differences in petiole P and K concentrations were observed at either location when different combinations of 2X2 banded and deep placement of P and K were implemented (Fig. 9A-D). At TAREC there were only three sampling intervals during the bloom period where the overall ANOVA was significant for petiole P concentrations (Fig. 9A). At Lewiston no differences were observed in petiole P throughout the first nine week of bloom (Fig. 9C). No differences were observed among placement combinations for petiole K at TAREC or Lewiston (Fig. 9B and 9D).

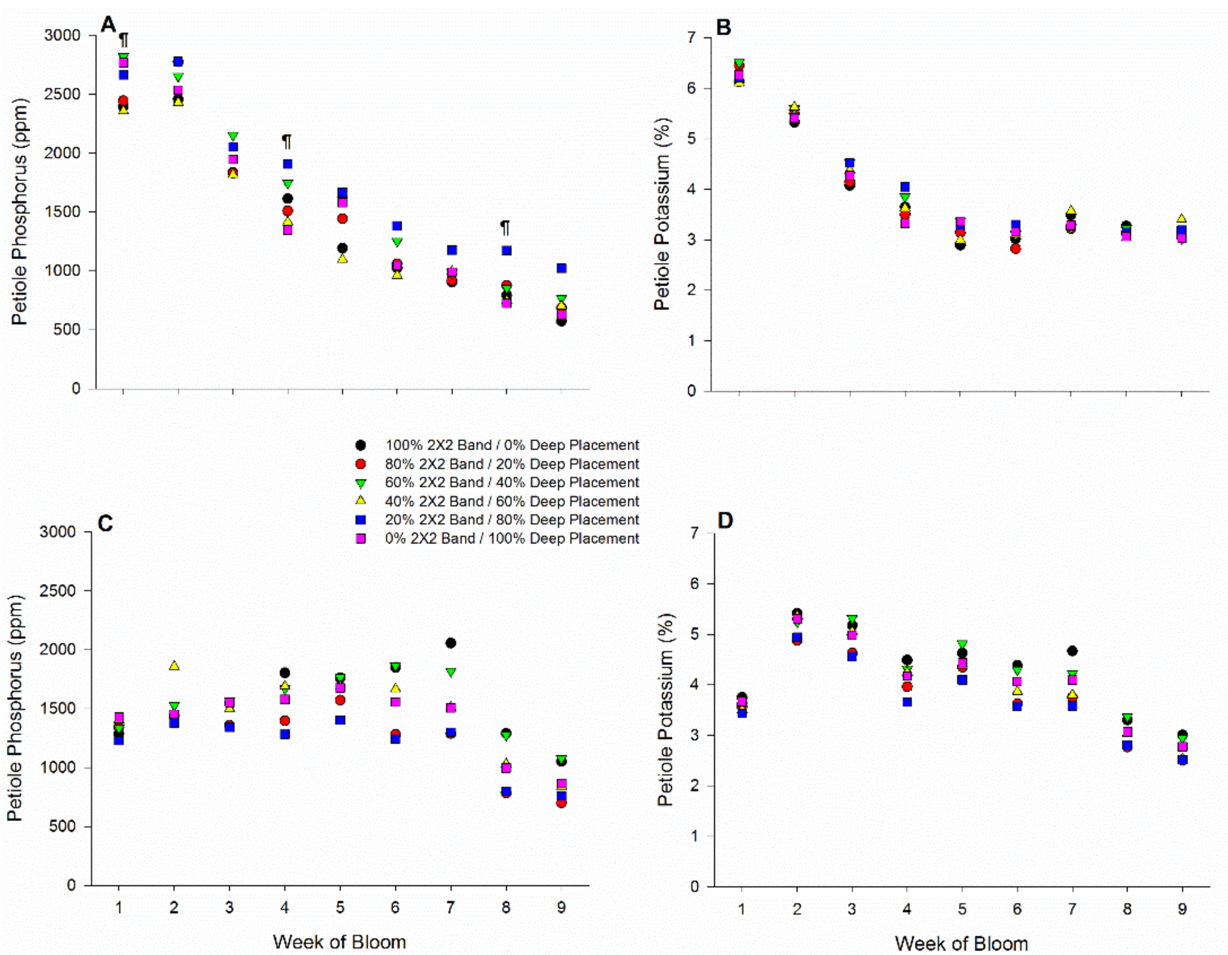

Fig. 9: Cotton petiole phosphorus (A and C) and potassium (B and D) concentrations during the bloom period with P and K applied in varying ratios of 2X2 band and deep placement at TAREC (A and B) and Lewiston (C and D)(¶ ANOVA was significant at α = 0.1 for that sampling interval).

