**Fluid Fertilizer Foundation Sponsored Cotton Trials 2014**

# 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 2014 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 nine weeks 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 nine weeks 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 tested 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. The unfertilized control at each location had the shortest plants during the 2014 study. Nutrient management systems which utilized banded P increased plant height at the TAREC location, but no differences in plant heights were detected at Lewiston when P and K were applied. Petiole P concentrations were elevated throughout the first nine week of bloom for the unfertilized control at TAREC where no side-dress N was applied. Elevated petiole P concentrations were not observed at Lewiston for the unfertilized control which received side-dress N. The unfertilized control produced 955 pounds of lint per acre at TAREC and was significantly lower than all other nutrient management systems which produced 1,700-2,000 pounds of lint per acre. At Lewiston lint yields among nutrient management systems were not significantly different, however the unfertilized control had the lowest lint yield of the nutrient management systems. The data suggest that nitrogen is the most limiting nutrient in cotton systems. When comparing placement and application rate of P and K at TAREC plant heights were responsive in 5 out of 6 sampling intervals to P and K application rate. The 150% P and K rate produce the tallest plants during these sampling intervals and the plants were significantly taller than the 50% P and K application rate. Deep placement produced 166 pounds of lint per acre more than the 2X2 banded placement at TAREC. In 2013, the 2X2 banded placement produced more lint per acre than deep placement. The difference in response to placement is most likely due to limited root growth during 2013 which had 60% more rainfall during May and June limiting root growth at greater depths. No differences in any of the measured variables was observed for the different combinations of 2X2 banded and deep placement of P and K during 2014. Overall 2014 was a highly productive year for cotton production in Virginia and the yields in this study support that, averaging 1,700-2,000 pounds of lint per acre.

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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 nine weeks 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 nine weeks of bloom, and lint yield and quality.

# Materials and Methods

## Site Characteristics

The trials were conducted at two locations during 2014: the Tidewater Agricultural Research and Extension Center (TAREC) of Holland, Virginia (36.663466 $^{o}$N, 76.736363 $^{o}$W), and the North Carolina Department of Agriculture and Consumer Services Peanut Belt Research Station located in Lewiston, North Carolina (36.133181 $^{o}$N, 77.171869 $^{o}$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 Norfolk sandy loam (Fine-loamy, kaolinitic, thermic Typic Kandiudults). 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 | 39 (H)[¶] | 106 (H) | 15 (M+) | 81 (M+) |
| 3-6 | 26 (H-) | 98 (H-) | 12 (M) | 60 (M) |
| 6-9 | 17 (M+) | 76 (M+) | 9 (M-) | 48 (M-) |
| 9-12 | 7 (M-) | 101 (H-) | 3 (L) | 42 (M-) |

¶ 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 2014 growing season**

| Location | Strip-tillage | Planted | Harvested |
|---|---|---|---|
| **TAREC** | 5/6 | 5/12 | 11/13 |
| **Lewiston** | 5/7 | 5/20 | 11/4 |

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 3). 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 3).

**Table 3: Treatment List for 2014 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 six days prior to planting at TAREC and 13 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. Other nutrients were

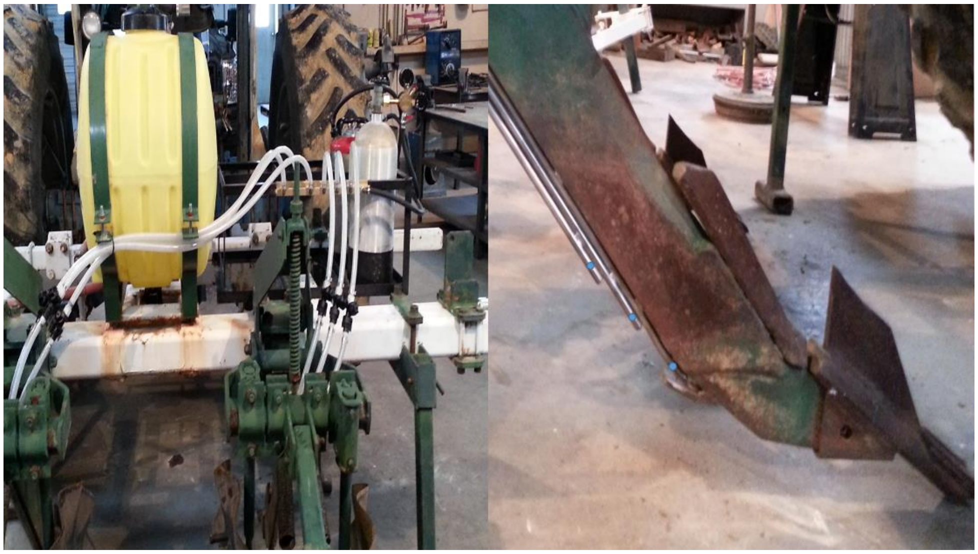

**Fig. 1: Picture of the strip-tillage fertilizer systems and shank to place fluid phosphorus and potassium fertilizers at 6, 9, and 12 inches below the soil surface during strip tillage.**

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. 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 $\leq$ 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 were 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 $\alpha = 0.05$ level of significance.

# Results

## General Comments

The 2014 growing season produced record cotton yields for Virginia with a state average over 1,200 pounds of lint per acre. This ranked first among states with predominantly dryland production. A warm month of May allowed for optimum stands to be established and allow cotton roots to develop uninhibited. Daytime temperatures were optimal with only one week having highs in the upper 90 $^{o}$F's which minimized heat stress throughout the growing season. Rainfall was consistent and adequate throughout the growing season, maintaining yield potential through the boll fill period.  No issues such as sand-burn or poor stands were present at any location during 2014, so no plant population data will be presented in this report. At the TAREC location, vigor ratings and Normalized Difference Vegetative Index were taken on the plots when noticeable differences in crop growth were present. This was done to evaluate different methods as potential future tools for distinguishing plant growth/vigor in season among different treatments. Differences in petiole and leaf nutrient concentrations were not seen when complete fertilizer programs were used during the study. Lint yield responses indicate that cotton is more responsive to nitrogen than phosphorus, potassium, and sulfur during the study. No responses in the lint quality parameters were observed over all analyses and no lint quality data will be presented in this report. Overall the 2014 trials were high yielding and differences among treatments were observed in plant growth and yield.

