ABSTRACT

SZILVAY, BLAKE LINDLEY. Fertility Management and Variety Mixtures of Cotton in North Carolina. (Under the Direction of Dr. Keith Edmisten and Dr. Guy Collins).

Nitrogen (N) and potassium (K) are the two most important nutrients in cotton production because they have the greatest effect on yield. The purpose of this research is to help better predict the effect on yield and quality that variable timings and rates of N and K have on cotton. Too much of either nutrient can result in luxury consumption or delayed maturity, while too little could result in plant stress or suboptimal yields. Poor application timing may render nutrients unavailable when needed, while multiple and frequent applications may be logistically inconvenient or economically draining. Optimal N rates and application timings must be determined on a case by case basis and will need to be adjusted based on environment and crop condition. Nitrogen rates at or below 22.4 kg ha^{-1} may result in N deficiency stress and lead to significant yield loss compared to higher rates. Multiple N applications can increase lint yield when there is excessive rainfall early in the growing season. Nitrogen deficiency stress increased micronaire. Potassium rate and application timing main effect for lint yield and fiber quality measurements were not significant in any environment.

Potassium treatments included a factorial arrangement of one, one and a half, and two times the recommended rate applied at planting, at planting and at layby, and at planting, at layby, and three weeks after layby, while N treatments included a total combination of 22.4, 89.6, or 123.2 kg N ha^{-1} at the same timings. Measurements included nodes above white flower at first bloom, three weeks after layby, and five weeks after layby, a petiole sample five weeks after layby, end of season plant mapping, defoliation rating, yield quality, and fiber quality. There were ten K treatments, three rates and three timings with a non-treated control, and eight N

treatments, two rates at three timings, a non-treated control, and a single 22.4 kg N ha^{-1} at pre-plant to represent a lower than recommended rate of N.

Five cultivars were chosen based on prior performance in replicated cultivar trials. Some cultivars were chosen based on a high degree of yield stability across a broad range of environments in years with frequent rainfall or in years where drought stress was noticeable. Other cultivars were chosen based on consistent performance in either high-yield or low-yield environments. There were eight treatments total, which included each cultivar planted alone, all five mixed in equal proportions by seed count, and two binary cultivar treatments in a 50 percent mixture by seed count. Trials were conducted across 23 environments during 2017 and 2018. Yield and fiber quality were collected at harvest.

Cultivar selection is a critical decision growers make. However, no single cultivar will outperform competitors in every environment, predicting which cultivar will perform best in subsequent years is improbable for all soils or environments. Blending cultivars that perform well in contrasting environments or blending highly competitive cultivars may help spread the risk when accounting for the uncertainty of growing conditions for any given year or environment. A mixture was as likely, or more likely, to produce a lint yield lower than the highest yielding cultivar in a given year, as opposed to producing a lint yield higher than the lowest yielding cultivar. In a given year, one cultivar will outperform another at least some of the time. The data suggests that using a cultivar mixture will not help improve yield stability the majority of the time compared to the highest of the component cultivars and it can improve micronaire and fiber length if the mixture is a pairing a low fiber quality and high fiber quality cultivar.

Fertility Management and Variety Mixtures of Cotton in North Carolina.

by
Blake Lindley Szilvay

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APPROVED BY:

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Randy Wells	Guy Collins Committee Co-Chair

_____
Keith Edmisten
Committee Co-Chair

DEDICATION

This thesis is dedicated to my grandmother, Barbara Szilvay, and to my parents, Joseph and Brenda Szilvay, for making this opportunity possible and for supporting me every step of the way. Every one of their lives has demonstrated faith in the Lord, hard work, honesty, and patience to me.

BIOGRAPHY

Blake Lindley Szilvay was the second born to Joseph Szilvay and Brenda Lindley Szilvay in Greensboro, North Carolina on 8 May 1995. He was raised in the Silk Hope community near Siler City in Chatham County, North Carolina and graduated from Jordan Matthews High School in 2013 where he enjoyed being a part of the FFA Chapter, Cross Country, and Track and Field team there.

In 2015, Blake graduated from North Carolina State Agricultural Institute with an Associate's Degree in Field Crop Technologies, then went on to get his Bachelor's Degree in Plant and Soil Science in 2017. During his time there he enjoyed being a member of the Agronomy Club on campus and part of Friends Campus Ministry Raleigh. In the summer of 2017, he was admitted into the graduate school of North Carolina State University in the Department of Crop Science. There he began to pursue a Master's of Science under the direction of Dr. Keith Edmisten while working closely with Dr. Guy Collins and Dr. Randy Wells. While working towards his Master's, Blake was given the opportunity to work as an Agricultural Extension Agent with the North Carolina Cooperative Extension at the Randolph County Office. Upon completion of his studies, Blake plans to continue his work with North Carolina Cooperative Extension and to build onto his professional career.

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CHAPTER ONE

Effects of Nitrogen Rates and Timing on Cotton Yield and Fiber Quality

B. L. Szilvay[1], K. L. Edmisten[2], G. D. Collins[3], R. Wells[2]

[1]Graduate Research Assistant, [2]Professor, Department of Crop and Soil Sciences, [3]Associate Professor, Department of Crop and Soil Science

North Carolina State University

Raleigh, North Carolina 27695-7620

Abstract

Nitrogen (N) is taken up by cotton in greater quantities than any other nutrient. Proper N nutrition is essential for both vegetative and reproductive growth. Excess N can cause luxury consumption or delayed maturity, while insufficient N can result in plant stress or reduced yield. Inadequate application timing may render nutrients unavailable when needed, while repeated applications may be logistically problematic and economically draining. Timing and rate decisions are produced on a case-by-case basis according to yield goals and are more accurate when there is relevant research available. Genetic improvement and management practices are steadily increasing cotton yields and potentially altering the fertility requirements for the crop. The goal of this research is to help discern the current N fertility requirements of cotton and the best fertility management practices with regard to application timing.

Experiments were conducted at the Upper Coastal Plain Research Station (UCPRS) and the Peanut Belt Research Station (PBRS) in 2017 and 2018 and, in 2018, at the Sandhills Research Station (SRS). Treatments include a total combination of 22.4, 89.6, or 123.2 kg N ha^{-1} applied at planting, at planting and at layby, and at planting, at layby, and three weeks after layby. Layby occurred between 45 and 62 days after planting (DAP). Measurements included nodes above white flower (NAWF) at first bloom, three weeks after layby, and five weeks after layby, a petiole sample five weeks after layby, a height, nodes to the first fruiting branch (NFFB), nodes to the uppermost cracked boll (NUCB), nodes to the uppermost harvestable boll (NUHB), and a total node count at 50-60 percent cracked boll, defoliation rating, yield quality, and fiber quality. There were eight treatments, two rates at three timings, a non-treated control, and a single 22.4 kg N ha^{-1} at pre-plant to represent a lower than recommended rate of N. Optimal N rates and application timings must be determined on a case-by-case basis and will

need to be adjusted based on environment and crop condition. Nitrogen rates at or below 22.4 kg ha^{-1} may result in N deficiency stress and lead to significant yield loss compared to higher rates. Multiple N applications can increase lint yield when there is excessive rainfall early in the growing season. Lint yield response to environment is variable. Nitrogen deficiency stress increased micronaire but affected no other fiber quality measurement.

Introduction

Nitrogen (N) is consistently the most deficient nutrient in non-legume crops (Havlin et al., 2005, Hou et al., 2007), and, in cotton, it can directly affect yield and sometimes fiber quality (Bradow and Davidonis, 2000; Reddy et al., 2004). The status of N in the plant will effect chlorophyll content, leaf development, and leaf photosynthetic potential and cause reduced growth and untimely maturity (Gerik et al., 1994). Uptake of N, along with many nutrients, is influenced heavily by the environment (Crozier and Hardy, 2018; Hons et al., 2004; Oosterhuis, 2001) and by the growth stage of cotton (Boquet and Breitenbeck, 2000; Gerik et al., 1998; Mullins and Burmester, 1990; Oosterhuis, 2001).

Cotton N Fertility

Due to a low demand for nutrients during early growth, less than 15 percent of the total N accumulated by a mature plant is required to attain first bloom (Bassett et al., 1970). Cotton's nutrient demands elevate prior to first bloom and recommendations dictate that the remaining required nitrogen be applied at this stage (Gerik et al., 1998; Oosterhuis, 2001). Cotton doesn't respond differently to various sources or formulations of N (Amer and Abuamin, 1969; Havlin et al., 2005; Mullins et al., 2003), but data indicate applications as a narrow band at side-dress optimizes performance (Guthrie, 1991). On sandy textured soils, it may be appropriate to reapply N a second time due to the leaching potential of the soil (Hons et al., 2004). Side-dressing N

twice is not exclusive to sandy soils as it may be necessary on heavier soils after a large or prolonged rain events (Crozier and Hardy, 2018). A foliar fertilizer application is beneficial if the crop displays deficiencies and the application can be made before three weeks after first bloom (Crozier and Hardy, 2018; Oosterhuis and Bondada, 2001). Timing applications to coincide with nutrient demand and accurate placement of N are key management decisions to consider.

N Assimilation and Partitioning

Nitrogen availability directly effects leaf growth, leaf area, and photosynthetic activity (Gerik et al., 1998). Along with being part of biochemical reactions in plants, N is a critical component of chlorophyll, explaining why deficiency symptoms appear as chlorosis in the older leaves and high N levels are depicted as dark green leaves (Havlin et al., 2005).

Before boll development, cotton plants allocate N to vegetative structures in similar proportions despite the amount of N applied (Boquet and Breitenbeck, 2000), and at the beginning of boll development around two-thirds of the plants accumulated N is held in the leaves (Bassett et al., 1970; Boquet and Breitenbeck, 2000). The leaves are generally four percent N early in the growing season (Bassett et al., 1970). Low to sufficient amounts of N produce similar reproductive to vegetative ratios, while excessive amounts of N drives greater vegetative growth and lowers the reproductive to vegetative ratio (Boquet and Breitenbeck, 2000). Over-applying N has been known to significantly decrease N uptake and N use efficiency by the plant (Boquet and Breitenbeck, 2000). On the other hand, N deficiency can cause poor fruit set (Gerik et al., 1994; Malavolta et al., 2004) and premature shedding of leaves (Malavolta et al., 2004), both of which lead to yield losses.

A developing boll gets most of the N it requires from its sympodial leaf and leaves on main stem (Oosterhuis et al., 1989). Bolls, more specifically the seeds, are the primary sink

during the boll fill period (Bassett et al., 1970; Crowther, 1944), which can lead to deprivation of assimilates in the roots causing decreased efficiency and uptake (Crowther, 1944). Cotton seeds average around 3.7 percent N throughout seed development (Bassett et al., 1970). A mature cotton plant will put around half of the accumulated N into fiber and seed (Oosterhuis et al., 1983). Nitrogen is a significant component of many plant functions, both vegetative and reproductive, however issues can occur from inadequate and excessive availability of the nutrient.

Growth Habits and N

Yield benefits are obtained, in part, by good early season growth, which can be maximized through proper use of fertilizer (Gardner and Tucker, 1967; Guthrie, 1991; Funderburg, 1988). However, too much N early in the season can lead to problems such as rank growth (York, 1983; Baker et al., 1972), delayed fruiting (Gerik et al., 1998; Bondada et al., 1996), boll rot (Roncadori et al., 1975), and greater expense for growth regulators (York, 1983). Cotton has a relatively low nutrient requirement early in the season (Oosterhuis, 2001). Nutrient requirements and uptake rise sharply between 28 and 71 DAP, first square, peaks from 63 to 98 DAP, two weeks after first bloom (Boquet and Breitenbeck, 2000; Mullins and Burmester, 1990; Oosterhuis, 2001), and then steadily declines regardless of how much N is available (Boquet and Breitenbeck, 2000). During periods of elevated accumulation, daily uptake can range from 0.17 to 0.34 kg N ha^{-1} (Bassett et al., 1970).

Excessive N can redirect carbon assimilates towards vegetative growth (Gerik et al., 1998). Nitrogen deficiency from the beginning of anthesis to the peak of flower causes significant yield loss (Gerik et al., 1998). Nitrogen fertility affects maturity (McConnell et al., 1993). Judicious applications of N are associated with increased photosynthetic activity (Havlin

et al., 2005) and are critical for maximizing cotton's lint yield (Gerik et al., 1998). Each stage of growth in cotton is of equal significance, however, considering the proper N nutrition for yield and fiber quality during each period of growth is of paramount.

Soil N Dynamics

The N-cycle plays a large role in N availability in the soil. Parts of the N cycle include denitrification, immobilization, volatilization, plant uptake, ammonification, nitrification, leaching, runoff, and mineralization (Havlin et al., 2005). Soil type, temperature, and rainfall play a major role in the level of influence these different factors have on N (Gerik et al., 1998). Fates of ammonium (NH_4^+) that negatively affect access of the nutrient to cotton include immobilization by bacteria, volatilization as ammonia (NH_3^+) into the atmosphere, and NH_4^+ fixation where clay ties the nutrient up. The soil cation exchange capacity (CEC) has a role in determining how tightly bound the NH_4^+ cation is to the soil particles, affects how much NH_4^+ is in the soil solution, and dictates how much is available for plant uptake (Havlin et al., 2005).

Cation exchange capacity does not affect nitrate (NO_3^-), which is the form of N most commonly taken up by cotton (Gerik et al., 1998). Nitrate is highly susceptible to leaching and can be converted to gases through denitrification (Meisinger and Delgado, 2002). Nitrate leaching plays a major role in nitrogen loss and can pose an environmental risk (Havlin et al., 2005). Factors that affect rate of leaching include fertilization rate (Bergström and Brink, 1986), timing, source, application method (Brown et al., 1982), soil characteristics (Brown et al., 1982; Havlin et al., 2005; Gerik et al., 1998), and precipitation quantity and duration (Wang et al., 2014). Two factors to consider for managing leaching include the volume of leachate (water with suspended solids) and the concentration of NO_3^- in the soil (Meisinger and Delgado, 2002). The

best way to avoid NO_3^- leaching is to plan N application timing and rates to coincide with known periods of elevated crop uptake (Havlin et al., 2005).

The ratio of percent carbon to percent N (C:N ratio) of crop residues in the field determine the scale of N immobilization and mineralization (Havlin et al., 2005). Since all the fields used in this trial were tilled clean, leaving no residue, we did not take this effect into consideration.

Mulder's chart is used to determine certain antagonistic and stimulative interactions between N and other nutrients (Goldy, 2016). Nitrogen in excessive amounts in the soil is known to suppress uptake for boron, potassium (K), and copper, and stimulate uptake for magnesium. When molybdenum is excessive in the soil it stimulates N uptake. Nitrogen reacts with multiple factors in the soil and environment, each of which produces a positive or negative effect on the availability of N to the crop.

N Effect on Fiber Quality

Many studies find no effect of N on strength, micronaire, uniformity, elongation or length (Boman and Westerman, 1994; Grimes et al., 1969; Saleem et al., 2010; MacKenzie and Schaik, 1963; Murray et al., 1965). However, some reports suggests that there may differences in fiber length, micronaire (Read et al., 2006; Reddy et al., 2004), or strength (Havlin et al., 2005; Read et al., 2006) as it relates to N fertility. The connections between fiber quality and N fertility are hard to conclude definitively, mainly due to fiber quality being strongly influenced by genetics and the environment (Bradow and Davidonis, 2000).

Proper nutrition for optimal yield and fiber quality in cotton requires the absence of stress from either deficient or excessive N. The amount of N in which cotton accumulates at any given point is dependent on crop uptake, nutrient requirement, and nutrient availability. The purpose of

this research is to help better predict the effect on yield and quality that variable timings and rates of N have on cotton.

Multiple N Applications

Experiments testing multiple applications of N have reported increase lint yield in certain environments (Yang et al. 2011; Constable and Rochester, 1988). Constable and Rochester (1988) conducted experiments on clay soils with low leaching potential and reported elevated N recovery from split applications in two environments and decreased N recovery from the same treatment at two other environments. They only reported a yield increase from split applications at one environment which had compacted and waterlogged soils.

Although many factors play a major role in the availability and movement of N, mainly environmental as mentioned in previous sections, some generalities can be made based on past research with regards to multiple N applications. Experiments time split applications to approximately coincide with any combination of three significant periods of growth in cotton. These stages include seedling, first bloom, and peak bloom (Yang et al. 2011, Gerik et al., 1998; Constable and Rochester, 1988; Amer and Abuamin, 1969). These stages are significant because they are based on the nutrient uptake requirement of cotton (Gardner and Tucker, 1967; Guthrie, 1991; Funderburg, 1988; Boquet and Breitenbeck, 2000; Mullins and Burmester, 1990; Oosterhuis, 2001). In a report by Amer and Abuamin (1969), the two and three split applications of N resulted in greater uptake and nitrate content in the petioles than the single application of N at planting. The overall objective for adopting multiple applications is to maintain proper uptake of N throughout the growing season in order to support productivity and profitability, and to avoid the problems associated with improper applications that were mentioned in previous

sections. This research was conducted to help form management decisions regarding application rate and timing N on current cotton cultivars.

Materials and Methods

Experiments were conducted in 2017 and 2018 at the Peanut Belt Research Station (PBRS), the Upper Coastal Plains Research Station (UCPRS), and the Sandhills Research Station (SRS). Soil series, soil pH, soil CEC, and planting date for each location is illustrated in Table 1. Two experiments were conducted at PBRS in 2017 and the separation is also illustrated in Table 1. Monthly and cumulative precipitation for each growing environment were obtained from the State Climate Office (CRONOS, 2018) of North Carolina located at North Carolina State University (Table 2). The cotton cultivar used was Stoneville 4848 GLT^{TM} at all environments (Stoneville®, Bayer CropScience, Memphis, Tennessee), with exception to both PBRS locations in 2017, which were planted with Phytogen 333 WRS^{TM} (Dow AgroScience®, Indianapolis, IN). Seeding rate at all locations was between 9.8 seed meter^{-1} and 13.1 seeds meter^{-1}. Treatments included a factorial arrangement of four different N rates and three different application timings. The experiment was a randomized complete block design with four replications at each location. Experiments at UCPRS were planted with a John Deere four-row 1700 planter (John Deere, Moline, IL) and had four 12.2 m long rows spaced 0.9 m apart. Experiments at PBRS were planted with a John Deere 7300 four-row planter and had four 12.2 m long rows spaced 0.9 m apart. Experiments at SRS were planted with a John Deere four-row 7300 vacuum planter and had four 12.2 m long rows spaced 0.9 m apart.

