Soil- and Foliar-Applied Potassium in Upland Cotton (*Gossypium hirsutum* L.) Production

by

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ABSTRACT

Soil test recommendations for upland cotton (*Gossypium hirsutum L.*) fertility are often based on varieties which are no longer in production, meriting questions on whether increased potassium (K) is needed for new varieties with higher yield potential. Additional K can be applied as soil-applied or foliar-applied K. However, recent studies have produced inconclusive data regarding the efficacy of foliar potassium applications in upland cotton. The objective of this work was to evaluate K uptake by cotton (Deltapine 1646 B2XF) as a function of foliar and soil-applied K. Field studies were established at Auburn University's E.V. Smith Research Center (Shorter, AL) and Wiregrass Research and Extension Center (Headland, AL). Four replicate treatments of soil-applied K (67.3, 100.9, 134.5, 168.1, 201.8, 235.4, and 269.0 kg K_2O ha^{-1}) were organized in a randomized complete block design. Foliar K treatments were added to create a split-plot design. Foliar treatments were applied at 4.5 kg K_2O ha^{-1} at the beginning of flowering, and again 10 days later. Results from E.V. Smith Research Center in 2018 indicated that foliar K did not have a significant effect on cotton lint yield. Cotton yield increased with added soil-applied K, up to 67.3 kg K_2O ha^{-1}. At E.V. Smith initial soil-test K was 105.4 kg K ha-1 (a 'Medium' soil-test level), with a K fertilization recommendation of 44.8 kg K_2O ha^{-1}. Thus, Alabama Cooperative Extension System's soil-test K recommendations were correct for K fertilization recommendations for optimum crop yield. At Headland, cotton yield was unaffected by either soil or foliar K, likely a result of K located below typical soil test depths. Over 2 locations and 2 years there was little evidence that soil K in excess of current recommendations increased yields, nor that foliar K increased yield.

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LIST OF ABBREVIATIONS

K	Potassium
Ca	Calcium
Mg	Magnesium
EVS	E.V. Smith Research Center, Shorter, AL
WREC	Wiregrass Research and Extension Center, Headland, AL
FCU	Field Crop Unit, E.V. Smith Research Center
PBU	Plant Breeding Unit, E.V. Smith Research Center

I. LITERATURE REVIEW

Introduction

Upland cotton (*Gossypium hirsutum* L.) is a perennial plant that was domesticated centuries ago. It is grown as an annual summer crop across the Cotton Belt of the United States. Similar to its wild ancestors, domestic cotton requires a tropical or subtropical climate for successful production, and the weather of the Southeast is well-suited for this. When temperatures drop below 15° C (~59° F), plants will not actively grow (Waddle, 1984). Along with the correct climate, a thorough fertility program is imperative to the production of a profitable cotton crop (Oosterhuis, 2001).

Potassium (K) is an essential element and macronutrient required by all plant life. Potassium is absorbed by plant roots from the soil solution as the potassium ion (K^+) and an adequate supply of K is necessary throughout the whole growth and development period of a cotton plant (Kerby and Adams, 1987). Similar to the accumulation pattern of dry matter, K uptake is between 2.2 and 5.0 kg ha^{-1} per day during the later weeks of flowering stage (Halevy, 1975; Oosterhuis, 1989). Studies have found that for every 100 kg of lint produced, approximately 13 kg of K is used by the plants (Kerby and Adams, 1987; Mullins and Burmester, 2010). Roughly two-thirds of K uptake by cotton occurs during a period of 6 weeks, beginning in the early bloom stage (Bassett et al., 1970). A study conducted by Gwathmey et al. (2009) also indicated that K is more readily absorbed during the period of flowering and boll filling. Additionally, applied K increases accumulation of biomass in the reproductive organs of cotton plants (Clement-Bailey and Gwathmey, 2007).

Common K management practices across the US Cotton Belt are based off soil test recommendations, and K is broadcast on the soil surface pre-plant or incorporated to a shallow depth when recommended (Oosterhuis, 1989). Some producers prefer to apply all K at once, but K can also be applied later in the season as a side-dress application while the plants are still young and small (Kerby and Adams, 1987).

Potassium and Plant Physiology

A thorough nutrient management program is often one of the first options that comes to mind when producers try to maximize yield and crop performance. All forms of plant life require certain macro- and micronutrients, with K being required in the second largest quantity after nitrogen (N). Additionally, it is the inorganic cation present in the largest concentration in plants (Gerardeaux et al., 2010). Potassium is highly mobile within the plant, both across short and long distances. Ideal conditions for plant growth occur when the K content (dry weight basis) is around 2-5% K (Marschner, 1995). Potassium content in cotton is 2.75-3.35% K at 90-days after planting, and 2-2.75% K at 120 days after planting according to Bennett et al. (1965). The primary mechanism for K uptake from the soil solution is diffusion, and is the dominant method for uptake when plant available K is present in high levels (Rosolem et al., 2003). However, mass flow and root interception also are of importance in certain situations, especially when the soil solution has a low level of available K (Rosolem et al., 2003).