## Nutrient Management Systems

*In-season Plant Growth Measurements*

Differences in plant growth were observed as early as the third week after planting at both locations during 2014 (Tables 4 and 5). The 2X2 band N-P-K-S band produced the tallest plants from the third week after planting through the fifth week after planting at TAREC (Table 4). From six weeks after planting through eight weeks after planting the deep placement of N-P-K-S produced the tallest plants at TAREC (Table 4). Deep placement of N-P-K-S produced the tallest plants during the early season growth measurements at each location during 2014. The unfertilized control produced the shortest plants at both locations during 2014. The broadcast control had significantly shorter plants than deep placement in three out of the six sampling intervals at TAREC which indicates that cotton the deep placement increased vegetative growth during the early season (Table 4). At the Lewiston location all fertilized treatments were similar in early season growth (Table 5). The weather during the early season in 2014 was warmer and drier than 2013, which allowed roots to explore a greater soil volume favoring the deep placement of nutrients with strip-tillage. From May 1$^{st}$ to June 15$^{th}$ the total rainfall was 8 and 5 inches at TAREC for 2013 and 2014 respectively.

Two new methods were used to differentiated differences in vigor/early season growth among the fertilizer treatments and were visual vigor ratings and normalized difference vegetative index (NDVI) measured with a Greenseeker® (Table 6). Visual vigor ratings were able to detect significant difference in early season vigor between the unfertilized control and fertilizer treatments at TAREC (Table 6). Normalized difference vegetative index values ranged from 0.36 to 0.55 and were able to detect significant differences among fertilizer systems (Table 6). The 2X2 banded system produced the highest NDVI value of the nutrient management systems and was significantly higher than the unfertilized and broadcast agronomic control (Table 6). The treatments where N and P were placed in the 2X2 band resulted in higher NDVI values. The

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

| Nutrient Systems | Plant Height | | | | | |
|---|---|---|---|---|---|---|
| | 3rd ǂ | 4th | 5th | 6th | 7th | 8th |
| | ---------- | ---------- | ---------- | in. | ---------- | ---------- |
| Unfertilized Control | 3.3 b | 5.8 b | 10.0 c | 14.6 b | 19.3 c | 23.7 c |
| Broadcast Agronomic Control | 3.6 ab | 7.0 ab | 10.3 bc | 17.7 a | 23.2 b | 29.2 b |
| Liquid Starter Control | 3.6 ab | 7.6 a | 12.0 ab | 19.3 a | 24.4 ab | 30.0 ab |
| 100% 2X2 N-P-K-S | 3.8 a | 7.6 a | 12.5 a | 19.5 a | 24.6 ab | 30.6 a |
| 100% Deep Placement N-P-K-S | 3.6 ab | 7.4 a | 12.3 a | 19.5 a | 24.8 a | 30.8 a |

*Values with the same letter are not significantly different at α=0.05

ǂ Week after Planting

**Table 5: Early season plant height of cotton grown under different nutrient management systems at Lewiston, NC**

| Nutrient Systems | Plant Height | | | | | |
|---|---|---|---|---|---|---|
| | 3rd ǂ | 4th | 5th | 6th | 7th | 8th |
| | ---------- | ---------- | ---------- | in. | ---------- | ---------- |
| Unfertilized Control | 3.5 b | 6.6 b | 10.4 b | 15.2 b | 20.0 b | 28.1 b |
| Broadcast Agronomic Control | 4.1 a | 7.5 a | 12.1 a | 17.8 a | 23.2 a | 31.9 a |
| Liquid Starter Control | 4.2 a | 7.7 a | 12.0 a | 18.4 a | 23.6 a | 32.1 a |
| 100% 2X2 N-P-K-S | 4.1 ab | 7.4 ab | 11.1 ab | 17.4 a | 23.6 a | 31.9 a |
| 100% Deep Placement N-P-K-S | 4.0 ab | 7.8 a | 12.1 a | 18.5 a | 24.1 a | 33.3 a |

*Values with the same letter are not significantly different at α = 0.05

ǂ Week after Planting

**Table 6: Vigor, normalized difference vegetative index (NDVI), total nodes, and nodes above white flower (NAWF) for cotton grown under different nutrient management systems at TAREC**

| Nutrient Systems | Vigor | NDVI | Nodes | Nodes Above White Flower | | |
|---|---|---|---|---|---|---|
| | 5th ǂ | | 9th | 9th | 10th | 11th |
| Unfertilized Control | 2.75 b* | 0.36 c | 10.4 b | 5.5 | 4.1 b | 2.5 c |
| Broadcast Agronomic Control | 4.25 a | 0.44 bc | 11.5 ab | 6.1 | 5.3 a | 4.0 a |
| Liquid Starter Control | 4.50 a | 0.48 ab | 11.9 a | 6.1 | 5.0 ab | 3.3 b |
| 100% 2X2 N-P-K-S | 5.25 a | 0.55 a | 11.6 a | 6.3 | 5.3 a | 3.7 ab |
| 100% Deep Placement N-P-K-S | 4.50 a | 0.45 abc | 11.9 a | 6.3 | 5.4 a | 3.4 ab |

*Values with the same letter are not significantly different at α=0.05

ǂ Week after planting

NDVI value has been highly correlated to overall biomass in numerous studies and the results indicate this type of measurement may be a useful tool in rating early season growth among various treatments. Normalized difference vegetative index was a more sensitive tool than visual ratings and removes the potential human bias from data collection.

Late season maturity was impacted more by nitrogen fertilization than phosphorus and potassium as unfertilized plots at TAREC had fewer NAWF than fertilized plots (Table 6) where unfertilized plots at Lewiston were not significantly different from fertilized treatments (Table 7). Early maturity or early "cut-out" can adversely affect yields as a shorter bloom period results in a lower total number of bolls per plant. Nitrogen management in cotton can affect maturity with low nitrogen rates decreasing the bloom period and high excessive (> 120 lbs N/acre) can delay maturity of cotton. The two locations during 2014 demonstrate this as TAREC was N deficient which resulted in cotton maturing earlier and limiting boll fill.