Nitrogen applied at planting was broadcast applied with a chest mounted fertilizer spreader using a granular 34-0-0-8S (Ammonium sulfate + urea) fertilizer to achieve total set rates 22.4, 89.6, 123.3 kg N ha^{-1} and a non-treated control. Treatments were broadcast applied

either at planting, at planting and layby, or at planting, at layby, and three weeks after layby. Layby occurred between 45 and 62 DAP. Treatments, application rates, and application timings are in Table 3. Mepiquat chloride (Mepex®, DuPont, Wilmington, DE.) and other growth regulators were not applied to any plots due to the different rate and extent of foliar growth between individual plots. All other management procedures were conducted according to the North Carolina Department of Agriculture (NCDA) soil test recommendations.

Stand counts were recorded approximately three weeks after planting. Plant height and nodes above white flower (NAWF) for five plants on the two center rows were recorded at first bloom, at three weeks after layby, and at five weeks after layby. A petiole sample was collected at five weeks after layby and sent to Water's Agricultural Laboratories, Incorporated (Warsaw, NC) for analysis of N, phosphorus (P), and K concentrations. End of season plant mapping was recorded on five plants on the two center rows when 50-60 percent of bolls are open by recording height, nodes to the first fruiting branch (NFFB), nodes to the uppermost cracked boll (NUCB), nodes to the uppermost harvestable boll (NUHB), and total nodes. Nodes above the uppermost cracked boll recorded on a specific date can be used to signify differences in maturity between treatments (Whitaker et al., 2008). A visual defoliation rating was recorded at harvest which captured the percentage of bolls open, the percentage of defoliation, and the percentage of desiccation. Desiccation was determined by the amount of dried, stuck leaves appearing on the plant.

The center two rows of the plots were harvested with a two row John Deere 9910 spindle-type picker (John Deere, Moline, IL). Each plot's total seedcotton yield was recorded and a 200 g sub-sample was collected for seed weight, lint weight, lint percentage, and High Volume Instrumentation (HVI) analysis. Samples were ginned with a Continental 12-saw cotton gin

without lint cleaners (Continental Eagle Corporation, Prattville, AL). The HVI analysis was conducted at Cotton Inc. (Cary, NC). The HVI data included micronaire, fiber length (upper half mean length), length uniformity, fiber strength, elongation, and short fiber content.

All data were subjected to analysis of variance using PROC GLIMMIX (GLIMMIX procedure) in SAS version 9.4 (SAS Inst., 2013). Means of significant main effects and interactions were separated using Tukey-Kramer's test at $p \leq 0.05$.

Results and Conclusions

Nitrogen rate and application timing main effect for lint yield was not significant at PBRS 2017-(2), UCPRS 2017 and SRS 2018 (Table 4). At PBRS 2017-(1) N significantly increased yield with increasing rate but timing did not make a significant difference. At PBRS 2018 the treatments above 22.4 kg N ha^{-1} significantly increased lint yield. At UCPRS 2018 as the N rate increased and as applications were split, the lint yield significantly increased. Rainfall was lower overall at the UCPRS 2018 than all other environments but was higher in May (Table 2). A leaching rain early in the season would explain the significance of split applications at that location. The environment at SRS is naturally low in fertility and has a low water holding capacity, therefore another environmental factor may have been more limiting than N and obscure the treatment effects.

There was a large lint yield difference between years with yearly means being 1362 and 464 kg N ha^{-1} in 2017 and 2018, respectively (Table 5). Differences were observed in lint yield for N rate, but not application timing in 2017 environments. Moderate and high rates showed no difference when compared to one another but were significantly higher than the low rate and untreated check. Differences were observed for N rates and application timing in 2018 environments. The moderate N rate applied exclusively at planting did not yield significantly

higher than the low rate or untreated check. However, when the applications were split, both moderate rate treatments did yield significantly higher than the low rate treatment and untreated check in 2018 environments. The high N rate treatment applied exclusively at planting resulted in yields significantly lower than the high N rate treatments when applications were split in 2018 environments.

Optimal N rates and application timings must be determined on a case-by-case basis and will need to be adjusted based on environment and crop condition. At two environments a low N rate of 22.4 kg ha^{-1} did not produce a yield higher than the untreated check. These two treatments resulted in N deficiency stress which led to significant yield loss compared to all other treatments. Increased application timing resulted in increased lint yield at one environment, like the findings of Yang et al. (2011). At three of the environments the N rate and application timing produced no significant difference in lint yield.

Nitrogen rate and timing significance was dependent on the growing conditions. In relatively good growing conditions, such as the 2017 environments, N rate and application timing made no difference above 22.4 kg N ha^{-1}. In relatively poor growing conditions such as the 2018 environments, N rate and application timing have significant impacts on lint yield. The significant difference between the 2017 and 2018 environments can be partially due to overall excessive rainfall in 2018 in addition to the course, low fertility soils at the SRS location. Sandhills Research Station 2018 experienced a significant hurricane late in the season that resulted in excessive precipitation for a prolonged amount of time which may have lowered lint yield. The data suggest that on a year with higher rainfall and on soils with greater leaching potential, splitting applications and increasing the rate of N and may significantly increase yield.

Nitrogen rate main effect for NAWF at first bloom was significant in all environments (Data not shown). The untreated check and the low N treatment had significantly decreased NAWF counts compared to all moderate and high N rate treatments over all growth stages. All moderate and high N rate treatments had significantly increased NAWF counts compared to the low N rate, with the exception of the moderate N rate treatment applied at planting, at layby, and at three weeks after layby. At individual locations only PBRS 2017-(1) and UCPRS 2018 had treatments with significantly different NAWF counts at first bloom. These two environments showed that the untreated check had a lower NAWF than all treatments except for the low N rate and the high N rate applied at planting, layby and three weeks after layby.

Nodes above white flower at three weeks after layby was significantly affected by N rate at all locations except for SRS 2018 (Table 6). At all locations except for UCPRS 2018 and SRS 2018 the untreated check has a lower node count than at least one treatment. At all locations except for PBRS 2017-(2) and UCPRS 2017 the low rate treatment had a lower node count than at least one other treatment. At UCPRS 2018 the high N rate treatment applied at planting and layby had a higher node count than the untreated check, the low rate, and the moderate and high rate applied at planting. This would be the only example of N rate and timing having a significant effect on NAWF at three weeks after layby.

Nodes above white flower at five weeks after layby was significantly affected by N rate at PBRS 2017-(2) and PBRS 2018 (Table 7). UCPRS was not recorded and is therefore not presented in this table. At PBRS 2017-(2) the untreated check and low rate produced a significantly lower node count than the high rate applied at planting and the high rate applied at planting, layby and three weeks after layby. At PBRS 2018 the untreated check and low rate had a lower node count than all other treatments. At the same locations the moderate rate applied at

planting had a lower node count than the same N rates with applications split and all the high rate treatments. The high rate treatment applied at planting also had a lower node count than the high rate treatments when applications were split. The data suggest that when a N application is absent or when a low rate is applied, cotton can mature significantly faster in some environments.

Nitrogen rate had a significant effect on plant heights at first bloom at PBRS 2017-(1), PBRS 2018, and UCPRS 2018 (Data not shown). At PBRS 2017-(1) the untreated check was shorter than the high rate treatment applied at planting and layby. At PBRS 2018 the untreated check was shorter than all other treatments, and the moderate rate treatment at planting was taller than the low rate and moderate rate with split applications. At UCPRS 2018 the untreated check was shorter than all treatments except for the low rate.

Nitrogen rate had a significant effect on plant heights at three weeks after layby at PBRS 2017-(1), PBRS 2017-(2), PBRS 2018, UCPRS 2018, and SRS 2018 (Data not shown). At PBRS 2017-(1), UCPRS 2018 and PBRS 2018 the untreated check and low rate were significantly shorter than all other treatments. At PBRS 2017-(2) the untreated check and low rate were shorter than all treatments except for the split application moderate rate treatments. Sandhills Research Station 2018 produced significantly shorter plants for the untreated check and low rate compared to all treatments other than the high rate treatment applied at planting and at planting and layby.

Nitrogen rate had a significant effect on plant heights at five weeks after layby at PBRS 2017-(1), PBRS 2017-(2), and SRS 2018 (Data not shown). At these locations the untreated check and low rate were significantly shorter than all the other treatments.

At 50-60 percent open bolls the N rate had a significant effect on plant heights at all locations except for UCPRS 2017 (Data not shown). At PBRS 2017-(1) and PBRS 2018 the untreated check and low rate were shorter than all other treatments. At PBRS 2017-(2), and SRS 2018 the untreated check was shorter than all treatments other than the low rate. Based on this data, beginning at first bloom, N rate significantly affected plant heights in the majority of environments, particularly when N was not applied or when 22.4 kg ha^{-1} are applied as compared to a higher N rate. Nitrogen application timing did not have a significant effect on plant heights.

Based on NAWF values and plant height measurements and depending on the environment, plants with a lower N rate are shorter and mature slower than others, which is similar to studies by McConnell et al. (1993) and Reddy et al. (2004). Differences in some growth measurements including, lint yield (Table 5) and height measurements (Data not shown), indicate that overall plant growth was greater and variability between treatments was decreased in 2017 environments when compared to 2018 environments (Data not shown). This is potentially due to better growing conditions in 2017 environments including overall natural soil fertility (Data not shown) and precipitation that was adequate and consistent (Table 2).

Nitrogen rate and application timing main effect in all environments was significant for the end of season plant mapping measurements NUHB (Table 8) and total nodes (Table 9). The NFFB measurements had no observed differences between treatments (Data not shown). The NUCB measurement had two environments with differences between two treatments but N rate or timing could not be linked to the results. This data indicated that NFFB and NUCB were not affected by N rates or application timings.

The NUHB measurements did not follow a consistent pattern across individual environments (Table 8). At PBRS 2017-(1) the untreated check and low rate had a significantly

lower node count than all the other treatments. At PBRS 2017-(2) and UCPRS 2018 there were significant differences between treatments but a pattern was not observed. At PBRS 2018 the untreated check had a lower node count than all treatments except for the low rate and moderate rate applied at planting. At SRS 2018 the untreated check and low rate had a lower node count than all treatments except for the moderate rate applied at planting, layby and three weeks after layby.

The total node measurement did not follow a consistent pattern across individual environments (Table 9). At PBRS 2017-(1) the untreated check and low rate had significantly less nodes than all the other treatments. At PBRS 2017-(2) the untreated check and low rate had significantly less nodes than all treatments other than the moderate rate applied at planting, layby and three weeks after layby. At UCPRS 2018 and SRS 2018 a few significant differences were observed but a trend wasn't apparent. Although differences were observed at multiple environments for NUCB and total nodes, there was no clear evidence that N rate or timing caused the interaction at the environments.

Nitrogen rate and application timing main effect for percent N in tissue samples in all environments was significant (Table 10). The untreated check and low N rate treatments had a significantly lower percent N than the rest of the treatments. The moderate N rate applied at planting had a statistically lower percent N than the other moderate N rate treatments applied at multiple times or than any of the high N rate treatments. The moderate N rate treatments applied at multiple times had a percent N that was not significantly different than the high N rate treatment applied at planting. The high N rate treatment applied at planting, layby, and three weeks after layby had a statistically higher percent N than all other treatments other than the high N rate treatment applied at planting and at layby. Among individual environments the N rate and

timing main effect for percent N in tissue samples was very consistent with the pattern observed when all environments were combined (Data not shown).

Nitrogen rate and application timing main effect for percent P in tissue samples in all environments was not significant (Table 10). A percent P content data point was dropped from UCPRS in 2018 because it was unusually high and more than likely due to an error either in the sampling or analysis process. Nitrogen rate and application timing main effect for percent K in tissue samples in all environments was not significant (Table 10). The moderate N rate treatment applied at planting, layby, and three weeks after layby had a significantly higher percent K than the all other treatments with the exception of the high N rate treatment applied at the same timings. No other clear relationship was indicated by this data.

Similar to the studies of Amer and Abuamin (1969), split applications of N resulted in greater N content in the plant tissue when compared to a single N application. Depending on the environment, N applied at preplant alone may not remain plant available or meet the requirement of the crop as well as split applications, resulting in yield loss. Although excessive N levels have been shown to suppress K uptake, tissue K and P content were not affected by N rate and timing.

None of the measurements recorded for defoliation rating in all environments were significantly different due to N rate and application timing (Data not shown). All treatments had at least 85 percent defoliation, at least 90 percent open bolls, no more than 10 percent desiccation, and no more than 3 percent regrowth. Unlike what was observed in studies by York (1983) and Baker et al. (1972), excessive vegetative growth from high N rates, did not have a negative effect on yield and did not lead to defoliation issues. This could be due to the improvement of genetics or the difference in N rates used in the experiments.

Nitrogen rate effect for micronaire in all environments was significantly different (Table 11). Micronaire averages were higher and closer to discount range (5.0) in the untreated check, low rate, and moderate rate. All the high rate applications had a statistically lower micronaire value than both the untreated check and the low rate application. Nitrogen application timing did not significantly affect micronaire. At individual environments N rate effect for micronaire was similar to all environments together (Data not shown). Upper half mean (UHM) followed the same trend as micronaire, where all of the high rate applications were statistically higher than the low rate and untreated check applications (Data not shown). Nitrogen application timing did not have an effect on UHM.

Nitrogen rate and application timing main effect for short fiber content, uniformity, and fiber strength in all environments was not significantly different (Table 11). There was no statistical difference in elongation between any treatments (Data not shown).

Fiber quality measurements were not affected by the year the crop was grown in as much as the treatment effects. Micronaire was more variable, but further from discount range (5.0) in 2017 environments compared to 2018 environments (Data not shown). All other lint quality measurements were similar between 2017 and 2018 environments.

Similar to the studies of Read et al. (2006) and Reddy et al. (2004), the plants that are under more N deficiency stress have higher micronaire. Like many other studies (Boman and Westerman, 1994; Grimes et al., 1969; Saleem, et al., 2010; MacKenzie and Schaik, 1963; Murray et al., 1965), N rate had no effect on strength, uniformity, elongation or length. Environment is only a part of what determines fiber quality. It is in large part due to genetics of the crop (Bradow and Davidonis, 2000).

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Table 1. Soil series, soil pH, CEC, and planting date at Peanut Belt (PBRS), Upper Coastal Plain (UCPRS), and Sandhills (SRS) research stations in 2017 and 2018.

Environment					
Location	**Year**	**Soil Series**	**Soil pH[z]**	**CEC[z]**	**Planting Date**
PBRS	**2017**	**Goldsboro sandy loam** ***Fine-loamy, siliceous, subactive, thermic Aquic Paleudults***	**6.1**	**4.5**	**May 19**
PBRS	**2017**	**Lynchburg sandy loam** ***Fine-loamy, siliceous, semiactive, thermic Aeric Pleaquults***	**6.1**	**6.5**	**May 31**
UCPRS	**2017**	**Norfolk loamy sand** ***Fine-loamy, kaolinitic, thermic Typic Kandiudults***	**5.8**	**6.0**	**May 19**
PBRS	**2018**	**Pantego loam** ***Fine-loamy, siliceous, semiactive, thermic Umbric Paleaquults***	**6.2**	**8.1**	**May 17**
UCPRS	**2018**	**Norfolk loamy sand** ***Fine-loamy, kaolinitic, thermic Typic Kandiudults***	**5.8**	**3.3**	**May 14**
SRS	**2018**	**Ailey loamy sand** ***Loam, Kaolinite, thermic Aerenic Kanhapludults***	**6.1**	**4.3**	**May 4**

[z] Soil samples were analyzed at the North Carolina Department of Agriculture and Consumer Services Agronomic Lab using the Mehlich-3 Analytical Method.

Table 2. Monthly and cumulative precipitation at Peanut Belt (PBRS), Upper Coastal Plain (UCPRS), and Sandhills (SRS) research stations in 2017 and 2018.

Month	PBRS 2017	UCPRS 2017	PBRS 2018	UCPRS 2018	SRS 2018
	---------- cm ----------				
April	14.4	16.5	11.7	10.7	11.7
May	14.8	12.5	24.8	16.6	4.6
June	14.2	12.2	14.1	7.3	3.9
July	18.8	15.1	29.2	18.1	12.8
August	12.8	17.6	15.8	9.4	22.5
September	8.2	7.6	14.8	13	48.4
October	6.9	8.7	7.7	4.9	16.1
Total	90.1	90.2	118.1	80	120

Table 3. Nitrogen treatments with rates and timings for split applications.

Treatment[z]	Nitrogen Rate[y]	kg N ha^{-1} at Planting	kg N ha^{-1} at Layby	kg N ha^{-1} 3 Weeks After Layby
UTC	None	0	0	0
LR	Low rate (LR)	22.4	0	0
MR, P	Moderate rate	89.6	0	0
MR, P, L	Moderate rate	22.4	67.2	0
MR, P, L, +3	Moderate rate	22.4	33.6	33.6
HR, P	High rate	123.2	0	0
HR, P, L	High rate	22.4	100.8	0
HR, P, L, +3	High rate	22.4	50.4	50.4

[z] Treatments – UTC: Untreated Check; LR: Low rate; MR: Moderate rate; HR: High rate; P: Application at planting; L: Application at lay-by; +3: Application at lay-by plus 3 weeks

[y] Rates based on the nitrogen fertilization recommendations according to the North Carolina Cooperative Extension Cotton Information (Crozier and Hardy, 2018)

Table 4. Treatment effects on fiber yield at Peanut Belt (PBRS), Upper Coastal Plain (UCPRS), and Sandhills (SRS) research stations in 2017 and 2018.

Treatment[z]	PBRS 2017-(1)	PBRS 2017-(2)	UCPRS 2017	PBRS 2018	UCPRS 2018	SRS 2018
			kg ha^{-1}			
UTC	880c[y]	1270a	1533a	325c	375d	374a
LR	975c	1324a	1414a	354c	376d	343a
MR, P	1784ab	1430a	1523a	505ab	521cd	390a
MR, P, L	1705b	1641a	1528a	508ab	602bc	573a
MR, P, L, +3	1644b	1433a	1565a	492b	789a	479a
HR, P	2006a	1448a	1498a	545ab	565c	471a
HR, P, L	2005a	1500a	1479a	597ab	745ab	598a
HR, P, L, +3	1968a	1589a	1499a	626a	751ab	590a

[z] Treatments – UTC: Untreated Check; LR: Low rate; MR: Moderate rate; HR: High rate; P: Application at planting; L: Application at lay-by; +3: Application at lay-by plus 3 weeks.