An adequate supply of K is needed by the cotton plant throughout the whole growing season, as K plays an important role in many plant physiological processes (Clarkson and Hanson, 1980; White and Karley, 2010). These processes include glycolysis, photophosphorylation, maintenance of turgor pressure, stomatal regulation, and regulation of the osmotic potential of cells (Snider and Oosterhuis, 2015; Raper, 2018). In the cotton plant, potassium concentration often increased (from flowering until maturity) while concentrations of other plant nutrients decreased (Leffler and Tubertini, 1976). Potassium management is also important because cotton plants appear to be more sensitive to K deficiency than several other agronomic crops such as corn (*Zea mays* L.), wheat (*Triticum aestivum* L.), and soybean (*Glycine max* L.) (Cope, 1981). In work by Cope (1981), it was found that cotton had a more noticeable response to varying rates of K application than the aforementioned crops.

Potassium is also vital to drought stress alleviation in cotton (Zhou et al., 2017). In the study by Zhou et al. (2017), K was applied at 0, 150, and 300 kg K_2O ha^{-1} to well-watered and water-stressed cotton plants, from low-K tolerant and low-K susceptible cultivars, in a nursery setting. When plants received 0 kg K_2O ha^{-1} and were exposed to drought conditions, a significant decrease occurred in net photosynthesis rate, intercellular CO_2 concentration, stomatal conductance, and ribulose-1,5-bisphosphate (Rubisco) activity. This resulted in a reduced synthesis of photo-assimilates and partitioning of K toward reproductive parts in both the low-K tolerant and susceptible cultivars. Conversely, cotton plants that received K had reduced decline of Rubisco activity, photosynthesis, and biomass partitioning and accumulation (Zhou et al., 2017). Both vegetative growth and boll development rely heavily on a sufficient K supply, and K is necessary for many plant processes that allow plants to combat varying forms of stress (Kafkafi, 1990; Oosterhuis et al., 2013). For example, increasing levels of K within a cotton plant help to combat stress caused by nematode damage (Kafkafi, 1990).

While the concentration of other minerals consistently declined in the bur and fiber during plant development, K concentration in the same plant parts accumulated continuously from 1.9% shortly after flowering, to 5.5% when the plants reached maturity (Leffler and Tubertini, 1976). The same study showed that mineral nutrients accumulated in the boll throughout all stages of development, with the majority of accumulation occurring in the first six weeks of boll development. The data suggested that a 'physiological continuum' was present among all boll components (lint, seed, and bur) during boll development (Leffler and Tubertini, 1976).

A 1999 summary of a 10-year study looked at the effect of various application rates and timing of potassium fertilizer in cotton (Mullins et al., 1999). In that study, rates of applied K varied from 0 to 202 kg K_2O ha^{-1} annually. In 6 of 10 years, significant yield responses were obtained when the study was performed on soils with an initial soil test rating of 'low' for K, according to the Auburn University Soil Testing Lab. When there was no significant yield difference among treatments, the lack of difference was accredited to yield limited by lack of rainfall or damage from insect pests. In some years applied K increased lint yields by 504 kg ha^{-1}. Largest increases were seen when annual applied K rates totaled 200 kg K_2O ha^{-1}. Of all the lint quality parameters that were evaluated, micronaire was the only parameter that showed a consistent improvement with increasing rates of potassium. The micronaire of cotton in this study increased as K fertilization increased. This agreed with results from a similar study with Acala cotton, where K fertilization increased micronaire and fiber length (Cassman et al., 1990). Significant differences in micronaire were only present during years in which lint yields were significantly different (Mullins et al., 1999).

Excess Potassium in Cotton

When a surplus of K is plant available, the yield and performance of the cotton crop can be adversely affected (Oosterhuis et al., 2013). Bennett et al. (1965) applied 0, 70, 140, 280, 420, or 560 kg of muriate of potash (MOP) ha^{-1}. Soil samples taken prior to the initiation of the study indicated an initial soil-test K of 62 kg K ha^{-1} (K was extracted using 0.05 N HCl + 0.025 N H_2SO_4). The occurrence of boll rot, as well as plant height, linearly increased as the rate of K applied to a field increased (Bennett et al., 1965).

Difficulty in managing the crop could potentially lead to problems later in the season with the pest management, as well as with the harvest efficiency of the crop. An overall delay in plant maturity was noted when there was more plant available K than needed (Clement-Bailey and Gwathmey, 2007). In that work, potassium had significant effects on the relative earliness of cotton. Earliness was determined by calculating the percentage of total yield picked at the first of two mechanical harvesting dates. When treatments of 112 kg K ha^{-1} were applied, 80% of total yield was picked at the first harvesting date. This was lower than that from plots receiving treatments of 56 kg K ha^{-1}, where 84% of total yield was picked at the first harvesting date (Clement-Bailey and Gwathmey, 2007). This supported findings from an earlier study, where cotton matured later when 112 kg K ha^{-1} was applied, as compared to when no K was applied (Gwathmey and Howard, 1998).

Potassium Deficiency in Cotton

Typically, potassium deficiency will appear as leaf-edge and interveinal chlorosis. Potassium deficiency symptoms are commonly visible in the upper canopy, which is contradictory to the understanding that K is a mobile nutrient within the plant (Raper, 2018). Research involving K deficiency in cotton dates back as far as 1937, where it was noted that growing conditions were conducive for the development of 'cotton rust,' which is what early researchers used to refer to extreme cases of K deficiency (Volk, 1946). Older research was conducted to determine how rates of applied K affected plant height and size, boll development, and yield (Bennett et al., 1965). Rates of 0, 70, 140, 280, 420, and 560 kg K ha^{-1} of muriate of potash were applied to plots. Plants receiving 70 or 140 kg K ha^{-1} showed severe symptoms of K deficiency (leaf-edge/interveinal chlorosis) by early September. Plant heights ranged from 140 cm in plots receiving no K to 203 cm in plots receiving 560 kg K ha^{-1}. Earlier natural boll openings were also associated with lower rates of applied K (Bennett et al., 1965).