**Table 7: Nodes above white flower for cotton grown under different nutrient management systems at Lewiston, NC**

| Nutrient Systems | Nodes | Nodes Above White Flower | | | |
|---|---|---|---|---|---|
| | 9th ǂ | 9th | 10th | 11th | 12th |
| Unfertilized Control | 12.4 | 7.5 | 7.0 a | 5.7 | 4.5 |
| Broadcast Agronomic Control | 12.3 | 7.5 | 6.6 ab | 5.3 | 4.3 |
| Liquid Starter Control | 13.1 | 7.3 | 6.4 b | 5.1 | 3.8 |
| 100% 2X2 N-P-K-S | 12.2 | 7.3 | 6.7 ab | 5.1 | 4.5 |
| 100% Deep Placement N-P-K-S | 12.8 | 7.3 | 6.8 ab | 5.2 | 4.4 |

*Values with the same letter are not significantly different at $\alpha$=0.05

ǂ Week after planting

*Petiole and Tissue Analyses*

Similar trends in petiole nutrient concentrations were observed during 2014 as in 2013. Nitrate-N, P, and K concentrations all decreased throughout the first nine weeks of bloom at both TAREC and Lewiston (Figs. 2 and 3). Petiole sulfur concentrations were the only nutrient to increase during the nine of sampling during bloom. Petiole nitrate-N concentrations at TAREC were nearly 50% of the petiole nitrate-N concentrations at Lewiston during the first week of bloom. The difference in nitrate-N between locations is unclear as both locations received the same N rates, however all nutrient management system were near or above 4,500 ppm nitrate-N, a common critical nitrate-N level for the first week of bloom. Nitrate-N concentrations at both locations decreased quickly and were below 2000 ppm by the fourth week of bloom (Figs. 2a and 3a).

Phosphorus concentrations in cotton petioles were similar at both locations, with concentrations of 1,500-2,000 ppm P during the first week of bloom and decreasing in a linear fashion to 1,000 ppm P by the ninth week bloom (Figs. 2b and 3b). The unfertilized control at TAREC again had significantly higher petiole P concentrations and confirms the findings during 2013 that N deficiency elevates P concentrations (Fig. 2b). When N was applied at side-dress at Lewiston the P concentrations in all nutrient management systems were similar (Fig. 3b). Petiole concentrations of P and K fluctuated during 2014 at both locations, with an overall trend declining through bloom period (Figs. 2 and 3). At TAREC, petiole P concentrations increased from weeks 2 and 3 as well as weeks 7 and 8, whereas petiole K concentrations increased from weeks 2 and 3 and weeks 4 and 5 (Figs. 2b and 2c). At Lewiston, fluctuations of P occurred between weeks 3 and 4 as well as 5 and 6 whereas for petiole K concentrations fluctuated between weeks 2 and 3 and again at 5 and 6 weeks (Figs. 3b and 3c). It is unclear whether these fluctuations are a product of increased uptake of nutrients or coincide with a weather event prior to petiole sampling.

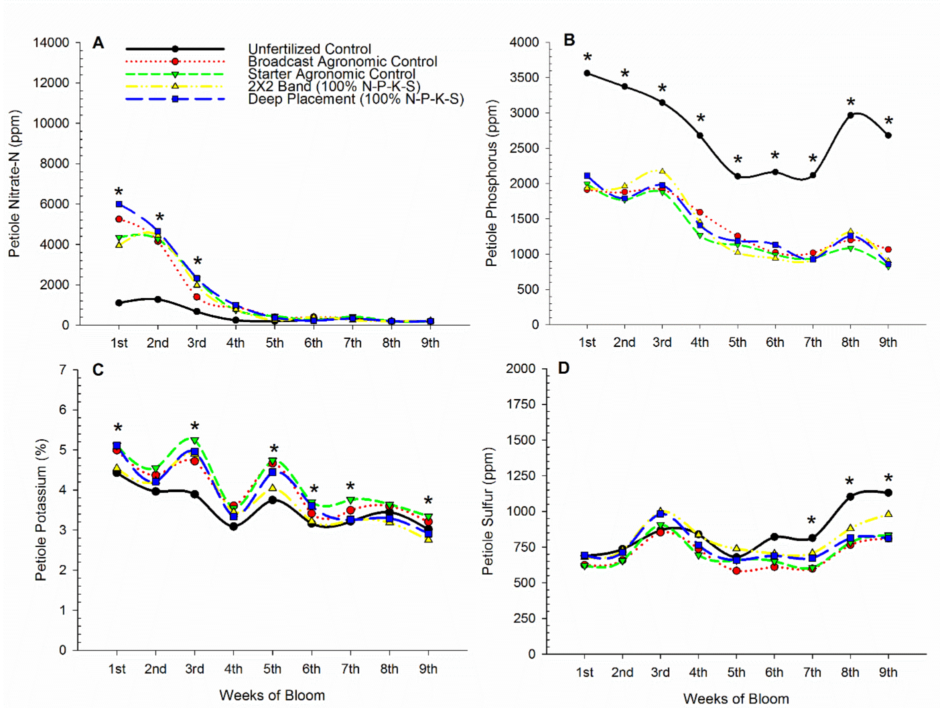


**Fig. 2: Nitrate-N (A), phosphorus (B), potassium (C), and sulfur (D) concentrations in cotton petioles using different nutrient application management systems during the 1st nine weeks of bloom at TAREC (*ANOVA was significant at α = 0.05 for that sampling interval).**