[y] Means with the same letter are not significantly different based on Tukey-Kramer's test (P >0.05).

Table 5. Nitrogen rate and application timing main effect for lint yield years separate.

Treatment[z]	Lint Yield	
	2017	2018
	---------- kg ha^{-1} ----------	
UTC	1095b[y]	318d
LR	1104b	319d
MR, P	1409a	421cd
MR, P, L	1449a	500abc
MR, P, L, +3	1380a	524abc
HR, P	1473a	470bc
HR, P, L	1482a	577ab
HR, P, L, +3	1503a	585a

[z] Treatments – UTC: Untreated Check; LR: Low rate; MR: Moderate rate; HR: High rate; P: Application at planting; L: Application at lay-by; +3: Application at lay-by plus 3 weeks

[y] Means with the same letter are not significantly different based on Tukey-Kramer's test (P >0.05).

Table 6. Treatment effect on nodes above white flower at 3 weeks after layby at Peanut Belt (PBRS), Upper Coastal Plain (UCPRS), and Sandhills (SRS) research stations in 2017 and 2018.

Treatment[z]	PBRS 2017-(1)	PBRS 2017-(2)	UCPRS 2017	PBRS 2018	UCPRS 2018	SRS 2018
			no.			
UTC	1.45c[y]	2.35c	1.15b	2.60cd	2.47e	1.38a
LR	1.95c	2.70bc	1.65ab	1.90d	2.07de	1.50a
MR, P	3.45ab	3.85abc	1.80ab	3.45abc	3.93bcd	3.25a
MR, P, L	3.85ab	3.50abc	1.80ab	4.35ab	4.80abc	3.20a
MR, P, L, +3	3.20b	3.15abc	1.65ab	4.0ab	5.40abc	3.20a
HR, P	4.15a	4.45a	1.90a	3.35bc	3.73cde	2.95a
HR, P, L	4.00a	4.20ab	1.75ab	4.50a	5.80a	3.10a
HR, P, L, +3	3.85ab	3.65abc	1.70ab	4.05ab	5.67ab	3.25a

[z] Treatments – UTC: Untreated Check; LR: Low rate; MR: Moderate rate; HR: High rate; P: Application at planting; L: Application at lay-by; +3: Application at lay-by plus 3 weeks

[y] Means with the same letter are not significantly different based on Tukey-Kramer's test (P >0.05).

Table 7. Treatment effect on nodes above white flower at 5 weeks after layby at Peanut Belt (PBRS), Upper Coastal Plain (UCPRS), and Sandhills (SRS) research stations in 2017 and 2018.

Treatment[z]	PBRS 2017-(1)	PBRS 2017-(2)	PBRS 2018	UCPRS 2018	SRS 2018
	---------- no. ----------				
UTC	1.10a[y]	1.70b	1.00d	1.00a	1.40a
LR	1.15a	2.00b	1.00d	1.00a	1.25a
MR, P	1.45a	2.75ab	2.25c	1.00a	2.85a
MR, P, L	1.60a	2.45ab	2.95ab	1.93a	3.40a
MR, P, L, +3	1.70a	2.40ab	2.95ab	1.93a	3.10a
HR, P	1.85a	3.30a	2.75bc	1.27a	3.60a
HR, P, L	2.05a	2.80ab	3.35a	1.93a	2.75a
HR, P, L, +3	2.05a	3.40a	3.45a	2.20a	2.75a

[z] Treatments – UTC: Untreated Check; LR: Low rate; MR: Moderate rate; HR: High rate; P: Application at planting; L: Application at lay-by; +3: Application at lay-by plus 3 weeks

[y] Means with the same letter are not significantly different based on Tukey-Kramer's test (P >0.05).

Table 8. Treatment effect on nodes to uppermost harvestable boll at Peanut Belt (PBRS), Upper Coastal Plain (UCPRS), and Sandhills (SRS) research stations in 2017 and 2018.

Treatment[z]	PBRS 2017-(1)	PBRS 2017-(2)	UCPRS 2017	PBRS 2018	UCPRS 2018	SRS 2018
			no.			
UTC	10.50b[y]	14.00c	12.70a	9.87d	10.53bcd	9.40c
LR	11.45b	14.15bc	12.65a	10.60cd	8.87d	10.40bc
MR, P	14.20a	16.55a	13.50a	12.47bcd	9.80cd	13.07ab
MR, P, L	14.40a	16.30ab	13.15a	12.67abc	11.73abcd	13.47ab
MR, P, L, +3	14.10a	15.10abc	13.40a	13.60ab	14.40a	12.27abc
HR, P	15.25a	17.00a	12.85a	12.80abc	11.27abcd	13.07ab
HR, P, L	15.20a	16.45a	12.70a	14.40ab	12.93abc	13.13ab
HR, P, L, +3	15.55a	15.70abc	13.00a	15.13a	13.60ab	13.73a

[z] Treatments – UTC: Untreated Check; LR: Low rate; MR: Moderate rate; HR: High rate; P: Application at planting; L: Application at lay-by; +3: Application at lay-by plus 3 weeks

[y] Means with the same letter are not significantly different based on Tukey-Kramer's test (P >0.05).

Table 9. Treatment effect on total nodes at Peanut Belt (PBRS), Upper Coastal Plain (UCPRS), and Sandhills (SRS) research stations in 2017 and 2018.

Treatment[z]	PBRS 2017-(1)	PBRS 2017-(2)	UCPRS 2017	PBRS 2018	UCPRS 2018	SRS 2018
			no.			
UTC	12.45c[y]	16.00b	15.20a	15.47bc	14.40b	13.20b
LR	13.30c	16.05b	14.95a	15.13c	14.60ab	13.40b
MR, P	15.90b	18.95a	15.40a	16.67abc	14.60ab	16.40ab
MR, P, L	16.40ab	18.25a	15.50a	16.87abc	15.87ab	16.60ab
MR, P, L, +3	15.85b	17.35ab	15.90a	17.27ab	17.87a	16.00ab
HR, P	17.50a	19.20a	15.45a	16.40abc	16.07ab	16.80a
HR, P, L	16.90ab	18.90a	15.95a	17.53a	16.73ab	16.00ab
HR, P, L, +3	17.20ab	18.40a	15.50a	17.87a	17.40ab	16.87a

[z] Treatments – UTC: Untreated Check; LR: Low rate; MR: Moderate rate; HR: High rate; P: Application at planting; L: Application at lay-by; +3: Application at lay-by plus 3 weeks

[y] Means with the same letter are not significantly different based on Tukey-Kramer's test (P >0.05).

Table 10. Treatment effects on tissue sample content of nitrogen, phosphorus and potassium across environments.

Treatment[z]	Nutrient Concentration		
	Nitrogen	Phosphorus	Potassium
	---------- % ----------		
UTC	2.39e[y]	0.28a	1.02b
LR	2.36e	0.26a	0.97b
MR, P	2.71d	0.25a	0.95b
MR, P, L	3.08c	0.26a	1.02b
MR, P, L, +3	3.15c	0.28a	1.17a
HR, P	3.22bc	0.27a	1.0b
HR, P, L	3.44ab	0.28a	1.02b
HR, P, L, +3	3.62a	0.28a	1.06ab

[z] Treatments – UTC: Untreated Check; LR: Low rate; MR: Moderate rate; HR: High rate; P: Application at planting; L: Application at lay-by; +3: Application at lay-by plus 3 weeks

[y] Means with the same letter are not significantly different based on Tukey-Kramer's test (P >0.05).

Table 11. Treatment effects on fiber yield and quality across environments.

Treatment[z]	Micronaire	Uniformity	Strength	Short Fiber Content
	---- Units ----	---- % ----	---- g tex^{-1} ----	---- % ----
UTC	4.8ab[y]	83.1a	28.9a	8.7a
LR	4.84a	83a	29.2a	8.8a
MR, P	4.65bcd	83.3a	29.4a	8.5a
MR, P, L	4.71abc	83.6a	29.6a	8.4a
MR, P, L, +3	4.73abc	83.3a	29.6a	8.4a
HR, P	4.62cd	83.5a	29.8a	8.4a
HR, P, L	4.53d	83.7a	29.4a	8.3a
HR, P, L, +3	4.61cd	83.7a	29.3a	8.2a

[z] Treatments – UTC: Untreated Check; LR: Low rate; MR: Moderate rate; HR: High rate; P: Application at planting; L: Application at lay-by; +3: Application at lay-by plus 3 weeks.

[y] Means with the same letter are not significantly different based on Tukey-Kramer's test (P >0.05).

CHAPTER TWO

Effects of Potassium Rates and Timing on Cotton Yield and Fiber Quality

B. L. Szilvay[1], K. L. Edmisten[2], G. D. Collins[3], R. Wells[2]

[1]Graduate Research Assistant, [2]Professor, Department of Crop and Soil Sciences, [3]Associate Professor, Department of Crop and Soil Science

North Carolina State University

Raleigh, North Carolina 27695-7620

Abstract

Potassium (K) is taken up in second greatest quantity, second only to nitrogen (N). The purpose of this research is to help better predict the effect on yield and quality that variable timings and rates of K have on cotton. Vegetative and reproductive growth of cotton is directly impacted by availability of K. Ensuring K is readily available for plant uptake during all stages of growth, especially during reproductive growth, is critical for cotton production. With improvements in cotton genetics and production and widespread problems, such as potassium deficiency syndrome, re-evaluating the current cotton K fertility recommendations is necessary.

Trials were conducted at the Sandhills Research Station (SRS) and the Peanut Belt Research Station (PBRS) in 2017 and 2018 and, in 2018, at the Upper Coastal Plains Research Station (UCPRS). Application timing and rate decisions are produced according to the soil test analysis. Treatments included one times (1x), one and a half times (1.5x), and two times (2x) the recommended rate applied as a broadcast granular at planting, at planting and at layby, and at planting, at layby, and three weeks after layby. Layby occurred between 45 and 62 days after planting (DAP). Measurements included nodes above white flower (NAWF) at first bloom, three weeks after layby, and five weeks after layby, a petiole sample two weeks after second layby, a height, nodes to the first fruiting branch (NFFB), nodes to the uppermost cracked boll (NUCB), nodes to the uppermost harvestable boll (NUHB), and total node count at 50-60 percent cracked boll, defoliation ratings, yield quality, and fiber quality. There were ten treatments, three rates and three timings with a non-treated control.

Potassium rate and application timing main effect for lint yield was not significant in any environments. None of the NAWF measurements had a significant response to any of the treatments. The concentration of tissue N did not vary with any treatment. K rate had a

significant effect on percent tissue phosphorus (P) content in the majority of environments, however K application timing did not. The concentration of tissue K did respond positively to K rates and timings in low K-index soils. None of the fiber quality measurements were significantly affected by K rate or timing in all environments.

Introduction

The amount of K absorbed by plants is second only to N (Havlin et al., 2005). Potassium's role in fruit development is more significant than its role in vegetative growth (Kerby and Adams, 1985; Pettigrew and Meredith, 1997). Cotton is sensitive to K deficiencies, more so than most other crops (Kerby and Adams, 1985; Khalifa et al., 2012). Yield benefits are observed through the promotion of strong early season development. Wise and timely inputs, such as fertilizer or crop protectants, help to produce profitable and healthy cotton (Dong et al., 2010; Edmisten and Collins, 2018; Javaid, 1990; Snipes and Baskin, 1994).

Cotton K Fertility

In 2015, 64 percent of cotton field soil samples submitted to the North Carolina Department of Agriculture (NCDA) were high or very high in K (Crozier and Hardy, 2018). Since seed and lint only constitute around 15 percent of the K accumulated in cotton plants, most of the K is left in the field for the following crop (Kerby and Adams, 1985). Applications of K fertilizer usually occur as a single preplant application (Oosterhuis, 2002), but in areas with high leaching potential, a split soil-applied K application, with half applied preplant and half applied at first bloom, has been reported as beneficial (Abaye, 1998). Choice of K fertilizer source does not seem to change efficacy (Howard et al., 1998; Makhdum et al., 2007). Management of K begins with consideration and knowledge of the amount of K in the soil and the soil type in question.

K Assimilation and Partitioning

Potassium is taken up solely as K^+. In the plant, K functions include water use, photosynthesis, starch synthesis, sugar transport, and water transport (Havlin et al., 2005). Since K is highly mobile in the plant (Havlin et al., 2005), K deficiency is normally seen in the older leaves as interveinal chlorosis and if prolonged, progresses to purple or necrotic leaves (Reedy et al., 2000; Kerby and Adams, 1985).

Compared to later in the season, the nutrient demand of cotton is minimal early in the season (Abaye, 2009; Bassett et al., 1970; Halevy, 1976), however, from 40 to 80 DAP, K uptake increases drastically (Bassett et al., 1970) and peaks at early squaring to early bloom (Halevy, 1976). Nutrient uptake follows a similar trend as growth, however uptake precedes growth. Makhdum et al. (2007) observed a steep upward trend in growth 60 DAP that didn't tapper off until nearly 120 DAP. Total K^+ uptake is at least 125 kg ha^{-1} for a fully mature plant (Bassett et al., 1970; Kerby and Adams, 1985). During periods of elevated uptake, as much as 2.1 to 3.4 kg K ha^{-1} can be taken up daily (Bassett et al., 1970).

Before reproductive growth begins, K accumulates in the leaves and stems (Bassett et al., 1970), which at this point only constitutes 15 percent of the total K that will be taken up and 7 percent of the total dry matter (Makhdum et al., 2007). The dry weight (DW) of vegetative growth and burs increases from 120 DAP to 150 DAP before decreasing because the plant reached cutout, while the DW of lint and seed persistently grows from 90 DAP to 150 DAP (Makhdum et al., 2007). Late in the season, leaf and stem K is translocated into the bolls (Halevy, 1976).

Cotton can exhibit K deficiency symptoms on fields with sufficient K (Cassman et al., 1989). According to Brouder and Cassman (1990), genetic traits and subsoil K supply are factors

that affect K availability. More specifically, the K-efficient cultivar in their study produced 58 percent more root dry matter and 25 percent more seedcotton than the sensitive cultivar. Therefore, it could be that the allocation of assimilates early in the growing season is not ideal for cotton to keep up with the bolls high energy requirement later in the season. Another explanation for the deficiency in K is that cotton is known to be a poor K absorber (Rosolem and Mikkelsen, 1991). Cotton retains high concentrations of K in leaves before reproductive growth begins in order to be capable of suppling sufficient K to fruiting structures later. In cases where the boll load is too much for the plant to adequately supply K, the deficiency symptoms will appear in the upper leaves (Reedy et al., 2000). According to a study done by Rosolem and Mikkelsen (1991), cotton can prevail in a K deficient environment late in the season for up to thirty days without experiencing yield loss.

In a study by Pettigrew and Meredith (1997), adequate K levels had a direct positive effect on N use efficiency in cotton (Havlin et al., 2005). They concluded that without proper K nutrition, higher rates of N may not be advantageous. Considering the growth stage and how it interacts with trends in uptake quantity is essential for understanding K assimilation and partitioning.

Growth Habits and K

Maturity is delayed in cotton that has access to very high levels of K in the soil (Gwathemy and Howard, 1998; Kerby and Adams, 1985) and is cut short by deficiency (Kerby and Adams, 1985). Boll growth requires sugars at very high rates which must be transported using energy from Adenosine triphosphate (ATP) that is synthesized using K (Havlin et al., 2005). Bennett et al. (1965) reported increased boll weights as a result of increased K rates. Potassium deficiencies can cause low lint yield (Pettigrew, 2003; Pettigrew and Meredith, 1997;

Read et al., 2006), low boll weight (Pettigrew and Meredith, 1997; Read et al., 2006), boll shedding (Kerby and Adams, 1985), and leaf shedding (Read et al., 2006).

Conclusions drawn about cotton's DW response to K tend to be contradictory. According to Pettigrew and Meredith (1997), excluding situations where K is deficient, DW does not respond to K fertilizer. According to Makhdum et al. (2007), DW responds significantly to K fertilizer. Much of the research suggests that lint and seed yield exhibits a response to K rates (Bennett et al., 1965; Cassman et al., 1989; Clement-Bailey and Gwathmey, 2007; Gormus, 2002; Kerby and Adams, 1985; Khalifa et al., 2012; Makhdum et al., 2007). Overall variable responses are reported for cotton yield and fiber quality in relation to the rate of K applied.

Soil K Dynamics

Although some soils may be high in K, only a portion, 1 to 10 percent, of that may be plant available. Weathering parent material gradually releases nonexchangeable K, which can slowly release exchangeable K that can desorb K into solution for plant uptake. Adding fertilizers or organic materials containing K will add K back into solution, but it can be leached or adsorbed by minerals into exchangeable K and then fixed into nonexchangeable K, ultimately making it unavailable to plants (Havlin et al., 2005). Potassium is less prone to leaching than N, but the degree of leaching increases with the amount of course soil present (Öborn et al., 2005). The soil cation exchange capacity (CEC) has a role in determining how tightly bound the potassium (K^+) cation is to the soil particles. This affects how much K is in the soil solution and how much is available for plant uptake. Potassium is naturally more abundant in fine-textured soils than course-textured soils (Havlin et al., 2005; Kerby and Adams, 1985).

Potassium in soil solution can be taken up by the root through mass flow, movement down a pressure gradient, or through diffusion, movement of molecules from areas of high to

low concentrations (Barber, 1985; Havlin et al., 2005). Mass flow is the primary way of taking up K, but can be limited by water availability (Barber, 1985). Diffusion is a slow process and is limited by the distance it can travel through the soil as well as soil moisture (Zeng and Brown, 2000). Diffusion allows roots to adsorb K only as far as one to four millimeters away (Barber, 1985; Havlin et al., 2005).

Mulder's chart (Goldy, 2016) is used to determine certain antagonistic and stimulative interactions between K and other nutrients. When K is at high levels in the soil, boron uptake can be suppressed and iron and manganese uptake is stimulated. However, when either calcium, magnesium, phosphorous, aluminum, sodium, or N is excessive, K uptake is suppressed (Havlin et al., 2005). Soil type, water availability, and soil chemistry are among many factors that affect the availability of K for uptake.