Leaf tissue nutrient analyses also resulted in very differences in P and K placement combinations during 2013 (Table 13). Differences in leaf N were significant during the 1st week of bloom with the 100% 2X2 band and 40% 2X2 band/60% deep placement having significantly higher leaf N than the 100% deep placement treatment (Table 14). The overall ANOVA for leaf K and S concentrations during the 5th week of bloom were also significant, however Tukey-Kramer HSD failed to differentiate any of the combinations of P and K placement. There were no differences in leaf nutrient concentrations at the Lewiston location during the 2013 study (data not shown).

Lint Yield and Fiber Quality

No differences were observed TAREC and Lewiston among the P and K placement combinations during 2013 (Table 14, Lewiston data not shown). Micronaire at TAREC was the only fiber quality characteristic found to be significantly different among the different combinations of 2X2 band and deep placement at TAREC (Table 14). No combinations of placement significantly affected fiber quality at Lewiston (data not shown).

Conclusions

The 2013 growing season in Virginia presented challenges to cotton producers, however the lint yields were exception for the study. Sand-burn injury at Lewiston introduced variability which ultimately could not be overcome during the growing season to produce a data set to detect treatment differences consistently. However, the injury did provide some data on nutrient status of cotton under early season stress and this could be valuable to producer and consultants when making management decisions in the future. The TAREC data indicates that the 2X2 placement of a complete nutrient blend increased early season growth. In areas such as Virginia early season vigor is extremely important in cotton production due to temperature changes and insect pressure. The experiment also demonstrated that placing liquid fertilizers under the row with strip-tillage

Table 13: Cotton leaf nutrient concentrations during the 1st and 5th week of bloom as affected by P and K placement combinations at TAREC

Placement Combinations†	Nitrogen		Phosphorus		Potassium		Sulfur		Boron	
% / %	Week of Bloom									
	1st	5th	1st	5th	1st	5th	1st	5th	1st	5th
	%								ppm	
100 / 0	4.20 a	3.79	0.33	0.24	1.79	1.37 a	0.70	0.68 a	32.0	46.5
80 / 20	4.15 ab	3.91	0.34	0.25	1.77	1.36 a	0.72	0.63 a	30.0	42.4
60 / 40	3.98 ab	3.98	0.36	0.26	1.76	1.43 a	0.67	0.65 a	29.9	40.9
40 / 60	4.20 a	3.77	0.33	0.23	1.73	1.53 a	0.69	0.70 a	30.0	46.5
20 / 80	4.01 ab	3.86	0.35	0.27	1.72	1.53 a	0.65	0.70 a	30.4	43.3
0 / 100	3.91 b	3.84	0.34	0.24	1.66	1.38 a	0.65	0.62 a	28.8	43.2
ANOVA (Pr > F)	0.0327	NS	NS	NS	NS	0.0687	NS	0.0833	NS	NS

* The overall ANOVA was not significant at α =0.1

¶ Values followed by the same letter are not significantly different at α =0.1

† Combinations of deep placement and 2x2 band of the P and K applied at the 100% (40lbs /acre) rate

Table 14: Lint yield and fiber quality as affected by P and K placement combinations at TAREC

Placement Combinations†	Lint Yield	Lint	Mic	Len. ǂ	Str. †	Uni. †
	lb/A			in.	g/tex	%
100 / 0	2024	0.43	4.7	1.18	30.8	85.2
80 / 20	1781	0.43	4.8	1.16	31.1	85.0
60 / 40	1920	0.43	4.7	1.18	31.2	84.9
40 / 60	1925	0.43	4.7	1.17	31.0	84.5
20 / 80	1839	0.43	4.6	1.18	30.2	84.9
0 / 100	1867	0.43	4.8	1.16	31.1	84.9
ANOVA (Pr > F)	NS	NS	0.0256	NS	NS	NS