In the early 1980s Ashworth and others (1982) noted that abnormal late-season K deficiency symptoms began to appear in California. This led to many studies to understand the cause of these non-characteristic deficiencies and searching for solutions to treat the problem areas. Even when producers applied recommended rates of K fertilizer, symptoms of mid-season K deficiency were observed in cotton on soils not considered K deficient. In part, cotton had increased sensitivity to low soil K levels, more than that observed in other field crops like corn and soybean (Cope, 1981; Cassman et al., 1990). Similar symptoms, recently observed in the Southeastern US, could be due to sandy surface textures, low organic matter, and low cation exchange capacity of Coastal Plain soils, making K management more challenging (Mitchell and Huluka, 2016), as Coastal Plain soils are limited in their ability to retain K.

Traditional potassium deficiencies were originally diagnosed by the presence of interveinal chlorosis and necrotic leaf margins on the mature lower leaves of the plant (Dong et al., 2004). The distribution of these traditional deficiency symptoms, however, has become somewhat sporadic and has been replaced by symptoms that occur in the upper portion of the plant, in the younger leaves (Maples et al., 1988). Cotton suffering from a K deficiency will often show an increased susceptibility to drought stress, with an adequate amount of water being necessary for the development of the plant's canopy (Coker et al., 2000). Potassium deficiency can cause the total number of leaves and size of leaves to be reduced, which leads to a reduced photosynthetic rate (Pettigrew, 2008). Other studies also showed that K deficiency also resulted in a reduction of lint percentages when cotton was harvested (Pettigrew and Meredith, 1997) and an overall reduction in fiber quality and yield (Cassman et al., 1990). In the latter study, rates of 0, 120, 240, and 480 kg K ha^{-1} were applied to plots. Potassium was surface applied as KCl and incorporated with a disk harrow. Rates were reapplied to the same plots each year of the 3-year study. During all 3 years of the study, seed cotton yield increased linearly as the rate of applied K increased. Fiber length also increased from 28.1 mm in plots receiving no K application, to 28.8 mm in plots receiving 480 kg K ha^{-1} ($p < 0.01$) (Cassman et al., 1990).

Other studies have investigated how different concentrations of K within a plant affect the elongation of cotton fibers within a boll, as the plant develops (Dhindsa et al., 1975). Results from this study led to the conclusion that K and malate (a product of nonautotrophic CO_2 fixation) are specifically required for the elongation of cotton fibers. When cultured in a lab setting, ovules did not produce cotton fibers unless the culture medium contained at least 0.50 mM of K. It was suggested that potassium and malate served as an important osmoticum that drove the extension of cotton fibers, and without the necessary levels of K in the ovary, cotton fibers would not extend properly.

Foliar Potassium Fertilization of Cotton

With the widespread findings of K deficiencies in cotton that were not related to levels of soil-test K, other methods for K application have been studied. One of these methods is the application of foliar K. Due to inefficient uptake of soil-applied K later in the growing season, foliar applications of K were seen as an alternative that would allow quick and efficient correction of deficiencies (Oosterhuis and Weir, 2010). Using a radioisotope of K with a short half-life (^{42}K), a study was conducted to determine the amount of time needed to move K from the leaves to other plant organs (Kafkafi, 1992). Radioactive $^{42}KNO_3$ was prepared and applied to the midrib of the leaf with a micro-pipette. It was determined that K from the leaf had moved into the bolls within twenty hours of application.

Results from other foliar K focused projects have been largely unpredictable (Howard et al., 1998; Pettigrew, 2010). One study was conducted to evaluate how foliar applications of potassium nitrate (KNO_3) impacted yield and fiber quality of cotton (Oosterhuis et al., 1990). Treatments consisted of the following: 1. No K/Control; 2. 40 kg K_2O ha^{-1}, soil applied; 3. 11 kg KNO_3 ha^{-1}, foliar applied; 4. 40 kg K_2O ha^{-1}, soil applied and 11 kg KNO_3 ha^{-1} foliar applied. Foliar K was applied at 2, 4, 6, and 8 weeks after first flower (Oosterhuis et al., 1990). When applied alone or in combination with soil-applied K, foliar KNO_3 increased both the average boll dry weight and overall seedcotton yield. Average boll dry weight increased from 3.51 g in the control treatment to 3.87 g in treatments receiving foliar- and soil-applied K. Average seedcotton yield increased from approximately 1,732 kg ha^{-1} in the control to 1,855 kg ha^{-1} in treatments receiving soil and foliar K applications (Oosterhuis et al., 1990). Soil- and foliar-applications of K also influenced certain fiber characteristics, with fiber uniformity and strength improving with the addition of soil- and foliar-applied K.