K Effect on Fiber Quality

Potassium deficiency can cause problems for certain fiber quality parameters (Pettigrew and Meredith, 1997) including decreased strength (Read et al., 2006), short staple (Bennett et al., 1965), and low micronaire (Bennett et al., 1965; Read et al., 2006) only when severely deficient for extended amount of time. Potassium at high or very high levels does not seem to affect cotton yield and is only occasionally a concern for fiber quality (Marcus-Wyner and Rains, 1982). Bennett et al. (1965) reported no changes in elongation at any rates, but did report a decrease in fiber strength at rates above 140 kg K ha^{-1}. Priority should be set on avoiding a K deficiency when considering fiber quality.

In recent years, cotton has experienced deficiency symptoms despite having access to an adequate supply of K in the soil. This problem could be due to factors such as leaching, increased boll load, or inadequate root genetics. The objective of this research is to help

understand and develop management decisions based on application rates and timings that will avoid K stress in cotton.

Potassium Deficiency Syndrome

Potassium deficiencies in cotton have begun to appear in the latter part of the growing season where soil reports suggest K levels are sufficient (Oosterhuis, 2002; Weir et al., 1986). This phenomenon has been called potassium deficiency syndrome by some. Reasoning behind these occurrences include infection from *Verticillum* wilt (Weir et al., 1986), root knot nematode (*Meloidohyne incognita*) damage (Oosterhuis, 2002), and that cotton is known to be a poor K absorber (Rosolem and Mikkelsen, 1991). While the pest pressure can be minimized through the use of pesticides, increasing K absorption in the roots is not as easily resolved. As mentioned previously, bolls are a major K sink (Halevy, 1976; Leffler and Tubertini, 1976; Weir et al., 1986) and genotypes have been developed with root systems that are more efficient K absorbers than others (Brouder and Cassman, 1990; Halevy, 1976). Foliar applications of K have been used effectively to proactively or retroactively relieve K deficiency that occurs during the boll fill period (Oosterhuis, 2002). Bolls receive a portion of K from leaves and other vegetative structures during the boll fill period (Reedy et al., 2000). Cotton accumulates K at elevated rates before reproductive growth when there is greater than sufficient quantities available in the soil (Bennett et al., 1965). Therefore, maintaining a high amount of K in the soil for luxury consumption may benefit cotton yield. However, since K is leachable and has many environmental factors that affect availability of the nutrient, considering the timing of application(s) is critical for profitability. This research was conducted to help form management decisions regarding rate and application timing of K on current cotton cultivars that help alleviate K deficiency problems.

Materials and Methods

Experiments were conducted in 2017 and 2018 at the Peanut Belt Research Station (PBRS), the Upper Coastal Plain Research Station (UCPRS), and the Sandhills Research Station (SRS). Soil series, soil pH, soil CEC, and planting date for each location is illustrated in Table 1. Monthly and cumulative precipitation for each growing environment is illustrated in Table 2 (CRONOS, 2018). The cultivar used at all locations in 2017 and 2018 was Stoneville 4848 GLT^{TM} (Stoneville®, Bayer CropScience, Memphis, Tennessee), with exception to SRS location in 2017, which was planted with ST 5115 GLT^{TM} (Stoneville®, Bayer CropScience, Memphis, Tennessee) due to issues with availability of ST 4848. Both cultivar's average performance over four years in the official variety test at SRS is similar according to the NC Cotton Variety Performance Calculator (NC State Extension, 2017). Seeding rate at all locations was between 9.84 seeds meter^{-1} and 13.12 seeds meter^{-1}. The experiment was a randomized complete block design with four replications at each location. Experiments at UCPRS were planted with a John Deere four row 1700 planter (John Deere, Moline, IL) and had four 12.2 m long rows spaced 0.91 m apart. Experiments at PBRS were planted with a John Deere 7300 four-row planter (John Deere, Moline, IL) and had four 12.2 m long rows spaced 0.91 m apart. Experiments at SRS were planted with a John Deere four-row 7300 vacuum planter (John Deere, Moline, IL) and had four 12.2 m long rows spaced 0.97 m apart.

Potassium (K) was broadcast applied with a chest mounted fertilizer spreader using a granular 0-0-60 (Potassium chloride) fertilizer to achieve total rates one times (1x), one and a half times (1.5x), and two times (2x) the recommended potash value (Table 1.), based on soil samples analyzed at the North Carolina Department of Agriculture and Consumer Services agronomic lab using the Mehlich-3 analytical method, and an non-treated control. Treatments

were applied either at planting, at planting and layby, or at planting, at layby, and three weeks after layby. Layby occurred between 45 and 62 days after planting (DAP). Treatments, application rates, and application timings are illustrated in Table 3. Mepiquat chloride (Mepex®, DuPont, Wilmington, DE.) and other growth regulators were not applied to any plots due to the different rate and extent of foliar growth between individual plots. All other management procedures were conducted according to the NCDA soil test recommendations.

Stand counts were recorded within three weeks after planting. Plant height and nodes above white flower (NAWF) for five plants on the two center rows were recorded at first bloom, at three weeks after layby, and at five weeks after layby. Petiole samples were collected at five weeks after layby and sent to Water's Agricultural Laboratories, Incorporated (Warsaw, NC) for analysis of nitrogen (N), phosphorus (P), and K concentrations. End of season plant mapping was recorded on five plants on the two center rows when 50-60 percent of bolls are open by recording height, nodes to the first fruiting branch (NFFB), nodes to the uppermost cracked boll (NUCB), nodes to the uppermost harvestable boll (NUHB), and total nodes. Nodes to the uppermost cracked boll recorded on a specific date can be used to signify differences in maturity between treatments (Whitaker et al., 2008). A visual defoliation rating was recorded at harvest which captured the percentage of bolls open, the percentage of defoliation, and the percentage of desiccation. Desiccation was determined by the amount of dried, stuck leaves appearing on the plant.

The center two rows of the plots were harvested with a two row John Deere 9910 spindle-type picker (John Deere, Moline, IL). Each plot's total seedcotton yield was recorded and a 200 g sub-sample was collected for seed weight, lint weight, lint percentage, and High Volume Instrumentation (HVI) analysis. Seed weight, lint weight, and lint percentage was collected by

ginning samples with a continental 12-saw cotton gin (Continental Eagle Corporation, Prattville, AL). The HVI analysis was conducted at Cotton Inc. (Cary, NC). The HVI data included micronaire, fiber length (upper half mean length), length uniformity, fiber strength, elongation, and short fiber content.

All data were subjected to analysis of variance using PROC GLIMMIX (GLIMMIX procedure) in SAS version 9.4 (SAS Inst., 2013). Means of significant main effects and interactions were separated using Tukey-Kramer's test at $p \leq 0.05$.

Results and Conclusions

Potassium rate and application timing main effect for lint yield was not significant in individual environments (Table 4) or in all environments (Table 5). The only exception is in SRS 2018 where the untreated check produced a lower yield than the 1x and 2x recommended K rate applied at planting (Table 4). Two environments, PBRS 2017 and UCPRS 2018, had a soil K-index of 47 and 52 respectively (Table 1). A K index around 50 would typically recommend a K application primarily for maintenance and would not necessarily be expected to produce a yield response. Lower K index values, such as the ones at SRS 2017, SRS 2018, and PBRS 2018 would be considered sub-optimal and a yield response would typically be expected from a K application. Separated by years, 2017 overall produced lint yields significantly higher than 2018 (Table 6). Neither 2017 nor 2018 environments separate showed any difference in lint yield between treatments despite the difference in overall lint yield seen from one year to the next. The range of average lint yields by treatment in 2017 was from 1081 kg ha^{-1} to 1202 kg ha^{-1}, while the range of average lint yields by treatment in 2018 was from 500 kg ha^{-1} to 664 kg ha^{-1}.

Increasing K rates in this experiment did not result in significantly greater lint yield, regardless of environment. In other similar studies, (Bennett et al., 1965; Cassman et al., 1989;

Clement-Bailey and Gwathmey, 2007; Gormus, 2002; Kerby and Adams, 1985; Khalifa et al., 2012; Makhdum et al., 2007), K rate was found to increase lint yield. Reasoning for this discrepancy could be that K that was available in the soil satisfied the total need of the crop, or that another environmental factor was more limiting than the K. Although there were locations that experienced excessive rainfall and had course soils, K is less prone to leaching than N which could lead to N being a more limiting factor. At SRS the course soils have a very low water holding capacity which can significantly limit K uptake if soil water availability is low. Similar to a study by Marcus-Wyner and Rains (1982), high K rates did not negatively affect lint yield. Potassium application timing also had no effect on lint yield. This is in contradiction to Gormus (2002), who found that split applications of K negatively affected lint yield.

No difference was observed between treatments for any of the NAWF measurements at individual locations (Data not shown), with two exceptions. The NAWF measurement recorded at three weeks after layby at SRS 2018 showed that 2x recommended K rate applied at planting and layby produced a higher node count than 1.5x recommended rate applied at planting, layby, and three weeks after layby. The other exception is at five weeks after layby where 1.5x recommended K rate applied at planting, layby, and three weeks after layby had a significantly higher node count than the 1x recommended K rate treatment applied at planting and layby. Plant heights in all environments were not significantly different for any height measurement (Data not shown). The only exception is at three weeks after layby where the treatment of 1.5x recommended K rate applied at planting, layby, and three weeks after layby was significantly taller, at 89 cm, than the 2x recommended K rate applied at planting and layby treatment, at 83 cm. Although these two treatments were statistically different, a trend was not observed.

Potassium rate and timings main effect for all plant mapping measurements in all environments combined and individual environments were not significant (Data not shown), with two exceptions. At SRS 2018, NFFB was higher for the 1x recommended K rate applied at planting than the 1.5x recommended K rate applied at planting, layby, and three weeks after layby (Data not shown). The other exception is at SRS 2018, NUHB was lower for the untreated check than the 1x and 2x recommended K rate applied at planting, the 1.5x recommended K rate applied at planting and layby, and the 2x recommended K rate applied at planting, layby, and three weeks after layby (Data not shown). Nodes to first fruiting branch, NUHB, and total nodes measurement are higher overall in 2017 than in 2018 (Data not shown). The range of total nodes by treatment in 2017 was from 17.3 to 18.6 nodes, while the range of total nodes by treatment in 2018 was from 15.2 to 16.6 nodes.

There was no difference in any defoliation rating measurements among any treatments due to K rate and timings in all environments (Data not shown). All treatments had at least 85 percent defoliation, at least 90 percent open bolls, no more than 7 percent desiccation, and no more than 2 percent regrowth.

Growth and maturity was not significantly affected by K rate or timing, which is in contradiction to other studies that concluded higher rates of K cause delayed maturity (Gwathemy and Howard, 1998; Kerby and Adams, 1985), lower rates of K can hasten maturity (Kerby and Adams, 1985), and that higher rates of K produced more growth in cotton (Bennett et al., 1965).

Potassium rate and application timing main effect for percent tissue N content in individual environments was not significant with the exception of PBRS 2018 where the untreated check having a significantly higher percentage than the treatment of 1.5x and 2x

recommended K value applied at planting and the 2x recommended K value applied at planting, layby, and three weeks after layby (Table 7). No pattern was observed in these results.

Potassium rate had a significant effect on percent tissue P content at SRS 2017 and 2018 and PBRS 2018. At PBRS 2018 the untreated check had a significantly higher percent tissue P content than the 1.5x recommended K rate applied at planting, layby, and three weeks after layby and the 2x recommended K rate applied at planting (Table 8). At SRS 2017 the untreated check had a significantly higher percent tissue P content than the 1.5x recommended K rate applied at planting and layby and the 2x recommended K rate applied at planting, layby, and three weeks after layby. At SRS 2018 the untreated check had a significantly higher percent tissue P content than all the treatments except for 2x recommended K rate applied and planting and the 1x and 1.5x recommended K rate applied at planting, layby, and three weeks after layby. None of the soil nutrient interactions from Mulder's chart (Goldy, 2016) can explain the significance between the treatments seen in the tissue N and P at PBRS 2018 and tissue P at SRS 2017 and 2018.

Potassium rate and timing had a significant effect on percent tissue K content at PBRS 2018 and SRS 2017 and 2018 (Table 9). At PBRS 2018 the untreated check had a lower percent tissue K content than the 1x, 1.5x, and 2x recommended K rate applied at planting and the 2x recommended K rate applied at planting and layby. At SRS 2017 the untreated check had a lower percent tissue K content than the 1.5x and 2x recommended K rate applied at planting and layby and at planting, layby, and three weeks after layby. At SRS 2017 the 2x recommended K rate applied at planting, layby, and three weeks after layby had a significantly higher percent tissue K content than all 1x recommended K rate treatments and the 1.5x recommended K rate treatment applied at planting. At SRS 2018 the untreated check had a significantly lower percent tissue K content than the 2x recommended K rate treatment applied at planting and at planting and layby.

The data from this study suggest that in an environment with low K-index soils, like SRS, increasing the K rate to double the recommended rate, splitting applications, or a combination of both may be necessary to produce a significant increase in tissue K concentration. The increased concentration of tissue K did not correlate into increase lint yield however.

Micronaire was significantly affected by K rate at SRS 2018 but not for any of the other environments (Table 10). At SRS 2018 the untreated check produced a micronaire value lower than all other treatments. No clear relationship between K rate and timing and micronaire was found. Potassium rate and application timing main effect for all other fiber quality measurements, including UHM, uniformity, strength, elongation and short fiber content, in all environments was not significant. None of these fiber quality measurements fell in the discount range for any of the treatments in all environments.

The data suggest that K rate and timing does not have a significant effect on micronaire, which can be supported by the findings by Gormus (2002), but is in contrast to findings by Bennett et al. (1965) and Cassman et al. (1990), who found a response to micronaire from K rate. All other fiber quality measures including UHM, uniformity, strength, elongation and short fiber content did not respond to K rate or timing. In other studies fiber strength (Gormus, 2002) and fiber length (Cassman et al., 1990; Gormus, 2002) responded positively to increasing K rate. Still, other experiments (Pettigrew et al., 1996) show no change in fiber strength due to K rate. Much is unknown about how fiber quality responds to K rate and timing, however studies tend to reveal a strong genotypic relationship between the interaction of these two variables.

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Table 1. Soil series, soil pH, recommended potash value, and planting date at Peanut Belt (PBRS), Upper Coastal Plain (UCPRS), and Sandhills (SRS) research stations in 2017 and 2018.

Environment		Soil Series	Soil pH[z]	K Index	Potash Value[z]	CEC[z]	Planting Date
Location	Year						
					---- kg ha^{-1} ----		
PBRS	2017	Lynchburg sandy loam *Fine-loamy, siliceous, semiactive, thermic Aeric Pleaquults*	6.2	47	67	4.5	May 11
SRS	2017	Candor sand *Sandy, kaolinitic, thermic Grossarenic Kandiudults*	6.6	26	112	4.2	May 1
PBRS	2018	Goldsboro sandy loam *Fine-loamy, siliceous, subactive, thermic Aquic Paleudults*	5.7	38	79	4.2	May 15
UCPRS	2018	Norfolk loamy sand *Fine-loamy, kaolinitic, thermic Typic Kandiudults*	5.8	52	56	3.3	May 14
SRS	2018	Candor sand *Sandy, kaolinitic, thermic Grossarenic Kandiudults*	6.1	21	123	4.3	May 4

[z] Soil samples were analyzed at the North Carolina Department of Agriculture and Consumer Services Agronomic Lab using the Mehlich-3 Analytical Method.

Table 2. Monthly and cumulative precipitation at Peanut Belt (PBRS), Upper Coastal Plain (UCPRS), and Sandhills (SRS) research stations in 2017 and 2018.

Month	PBRS 2017	SRS 2017	PBRS 2018	UCPRS 2018	SRS 2018
	---------- cm ----------				
April	14.4	12	11.7	10.7	11.7
May	14.8	16.1	24.8	16.6	4.6
June	14.2	9.5	14.1	7.3	3.9
July	18.8	9.4	29.2	18.1	12.8
August	12.8	7.5	15.8	9.4	22.5
September	8.2	6.4	14.8	13	48.4
October	6.9	8.8	7.7	4.9	16.1
Total	90.1	69.7	118.1	80	120

Table 3. Potassium treatments with rates and timings for split applications.

UTC	**None**	**0**	**0**	**0**
1x, P	**1x**	**100**	**0**	**0**
1x, P, L	**1x**	**50**	**50**	**0**
1x, P, L, +3	**1x**	**33**	**33**	**33**
1.5x, P	**1.5x**	**150**	**0**	**0**
1.5x, P, L	**1.5x**	**75**	**75**	**0**
1.5x, P, L, +3	**1.5x**	**50**	**50**	**50**
2x, P	**2x**	**200**	**0**	**0**
2x, P, L	**2x**	**100**	**100**	**0**
2x, P, L, +3	**2x**	**67**	**67**	**67**

[z] **Treatments – UTC: Untreated Check; 1X: Recommended rate; 1.5X: 1.5 x Recommended rate; 2X: 2 x Recommended rate; P: Application at planting; L: Application at lay-by; +3: Application at lay-by plus 3 weeks**

[y] **Recommended value based on soil analysis by the North Carolina Department of Agriculture and Consumer Services Agronomic Lab using the Mehlich-3 Analytical Method.**

Table 4. Treatment effects on fiber yield at Peanut Belt (PBRS), Upper Coastal Plain (UCPRS), and Sandhills (SRS) research stations in 2017 and 2018.

Treatment[z]	PBRS 2017	SRS 2017	PBRS 2018	UCPRS 2018	SRS 2018
		---------- kg ha^{-1} ----------			
UTC	1745a[y]	612a	620a	562a	318b
1x, P	1673a	647a	584a	559a	784a
1x, P, L	1607a	683a	633a	630a	729ab
1x, P, L, +3	1575a	737a	613a	533a	700ab
1.5x, P	1635a	652a	615a	624a	624ab
1.5x, P, L	1510a	743a	617a	552a	693ab
1.5x, P, L, +3	1618a	785a	632a	553a	674ab
2x, P	1628a	658a	636a	511a	814a
2x, P, L	1637a	712a	632a	632a	554ab
2x, P, L, +3	1487a	676a	598a	618a	596ab

[z] Treatments – UTC: Untreated Check; 1X: Recommended rate; 1.5X: 1.5 x Recommended rate; 2X: 2 x Recommended rate; P: Application at planting; L: Application at lay-by; +3: Application at lay-by plus 3 weeks.

[y] Means with the same letter are not significantly different based on Tukey-Kramer's test (P >0.05).