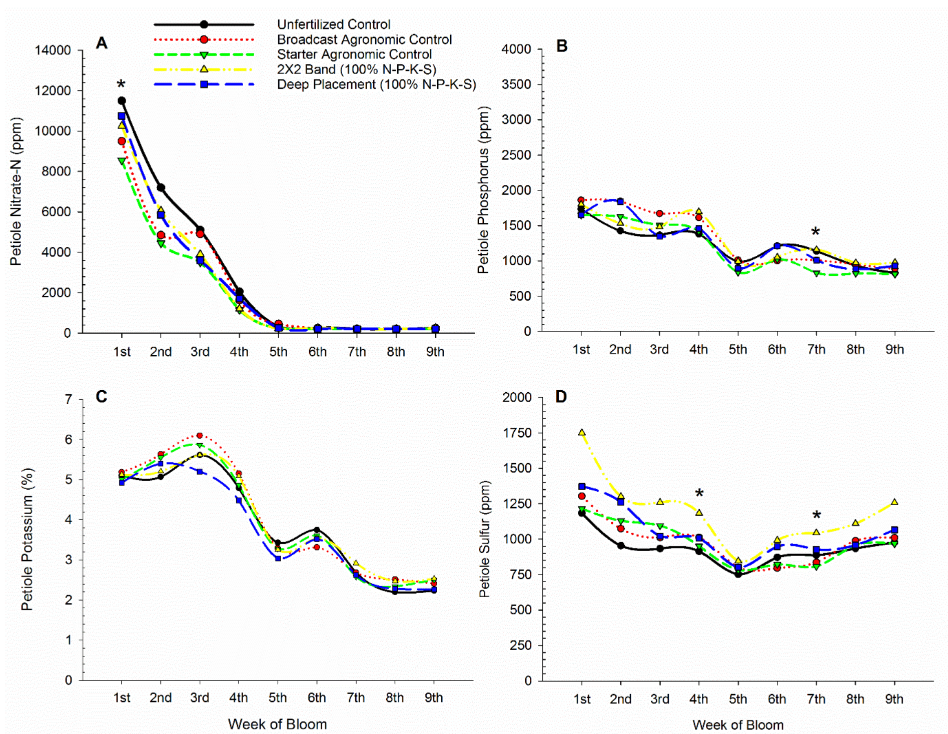


**Fig. 3: Nitrate-N (A), phosphorus (B), potassium (C), and sulfur (D) concentrations in cotton petioles using different nutrient application management systems during the 1st nine weeks of bloom at Lewiston, NC (*ANOVA was significant at α = 0.05 for that sampling interval).**

Petiole K concentrations gradually decreased through the bloom at both locations with TAREC having a slower decline than Lewiston (Figs. 2c and 3c). Both locations had similar petiole K levels during the first week of bloom, however TAREC had petiole K levels near 3% during the ninth week of bloom and Lewiston had petiole K levels near 2% during the ninth week of bloom. Petiole K concentrations at TAREC were significantly different during six of the nine sampling intervals (Fig. 2c). The broadcast and liquid starter treatments had significantly higher petiole potassium than the unfertilized control during the first and fifth weeks of bloom at TAREC. During the third, sixth, and seventh weeks of bloom the liquid starter control had significantly higher petiole K levels than the unfertilized control (Fig. 2c). During the ninth week of bloom the liquid starter control produced significantly higher petiole K levels than the unfertilized control, 100% 2X2 band, and the 100% deep placement treatments and the broadcast agronomic control had significantly higher petiole K levels than 100% 2X2 band and the 100% deep placement treatments (Fig. 2c). These results indicate that when soil moisture is optimal broadcasting K may be more efficient as K moves to the plant roots via mass flow and a larger greater number of plant roots are able to intercept and utilize K compared to banded applications.

Petiole sulfur concentrations remained constant or decreased slightly for the first five weeks of bloom for TAREC and Lewiston (Figs. 2d and 3d). During the last four weeks of bloom petiole sulfur concentrations increased at both locations. The unfertilized control had significantly higher petiole sulfur concentrations at TAREC during weeks 7-9 (Fig 2d). The increase in sulfur concentrations could be correlated to low N status during late bloom, however more data is needed to ascertain why sulfur levels increased at both locations.

Leaf nutrient concentrations reinforced the petiole nutrient concentration data during 2014. At TAREC, the unfertilized control had significantly lower leaf N concentration and higher leaf P concentrations during the first and fifth weeks of bloom (Table 8). Leaf K concentrations were significantly higher with deep placement compared to the unfertilized control during the fifth week of bloom at TAREC (Table 8). No differences among nutrient management systems were observed at Lewiston for leaf N, P and K during the first and fifth weeks of bloom (Table 9). At three out of the four leaf sampling intervals the 2X2 banding of N-P-K-S resulted in the highest leaf sulfur concentrations and was significantly higher than unfertilized control at Lewiston (Tables 8 and 9). Leaf sulfur levels also increased at both locations from the first to the fifth weeks of bloom. More research is needed to determine the optimal rate and timing of sulfur application in coastal plain cotton production. Current studies in Virginia show an increase of 97 lbs lint/acre with an S application rate of 12lbs S/acre.

*Lint Yield*

At TAREC, the unfertilized control produced significantly less pounds of lint per acre compared to the other fertilized nutrient management systems (Fig. 4). The unfertilized control yielded 955 pounds of lint per acre at TAREC while the other nutrient management systems produced 1,742-2,026 pounds of lint per acre. None of the fertilized nutrient management systems were significantly different in lint yield at TAREC (Fig. 4). Nutrient management systems at Lewiston were not significantly different in lint yield, however the unfertilized control had the lowest lint yield and the liquid banded nutrient systems were numerically higher than the broadcast nutrient management system (Fig. 4). The results at Lewiston indicate that the sites were N limited and once N was applied very little response to P and K was observed. Though not statistically different the yields at Lewiston responded to P and K fertilization as well as banding liquid fertilizers, however the broadcast nutrient system was the highest yielding at TAREC. At both locations lint yields were exceptional and were well above the 1,239 pounds of lint per acre average for Virginia during 2014.

**Table 8: Nitrogen, phosphorus, potassium, and sulfur concentrations in cotton leaf tissue during the 1st and 5th weeks of bloom at TAREC**

| Nutrient Systems | Leaf Nutrient Concentrations | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1st‡ | | | | 5th | | | |
| | N | P | K | S | N | P | K | S |
| | ------------------------------------------ % ------------------------------------------ | | | | | | | |
| Unfertilized Control | 2.65 b* | 0.34 b | 1.68 | 0.56 ab | 2.30 b | 0.26 a | 1.31 b | 0.84 |
| Broadcast Agronomic Control | 3.67 a | 0.26 a | 1.81 | 0.61 ab | 3.04 a | 0.23 ab | 1.65 a | 0.82 |
| Liquid Starter Control | 3.33 a | 0.25 a | 1.69 | 0.48 b | 3.08 a | 0.20 b | 1.55 ab | 0.79 |
| 100% 2X2 N-P-K-S | 3.45 a | 0.26 a | 1.98 | 0.68 a | 2.95 a | 0.20 b | 1.51 ab | 0.89 |
| 100% Deep Placement N-P-K-S | 3.48 a | 0.25 a | 1.74 | 0.52 b | 3.22 a | 0.22 ab | 1.61 a | 0.92 |