Others have evaluated the interaction of soil- and foliar-applied K fertilizer at 12, 10, and 13 sites in 1991, 1992, and 1993, respectively (Oosterhuis et al., 1994). In this study, 5 treatments of KCl (soil) and KNO_3 (foliar) were used: 1. no soil or foliar K; 2. 30 kg K ha^{-1} soil applied; 3. 60 kg K ha^{-1} soil applied; 4. 30 kg K ha^{-1} soil applied and 11.2 kg K ha^{-1} foliar applied; 5. 60 kg K ha^{-1} soil applied and 11.2 kg K ha^{-1} foliar applied. Foliar K treatments were applied 4 times weekly, beginning at the start of flowering. Results from this study showed a significant difference in yield due to foliar treatments in 4 locations in 1991, 6 locations in 1992, and three locations in 1993 (Oosterhuis et al., 1994).

A field study in Arkansas compared 5 foliar potassium sources on a silt loam soil that tested 'medium' for K levels (Miley and Oosterhuis, 1994). Potassium levels in the upper 15 cm of soil ranged from 200 to 237 kg K ha^{-1} and ranged from 176 to 197 kg K ha^{-1} at a depth of 16 to 30 cm. Foliar K sources used included the following salts of K: nitrate, sulfate, thiosulfate, chloride, and carbonate. Sources were applied at a rate of 11.2 kg K ha^{-1}, with 1.5 kg N ha^{-1} added to plots receiving K sources other than KNO_3. Results showed that application of KNO_3 caused the largest yield increase, with K-thiosulfate and K-sulfate causing the second and third largest increase, respectively. There was no noticeable effect on yield from the application of K chloride, and the use of K carbonate caused a significant drop in yield (Miley and Oosterhuis, 1994). It was hypothesized that the negative effects of K carbonate and lack of any noticeable effect from K chloride correlated with cell membrane integrity, and the physiological aspect of photosynthesis in the leaf.

Objective

The research on foliar K for cotton is limited, and rarely combined with soil-K treatments. Recent anecdotal reports indicate that soil-K in excess of that currently recommended may be needed. This lack of information about foliar K, coupled with a renewed interest in soil-test K, indicates that a study that examines these combined treatments is warranted. Thus, the objective of this project was to examine combined and separate foliar and soil K rates and sources for their impact on cotton yield.

II. MATERIALS AND METHODS

Two separate studies were conducted. The first was a study that examined initial uptake of K from various foliar K sources, conducted at two locations for one year. The second was an evaluation of soil and foliar K, conducted for two years at two locations.

Field Study 1

Field study 1 was conducted the Field Crops Unit (FCU) at E.V. Smith Research Center in Shorter, AL, on a Compass loamy sand (Coarse-loamy, siliceous, subactive, thermic Plinthic Paleudults) and at the Plant Breeding Unit (PBU) at E.V. Smith Research Center in Shorter, AL, on a Kalmia loamy sand (Fine-loamy over sandy or sandy-skeletal, siliceous, semiactive, thermic Typic Hapludults). The objective of this study was to evaluate uptake of foliar K sources as a function of sampling time and K source.

Seven treatments were evaluated, including a non-treated control, and 6 K sources applied as a foliar application (Table 1). Potassium sources (expressed as N-P_2O_5-K_2O) were: potassium sulfate (Ultrasol SOP 52®, 0-0-52-18S), potassium thiosulfate (ReNforce K®, 5-0-20-13S), potassium hydroxide (Super K®, 0-0-40), potassium sulfite/bisulfite (K-Row 23®, 0-0-23-8S), potassium formate (Safe K®, 3-0-34), and potassium acetate (LoKomotive®, 2-0-25) (Table 1). All foliar K treatments were applied at a rate of 4.5 kg K_2O ha^{-1} in a 108.5-liter ha^{-1} carrier volume. Treatments were applied to cotton plants in a field setting with a CO_2-powered backpack sprayer. Applications were made when cotton reached the early bloom growth stage, approximately 55-60 days after planting.

The cultivar 'Deltapine 1646 B2XF' was used for the study at the PBU location and was planted at a population of 125,970 seeds ha^{-1} on May 22, 2019. At the FCU location, ‘Stoneville 5471 GLTP’ was planted on May 16, 2019 at a population of 114,766 seeds ha^{-1}. Neither location was irrigated. Treatments were organized in a randomized complete block design, with each treatment replicated four times. Plots were 4 rows wide (3.7 m wide, 91.4 cm row spacing) and 6 m long. Following the application of treatments, three whole-plant samples were taken at 4, 12, 24, and 48-hours after application.

The FCU location received foliar applications on July 25, 2019, between approximately 10:00am and 10:45am. Therefore, samples were collected on July 25, 26, and 27. The PBU location received applications on August 1, 2019, between approximately 9:00am and 9:45am, and samples were collected on August 1, 2, and 3 (Table 2). No rainfall or irrigation occurred during the study period, and soil samples were taken to 15 cm prior to the initiation of the study (Table 3).

To collect the samples an entire plant was randomly selected and clipped at ground level. Samples were placed in paper bags and placed into a dryer at 46°C for a minimum of 48 hours. After drying, leaves were removed and analyzed for K content. Samples were then weighed and ground to pass a 20 mesh (1.0 mm) screen. After grinding, leaves were analyzed for K following wet digestion, with analysis via inductively coupled argon plasma emission spectrophotometer/vacuum (ICP) (Isaac and Johnson, 1985).