Table 5. Treatment effects on fiber yield and quality across environments.

Treatment[z]	Lint Yield	Micronaire	Uniformity	Strength	Short Fiber Content
	----- kg ha^{-1} -----	----- Units -----	----- % -----	----- g tex^{-1} -----	----- % -----
UTC	688a[y]	4.56b	82.71a	29.29a	8.67a
1x, P	758a	4.78a	82.96a	29.94a	8.46a
1x, P, L	764a	4.83a	82.35a	29.61a	8.76a
1x, P, L, +3	742a	4.74ab	82.64a	29.97a	8.77a
1.5x, P	740a	4.73ab	82.55a	29.27a	8.72a
1.5x, P, L	734a	4.73ab	82.99a	29.71a	8.48a
1.5x, P, L, +3	761a	4.69ab	82.75a	29.42a	8.47a
2x, P	758a	4.77a	82.49a	29.67a	8.59a
2x, P, L	743a	4.78a	83.06a	29.34a	8.46a
2x, P, L, +3	709a	4.7ab	82.57a	29.36a	8.72a

[z] Treatments – UTC: Untreated Check; 1X: Recommended rate; 1.5X: 1.5 x Recommended rate; 2X: 2 x Recommended rate; P: Application at planting; L: Application at lay-by; +3: Application at lay-by plus 3 weeks.

[y] Means with the same letter are not significantly different based on Tukey-Kramer's test (P >0.05).

Table 6. Potassium rate and application timing main effect for lint yield years separate.

Treatment[z]	Lint Yield	
	2017	2018
	---------- kg ha^{-1} ----------	
UTC	1178a[y]	500a
1x, P	1160a	642a
1x, P, L	1146a	663a
1x, P, L, +3	1157a	615a
1.5x, P	1143a	621a
1.5x, P, L	1127a	621a
1.5x, P, L, +3	1202a	620a
2x, P	1143a	654a
2x, P, L	1127a	605a
2x, P, L, +3	1081a	603a

[z] Treatments – UTC: Untreated Check; 1X: Recommended rate; 1.5X: 1.5 x Recommended rate; 2X: 2 x Recommended rate; P: Application at planting; L: Application at lay-by; +3: Application at lay-by plus 3 weeks.
[y] Means with the same letter are not significantly different based on Tukey-Kramer's test (P >0.05).

Table 7. Treatment effects on tissue sample content of nitrogen at Peanut Belt (PBRS), Upper Coastal Plain (UCPRS), and Sandhills (SRS) research stations in 2017 and 2018.

Treatment[z]	PBRS 2017	SRS 2017	PBRS 2018	UCPRS 2018	SRS 2018
	---------- % ----------				
UTC	2.91a[y]	3.74a	4.27a	2.59a	2.75a
1x, P	2.79a	3.46a	3.76ab	2.63a	3.07a
1x, P, L	2.76a	3.48a	3.81ab	2.70a	2.72a
1x, P, L, +3	2.90a	3.56a	3.91ab	2.69a	2.34a
1.5x, P	2.69a	3.45a	3.53b	2.62a	2.25a
1.5x, P, L	2.63a	3.55a	3.75ab	2.70a	2.76a
1.5x, P, L, +3	2.73a	3.37a	3.79ab	2.53a	3.02a
2x, P	2.79a	3.33a	3.53b	2.42a	3.13a
2x, P, L	2.82a	3.65a	3.69b	2.71a	2.16a
2x, P, L, +3	2.85a	3.46a	3.94ab	2.60a	2.68a

[z] Treatments – UTC: Untreated Check; 1X: Recommended rate; 1.5X: 1.5 x Recommended rate; 2X: 2 x Recommended rate; P: Application at planting; L: Application at lay-by; +3: Application at lay-by plus 3 weeks.

[y] Means with the same letter are not significantly different based on Tukey-Kramer's test (P >0.05).

Table 8. Treatment effects on tissue sample content of phosphorus at Peanut Belt (PBRS), Upper Coastal Plain (UCPRS), and Sandhills (SRS) research stations in 2017 and 2018.

Treatment[z]	PBRS 2017	SRS 2017	PBRS 2018	UCPRS 2018	SRS 2018
	---------- % ----------				
UTC	0.26a[y]	0.30a	0.51a	0.30a	0.36a
1x, P	0.26a	0.29ab	0.42ab	0.25a	0.23b
1x, P, L	0.24a	0.25ab	0.42ab	0.26a	0.20b
1x, P, L, +3	0.26a	0.25ab	0.43ab	0.26a	0.26ab
1.5x, P	0.24a	0.26ab	0.41ab	0.26a	0.21b
1.5x, P, L	0.25a	0.23b	0.43ab	0.28a	0.22b
1.5x, P, L, +3	0.26a	0.24ab	0.39b	0.23a	0.24ab
2x, P	0.25a	0.24ab	0.39b	0.24a	0.25ab
2x, P, L	0.24a	0.25ab	0.42ab	022a	0.21b
2x, P, L, +3	0.26a	0.23b	0.42ab	0.26a	0.21b

[z] Treatments – UTC: Untreated Check; 1X: Recommended rate; 1.5X: 1.5 x Recommended rate; 2X: 2 x Recommended rate; P: Application at planting; L: Application at lay-by; +3: Application at lay-by plus 3 weeks.

[y] Means with the same letter are not significantly different based on Tukey-Kramer's test (P >0.05).

Table 9. Treatment effects on tissue sample content of potassium at Peanut Belt (PBRS), Upper Coastal Plain (UCPRS), and Sandhills (SRS) research stations in 2017 and 2018.

Treatment[z]	PBRS 2017	SRS 2017	PBRS 2018	UCPRS 2018	SRS 2018
	---------- % ----------				
UTC	1.02a[y]	0.65c	1.14b	1.53a	0.57b
1x, P	1.09a	0.83bc	1.41ab	1.52a	0.95ab
1x, P, L	0.93a	0.86bc	1.64a	1.52a	0.81ab
1x, P, L, +3	1.03a	0.88bc	1.70a	1.44a	0.90ab
1.5x, P	1.06a	0.86bc	1.50ab	1.77a	1.00ab
1.5x, P, L	1.06a	1.00ab	1.64a	1.60a	0.93ab
1.5x, P, L, +3	1.13a	0.97ab	1.75a	1.26a	1.04ab
2x, P	0.93a	0.95abc	1.54ab	1.72a	1.27a
2x, P, L	1.05a	1.11ab	1.58ab	1.56a	1.14a
2x, P, L, +3	1.14a	1.23a	1.85a	1.64a	1.02ab

[z] Treatments – UTC: Untreated Check; 1X: Recommended rate; 1.5X: 1.5 x Recommended rate; 2X: 2 x Recommended rate; P: Application at planting; L: Application at lay-by; +3: Application at lay-by plus 3 weeks.

[y] Means with the same letter are not significantly different based on Tukey-Kramer's test (P >0.05).

Table 10. Treatment effects on micronaire at Peanut Belt (PBRS), Upper Coastal Plain (UCPRS), and Sandhills (SRS) research stations in 2017 and 2018.

Treatment[z]	PBRS 2017	SRS 2017	PBRS 2018	UCPRS 2018	SRS 2018
		---------- Units ----------			
UTC	4.41ab[y]	4.55a	5.11a	4.82a	3.93b
1x, P	4.66a	4.58a	4.94a	4.81a	4.92a
1x, P, L	4.59ab	4.62a	5.20a	4.95a	4.77a
1x, P, L, +3	4.44ab	4.87a	5.10a	4.78a	4.54a
1.5x, P	4.35ab	4.62a	5.15a	4.80a	4.72a
1.5x, P, L	4.56ab	4.58a	5.05a	4.84a	4.64a
1.5x, P, L, +3	4.41ab	4.56a	4.99a	4.92a	4.60a
2x, P	4.45ab	4.62a	5.10a	4.84a	4.83a
2x, P, L	4.32ab	4.84a	5.17a	4.82a	4.75a
2x, P, L, +3	4.38b	4.56a	5.15a	4.87a	4.56a

[z] Treatments – UTC: Untreated Check; 1X: Recommended rate; 1.5X: 1.5 x Recommended rate; 2X: 2 x Recommended rate; P: Application at planting; L: Application at lay-by; +3: Application at lay-by plus 3 weeks.

[y] Means with the same letter are not significantly different based on Tukey-Kramer's test (P >0.05).

CHAPTER THREE

Using Cultivar Mixtures to Improve Yield Stability of Cotton (*Gossypium hirsutum* L.) in Unpredictable Environments

B. L. Szilvay[1], K. L. Edmisten[2], G. D. Collins[3], R. Wells[2]

[1]Graduate Research Assistant, [2]Professor, Department of Crop and Soil Sciences, [3]Associate Professor, Department of Crop and Soil Science

North Carolina State University

Raleigh, North Carolina 27695-7620

Abstract

Cultivar selection is a critical decision growers make before the growing season begins. One of the best predictors for a cultivar's performance is yield stability, or consistent performance across soil types, rainfall patterns, years, seeding rates, tillage practices, management practices, etc. However, there is not one cultivar that will outperform competitors in all environments, and attempts to predict which cultivar will perform best for all soils or environments in subsequent years is improbable. Additionally, cotton produced in dryland environments can yield both high, if rainfall is timely during critical growth stages, and low, if significant drought stress prevails. Blending cultivars that perform well in contrasting environments, or blending cultivars known to portray a high degree of yield stability across environments, may help spread the risk and improve yield stability in multiple environments when accounting for the uncertainty of growing conditions for any given year.

Using the NC Cotton Variety Performance Calculator (NC State Extension, 2017), five cultivars were chosen for this experiment based on prior performance in replicated trials (On-farm large-plot trials, and small-plot Official Variety Trials) that each have unique ideal environments and growing conditions. Some cultivars were chosen based on a high degree of yield stability across a broad range of environments in years with frequent rainfall and years with noticeable drought stress. Other cultivars were chosen based on consistent performance in either high-yield or low-yield environments. There were eight treatments which included each cultivar planted alone, all five mixed in equal proportions by seed count, and two binary cultivar treatments in a 50 percent mixture by seed count. Trials were conducted across 23 environments during 2017 and 2018. Stand counts were collected within three weeks after planting along with yield and fiber quality at harvest.

Statistically, mixtures did not produce a yield significantly different than an individual cultivar 61 percent of the time. A mixture was as likely, or more likely, to produce a lint yield lower than the highest yielding cultivar in a given year, as opposed to producing a lint yield higher than the lowest yielding cultivar. In a given year, one cultivar will outperform another at least some of the time. The data suggest that using a cultivar mixture will not help improve yield stability the majority of the time compared to the highest of the component cultivars. Using a mixture that pairs one cultivar that has historically good fiber quality with another cultivar that has historically high micronaire will improve micronaire the majority of the time. Using a five-way cultivar mixture raised micronaire more often than lowering it. Fiber length can be improved if the mixture is a pairing a low fiber quality and high fiber quality cultivar.

Introduction

Cultivar Selection

Cotton cultivar performance and classification includes a number of factors such as transgenic traits (York et al., 2004), yield potential (Bridge and Meredith, 1983; Poehlman and Sleper, 2006), yield stability (Thomson and Cunningham, 1979), maturity (Bowman, 2016; Poehlman and Sleper, 2006), fiber quality (Thomson and Cunningham, 1979; Poehlman and Sleper, 2006), stormproof (Poehlman and Sleper, 2006), leaf pubescence (Bourland et al., 2003), and seed size (Khan et al., 2014). Cultivars should be placed in environments where they are likely to perform competitively. For instance, herbicide resistance may be a more important selection criteria to consider for an environment with heavy weed pressure, or a three-gene Bt insect resistant cultivar may be desired over a two-gene cultivar in cases where bollworm resistance to two-gene cultivars is observed. Understanding a cultivar's performance is best achieved by evaluating its average across as many environments as possible as opposed to single

location data from trials in close proximity to a grower's farm (Hicks, 1992). Cultivar performance assessments are far more accurate when based on trial results from as many locations and years as possible (Bowman, 1998; Collins and Whitaker, 2014; Hicks et al., 1992). Evaluating multi-year data may be difficult due to the rapid turnover rate of cultivars that has been observed in recent years, which averages 37 percent annually (Bowman, 1998), therefore it is important for a high number of replicated trials to be conducted in order to effectively evaluate cultivar yield stability. Hicks et al. (1992) reported higher yields in subsequent cultivar trials when the three highest yielding cultivars were selected from data sets based on multi-location data only as compared to multi-year data only. The highest yields were observed when cultivars were selected from three-year, three-location data. Therefore, although both are significant, emphasis should be given to multi-location data rather than multi-year data. Still, in the time cultivars are commercially available, conducting a high number of cultivar trials often identify strengths and weaknesses of modern cultivars more clearly than a few locations of data. Planting a high proportion of acreage in a single cultivar is not advised, as it is risky due to the unpredictability of the weather and other environmental factors, which increases the likelihood of exposing a cultivar's weakness. In a study by Himanen et al. (2013), a greater diversity in barley cultivars in a region resulted in yield benefits. However, when an environment provides suitable conditions for an individual cultivar, cultivar diversity may not be as significant. Little reliable information is available to predict the environment a crop will encounter across geographies or years. Therefore, it is recommended that growers utilize multiple cultivars in a cropping system (Wolfe, 1988) to offset risks and capture rewards in yields.

Practical Uses of Cultivar Mixtures

Mixing cultivars has been used extensively in numerous crops in attempts to address various problems at a low cost (Wolfe, 1997). Perhaps the most widely adopted use of cultivar mixtures thus far is refuge crops and refuge-in-a-bag planting systems (Yang, 2015). In corn and cotton, these systems are designed to slow the buildup of *Bacillus thuringiensis* (Bt) resistant insects by planting non-Bt cultivars with the Bt cultivars which allows the susceptible insects to survive and breed (Agi et al., 2001; Gould, 2000).

Some cotton genotypes exhibit higher sensitivity to Tarnished plant bugs (*Lygus lineolaris* Palisot de Beauvois) than others. In a study by Bourland and Tugwell (1999), sensitive and resistant cultivars were planted together to evaluate the effect it had on overall resistance to tarnished plant bug damage. They, and others, concluded the mixtures did not improve susceptible cultivars to slow or buffer the spread of disease with a high degree of success (Castro, 2007; Creissen, 2016; Wolfe, 1988). Cultivar mixtures have been studied in cereal grains, such as barley and oats, for the effect it has on characteristics including yield (Jokinen, 1991; Kiær, 2012), yield stability (Creissen et al., 2016; Kiær et al., 2012), disease resistance (Finckh et al., 2000), lodging resistance (Grafius, 1966), and intraspecific competition (Jokinen, 1991). There are potential advantages to cultivar monocultures as compared to mixtures, primarily increased uniformity to assist in harvesting, marketing, and processing (Castro, 2007).

For cotton specifically, experiments have been conducted to evaluate the effect cultivar mixtures have on fiber quality enhancement (Faircloth et al. 2003), maximum yield (Innes and Jones, 2001), and insect resistance development (Agi et al., 2001). Faircloth et al. (2003) mixed high yielding cultivars with high fiber quality cultivars in an attempt to counteract a recurring trend towards low fiber quality associated with high yielding cultivars at the time. They concluded that blending cultivars may offer only a short-term solution. A study by Agi et al.

(2001) examined the bollworm damage of mixtures containing various proportions of Bollgard Bt cotton and non-Bt cotton. *Bacillus thuringiensis* (*Bt*) is a bacterium that is expressed through a transgenic Bt gene in plants and that produces a toxic protein, *cry*1Ac, that provides a level of control for lepidopteran larval pests. They found that as the percentage of Bt cotton increased in the mixture, the level of insect damage decreased and yield increased. In five experiments designed to investigate possible lint yield improvements in cultivar mixtures, Innes and Jones (1977) found that no yield benefits were provided from using mixtures over the individual cultivars. For all of these experiments, certain mixtures achieved their intended goal of preserving a Bt gene, improving yield, disease resistance, improving fiber quality, or minimizing insect damage, while others mixtures were less impactful or even antagonistic, which suggests that selecting the correct cultivars to blend should be strategic and is just as significant as choosing a singular cultivar.

Yield and Yield Stability

Yield stability can be defined as how frequently a cultivar yields competitively (compared to other cultivars) across a wide range of environments. Factors that may affect the environment include planting date, harvest date, management practices, soil type, seeding rate, tillage, rainfall/irrigation timing and rate, etc. (Collins and Whitaker, 2014). Stability is primarily described by the frequency in which a cultivar performs at or within the statistically highest yielding group in a cultivar trial over a range of environments or within a specific type of environment. This could be exhibited as an average across all trials or as a proportion such as the percentage of trials that the cultivar performed within the highest yielding group (Collins and Whitaker, 2014).

Bechere et al. (2008) reported an increase in yield stability with the use of cultivar mixtures in their experiment, however Innes and Jones (1977) found that mixtures did not improve stability. Cultivar mixtures function with the understanding that when the variation or biodiversity increases, the environmental stability increases as well (Yachi and Loreau, 1999). Plant breeding efforts to genetically increase yield stability of single cultivars have been in use for decades. Rating stability involves evaluating genotype x environment (GxE) interactions (Eberhart and Russell, 1966). Genotype x environment interactions can be used to evaluate the stability of cultivar mixtures as well (Creissen et al., 2016). There are three typical responses when comparing GxE interactions of two cultivars. The response that coincides with yield stability is, "In the environment where one cultivar lacks, the other is superior" (Poehlman and Sleper, 2006). Cultivar mixtures provide the ability to stabilize yield from unpredicted stresses and without considerable plant breeding through mechanisms that occur in non-uniform systems such as compensation, facilitation, and complementation (Creissen et al., 2016). Mixtures are sometimes described as having increased environmental plasticity, which is the ability of cultivars to respond and adapt to a change in the environment (Merz and Valenghi, 1997).

Binary cultivar mixtures tend to have yields intermediate of the two component cultivars (Trentbath, 1974; Craig and Gwathmey, 2003; Bechere et al., 2008; Bridge, 1984). Innes and Jones (1977) concluded from their five cultivar mixture experiments in Uganda, that component cultivars did not interact to yield higher in mixture than in monoculture (Innes and Jones, 1977). Riggs (1970) concluded from his two year, four cultivar mixture experiment, that the mixtures resulted in yields as high as the component cultivar with the highest yield. In a study in barley by Creissen et al. (2016), the cultivar mixture resulted in yields equivalent to the component cultivar

with the highest yield. Kiær et al. (2012) found that wheat yields in mixtures were greater than the component cultivars in five out of the six treatments.