*Values with the same letter are not significantly different at α = 0.05
‡ Week of bloom

**Table 9: Nitrogen, phosphorus, potassium, and sulfur concentrations in cotton leaf tissue during the 1st and 5th weeks of bloom at Lewiston, NC**

| Nutrient Systems | Leaf Nutrient Concentrations | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1st‡ | | | | 5th | | | |
| | N | P | K | S | N | P | K | S |
| | ------------------------------------------ % ------------------------------------------ | | | | | | | |
| Unfertilized Control | 5.01 | 0.33 | 1.26 | 0.59 b* | 3.57 | 0.26 | 1.48 | 0.73 b |
| Broadcast Agronomic Control | 4.65 | 0.31 | 1.26 | 0.62 ab | 3.50 | 0.26 | 1.33 | 0.79 ab |
| Liquid Starter Control | 4.84 | 0.28 | 1.29 | 0.63 ab | 3.35 | 0.24 | 1.35 | 0.76 ab |
| 100% 2X2 N-P-K-S | 4.83 | 0.30 | 1.26 | 0.75 a | 3.55 | 0.26 | 1.51 | 0.91 a |
| 100% Deep Placement N-P-K-S | 4.69 | 0.33 | 1.34 | 0.73 ab | 3.56 | 0.24 | 1.32 | 0.82 ab |

*Values with the same letter are not significantly different at α = 0.05
‡ Week of bloom

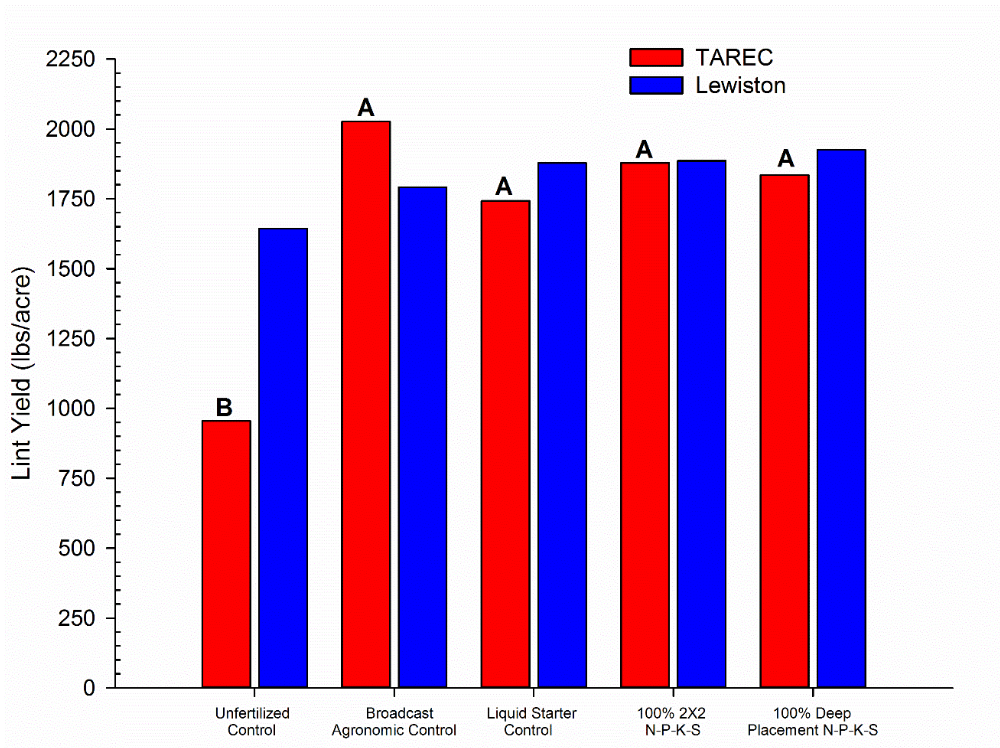


**Fig. 4: Lint yield and nutrient management systems at TAREC and Lewiston, NC. Bars with the same letter are not significantly different at $\alpha = 0.05$ within location.**

## Phosphorus and Potassium Placement and Rate

*In-season Plant Growth Measurements*

Plant growth responses to placement and rates of P and K were sparse during the 2014 study. At TAREC, plant heights were significantly different over the three P and K rates for the first five weeks of sampling (Tables 10 and 11). The 150% P and K rate produced the tallest plants during the first eight weeks after planting and were significantly taller than the 50% application rate through seven weeks after planting (Table 10). At TAREC, vigor ratings were significant for rate and the rate*interaction (Table 11). The 150% P and K application rate had the highest vigor ratings, however the interaction between rate and placement difficult to interpret and could not be supported biologically. No differences were observed for any model effect for NAWF or NDVI at TAREC.

**Table 10: Early season plant height of cotton grown using different rates of applied P and K at TAREC**

| P and K Rate | Plant Height | | | | | |
|---|---|---|---|---|---|---|
| %¶ | 3rd‡ | 4th | 5th | 6th | 7th | 8th |
| | ------------------------------- in. ------------------------------- | | | | | |
| 50 | 3.5 b* | 7.6 b | 12.2 b | 19.0 b | 24.2 b | 30.5 |
| 100 | 3.7 ab | 7.5 b | 12.4 b | 19.4 ab | 24.6 ab | 30.7 |
| 150 | 3.8 a | 8.3 a | 13.1 a | 20.4 a | 25.4 a | 31.2 |

*Values with the same letter are not significantly different at $\alpha$=0.05

‡ Week after planting

¶Percent of recommended P and K (40 lbs $P_2O_5$/acre and 40 lbs. $K_2O$ per acre)

At Lewiston, plant heights were significantly different among placements of P and K and this was the only sampling interval where differences were detected for plant heights (Table 12). Deep placement of P and K produced significantly taller plants than the 2X2 band with plant heights of 32.9 and 31.4 inches for deep placement and 2X2 band, respectively. This correlates to the nutrient system plant heights where deep placement produced taller plants in the sampling intervals further into the growing season. The delay in plant height differences may be due to the time it takes the plant roots to access the nutrients in the deep placement system compared to placement in the 2X2 band. No analysis of variance model effects were found to be different for total nodes and NAWF at Lewiston during 2014 (Table 12).