Field Study 2

In 2018, field study 2 was conducted at the Field Crops Unit at E.V. Smith Research Center in Shorter, AL, on a Marvyn sandy loam (Fine-loamy, kaolinitic, thermic Typic Kanhapludult) and at the Wiregrass Research and Extension Center in

Headland, AL, on a Lucy loamy sand (Loamy, kaolinitic, thermic Arenic Kandiudult). In 2019, the study in Shorter was conducted on a Marvyn sandy loam (Fine-loamy, kaolinitic, thermic Typic Kanhapludult), and the study in Headland was conducted on a plot that was a complex of 84% Dothan fine sandy loam (Fine-loamy, kaolinitic, thermic Plinthic Kandiudults) and 16% Orangeburg sandy loam (Fine-loamy, kaolinitic, thermic Typic Kandiudults). Soil test information from 15 cm samples for each location is shown in Table 4.

Studies were conducted on sites in which soil-test K was rated as 'medium' to 'high' (Table 4). In this study, eight soil-applied K treatments were evaluated: 1) 0 kg ha^{-1}, 2) 67 kg ha^{-1}, 3) 101 kg ha^{-1}, 4) 135 kg ha^{-1}, 5) 168 kg ha^{-1}, 6) 202 kg ha^{-1}, 7) 235 kg ha^{-1}, and 8) 269 kg ha^{-1}, expressed as K_2O. Treatments were arranged in a split-plot design, with soil applied K fertilizer as the main plot and foliar applied K fertilizer as the split, and were replicated four times at each location. Plots were four rows wide (3.7 m) and 7.6 m long, with 'Deltapine 1646 B2XF' cotton planted on a 91 cm row spacing. The target population was 78,249 seed ha^{-1}, planted as a 2 seed hill-drop. Plots at EVS were planted on May 2, 2018, and May 16, 2019. Plots at WREC were planted on May 2, 2018, and May 10, 2019.

For soil-applied K, the K source was granular potassium chloride (Peafowl Fertilizers, Muriate of Potash, 0-0-60). All soil K was hand-applied to the soil surface of plots within one week after planting and was not incorporated. For foliar-applied K, the K source was a blended potassium carbonate/potassium polyphosphate product (YaraVita, AgriPotash®, 0-5-32). Foliar K was applied first at the early bloom stage, then again two weeks after the first application, using a boom sprayer. Foliar K was applied at a rate of

4.5 kg K ha^{-1}, in a spray volume of 140 L ha^{-1}. In 2018, applications were made on July 11 and 27 at EVS and July 14 and 25 at WREC. In 2019, applications were made on July 25 and August 7 at EVS and July 8 and 22 at WREC.

During the growing season, plant leaf samples were taken to monitor the concentration of K within the plant over time (Table 5). Leaf samples were collected prior to the first application of foliar K, approximately two weeks after the first application of foliar K, and approximately 2 weeks after the second application of foliar K. Dates of sampling are outlined in Table 5. In each plot, approximately 20 leaves were collected at the time of each sampling. Leaves collected for sampling were fully expanded and recently emerged, so for consistency the 4th fully expanded leaf below the terminal bud of the plant was collected. After sampling, leaves were placed in a paper bag and placed in the plant dryer at 46°C for a minimum of 48 hours. After drying, samples were removed and ground to pass a 20 mesh (1.0 mm) screen. After grinding, samples were analyzed for K following wet digestion, with analysis via inductively coupled argon plasma emission spectrophotometer/vacuum (ICP) (Isaac and Johnson, 1985)

At the end of the growing season, seed cotton yield data were collected from each subplot and analyzed for variance due to fertilizer treatments. In 2018, the crop at EVS was machine harvested on September 19. No harvest occurred at WREC in 2018 due to crop loss caused by Hurricane Michael. In 2019, EVS cotton was harvested on October 23 and WREC cotton was harvested on October 11. A conversion factor of 0.47 was used to convert seedcotton yield numbers to an estimated lint yield. Following harvest, three soil cores were taken from each of the main plots using a Giddings Soil Probe (Windsor, CO). In 2018, soil cores at EVS were collected on October 24 and WREC on October 29. In 2019, soil cores at EVS were collected on October 24 and WREC on November 7. Plots receiving 0, 134, and 269 kg ha^{-1} of K_2O were sampled to evaluate the effect of fertilizer rate on the movement of K through the soil profile over the course of the growing season. Samples were taken to a depth of 91 cm or until further penetration was not possible. For each individual plot, cores were divided into 15 cm sections. For each plot, 0-15 cm segments from three sub-samples were composited to provide a single sample, and the same procedure was followed for the 15-30 cm, 30-45 cm, 45-60 cm, 60-75 cm and 75+ cm segments. Samples were extracted with Mehlich I and analyzed with ICP-OES (Spectro-Ciros ICP, SPECTRO Analytical Instruments, Kleve, Germany) to determine levels of potassium, magnesium, and calcium and to evaluate their movement through the soil profile (Mylavarapu and Miller, 2014).

Data Analysis

All data were analyzed using the SAS 9.4 (SAS Institute, Inc., Cary, NC) software program. Normality was tested in both studies using the PROC UNIVARIATE command. This allowed Q-Q plots and histograms to be created, as well as providing normality statistics for tests like the Shapiro-Wilk test. In Field Study 1, the only variable was fertilizer source, so the PROC GLM command was used to model plant K levels by product and location at each time interval in the study. PROC GLM was also used to provide means separation by product and location for each time interval. Duncan's multiple range test was used to test all main effect means. An alpha level of 0.05 was used for both studies.