Enhanced Fiber Quality

Previous research has been done focusing on addressing fiber quality issues in cotton (Craig and Gwathmey, 2003; Bechere et al., 2008; Faircloth et al., 2003; McConnell et al., 1991; Bridge et al., 1984; Simpson and Fiori, 1974). Aside from Simpson and Fiori (1974), the hypothesis for this research is that by mixing a high yielding, low fiber quality cultivar with a low yielding, high quality cultivar, the negative traits for quality will be suppressed by the positive ones. Simpson and Fiori (1974) were concerned with blending cultivars based solely on micronaire values.

Among the current research of mixtures in cotton, there seems to be a fair amount of variation, presumably due to differences in environments. Bridge et al. (2008) and McConnell et al. (1991) observed an increase in fiber strength among mixtures, while Simpson and Fiori (1974) and Bechere et al. (2008) found no significant difference in fiber strength. Faircloth et al. (2003) and Bechere et al. (2008) found that uniformity was lower for mixtures, but Craig and Gwathmey (2003) found that uniformity was not affected. Micronaire was found to be higher than the individual component cultivars (Bridge et al., 1984), or similar to the high yielding cultivar (Faircloth et al., 2003). Elongation was not significantly affected (Bechere et al., 2008; Bridge et al., 1984). Bridge et al. (1984) reported no change in staple length, while Bechere et al. (2008) reported an improvement.

The objective of this study is to evaluate if and how frequently the cultivar mixtures improve yield stability across a large number of environments. Using cultivar mixtures to avoid

fluctuation in yield and discounts for poor fiber quality has the potential to be easily adopted with very little added cost.

Materials and Methods

Using historical data collected from multiple on-farm and official variety trials (OVT) in 2015 and 2016 across the state of North Carolina and the NC Cotton Variety Performance Calculator (NC State Extension, 2017), the following five cultivars were selected. The cultivars selected included Deltapine (DP) 1538 B2XF™ (Deltapine®, Monsanto, Scott, MS), Phytogen (PHY) 312 WRF™ (Dow AgroScience®, Indianapolis, IN), DP 1646 B2XF™ (Deltapine®, Monsanto, Scott, MS), NexGen (NG) 3522 B2XF™ (NexGen®, Americot Inc, Lubbock, TX), and Stoneville (ST) 4848 GLT™ (Stoneville®, Bayer CropScience, Memphis, Tennessee). There were eight treatments total which included each cultivar planted alone, DP 1538 mixed with DP 1646 (Mixture A), PHY 312 with ST 4848 (Mixture B), and all five cultivars mixed (Mixture C). Mixtures were based on equal proportions of each cultivar based on seed count. Deltapine 1538 was chosen because its prior performance data suggested consistently competitive yields across all environments in relatively dry years, but it has resulted in consistently high micronaire and short staple. Deltapine 1646 was chosen due to its consistent yield stability across all environments in relatively wet years, and because it had very good lint quality. Phytogen 312 was chosen for its prior performance in low-yield environments (less than 1121 kg ha^{-1} yield potential) in a relatively wet year. Stoneville 4848 was chosen based on its yield potential in high-yield environments (greater than 1121 kg ha^{-1} yield potential) in a relatively wet year. NexGen 3522 was chosen based on its relatively consistent performance across multiple environments, and it's much earlier maturity than other cultivars included in this experiment. Mixture A was combined to evaluate the potential for PHY 312 to produce a higher yield in

relatively wet, low-yield environments where ST 4848 would produce a lower yield. Likewise, in a relatively dry, high-yield environment, mixture A would be evaluated for the potential of ST 4848 to yield higher than PHY 312. Mixture B was combined to evaluate the potential for DP 1538 to yield higher in dry environments where DP 1646 would historically yield lower, leading to yield stability. The same is true in a wet environment for mixture B, where DP 1646 would potentially yield higher and DP 1538 would yield lower. In mixture B, DP 1538 has historically exhibited poor fiber quality in trials, whereas DP 1646 has exhibited good fiber quality. Mixture C was designed so that the individual cultivars had distinct environments that are ideal to them. In mixture C, we are evaluating the ability of at least one cultivar in the mixture to respond to and compensate for being in an environment better suited for its genetics than the others.

Seeds mixtures were divided into equal proportions based on seed count, 50 percent for the binary mixtures, and 20 percent for the treatment that included all five cultivars. Treatments were added to OVT where each cultivar planted singularly was already included, and treatments were also evaluated in separate large plot replicated trials. Both the OVT and large plot trials were conducted using a randomized complete block design including either three to four replications. Plots were two rows wide and either 0.91 or 0.97 m apart in OVT, and four rows wide and either 0.91 or 0.97 m apart in large plot trials. Stand counts were within three weeks after planting and yield and fiber quality were collected at, or post-harvest to evaluate stability of cultivar mixtures compared to each cultivar of the mixture planted alone. Trials were conducted in 13 locations in 2017 and 10 locations in 2018. In 2017, seven of the 13 locations were in OVT at the Upper Coastal Plains Research Station (UCPRS), the Peanut Belt Research Station (PBRS), the Tidewater Research Station (TRS), the Piedmont Research Station (PRS), the Central Crops Research Station (CCRS), the Sandhills Research Station (SRS) and an on-farm

site in Scotland County (SCC), NC. Six of the 13 locations in 2017 were conducted using large plots at UCPRS, PBRS, TRS, Cherry Research Station (CRS), and twice at the SRS in both dryland and irrigated environments. In 2018, five of the 10 locations were included in OVT at the UCPRS, the PBRS, the TRS, the CCRS, and the SRS. The other five locations in 2018 were conducted using large plots at UCPRS, the PBRS, the TRS, and twice at the SRS in both dryland and irrigated environments. Soil series and planting date for each environment is illustrated in Table 1. Monthly and cumulative precipitation for each environment is illustrated in Table 2 (CRONOS, 2018). All management procedures were conducted according to the North Carolina Cooperative Extension recommendations (Edmisten and Collins, 2018).

Plots were harvested using a two row John Deere 9910 spindle-type picker (John Deere, Moline, IL). Seedcotton yields were recorded and a 200 g sub-sample was collected for seed weight, lint weight, lint percentage, and High Volume Instrumentation (HVI) analysis. Seed weight, lint weight, and lint percentage was gathered by ginning samples with a continental 12-saw cotton gin (Continental Eagle Corporation, Prattville, AL). The HVI analysis was conducted at Cotton Inc. (Cary, NC). The HVI data included micronaire and fiber length (upper half mean length).

All data were subjected to analysis of variance using PROC GLM or PROC GLIMMIX (GLIMMIX procedure) in SAS version 9.4 (SAS Inst., 2013). Means of significant main effects and interactions were separated using Fisher's Least Significant Difference at $p \leq 0.05$.

Results and Conclusions

In 2017 there were no significant yield difference between individual component cultivars or mixture A 69 percent of the time (Table 3). Fifteen percent of the time mixture A in 2017 produced a yield significantly higher than the lowest yielding cultivar and 23 percent of the

time produced a yield significantly lower than the highest yielding cultivar. For mixture A in 2017, either component cultivar would have produced the highest or statistically similar yield 92 percent of the time.

In 2018 there were no significant yield difference between individual component cultivars or mixture A 60 percent of the time (Table 4). Forty percent of the time mixture A in 2018 produced a yield significantly higher than the lowest yielding cultivar and 10 percent of the time produced a yield significantly lower than the highest yielding cultivar. For mixture A in 2018, PHY 312 produced yields higher than ST 4848 50 percent of the time and was statistically similar 50 percent of the time when there was a difference.

In 2017 there were no significant yield difference between individual component cultivars or mixture B 69 percent of the time (Table 5). Fifteen percent of the time mixture B in 2017 produced a yield significantly higher than the lowest yielding cultivar and 23 percent of the time produced a yield significantly lower than the highest yielding cultivar. For mixture B in 2017, DP 1646 produced a higher yield than DP 1538 15 percent of the time and was statistically similar 85 percent of the time.

In 2018 there were no significant yield difference between individual component cultivars or mixture B 80 percent of the time (Table 6). Ten percent of the time mixture B in 2018 produced a yield significantly higher than the lowest yielding cultivar and 20 percent of the time produced a yield significantly lower than the highest yielding cultivar. For mixture B in 2018, DP 1646 produced a higher yield than DP 1538 30 percent of the time and was statistically similar 70 percent of the time.

Mixture C in 2017 showed no significant difference between individual component cultivars or the mixture 23 percent of the time (Table 7). Thirty-nine percent of the time mixture

C in 2017 produced a yield significantly higher than the lowest yielding cultivar and 39 percent of the time produced a yield significantly lower than the highest yielding cultivar.

Mixture C in 2018 showed no significant difference between individual component cultivars or the mixture 30 percent of the time (Table 8). Thirty percent of the time mixture C in 2018 produced a yield significantly higher than the lowest yielding cultivar and 30 percent of the time produced a yield significantly lower than the highest yielding cultivar.

The only two environments that experienced lower than average rainfall for the area, weren't irrigated, and were in naturally low moisture holding capacity soils were both in 2017 at the SRS large plot dryland and SRS OVT environments. The average rainfall for SRS from April to October is 76 cm. All other environments received average rainfall amounts, above average rainfall amounts, or were irrigated (Data not shown). From April to October, average rainfall is 67 cm for UCPRS, 72 cm for PBRS, 86 cm for TRS, 86 cm for CRS, 63 cm for PRS, 70 cm for CCRS, and 75 cm for SCC. Deltapine 1538 did not produce higher yields than DP1646 in either of the dry environments (Table 5), although it historically performed better in dry environments in previous cultivar trials (NC State Extension, 2017).

Statistically, mixtures did not produce a yield significantly different than an individual cultivar 61 percent of the time. All mixtures produced a yield significantly higher than the lowest yielding cultivar 25 percent of the time and produced a yield significantly lower than the highest yielding cultivar 25 percent of the time.

Mixture A in 2018 was the only scenario where using a mixture was as good as the top yielding cultivar the majority of the time. A mixture was as likely, or more likely, to produce a lint yield lower than the highest yielding cultivar in a given year, as opposed to producing a lint yield higher than the lowest yielding cultivar. Therefore, mixtures did not improve yield stability

the majority of the time. This is opposed to findings by Bechere et al. (2008) and similar to findings by Innes and Jones (1977) where no yield stability was reported from the use of cotton cultivar mixtures.

In 2017 there were no significant change in micronaire between individual component cultivars or mixture A 69 percent of the time (Table 9). Eight percent of the time mixture A in 2017 significantly decreased micronaire compared to the cultivar with the highest micronaire value and significantly increased micronaire compared to the cultivar with the lowest micronaire value 23 percent of the time.

Mixture A in 2018 showed no significant micronaire value differences between individual component cultivars or mixture 60 percent of the time (Table 10). Ten percent of the time the higher value component cultivar, ST 4848, was above 5.0 and in the discount range, while mixture A and PHY 312 were both below 5.0 and not in the discount range. Thirty percent of the time mixture A in 2018 significantly decreased micronaire compared to the cultivar with the highest micronaire value and significantly increased micronaire compared to the cultivar with the lowest micronaire value 10 percent of the time. In 2018, ST 4848 had a higher micronaire value than PHY 312 40 percent of the time.

Mixture B in 2017 showed no significant micronaire value differences between individual component cultivars or mixture 69 percent of the time (Table 11). Twenty-three percent of the time mixture B in 2017 significantly decreased micronaire compared to the cultivar with the highest micronaire value and significantly increased micronaire compared to the cultivar with the lowest micronaire value 15 percent of the time. In 2017 DP 1536 had a higher micronaire value than DP 1646 54 percent of the time.

Mixture B in 2018 showed no significant micronaire value differences between individual component cultivars or mixture 70 percent of the time (Table 12). Thirty percent of the time mixture B in 2018 significantly decreased micronaire compared to the cultivar with the highest micronaire value and significantly increased micronaire compared to the cultivar with the lowest micronaire value 10 percent of the time. In 2018 DP 1536 had a higher micronaire value than DP 1646 50 percent of the time.

Mixture C in 2017 showed no significant micronaire value differences between individual component cultivars or mixture 54 percent of the time (Table 13). Eight percent of the time mixture C in 2017 significantly decreased micronaire compared to the cultivar with the highest micronaire value and significantly increased micronaire compared to the cultivar with the lowest micronaire value 8 percent of the time.

Mixture C in 2018 showed no significant micronaire value differences between individual component cultivars or mixture 30 percent of the time (Table 14). Twenty percent of the time mixture C in 2018 significantly decreased micronaire compared to the cultivar with the highest micronaire value and significantly increased micronaire compared to the cultivar with the lowest micronaire value 30 percent of the time.

All mixtures produced a micronaire significantly lower than the highest micronaire cultivar 22 percent of the time and produced a micronaire significantly higher than the lowest micronaire cultivar 13 percent of the time. Micronaire was not in the discount range, above 5.0, in any treatment for the majority of the locations. At PBRS LP18, the historically high micronaire cultivar, DP 1538, was significantly higher and in the discount range while mixture B and DP 1648 where below the discount range. This is the only instance of DP 1538 showing a significantly higher micronaire that fell into discount range while the other treatments did not.

Mixture C produced micronaire values that were higher than the lowest cultivar either as much or more times than lowering it compared to the highest. Similar to other studies, micronaire was found to be higher than the individual component cultivars (Bridge et al., 1984). Using a mixture that pairs one cultivar that has historically good fiber quality with another cultivar that has historically high micronaire will improve micronaire the majority of the time.

Mixture A in 2017 showed no significant differences in fiber length between individual component cultivars or mixture 85 percent of the time (Table 15). Eight percent of the time mixture A in 2017 significantly increased fiber length compared to the cultivar with the shortest fiber length and significantly decreased fiber length compared to the cultivar with the longest fiber length 8 percent of the time. In 2017 PHY 312 had longer fiber length than ST 4848 8 percent of the time.

Mixture A in 2018 showed no significant differences in fiber length between individual component cultivars or mixture 80 percent of the time (Table 16). Ten percent of the time mixture A in 2018 significantly increased fiber length compared to the cultivar with the shortest fiber length and never significantly decreased fiber length compared to the cultivar with the longest fiber length. In 2018 PHY 312 had longer fiber length than ST 4848 20 percent of the time.

Mixture B in 2017 showed no significant differences in fiber length between individual component cultivars or mixture 23 percent of the time (Table 17). Fifty-four percent of the time mixture B in 2017 significantly increased fiber length compared to the cultivar with the shortest fiber length and significantly decreased fiber length compared to the cultivar with the longest fiber length 31 percent of the time. In 2017 DP 1646 had longer fiber length than DP 1538 77 percent of the time.

Mixture B in 2018 showed no significant differences in fiber length between individual component cultivars 10 percent of the time (Table 18). Eighty percent of the time mixture B in 2018 significantly increased fiber length compared to the cultivar with the shortest fiber length and significantly decreased fiber length compared to the cultivar with the longest fiber length 40 percent of the time. In 2018 cultivars DP 1646 had longer fiber length than DP 1538 90 percent of the time.

Mixture C in 2017 showed no significant differences in fiber length between individual component cultivars or mixture 31 percent of the time (Table 19). Thirty-one percent of the time mixture C in 2017 significantly increased fiber length compared to the cultivar with the shortest fiber length and significantly decreased fiber length compared to the cultivar with the longest fiber length 69 percent of the time.

Mixture C in 2018 showed significant differences in fiber length between individual component cultivars at every location (Table 20). Sixty percent of the time mixture C in 2018 significantly increased fiber length compared to the cultivar with the shortest fiber length and significantly decreased fiber length compared to the cultivar with the longest fiber length 70 percent of the time.

Fiber length was affected by cultivar more than year. For mixture B in 2017 and 2018, DP 1538 had shorter fiber than 1646, which matches the historical data on these cultivars. For mixture B in 2017, 77 percent of the time mixture B improved fiber length compared to the shortest fiber length cultivar, and in 2018, 90 percent of the time mixture B improved fiber length stability.

Based on this data, fiber quality stability has the ability to be improved through the use of a cultivar mixture if a cultivar that historically shows poor fiber quality, including fiber length, is

paired with a historically better fiber quality cultivar. In other studies, the same and the opposite effect was found. Bechere et al. (2008) reported an improvement, while Bridge et al. (1984) reported no change in staple length.

In a given year, one cultivar will outperform another at least some of the time. The data suggest that using a cultivar mixture will not help improve yield stability the majority of the time and it can improve micronaire and fiber length if the mixture is a pairing a low fiber quality and high fiber quality cultivar.

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Table 1. Soil series and planting date for each environment.

Environment		Soil Series	Planting date
Location[z]	Experimental Conditions[y]		
UCPRS	LP	Norfolk loamy sand, *Fine-loamy, kaolinitic, thermic Typic Kandiudults*	May 1, 2017
PBRS	LP	Goldsboro sandy loam, *Fine-loamy, siliceous, subactive, thermic Aquic Paleudults*	May 9, 2017
SRS	D, LP	Candor sand, *Sandy, kaolinitic, thermic Grossarenic Kandiudults*	April 28, 2017
SRS	I, LP	Candor sand, *Sandy, kaolinitic, thermic Grossarenic Kandiudults*	April 28, 2017
TRS	LP	Cape Fear loam, *Fine, semiactive, thermic Typic Umbraquults*	May 19, 2017
CRS	LP	Wickham loamy sand, *Fine-loamy, mixed, semiactive, thermic Typic Hapludults*	May 19, 2017
UCPRS	OVT	Norfolk loamy sand, *Fine-loamy, kaolinitic, thermic Typic Kandiudults*	May 3, 2017
PBRS	OVT	Norfolk sandy loam, *Fine-loamy, kaolinitic, thermic Typic Kandiudults*	May 9, 2017
TRS	OVT	Cape Fear loam, *Fine, semiactive, thermic Typic Umbraquults*	May 30, 2017
SCC	OVT	Norfolk loamy sand, *Fine-loamy, kaolinitic, thermic Typic Kandiudults*	May 31, 2017
PRS	OVT	Mecklenburg clay loam, *Fine, mixed, active, thermic Ultic Hapludalfs*	June 2, 2017
CCRS	OVT	Norfolk loamy sand, *Fine-loamy, kaolinitic, thermic Typic Kandiudults*	May 17, 2017
SRS	OVT	Candor sand, *Sandy, kaolinitic, thermic Grossarenic Kandiudults*	May 1, 2017
PBRS	LP	Rains sandy loam, *Fine-loamy, siliceous, semiactive, thermic Typic Paleaquults*	May 4, 2018
TRS	LP	Cape Fear loam, *Fine, semiactive, thermic Typic Umbraquults*	May 9, 2018

Table 1 continued.