*Petiole and Tissue Analyses*

Responses in petiole and tissue concentrations to placement and rate of P and K were not consistent over sampling intervals and locations during 2014. Petiole P and K concentrations followed the same trends as those observed in Figs. 2 and 3. At TAREC, the interaction term for rate*placement was significant for petiole P during the sixth week of bloom and first and sixth week of bloom for petiole K (Table 13). The Tukey-Kramer mean separation procedure did not

**Table 11: Analysis of variance results for the model effects of phosphorus (P) and potassium (K) application rates and placement on early season plant height, vigor, normalized difference vegetative index (NDVI), total nodes, and nodes above white flowers (NAWF) at TAREC**

| Model Effect | Plant Height | | | | | | Vigor | NDVI | Nodes | NAWF | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 3rd¶ | 4th | 5th | 6th | 7th | 8th | 5thǂ | | 9th | 9th | 10th | 11th |
| Placement | NSǂ | NS | NS | NS | * | NS | NS | NS | NS | NS | NS | NS |
| Rate | * | * | * | * | * | NS | * | NS | NS | NS | NS | NS |
| Rate*Placement | NS | NS | NS | NS | NS | NS | * | NS | NS | NS | NS | NS |

ǂ Indicates that the model effect p-value was not significant at α = 0.05
* Indicates that the model effect p-value was significant at α = 0.05
¶ Week after planting

**Table 12: Analysis of variance results for the model effects of phosphorus (P) and potassium (K) application rates and placement on early season plant height, total nodes, and nodes above white flowers (NAWF) at Lewiston, NC**

| Model Effect | Plant Height | | | | | | Nodes | Nodes Above White Flower | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 3rd¶ | 4th | 5th | 6th | 7th | 8th | 9th | 9th | 10th | 11th | 12th |
| Placement | NSǂ | NS | NS | NS | NS | * | NS | NS | NS | NS | NS |
| Rate | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS |
| Rate*Placement | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS |

ǂ Indicates that the model effect p-value was not significant at α = 0.05
* Indicates that the model effect p-value was significant at α = 0.05
¶ Week after planting

**Table 13: Analysis of variance results for the model effects of phosphorus (P) and potassium (K) application rates and placement on petiole phosphorus and potassium concentrations during the first nine weeks of bloom at TAREC.**

| **Model Effect** | **Petiole Phosphorus During First Nine Weeks of Bloom** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1st | 2nd | 3rd | 4th | 5th | 6th | 7th | 8th | 9th |
| Placement | NSǂ | NS | NS | NS | NS | NS | NS | NS | NS |
| Rate | NS | NS | NS | NS | NS | NS | NS | NS | NS |
| Rate*Placement | NS | NS | NS | NS | NS | * | NS | NS | NS |
| | **Petiole Potassium During First Nine Weeks of Bloom** | | | | | | | | |
| Placement | NS | NS | NS | NS | NS | NS | NS | NS | NS |
| Rate | NS | NS | NS | NS | NS | NS | NS | NS | NS |
| Rate*Placement | * | NS | NS | NS | NS | * | NS | NS | NS |

ǂ Indicates that the model effect p-value was not significant at $\alpha = 0.05$
* Indicates that the model effect p-value was significant at $\alpha = 0.05$

separate out the means for each treatment during these sampling intervals and no clear trend existed to the response that could be explained biologically

At Lewiston, petiole nutrient results were again inconsistent and no clear trend was observed in nutrient concentrations analyzed over placement and rate of P and K (Table 14). For example, during the fourth and sixth weeks of bloom the ANOVA found P and K rate to be significant, however during the fourth week of bloom the 150% P and K rate produced petiole P levels significantly higher than the 50% rate. During the sixth week of bloom the 150% P and K rate had the lowest petiole P concentrations of the different application rates. Only two sampling intervals were found to be significantly for petiole K at Lewiston with placement being significant during the ninth week of bloom and P and K rate significant during the sixth week of bloom.

Leaf nutrient concentrations during the first and fifth weeks of bloom was also inconsistent and differences detected with ANOVA were conflicting across sampling intervals and nutrients. The lack of consistent response in petiole and tissue analyses for P and K rate and placement could be due to the medium to high soil test levels of P and K at the sites during 2014. With optimal growing conditions plants were not stressed and roots could explore and extract adequate levels of nutrients regardless of rate and placement strategies. Larger differences in P and K rates are likely needed to detect differences in nutrient status of cotton at the soil test levels evaluated at each location during 2014.

*Lint Yield*

Despite the lack of response in early season growth as well as petiole and leaf nutrient concentrations, there were apparent trends in lint yield for the placement and application rate of P and K during the 2014 studies. At TAREC, deep placement had significantly higher yields than the 2X2 banding of P and K (Fig. 5). In 2013, 2X2 banding of P and K produced significantly higher yields than deep placement at the TAREC location. One explanation for the differences over years is most likely due to root development during the early growing season for each year. In 2013, May and June had 60% more rainfall than May and June in 2014 which may have restricted root growth at greater depths resulting in a proliferation of roots in the 2X2 banded zone. In 2014, cotton roots were not hindered by excess moisture and were able to access the

**Table 14: Analysis of variance results for the model effects of phosphorus (P) and potassium (K) application rates and placement on petiole phosphorus and potassium concentrations during the first nine weeks of bloom at Lewiston.**

| Model Effect | Petiole Phosphorus During First Nine Weeks of Bloom | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1st | 2nd | 3rd | 4th | 5th | 6th | 7th | 8th | 9th |
| Placement | NSǂ | NS | NS | NS | NS | NS | NS | NS | NS |
| Rate | NS | NS | NS | * | NS | * | NS | NS | NS |
| Rate*Placement | NS | NS | NS | NS | NS | NS | * | * | NS |
| | **Petiole Potassium During First Nine Weeks of Bloom** | | | | | | | | |
| Placement | NS | NS | NS | NS | NS | NS | NS | NS | * |
| Rate | NS | NS | NS | NS | NS | * | NS | NS | NS |
| Rate*Placement | NS | NS | NS | NS | NS | NS | NS | NS | NS |

ǂ Indicates that the model effect p-value was not significant at $\alpha = 0.05$
* Indicates that the model effect p-value was significant at $\alpha = 0.05$