In Field Study 2, data collection was more intensive and therefore analyses were more intensive. For the in-season leaf samples, PROC MIXED and PROC GLIMMIX were used because they allow randomization of blocks and treatments to be accounted for. Both MIXED and GLIMMIX were used to model leaf K content by fertilizer rate, type of fertilizer used, and an interaction of both variables. These two commands were also used to analyze yield data from the field study. Yield was modeled by fertilizer rate, type of fertilizer used, and an interaction of the two. Means separation for both leaf and yield data was provided using Tukey's studentized range test (HSD) on main effect means. Soil sample results from this study were only taken from plots receiving soil-applied K fertilizer, so a statistical analysis that accounted for split-plot designs was not necessary. PROC GLM was used to model K levels in the soil as a function of fertilizer treatment and trial location. Duncan's multiple range test was used to provide means separation.

III. RESULTS AND DISCUSSION

Results – Field Study 1

This study was conducted in two locations at Auburn University's E.V. Smith Research Center in 2018, with one study located at the FCU and the other at the PBU. The variable 'location' was highly significant for each sampling time. Due to this, data from each study location were analyzed separately, and results shown separately.

Field Crops Unit

While there were some differences in leaf K due to K sources at 4 and 48 hours, they were not consistent across sampling times at FCU (Table 6). For example, at the 4-hour sampling, plants to which potassium thiosulfate, potassium sulfate or potassium formate had been applied had greater leaf K content than that of leaves receiving no K (Figure 1). Such differences disappeared by hours 12 and 24, and K content in the cotton leaves from any treatment (including the control) was the same (Table 6).

Plant Breeding Unit

There were few consistent differences in leaf K due to K sources at any sampling time at PBU. At 4- and 12-hours leaf K was unaffected by the application of any foliar K, regardless of source (Table 7). At 24-hours, plants to which K hydroxide had been applied had more K in the leaves than plants to which K formate, K sulfite/bisulfite, or no K had been applied. At 48 hours after application, cotton to which K hydroxide or K sulfite/bisulfite had been applied had leaves with more K than in leaves to which K formate or K sulfate had been applied. There were no consistent positive effects from the application of any K source across locations (Figures 1 and 2). Results were inconsistent across locations and K sources.

Discussion – Field Study 1

Early work to evaluate different foliar sources of K had similar outcomes to these findings: no one particular source of foliar K increased tissue K content, when compared to other sources (Howard et al., 1998). In this study, the K concentration in the petioles of cotton leaves was never different due to K source, and treated plots had K contents that were not significantly different from those measured in the control plots. Evaluating the K concentration in leaf blades resulted in similar findings, with no difference in leaf K due to K source at three of four sampling times. At the one sampling time that there were differences, K thiosulfate performed significantly better than K nitrate and the control plots (Howard et al., 1998).

One factor that could have affected results is the rate at which K can be absorbed into the leaves of a cotton plant. Work conducted by Kafkafi determined that KNO_3, when applied to the midrib of a cotton leaf, was translocated to the bolls of the plant within twenty hours after application (Kafkafi, 1992). The lack of noticeable differences in K levels at the 4- and 12-hour intervals in this study could be attributed to not having a long enough sampling interval to determine K uptake.

It is possible that the lack of differences among the plots receiving foliar K and the control plots could be due to levels of soil K present prior to the application of foliar products. The location where the trial was conducted at FCU had a soil test K level of 139 kg K ha^{-1}. This level of soil test K is considered in the 'high' range by the Auburn University Soil Testing Laboratory. The soil test K level at PBU was 185 kg K ha^{-1}, which is considered in the 'very high' range by the Auburn University Soil Testing Lab. With soil test K being so high, the K requirement of the crop could have been satisfied by

K already present in the soil. A study by Howard et al. (1998) evaluated foliar K sources at two locations. One location was on a Memphis silt loam and the other on a Collins silt loam. Lint yield of the trial on the Collins silt loam location was increased by foliar K application, whereas the yield at the Memphis silt loam location showed no effect of foliar K on lint yield (Howard et al., 1998). The Memphis silt loam had 222 kg ha^{-1} of Mehlich-I extractable K, which is believed to have provided sufficient K via soil uptake to the cotton plants in this study (Howard et al., 1998).

In terms of tissue K content, one early article stated that ideal K content for optimal plant growth was 2-5%, but recent work has shown that this K level is rarely attained during cotton production, due to a number of factors in the plant growth environment (Marschner, 1995; Oosterhuis et al., 2013). Leaf K levels in this study were more in the range described by Oosterhuis et al. (2013) with average leaf K falling between 1% and 1.5%. This falls within the late bloom K sufficiency range of 0.75 to 2.5% K for cotton provided by the Southern Cooperative Series Bulletin (Baker et al, 2013).