Environment		Soil Series	Planting Date
Location	**Experimental Conditions**		
UCPRS	**LP**	**Norfolk loamy sand,** ***Fine-loamy, kaolinitic, thermic Typic Kandiudults***	**May 3, 2018**
SRS	**D, LP**	**Candor sand,** ***Sandy, kaolinitic, thermic Grossarenic Kandiudults***	**April 30, 2018**
SRS	**I, LP**	**Candor sand,** ***Sandy, kaolinitic, thermic Grossarenic Kandiudults***	**April 30, 2018**
UCPRS	**OVT**	**Norfolk loamy sand,** ***Fine-loamy, kaolinitic, thermic Typic Kandiudults***	**May 14, 2018**
PBRS	**OVT**	**Lynchburg sandy loam,** ***Fine-loamy, siliceous, semiactive, thermic Aeric Pleaquults***	**May 15, 2018**
TRS	**OVT**	**Portsmouth fine sandy loam,** ***Fine-loamy over sandy, mixed, semiactive, thermic Typic Umbraquults***	**May 21, 2018**
CCRS	**OVT**	**Varina loamy sand,** ***Fine, Kaolinitic, thermic Plinthic Paleudults***	**May 25, 2018**
SRS	**OVT**	**Ailey loamy sand,** ***Loam, Kaolinite, thermic Aerenic Kanhapludults***	**May 4, 2018**

[z] Locations – UCPRS: Upper Coastal Plain Research Station; PBRS: Peanut Belt Research Station; SRS: Sandhills Research Station; TRS: Tidewater Research Station; CRS: Cherry Research Station; SCC: Scotland County; PRS: Piedmont Research Station; CCRS: Central Crops Research Station

[y] Experimental conditions – LP: Large Plot; D: Dryland; I: Irrigated; OVT: Official Variety Test

Table 2. Monthly and cumulative precipitation for each growing environment.

Environment		Month							
Location[z]	Year	April	May	June	July	August	September	October	Total
UCPRS	2017	16.5	12.5	12.2	15.1	17.6	7.6	8.7	90.2
PBRS	2017	14.4	14.8	14.2	18.8	12.8	8.2	6.9	90.1
SRS	2017	12	16.1	9.5	9.4	7.5	6.4	8.8	69.7
TRS	2017	9.1	18.4	13	16	20.7	7.8	7	92
CRS	2017	18.1	18.2	14.1	8.5	11.3	15.6	4.5	90.3
SCC	2017	13.8	9.2	9.8	12.3	7.7	12.9	9.4	75.1
PRS	2017	17.4	19.1	18.4	11.5	6.5	13	8.7	94.6
CCRS	2017	23.3	11.9	16.5	5.1	14.3	16.6	10.1	97.8
PBRS	2018	11.7	24.8	14.1	29.2	15.8	14.8	7.7	118.1
TRS	2018	14.5	15.2	21	22.6	12.1	19.9	5.3	110.6
UCPRS	2018	10.7	16.6	7.3	18.1	9.4	13	4.9	80
SRS	2018	11.7	4.6	3.9	12.8	22.5	48.4	16.1	120
CCRS	2018	8.8	11.8	6.5	18	9	21.6	9.8	85.5

[z] Locations – UCPRS: Upper Coastal Plain Research Station; PBRS: Peanut Belt Research Station; SRS: Sandhills Research Station; TRS: Tidewater Research Station; CRS: Cherry Research Station; SCC: Scotland County; PRS: Piedmont Research Station; CCRS: Central Crops Research Station

Table 3. Mixture A and component cultivars average yield and comparisons over individual environments in 2017.

Environment		Average Yield				Comparison		
Location[z]	Experimental Conditions[y]	PHY 312	ST 4848	Mixture A[x]	Mean Yield of Environment	Mixture A vs PHY312	Mixture A vs ST4848	PHY 312 vs ST4848
		---------- kg ha^{-1} ----------				---------- P ----------		
SCC	OVT	1724	1706	1569	1666	0.398	0.454	0.917
PBRS	OVT	1632	1608	1667	1636	0.720	0.541	0.795
PRS	OVT	1864	1611	1235	1570	0.117	0.321	0.495
SRS	I, LP	1620	1545	1492	1552	0.248	0.581	0.490
TRS	OVT	1589	1539	1438	1522	0.191	0.365	0.646
UCPRS	LP	1335	1460	1554	1450	0.003*[w]	0.165	0.069
PBRS	LP	1521	1469	1465	1485	0.202	0.934	0.230
CRS	LP	1091	1506	1270	1289	0.010*	0.002*	<.001*
TRS	LP	1262	1235	1202	1233	0.641	0.795	0.836
UCPRS	OVT	1276	1105	1308	1230	0.758	0.085	0.136
SRS	OVT	1174	1151	1029	1118	0.519	0.583	0.920
CCRS	OVT	1446	818	679	981	0.015*	0.578	0.034*
SRS	D, LP	652	582	507	580	0.035*	0.248	0.282

[z] Locations – UCPRS: Upper Coastal Plain Research Station; PBRS: Peanut Belt Research Station; SRS: Sandhills Research Station; TRS: Tidewater Research Station; CRS: Cherry Research Station; SCC: Scotland County; PRS: Piedmont Research Station; CCRS: Central Crops Research Station

[y] Experimental conditions – LP: Large Plot; D: Dryland; I: Irrigated; OVT: Official Variety Test

[x] Mixture A: PHY312 + ST4848

[w] *: asterisk denotes significance at $p < 0.05$

Table 4. Mixture A and component cultivars average yield and comparisons over individual environments in 2018.

Environment		Average Yield				Comparison		
Location[z]	Experimental Conditions[y]	PHY 312	ST 4848	Mixture A[x]	Mean Yield of Environment	Mixture A vs PHY312	Mixture A vs ST4848	PHY 312 vs ST4848
		---------- kg ha^{-1} ----------				---------- P ----------		
PBRS	LP	2307	2030	2176	2171	0.006*[w]	0.003*	<.001*
SRS	I, LP	2312	2105	1941	2119	0.138	0.492	0.394
UCPRS	LP	1967	1575	1910	1817	0.423	0.001*	<.001*
SRS	OVT	1706	1808	1559	1691	0.381	0.158	0.540
PBRS	OVT	1488	1361	1432	1427	0.551	0.450	0.197
UCPRS	OVT	1487	1113	1183	1261	0.093	0.674	0.049*
CCRS	OVT	1321	1071	1293	1228	0.824	0.112	0.080
TRS	LP	1237	987	1165	1130	0.411	0.049*	0.008*
SRS	D, LP	1129	1085	1073	1096	0.677	0.924	0.748
TRS	OVT	766	462	688	639	0.362	0.027*	0.008*

[z] Locations – UCPRS: Upper Coastal Plain Research Station; PBRS: Peanut Belt Research Station; SRS: Sandhills Research Station; TRS: Tidewater Research Station; CRS: Cherry Research Station; SCC: Scotland County; PRS: Piedmont Research Station; CCRS: Central Crops Research Station

[y] Experimental conditions – LP: Large Plot; D: Dryland; I: Irrigated; OVT: Official Variety Test

[x] Mixture A: PHY312 + ST4848

[w] *: asterisk denotes significance at $p < 0.05$

Table 5. Mixture B and component cultivars average yield and comparisons over individual environments in 2017.

Environment		Average Yield				Comparison		
Location[z]	Experimental Conditions[y]	DP 1538[x]	DP 1646	Mixture B	Mean Yield of Environment	Mixture B vs DP1538	Mixture B vs DP1646	DP 1538 vs DP 1646
		---------- kg ha^{-1} ----------				---------- P ----------		
PBRS	OVT	1706	2003	1543	1751	0.119	0.002*[w]	0.015*
CRS	LP	1488	1998	1743	1743	<.001*	<.001*	<.001*
SCC	OVT	1614	1683	1789	1695	0.343	0.555	0.703
UCPRS	LP	1499	1458	1599	1519	0.142	0.043*	0.535
SRS	I, LP	1567	1453	1344	1455	0.054	0.264	0.294
TRS	OVT	1408	1594	1363	1455	0.680	0.063	0.118
PBRS	LP	1346	1463	1418	1409	0.106	0.306	0.202
PRS	OVT	1007	1832	1277	1372	0.469	0.158	0.052
CCRS	OVT	1287	1644	981	1304	0.241	0.028*	0.180
UCPRS	OVT	1330	1103	1239	1224	0.403	0.222	0.061
SRS	OVT	1026	1232	1216	1158	0.399	0.946	0.365
TRS	LP	1027	1250	1189	1155	0.227	0.645	0.105
SRS	D, LP	566	630	603	600	0.564	0.676	0.326

[z] Locations – UCPRS: Upper Coastal Plain Research Station; PBRS: Peanut Belt Research Station; SRS: Sandhills Research Station; TRS: Tidewater Research Station; CRS: Cherry Research Station; SCC: Scotland County; PRS: Piedmont Research Station; CCRS: Central Crops Research Station

[y] Experimental conditions – LP: Large Plot; D: Dryland; I: Irrigated; OVT: Official Variety Test

[x] Mixture B: DP1538 + DP1646

[w] *: asterisk denotes significance at $p < 0.05$

Table 6. Mixture B and component cultivars average yield and comparisons over individual environments in 2018.

Environment		Average Yield				Comparison		
Location[z]	Experimental Conditions[y]	DP 1538[x]	DP 1646	Mixture B	Mean Yield of Environment	Mixture B vs DP1538	Mixture B vs DP1646	DP 1538 vs DP 1646
		---------- kg ha^{-1} ----------				---------- P ----------		
SRS	I, LP	1988	2229	2232	2150	0.409	0.989	0.416
PBRS	LP	1840	2261	2093	2065	<.001*[w]	<.001*	<.001*
UCPRS	LP	1835	1926	1809	1857	0.712	0.106	0.201
SRS	OVT	1650	1809	1633	1697	0.918	0.302	0.348
CCRS	OVT	1388	1380	1363	1377	0.844	0.897	0.947
SRS	D, LP	1084	1239	1291	1205	0.185	0.696	0.315
PBRS	OVT	1114	1189	1251	1185	0.169	0.510	0.428
TRS	LP	942	1129	1054	1042	0.203	0.382	0.039*
UCPRS	OVT	1026	957	1049	1011	0.882	0.573	0.674
TRS	OVT	404	697	673	591	0.014*	0.767	0.009*

[z] Locations – UCPRS: Upper Coastal Plain Research Station; PBRS: Peanut Belt Research Station; SRS: Sandhills Research Station; TRS: Tidewater Research Station; CCRS: Central Crops Research Station

[y] Experimental conditions – LP: Large Plot; D: Dryland; I: Irrigated; OVT: Official Variety Test

[x] Mixture B: DP1538 + DP1646

[w] *: asterisk denotes significance at $p < 0.05$

Table 7. Mixture C and component cultivars average yield and comparisons over individual environments in 2017.

Environment		Average Yield						
Location[z]	Experimental Conditions[y]	DP 1538	DP 1646	PHY 312	NG 3522	ST 4848	Mixture C[x]	Mean Yield of Environment
		---------- kg ha^{-1} ----------						
PBRS	OVT	1706ab[w]	2003a	1632b	1776ab	1608b	1694b	1737
SCC	OVT	1614ab	1683ab	1724a	1245b	1706ab	1804a	1629
PRS	OVT	1007a	1832a	1864a	1674a	1611a	1508a	1583
CRS	LP	1488b	1998a	1091c	1537b	1506b	1630b	1542
SRS	I, LP	1567ab	1453ab	1620a	1517ab	1545ab	1336b	1506
UCPRS	LP	1499ab	1458ab	1335b	1611a	1460ab	1417b	1463
PBRS	LP	1346c	1463ab	1521a	1427bc	1469ab	1442ab	1445
TRS	OVT	1408ab	1594a	1589a	765c	1539a	1308b	1367
CCRS	OVT	1287ab	1644a	1446ab	1464ab	818b	1447ab	1351
TRS	LP	1027b	1250ab	1262ab	1305ab	1235ab	1343a	1237
UCPRS	OVT	1330a	1103a	1276a	1025a	1105a	1372a	1201
SRS	OVT	1026a	1232a	1174a	1135a	1151a	1200a	1153
SRS	D, LP	566ab	630ab	652a	489b	582ab	565ab	581

[z] Locations – UCPRS: Upper Coastal Plain Research Station; PBRS: Peanut Belt Research Station; SRS: Sandhills Research Station; TRS: Tidewater Research Station; CRS: Cherry Research Station; SCC: Scotland County; PRS: Piedmont Research Station; CCRS: Central Crops Research Station

[y] Experimental conditions – LP: Large Plot; D: Dryland; I: Irrigated; OVT: Official Variety Test

[x] Mixture C: DP1538 + DP1646 + PHY312 + NG3522 + ST4848

[w] Comparisons are made by row

Table 8. Mixture C and component cultivars average yield and comparisons over individual environments in 2018.

Environment		Average Yield						
Location[z]	Experimental Conditions[y]	DP 1538	DP 1646	PHY 312	NG 3522	ST 4848	Mixture C[x]	Mean Yield of Environment
		---------- kg ha^{-1} ----------						
PBRS	LP	1840c[w]	2261a	2307a	2077b	2030b	2077b	2099
SRS	I, LP	1988a	2229a	2312a	1901a	2105a	1954a	2082
UCPRS	LP	1835bc	1926ab	1967a	1710d	1575e	1761cd	1796
SRS	OVT	1650ab	1809a	1706ab	1410b	1808a	1472ab	1643
PBRS	OVT	1114c	1189bc	1488a	1415ab	1361ab	1262abc	1305
CCRS	OVT	1388a	1380a	1321a	1212a	1071a	1286a	1276
UCPRS	OVT	1026bc	957c	1487a	1409ab	1113abc	1058bc	1175
SRS	D, LP	1084a	1239a	1129a	1000a	1085a	1127a	1111
TRS	LP	942b	1129ab	1237a	983b	987b	1109ab	1065
TRS	OVT	404c	697a	766a	779a	462bc	627ab	623

[z] Locations – UCPRS: Upper Coastal Plain Research Station; PBRS: Peanut Belt Research Station; SRS: Sandhills Research Station; TRS: Tidewater Research Station; CCRS: Central Crops Research Station

[y] Experimental conditions – LP: Large Plot; D: Dryland; I: Irrigated; OVT: Official Variety Test

[x] Mixture C: DP1538 + DP1646 + PHY312 + NG3522 + ST4848

[w] Comparisons are made by row

Table 9. Mixture A and component cultivars average micronaire and comparisons over individual environments in 2017.

Environment		Average Micronaire			Comparison		
Location[z]	Experimental Conditions[y]	PHY 312	ST 4848	Mixture A[x]	Mixture A vs PHY312	Mixture A vs ST4848	PHY 312 vs ST4848
		---------- Units ----------			---------- P ----------		
UCPRS	OVT	5.15	5.07	5.22	0.508	0.151	0.392
CCRS	OVT	4.79	4.98	5.31	0.005*[w]	0.035*	0.177
SRS	OVT	4.92	4.94	5.10	0.378	0.429	0.922
SRS	I, LP	4.82	4.65	4.47	0.228	0.467	0.558
TRS	LP	4.52	4.49	4.30	0.198	0.262	0.856
PBRS	OVT	4.43	4.36	4.34	0.596	0.905	0.679
CRS	LP	4.46	4.31	4.24	0.052	0.516	0.166
SRS	D, LP	4.22	4.49	4.22	0.985	0.142	0.138
PBRS	LP	4.27	4.20	4.09	0.028*	0.149	0.370
SCC	OVT	4.48	4.02	3.86	0.030*	0.492	0.086
TRS	OVT	4.14	4.11	4.08	0.594	0.788	0.788
PRS	OVT	3.80	3.56	3.85	0.876	0.380	0.463
UCPRS	LP	3.63	3.41	3.25	0.009*	0.268	0.099

[z] Locations – UCPRS: Upper Coastal Plain Research Station; PBRS: Peanut Belt Research Station; SRS: Sandhills Research Station; TRS: Tidewater Research Station; CRS: Cherry Research Station; SCC: Scotland County; PRS: Piedmont Research Station; CCRS: Central Crops Research Station

[y] Experimental conditions – LP: Large Plot; D: Dryland; I: Irrigated; OVT: Official Variety Test

[x] Mixture A: PHY312 + ST4848

[w] *: asterisk denotes significance at $p < 0.05$

Table 10. Mixture A and component cultivars average micronaire and comparisons over individual environments in 2018.

Environment		Average Micronaire			Comparison		
Location[z]	Experimental Conditions[y]	PHY 312	ST 4848	Mixture A[x]	Mixture A vs PHY312	Mixture A vs ST4848	PHY 312 vs ST4848
		---------- Units ----------			---------- P ----------		
PBRS	LP	4.82	5.11	4.96	0.018*[w]	0.012*	<.001*
PBRS	OVT	4.75	4.86	4.75	0.989	0.771	0.760
SRS	I, LP	4.71	4.96	4.67	0.802	0.087	0.132
SRS	OVT	4.49	4.85	4.73	0.175	0.466	0.057
TRS	OVT	4.77	4.7	4.6	0.401	0.608	0.731
UCPRS	LP	4.53	4.73	4.51	0.890	0.027*	0.036*
TRS	LP	4.52	4.67	4.52	0.971	0.033*	0.036*
SRS	D, LP	4.32	4.62	4.44	0.387	0.194	0.041*
UCPRS	OVT	4.17	4.35	4.32	0.477	0.904	0.410
CCRS	OVT	3.77	4.12	3.75	0.893	0.079	0.097

[z] Locations – UCPRS: Upper Coastal Plain Research Station; PBRS: Peanut Belt Research Station; SRS: Sandhills Research Station; TRS: Tidewater Research Station; CRS: Cherry Research Station; SCC: Scotland County; PRS: Piedmont Research Station; CCRS: Central Crops Research Station

[y] Experimental conditions – LP: Large Plot; D: Dryland; I: Irrigated; OVT: Official Variety Test

[x] Mixture A: PHY312 + ST4848

[w] *: asterisk denotes significance at $p < 0.05$

Table 11. Mixture B and component cultivars average micronaire and comparisons over individual environments in 2017.