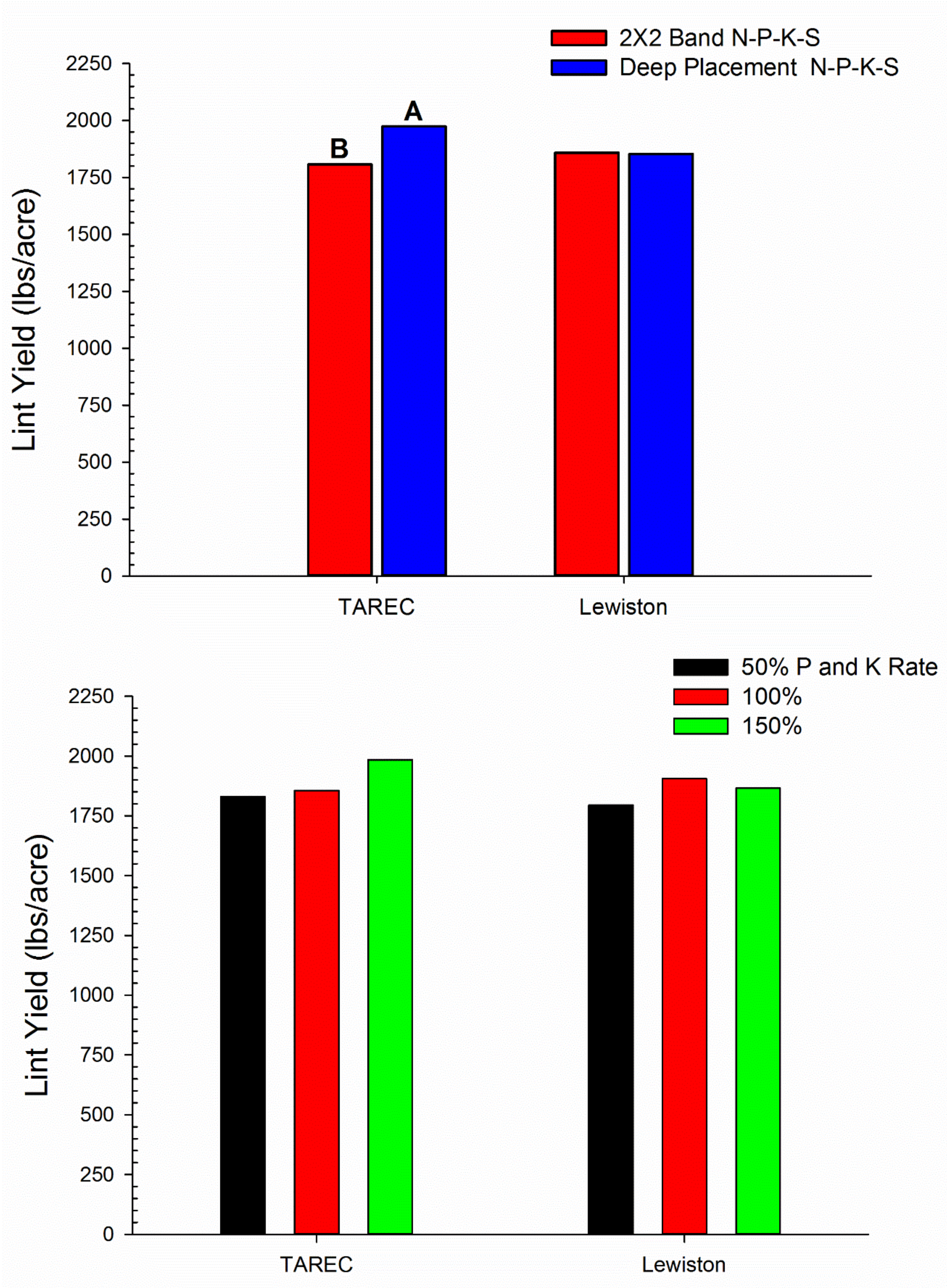


**Fig. 5: Effect of phosphorus and potassium placement (top) and application rate (bottom) on cotton lint yields at TAREC and Lewiston, NC during 2014. Columns with the same letter are not significantly different at α = 0.05.**

nutrients in the deep placement bands earlier which produced greater yields than the 2X2 banded treatments. No differences were observed between the 2X2 band and the deep placement of P and K at Lewiston during 2014 (Fig. 5).

No statistically significant differences in lint yield over P and K application rates were detected at either location during 2014. However, both locations had numerical increases in lint yield as P and K application rates increased (Fig. 5). At TAREC, the 150% P and K application rate maximized lint yields while the 100% P and K rate maximized yields at Lewiston (Fig. 5). At both locations the 50% P and K application rate produced the lowest lint yields. The similar trends in lint yield suggest that both locations had a limited response to P and K fertilization.

## Placement Combinations

### *In-Season Plant Growth Measurements*

When applying P and K at varying ratios in a 2X2 band and deep placement, no differences were observed in early season plant height, total nodes, and NAWF among the different ratios tested. Plant heights for the TAREC location can be found in Table 15 and no combination of 2X2 banding or deep placement had a distinct advantage over the others. Detecting differences in 2014 among the different placement combinations could have been confounded by conditions which optimized over plant growth and lint yields. Based on lint yield results from the P and K application rate and placement analysis, cotton at both locations was able to utilize nutrients regardless of placement depth. Placing nutrients through the rooting depth profile is a novel concept and may could benefit nutrient utilization under conditions that inhibit root growth such as compact soil layers or saturated soil conditions.

**Table 15: 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 Height | | | | | |
|---|---|---|---|---|---|---|
| | 3rd¶ | 4th | 5th | 6th | 7th | 8th |
| | ---------------------- in. ---------------------- | | | | | |
| 100% 2X2 Band N-P-K-S | 3.8 | 7.6 | 12.5 | 19.5 | 24.6 | 30.6 |
| 80% 2X2 Band + 20% Deep Placement | 3.7 | 7.8 | 12.6 | 19.9 | 24.5 | 30.6 |
| 60% 2X2 Band + 40% Deep Placement | 3.6 | 7.3 | 12.4 | 19.2 | 23.2 | 29.5 |
| 40% 2X2 Band + 60% Deep Placement | 3.5 | 8.0 | 12.8 | 19.5 | 24.8 | 31.6 |
| 20% 2X2 Band + 80% Deep Placement | 3.7 | 7.5 | 12.2 | 20.0 | 24.5 | 30.2 |
| 100% Deep Placement N-P-K-S | 3.6 | 7.4 | 12.3 | 19.5 | 24.8 | 30.8 |

¶ Week after planting

*Petiole and Tissue Analyses*

No difference in petiole of leaf nutrient concentrations were detected among the different nutrient placement combinations (data not shown) during 2014. Each combination received the same application rate of N, P, K, and S per acre so no differences should have been observed unless the placement combinations inhibited nutrient availability or uptake.