Another factor to be considered is the argument of K 'in' the plant versus 'on' the plant. Some argue that washing plant samples prior to analysis provides a more accurate depiction of K that is actually in the leaf, and that not washing the plants could skew results and provide inaccurate data, by measuring K left on the leaf surface not yet absorbed. A study evaluating the foliar application of boron (B) in cotton (*Gossypium hirsutum* L.) and soybean (*Glycine max* L.) addressed this issue specifically. Two weeks after foliar applications of B were made, four plants were harvested from each pot. Two plants were washed with distilled water and the remaining two were unwashed. Plants that were to be washed were held under a stream of running distilled water for approximately one minute. When harvested soybean leaf tissue was washed, B concentrations in the leaf were not affected. Cotton leaves, however, showed a significant reduction in B content of plant tissue when washed (Guertal et al., 1996). Based on the findings of this study, washing of plant tissue was not included in this study to prevent K content of cotton leaves from being unintentionally reduced.

Results – Field Study 2

Leaf Tissue K

2018 - EVS

In 2018, the variable 'location' was highly significant and data for each location were analyzed separately. At E.V. Smith Research Center (EVS) in 2018, the main effects of K rate and K fertilizer source (soil-applied or soil- and foliar-applied) affected leaf K content at the pre-foliar application sampling time (Table 8). There was only one sampling period where the interaction of K rate and K source was significant. Thus, all data is discussed as a function of main effects.

In 2018 there was a significant difference in leaf K due to foliar application, even prior to any foliar K application (Table 8). This was observed at both locations. Data were examined for outliers, and all that can be assumed is that results observed were due to natural variation in tissue K.

After the first foliar K application at EVS, soil-applied K did not affect leaf K, but the application of foliar K did. On average, plants receiving a foliar K application had a tissue K content of 1.34%, while plants receiving only soil-applied K averaged 1.22% tissue K content. After the second foliar K application at EVS in 2018, application of foliar K again increased tissue K content. Neither soil-applied K rate nor the interaction of rate and source significantly affected leaf K (Figure 3).

2019 - EVS

In 2019 at EVS, the main effects of K rate and K source once again affected tissue K content prior to the first foliar K application, but the interaction was not significant (Table 8). After the first foliar K application, soil-applied K did not affect tissue K, but application of foliar K once again increased leaf K. The same effect was observed after the second foliar K application, where leaf K was increased in foliar treatments, and soil-applied K had no effect (Table 8). After the second application of foliar K, plots not receiving the foliar treatment had an average tissue K content of 1.35%, while plots receiving foliar K averaged 1.09% (Figure 3).

2018 - WREC

Similar to the E.V. Smith data, in 2018 at the Wiregrass Research and Extension Center (WREC) leaf tissue K content was affected by the foliar K treatment, even before any application had occurred (Table 8). After the first application of foliar K was made, neither soil K fertilization nor foliar K, or their interaction, affected tissue K content. However, when the second foliar K treatment was applied, leaf K was increased. After the second foliar K application, plots receiving the foliar K treatments had an average tissue K content of 1.78%, and plots that did not receive a foliar treatment averaged 1.28% (Figure 4).

2019 - WREC

In 2019 at WREC, leaf K was affected by both soil K fertilization and foliar K after the first foliar application, and by only foliar K after the second foliar treatment (Table 8). After the first foliar K application, plots receiving a foliar K treatment had an average tissue K content of 1.76%. Plots that received no foliar K treatment had an average tissue K content of 1.64% (Figure 4). After the second application of foliar K, plots receiving foliar K treatments had an average tissue K content of 1.42%. Plots not receiving foliar K treatments had an average tissue K content of 1.32%.

Although increases in leaf K were sometimes noted, K content in leaves was still lower than that reported elsewhere. Leaf K of 2-5% (dry weight basis) is often considered suitable (Marschner, 1995). Average K content of leaves in our study was between 1 and 2%.

Yield Data

WREC - 2018

In 2018, yield data was only collected from the research site at E.V. Smith. This was due to Hurricane Michael hitting the Wiregrass Research and Extension Center, resulting in a large portion of the cotton crop in South Alabama being lost and the yield of the research plot at WREC being lost as well.

EVS - 2018

In 2018, cotton yield at EVS was not significantly affected by fertilizer rate, fertilizer source, or the interaction of foliar K and soil K (Table 9). Cotton yield increased with added soil-applied K_2O, up to a soil applied K rate of approximately 176 kg K_2O ha^{-1} (Figure 6). The application of foliar K was slightly significant ($P = 0.06$). Mean cotton lint yield for plots receiving the two foliar K applications, in addition to soil-applied K was 2144 kg ha^{-1}. Mean cotton lint yield for plots receiving only soil-applied K was 2036 kg ha^{-1}. Therefore, there was an average lint yield increase of 108 kg ha^{-1} between plots receiving foliar-applied K and plots not receiving foliar-applied K at the EVS location in 2018 (Figure 5).

A soil-applied K rate of 101 kg K_2O ha^{-1} is typically used for cotton production in the Southeastern United States. At EVS in 2018, plots receiving 101 kg K_2O ha^{-1} of soil-applied K had a mean lint yield of 2154 kg ha^{-1}. Plots receiving two foliar applications of

4.5 kg K_2O ha^{-1} in addition to 101 kg K_2O ha^{-1} of soil-applied K had a mean cotton lint yield of 2257 kg ha^{-1} (Figure 5). This shows a cotton lint yield difference of approximately 103 kg ha^{-1} between plots when a foliar treatment was added.