* The overall ANOVA was not significant at α =0.1

¶ Values followed by the same letter are not significantly different at α =0.1

† Combinations of deep placement and 2x2 band of the P and K applied at the 100% (40lbs /acre) rate

ǂ Len. =Length, Str. = strength, and Uni. = uniformity could be achieved and performance with this technique was similar to current nutrient management systems. When comparing the 2X2 band to the deep placement, the 2X2 band increased early season growth and higher yields at TAREC during 2013. More data is needed to confirm the findings of the 2013 study, but preliminary results indicate that nutrients placed in banded zones, especially a 2X2 band, are equal to current nutrient management systems.

Appendix

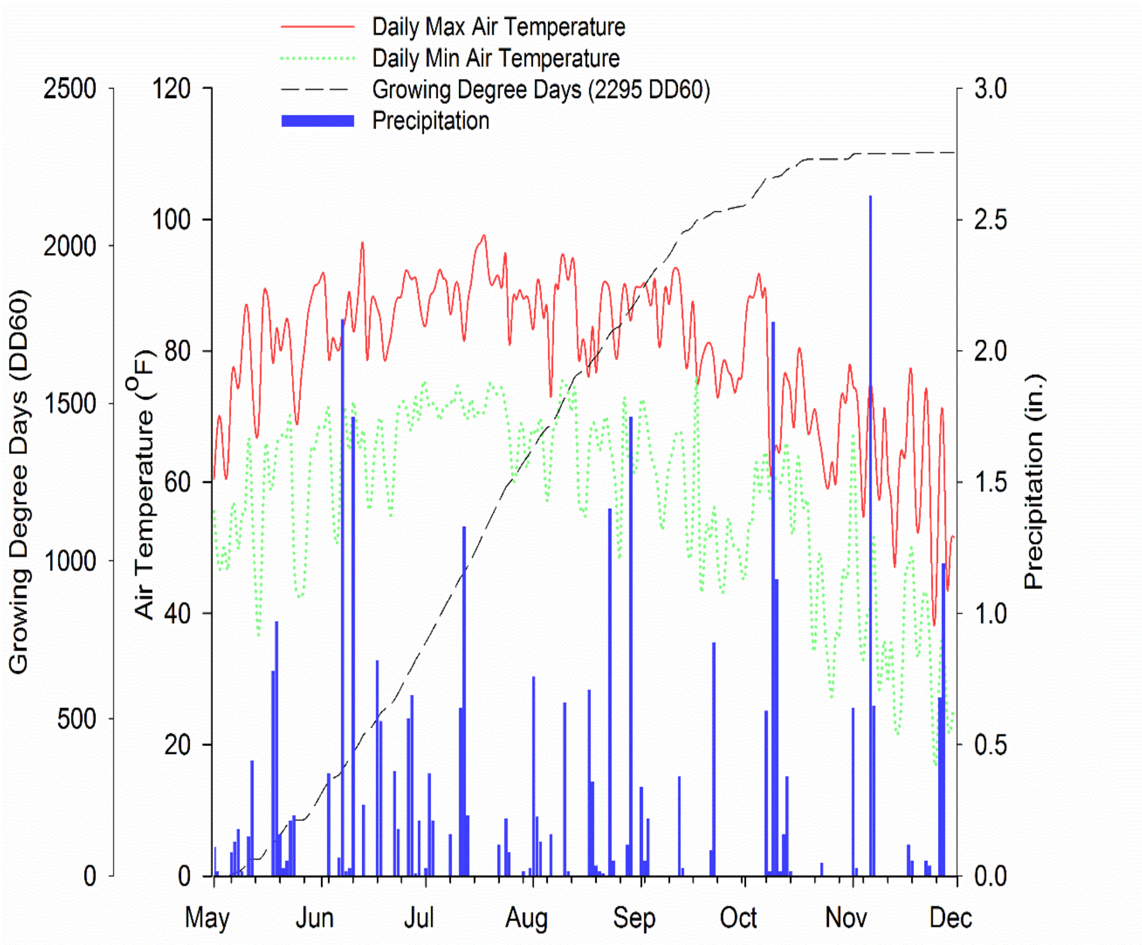

Fig. 10: Weather data for TAREC for 2013 growing season

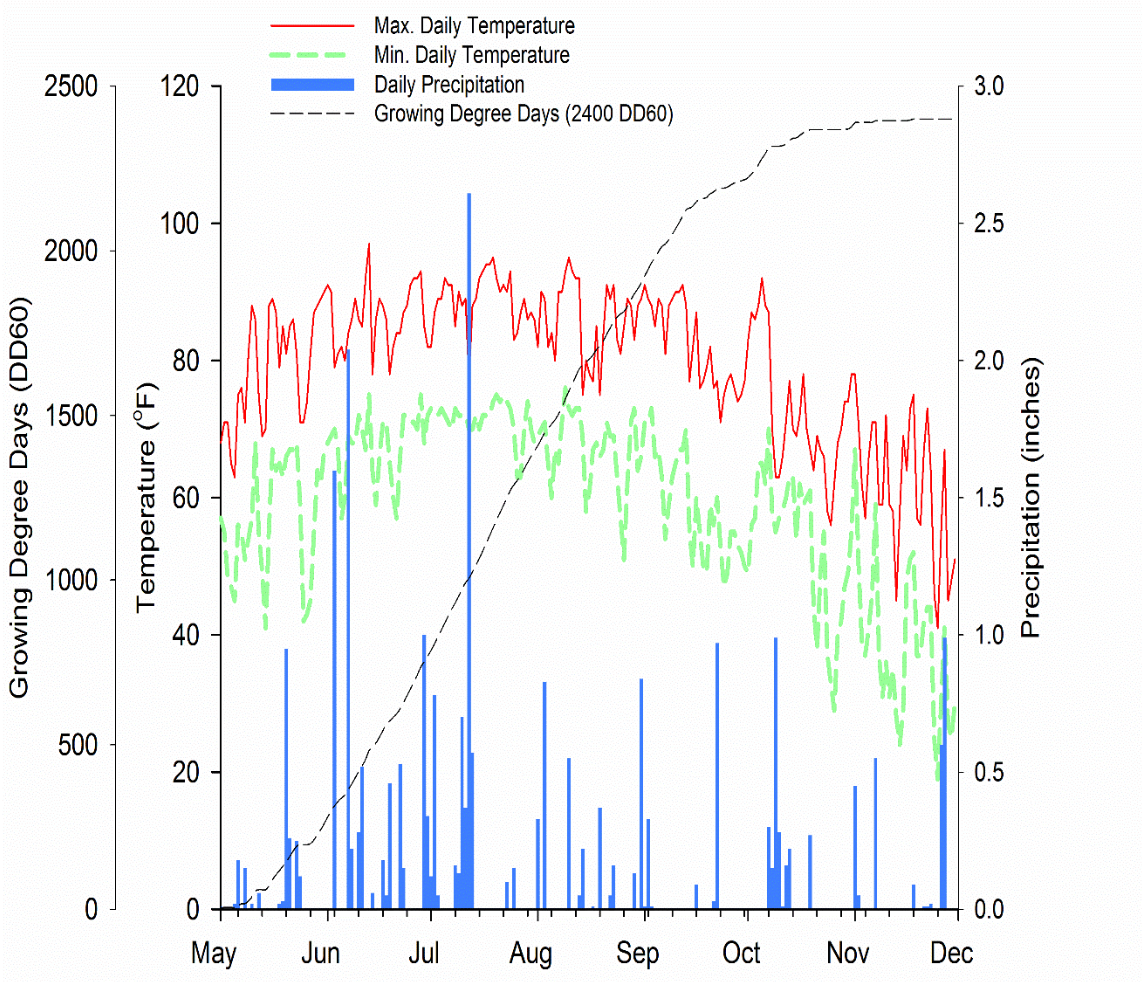

Fig. 11: Weather data for Lewiston, NC for 2013 growing season