*Lint Yield*

Lint yield was not significantly different among placement combinations during the 2014 study (Fig. 6). The cotton was able to access the applied nutrients at both locations regardless of the placement during 2014. Placing N-P-K-S blends throughout the soil profile during strip-tillage and planting is a novel concept and data from the first two years of this study show no adverse effects on performance of cotton when this type of nutrient system is implemented. More data is needed, especially data on how this nutrient systems perform under drought conditions in the southeast coastal plain.

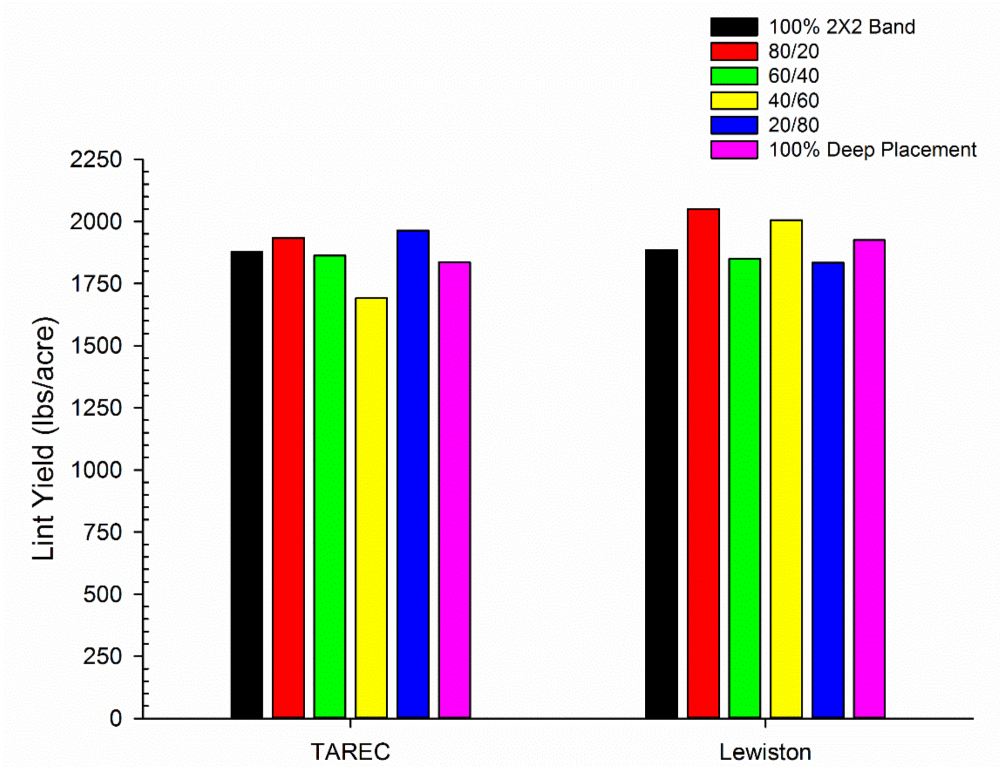


**Fig. 6: Effect of different ratios of applied P and K in the 2X2 band and deep placement on cotton lint yields at TAREC and Lewiston, NC during 2014.**

## Summary

In many ways the 2014 study produced similar results as the 2013 study, however 2014 had optimal growing conditions during May and June which may have allowed root growth to develop uninhibited. The nutrient management systems where P and K were banded as liquids produced taller plant heights during the early part of the growing season at TAREC, where no differences were observed among nutrient management systems where P and K were applied at Lewiston. Petiole P concentrations at TAREC were elevated when no N was applied at side-dress which reinforces the same observations during the 2013 study. If producers are going to use petiole testing to monitor in-season nutrient status then they must evaluate N status before making inferences on P status during the bloom period. At TAREC, the deep placement produced significantly higher yields than the 2X2 banding of P and K, whereas in 2013 the relationship was reversed at TAREC. Lint yields at Lewiston were not affected by P and K placement during 2014. Different combinations of 2X2 banding and deep placement had little effect on early season growth and maturity, petiole and tissue nutrient concentration, and lint yield. No differences were observed in lint quality for any of the analyses during 2014. Overall the 2014 growing season was a record breaking year and lint yields for the trial reflect these optimal conditions for cotton.

# Appendix

**Table 16: Monthly average maximum and minimum temperatures, cumulative growing degree days, and total monthly rainfall for TAREC and Lewiston during 2014.**

| Month | Suffolk, VA | | | | Lewiston, NC | | | |
|---|---|---|---|---|---|---|---|---|
| | Avg. Max Temp. | Avg. Min. Temp. | Cum. DD60 | Total Precip. | Avg. Max Temp. | Avg. Min. Temp. | Cum. DD60 | Total Precip. |
| | $^oF$ | | | in. | $^oF$ | | | in. |
| May | 82.2 | 58.3 | 331 | 3.0 | 81.0 | 60.4 | 330 | 3.6 |
| June | 88.7 | 64.1 | 815 | 3.0 | 86.8 | 66.0 | 820 | 4.3 |
| July | 88.5 | 67.4 | 1350 | 4.0 | 85.3 | 68.3 | 1338 | 10.3 |
| August | 86.3 | 66.6 | 1836 | 6.9 | 82.9 | 66.9 | 1799 | 8.2 |
| September | 83.4 | 65.1 | 2233 | 6.1 | 79.9 | 64.7 | 2166 | 7.3 |
| October | 75.8 | 50.2 | 2417 | 1.6 | 74.7 | 51.2 | 2306 | 1.4 |
| November | 59.4 | 35.1 | 2452 | 4.5 | 58.2 | 36.5 | 2320 | 3.2 |