Environment		Micronaire			Comparison		
Location[z]	Experimental Conditions[y]	DP 1538[x]	DP 1646	Mixture B	Mixture B vs DP1538	Mixture B vs DP1646	DP 1538 vs DP 1646
		Units			P		
SRS	OVT	5.32	5.29	5.1	0.300	0.366	0.883
UCPRS	OVT	5.36	4.97	4.96	0.004*[w]	0.959	0.004*
CCRS	OVT	4.83	4.7	4.75	0.572	0.704	0.356
PBRS	OVT	4.81	4.28	4.61	0.268	0.077	0.014*
SRS	I, LP	4.62	4.62	4.45	0.547	0.679	0.811
TRS	LP	4.68	4.28	4.54	0.415	0.128	0.028*
SRS	D, LP	4.57	4.31	4.37	0.242	0.728	0.138
CRS	LP	4.73	3.94	4.4	0.008*	0.001*	<.001*
TRS	OVT	4.53	4.27	4.27	0.046*	0.964	0.043*
PBRS	LP	4.49	4.03	4.34	0.051	<.001*	<.001*
SCC	OVT	4.17	4.19	3.75	0.111	0.094	0.916
PRS	OVT	4.16	3.86	3.98	0.569	0.721	0.365
UCPRS	LP	3.63	3.31	3.37	0.093	0.671	0.040*

[z] Locations – UCPRS: Upper Coastal Plain Research Station; PBRS: Peanut Belt Research Station; SRS: Sandhills Research Station; TRS: Tidewater Research Station; CRS: Cherry Research Station; SCC: Scotland County; PRS: Piedmont Research Station; CCRS: Central Crops Research Station

[y] Experimental conditions – LP: Large Plot; D: Dryland; I: Irrigated; OVT: Official Variety Test

[x] Mixture B: DP1538 + DP1646

[w] *: asterisk denotes significance at $p < 0.05$

Table 12. Mixture B and component cultivars average micronaire and comparisons over individual environments in 2018.

Environment		Average Micronaire			Comparison		
Location[z]	Experimental Conditions[y]	DP 1538[x]	DP 1646	Mixture B	Mixture B vs DP1538	Mixture B vs DP1646	DP 1538 vs DP 1646
		---------- Units ----------			---------- P ----------		
PBRS	LP	4.95	4.62	4.71	<.001*[w]	0.109	<.001*
TRS	LP	4.91	4.36	4.52	<.001*	0.026*	<.001*
TRS	OVT	4.85	4.33	4.55	0.163	0.308	0.033*
SRS	I, LP	4.61	4.54	4.52	0.665	0.918	0.740
UCPRS	LP	4.74	4.42	4.46	0.006*	0.601	0.002*
SRS	OVT	4.47	4.42	4.54	0.666	0.466	0.757
PBRS	OVT	4.49	4.31	4.52	0.934	0.564	0.620
SRS	D, LP	4.42	4.27	4.46	0.777	0.166	0.324
UCPRS	OVT	4.44	4.17	4.42	0.923	0.243	0.211
CCRS	OVT	4.57	3.99	4.26	0.123	0.184	0.015*

[z] Locations – UCPRS: Upper Coastal Plain Research Station; PBRS: Peanut Belt Research Station; SRS: Sandhills Research Station; TRS: Tidewater Research Station; CCRS: Central Crops Research Station

[y] Experimental conditions – LP: Large Plot; D: Dryland; I: Irrigated; OVT: Official Variety Test

[x] Mixture B: DP1538 + DP1646

[w] *: asterisk denotes significance at $p < 0.05$

Table 13. Mixture C and component cultivars average micronaire and comparisons over individual environments in 2017.

Environment		Average Micronaire					
Location[z]	Experimental Conditions[y]	DP 1538	DP 1646	PHY 312	NG 3522	ST 4848	Mixture C[x]
		---------- Units ----------					
UCPRS	OVT	5.36a[w]	4.97b	5.15ab	5.04ab	5.07ab	5.23ab
SRS	OVT	5.32a	5.29a	4.92a	5.1a	4.94a	4.97a
CCRS	OVT	4.83a	4.7a	4.79a	4.8a	4.98a	4.93a
SRS	I, LP	4.62a	4.62a	4.82a	4.67a	4.65a	4.74a
PBRS	OVT	4.81a	4.28b	4.43ab	4.36b	4.36b	4.63ab
TRS	LP	4.68a	4.28a	4.52a	4.41a	4.49a	4.49a
CRS	LP	4.73a	3.94c	4.46ab	4.22b	4.31b	4.4b
SRS	D, LP	4.57a	4.31ab	4.22ab	4.13b	4.49ab	4.33ab
TRS	OVT	4.53a	4.27a	4.14a	4.24a	4.11a	4.48a
PBRS	LP	4.49a	4.03b	4.27ab	4.08b	4.2ab	4.35ab
SCC	OVT	4.17a	4.19a	4.48a	3.89a	4.02a	3.92a
PRS	OVT	4.16a	3.86ab	3.8ab	3.87ab	3.56b	3.77ab
UCPRS	LP	3.63a	3.31a	3.63a	3.45a	3.41a	3.45a

[z] Locations – UCPRS: Upper Coastal Plain Research Station; PBRS: Peanut Belt Research Station; SRS: Sandhills Research Station; TRS: Tidewater Research Station; CRS: Cherry Research Station; SCC: Scotland County; PRS: Piedmont Research Station; CCRS: Central Crops Research Station

[y] Experimental conditions – LP: Large Plot; D: Dryland; I: Irrigated; OVT: Official Variety Test

[x] Mixture C: DP1538 + DP1646 + PHY312 + NG3522 + ST4848

[w] Comparisons are made by row

Table 14. Mixture C and component cultivars average micronaire and comparisons over individual environments in 2018.

Environment		Average Micronaire					
Location[z]	Experimental Conditions[y]	DP 1538	DP 1646	PHY 312	NG 3522	ST 4848	Mixture C[x]
		---------- Units ----------					
PBRS	LP	4.95b[w]	4.62d	4.82c	4.79c	5.11a	4.8c
SRS	I, LP	4.61b	4.54b	4.71ab	4.51b	4.96a	4.76ab
TRS	OVT	4.85a	4.33a	4.77a	4.57a	4.7a	4.68a
PBRS	OVT	4.49a	4.31a	4.75a	4.66a	4.86a	4.56a
UCPRS	LP	4.74a	4.42c	4.53bc	4.47bc	4.73a	4.66ab
SRS	OVT	4.47b	4.42b	4.49b	4.65ab	4.85a	4.51b
TRS	LP	4.91a	4.36d	4.52c	4.47cd	4.67b	4.48cd
SRS	D, LP	4.42a	4.27b	4.32b	4.53ab	4.62ab	4.47ab
UCPRS	OVT	4.44a	4.17a	4.17a	4.4a	4.35a	4.29a
CCRS	OVT	4.57a	3.99b	3.77b	3.77b	4.12ab	4.09ab

[z] Locations – UCPRS: Upper Coastal Plain Research Station; PBRS: Peanut Belt Research Station; SRS: Sandhills Research Station; TRS: Tidewater Research Station; CCRS: Central Crops Research Station

[y] Experimental conditions – LP: Large Plot; D: Dryland; I: Irrigated; OVT: Official Variety Test

[x] Mixture C: DP1538 + DP1646 + PHY312 + NG3522 + ST4848

[w] Comparisons are made by row

Table 15. Mixture A and component cultivars average fiber length and comparisons over individual environments in 2017.

Environment		Average Fiber Length			Comparison		
Location[z]	Experimental Conditions[y]	PHY 312	ST 4848	Mixture A[x]	Mixture A vs PHY312	Mixture A vs ST4848	PHY 312 vs ST4848
		cm			P		
PRS	OVT	3.05	3.00	3.05	1.000	0.522	0.522
SCC	OVT	3.07	2.97	3.02	0.622	0.622	0.337
TRS	LP	3.02	2.92	3.05	0.781	0.178	0.276
CRS	LP	2.97	2.97	3.02	0.270	0.354	0.851
PBRS	OVT	3.07	2.95	2.95	0.022*[w]	1.000	0.022*
UCPRS	LP	2.97	3.00	2.97	0.903	0.807	0.903
PBRS	LP	3.00	2.92	2.97	0.418	0.315	0.082
TRS	OVT	2.97	2.90	3.00	0.420	0.037*	0.130
CCRS	OVT	2.87	2.95	2.84	0.845	0.200	0.264
SRS	OVT	2.92	2.84	2.84	0.263	0.867	0.332
UCPRS	OVT	2.77	2.79	2.87	0.166	0.284	0.710
SRS	D, LP	2.77	2.79	2.77	1.00	0.838	0.838
SRS	I, LP	2.72	2.79	2.77	0.585	0.838	0.469

[z] Locations – UCPRS: Upper Coastal Plain Research Station; PBRS: Peanut Belt Research Station; SRS: Sandhills Research Station; TRS: Tidewater Research Station; CRS: Cherry Research Station; SCC: Scotland County; PRS: Piedmont Research Station; CCRS: Central Crops Research Station

[y] Experimental conditions – LP: Large Plot; D: Dryland; I: Irrigated; OVT: Official Variety Test

[x] Mixture A: PHY312 + ST4848

[w] *: asterisk denotes significance at $p < 0.05$

Table 16. Mixture A and component cultivars average fiber length and comparisons over individual environments in 2018.

Environment		Average Fiber Length			Comparison		
Location[z]	Experimental Conditions[y]	PHY 312	ST 4848	Mixture A[x]	Mixture A vs PHY312	Mixture A vs ST4848	PHY 312 vs ST4848
		---------- cm ----------			---------- P ----------		
PBRS	OVT	3.02	3.00	3.02	0.919	0.838	0.760
PBRS	LP	3.00	3.00	2.97	0.379	0.379	1.000
SRS	OVT	2.97	2.97	2.92	0.175	0.396	0.566
UCPRS	LP	3.00	2.92	2.95	0.071	0.219	0.005*[w]
CCRS	OVT	3.00	2.90	2.92	0.253	0.842	0.190
SRS	I, LP	2.97	2.87	2.97	0.597	0.020*	0.008*
UCPRS	OVT	2.95	2.92	2.95	1.000	0.736	0.736
TRS	OVT	2.97	2.90	2.87	0.328	0.899	0.389
SRS	D, LP	2.97	2.84	2.90	0.332	0.387	0.079
TRS	LP	2.90	2.84	2.90	0.694	0.126	0.059

[z] Locations – UCPRS: Upper Coastal Plain Research Station; PBRS: Peanut Belt Research Station; SRS: Sandhills Research Station; TRS: Tidewater Research Station; CRS: Cherry Research Station; SCC: Scotland County; PRS: Piedmont Research Station; CCRS: Central Crops Research Station

[y] Experimental conditions – LP: Large Plot; D: Dryland; I: Irrigated; OVT: Official Variety Test

[x] Mixture A: PHY312 + ST4848

[w] *: asterisk denotes significance at $p < 0.05$

Table 17. Mixture B and component cultivars average fiber length and comparisons over individual environments in 2017.

Environment		Fiber Length			Comparison		
Location[z]	Experimental Conditions[y]	DP1538[x]	DP1646	Mixture B	Mixture B vs DP1538	Mixture B vs DP1646	DP 1538 vs DP 1646
		cm			P		
SCC	OVT	2.92	3.33	3.20	0.025*[w]	0.239	0.004*
PRS	OVT	3.00	3.30	3.10	0.051	0.039*	0.002*
CRS	LP	2.87	3.25	3.10	<.001*	0.006*	<.001*
TRS	OVT	2.87	3.18	3.18	<.001*	1.000	<.001*
PBRS	LP	2.90	3.20	3.07	<.001*	0.003*	<.001*
PBRS	OVT	2.87	3.23	3.05	0.004*	0.002*	<.001*
TRS	LP	2.92	3.12	3.05	0.240	0.361	0.047*
UCPRS	LP	2.92	3.05	3.02	0.364	0.807	0.253
CCRS	OVT	2.82	3.02	3.02	0.014*	0.845	0.011*
SRS	OVT	2.82	3.05	2.97	0.076	0.263	0.013*
UCPRS	OVT	2.67	3.07	2.92	0.005*	0.071	<.001*
SRS	I, LP	2.82	2.87	2.79	0.891	0.316	0.442
SRS	D, LP	2.77	2.87	2.79	0.838	0.315	0.231

[z] Locations – UCPRS: Upper Coastal Plain Research Station; PBRS: Peanut Belt Research Station; SRS: Sandhills Research Station; TRS: Tidewater Research Station; CRS: Cherry Research Station; SCC: Scotland County; PRS: Piedmont Research Station; CCRS: Central Crops Research Station

[y] Experimental conditions – LP: Large Plot; D: Dryland; I: Irrigated; OVT: Official Variety Test

[x] Mixture B: DP1538 + DP1646

[w] *: asterisk denotes significance at $p < 0.05$

Table 18. Mixture B and component cultivars average fiber length and comparisons over individual environments in 2018.

Environment		Average Fiber Length			Comparison		
Location[z]	Experimental Conditions[y]	DP1538[x]	DP1646	Mixture B	Mixture B vs DP1538	Mixture B vs DP1646	DP 1538 vs DP 1646
		---------- cm ----------			---------- P ----------		
PBRS	OVT	3.02	3.25	3.12	0.373	0.373	0.098
PBRS	LP	2.90	3.20	3.15	<.001*[w]	0.379	<.001*
SRS	OVT	2.87	3.10	3.12	0.001*	0.566	0.001*
SRS	I, LP	2.84	3.12	3.02	0.001*	0.012*	<.001*
TRS	OVT	2.77	3.15	3.02	0.028*	0.276	0.006*
SRS	D, LP	2.77	3.15	2.92	0.095	0.012*	0.001*
UCPRS	LP	2.79	3.10	2.97	<.001*	0.002*	<.001*
CCRS	OVT	2.77	3.07	2.97	0.010*	0.190	0.002*
UCPRS	OVT	2.77	3.05	3.00	0.013*	0.615	0.006*
TRS	LP	2.69	3.05	2.95	<.001*	0.003*	<.001*

[z] Locations – UCPRS: Upper Coastal Plain Research Station; PBRS: Peanut Belt Research Station; SRS: Sandhills Research Station; TRS: Tidewater Research Station; CCRS: Central Crops Research Station

[y] Experimental conditions – LP: Large Plot; D: Dryland; I: Irrigated; OVT: Official Variety Test

[x] Mixture B: DP1538 + DP1646

[w] *: asterisk denotes significance at $p < 0.05$

Table 19. Mixture C and component cultivars average fiber length and comparisons over individual environments in 2017.

Environment		Average Fiber Length					
Location[z]	Experimental Conditions[y]	DP 1538	DP 1646	PHY 312	NG 3522	ST 4848	Mixture C[x]
		---------- cm ----------					
PRS	OVT	3.00c[w]	3.30a	3.05b	2.97bc	3.00bc	3.00bc
SCC	OVT	2.92b	3.33a	3.07b	2.90b	2.97b	3.07b
CRS	LP	2.87d	3.25a	2.97c	2.84d	2.97c	3.07b
UCPRS	LP	2.92a	3.05a	2.97a	3.02a	3.00a	3.02a
PBRS	OVT	2.87c	3.23a	3.07b	2.95c	2.95c	2.90c
PBRS	LP	2.90c	3.20a	3.00b	2.84c	2.92bc	3.00b
TRS	LP	2.92a	3.12a	3.02a	2.97a	2.92a	2.92a
TRS	OVT	2.87b	3.18a	2.97b	2.90b	2.90b	3.00b
CCRS	OVT	2.82bc	3.02a	2.87bc	2.77c	2.95ab	2.87bc
SRS	OVT	2.82bc	3.05a	2.92ab	2.72c	2.84bc	2.90b
UCPRS	OVT	2.67c	3.07a	2.77bc	2.67bc	2.79bc	2.84b
SRS	D, LP	2.77a	2.87a	2.77a	2.74a	2.79a	2.72a
SRS	I, LP	2.82a	2.87a	2.72a	2.74a	2.79a	2.72a

[z] Locations – UCPRS: Upper Coastal Plain Research Station; PBRS: Peanut Belt Research Station; SRS: Sandhills Research Station; TRS: Tidewater Research Station; CRS: Cherry Research Station; SCC: Scotland County; PRS: Piedmont Research Station; CCRS: Central Crops Research Station

[y] Experimental conditions – LP: Large Plot; D: Dryland; I: Irrigated; OVT: Official Variety Test

[x] Mixture C: DP1538 + DP1646 + PHY312 + NG3522 + ST4848

[w] Comparisons are made by row

Table 20. Mixture C and component cultivars average fiber length and comparisons over individual environments in 2018.

Environment		Average Fiber Length					
Location[z]	Experimental Conditions[y]	DP 1538	DP 1646	PHY 312	NG 3522	ST 4848	Mixture C[x]
		---------- cm ----------					
PBRS	OVT	3.02ab[w]	3.25a	3.02ab	2.87b	3.00ab	3.15ab
PBRS	LP	2.90c	3.20a	3.00b	2.82c	3.00b	3.02b
TRS	OVT	2.77b	3.15a	2.97ab	2.87b	2.90b	2.97ab
SRS	OVT	2.87c	3.10a	2.97b	2.74d	2.97bc	2.95bc
UCPRS	LP	2.79d	3.10a	3.00b	2.82d	2.92c	2.92c
CCRS	OVT	2.77c	3.07a	3.00ab	2.77c	2.90b	3.00ab
SRS	I, LP	2.84d	3.12a	2.97b	2.77e	2.87cd	2.90c
SRS	D, LP	2.77c	3.15a	2.97ab	2.74c	2.84bc	2.90bc
UCPRS	OVT	2.77c	3.05a	2.95ab	2.82bc	2.92abc	2.79bc
TRS	LP	2.69e	3.05a	2.90bc	2.77d	2.84c	2.92b

[z] Locations – UCPRS: Upper Coastal Plain Research Station; PBRS: Peanut Belt Research Station; SRS: Sandhills Research Station; TRS: Tidewater Research Station; CCRS: Central Crops Research Station

[y] Experimental conditions – LP: Large Plot; D: Dryland; I: Irrigated; OVT: Official Variety Test

[x] Mixture C: DP1538 + DP1646 + PHY312 + NG3522 + ST4848

[w] Comparisons are made by row