EVS - 2019

In 2019, cotton lint yield at EVS was not affected by fertilizer rate or the interaction of fertilizer rate and source (Table 9). It was, however, affected by foliar K. No clear trend was observed in lint yield response to fertilizer rate, and some plots receiving fertilizer treatments had lower yield than that of the control plots (Figure 6). Irregularities in yield could be contributed to a sporadic, gapped plant stand. The poor stand is believed to be caused by a combination of the heavy rye cover crop residue and heavy rainfall throughout the early growing season that flooded several plots and drowned a considerable number of plants.

Cotton lint yield was significantly affected by fertilizer source, but this time in an opposite manner from the 2018 yield at EVS. Plots receiving only soil applied K yielded 1049 kg lint ha^{-1}, on average. Plots receiving two foliar K applications in addition to soil applied K yielded 937 kg lint ha^{-1}, on average. Contrary to the yield results of the previous year at the same location, plots receiving additional K by means of a foliar treatment yielded 112 kg ha^{-1} less cotton lint than plots receiving only soil-applied K.

WREC - 2019

Lint yield in 2019 at the WREC location was not affected by fertilizer rate, fertilizer source, or the interaction of the two variables (Table 9). Similar to the EVS location in 2019, no clear trend or response to increasing K fertilizer was noted (Figure 7). Control plots that received no treatment sometimes numerically out-yielded plots that received a heavy rate of soil-applied K and additional foliar treatments, although not statistically different.

Although it wasn't a significant effect, plots receiving foliar treatments of K tended to have a higher lint yield than plots receiving only soil-applied K. On average, plots receiving two foliar treatments in addition to the soil applied-fertilizer yielded 972 kg lint ha^{-1}. Plots that only received soil-applied K yielded 938 kg lint ha^{-1} on average.

Soil Data

EVS - 2018

In 2018 soil levels of K, Calcium (Ca), Magnesium (Mg), and soil pH all were significantly affected by the variable 'location'. Due to this, the 2018 soil data were analyzed on a 'by location' basis. See Table 6 for ANOVA of soil data.

At EVS in 2018, sampling depth was the only variable that affected soil K level (Table 10). Neither soil K application, nor the interaction of K rate and sample depth had an effect on soil K level. Across all three fertilizer rates, soil K level tended to decrease with each increase in sampling depth (Figure 8). Soil calcium (Ca) level was not affected by rate or the interaction of rate and sample depth, but it was affected by sampling depth alone (Table 10). Plots receiving no K fertilizer had numerically the highest calcium levels. There did not appear to be a consistent pattern in calcium levels as depth increased. Soil magnesium (Mg) levels followed the same trend as K and Ca: they were only affected by depth of sample (Table 10). Magnesium levels were low at the shallower two depths, increased to the middle two depths, and then falling off again at the deepest two depths. Soil pH was also only affected by sample depth (Table 10). Soil pH tended to decrease as sample depth increased and tended to decrease as rate of applied K fertilizer increased.

WREC - 2018

At WREC in 2018, soil K application, sample depth, and the interaction of the two had a highly significant effect on soil K levels (Table 10). Mean soil K levels in the upper 30 cm of the soil profile were higher on average plots receiving higher rates of applied K, and lowest in plots not receiving any fertilizer (Figure 9). Levels of soil Ca and Mg in the soil were only affected by sample depth (Table 10). Soil Ca levels increased consistently from 0 cm to 45 cm, dropped, then increased again from 45 cm to 90+ cm. Soil Mg levels gradually increased as depth of sample increased. Soil pH was affected by fertilizer rate and sample depth (Table 10). There was an increase in pH as depth of sample increased, and the plots receiving the highest level of applied K fertilizer had the highest pH.

At EVS in 2018, soil pH decreased with increasing rates of soil applied K. Soil Ca levels were also lower than the control when K was soil applied. However, soil pH results from WREC in 2018 were dissimilar. Numerically, the highest soil pH was in the plot receiving the highest fertilizer rate and the lowest pH was in the plot receiving the lower rate of fertilizer, with the pH of the control plot falling between the two plots that received fertilizer.

Discussion – Field Study 2

It has long been known that K fertilization can positively impact cotton production in several ways. The effect of fertilizer rate on plant K content is well known, with results from an early study showing that K content of cotton plants had a direct relationship to the rate of K applied (Bennett et al., 1965). In this study, leaf K content was significantly affected by soil-applied K rate at 3 of 4 sampling times prior to the application of foliar K. This agrees with the findings of Bennet et al. showing the relationship between applied K rate and plant K content.

More recent work showed that cotton leaves, which were used to monitor tissue K content in this study, were prone to K content changes of larger magnitude than that of other plant parts in situations of both high and low soil K levels (Coker et al., 2000). From the same study it was also determined that foliar applied K significantly increased leaf K content under irrigated and dryland situations (Coker et al., 2000). The findings of Coker's work agree with the results of this study, as foliar K application significantly affected tissue K content at 7 of 8 sampling times after the application of foliar K. It is also important to note that both study sites were irrigated during both years of this project, which further agrees with results obtained by Coker.

Cotton yield can also benefit from K fertilization. Early research conducted in Alabama showed that seedcotton yield, along with boll size and micronaire, improved with the application of K fertilizer (Bennett et al., 1965). In 2018 at the EVS location, cotton yield responded positively to added K and followed an expected trend of increased yield with increasing fertilizer up to a certain point. However, neither of the locations in 2019 had significant yield responses to added potassium.

There are also differences between this study and others regarding the effect of foliar applied K fertilizers on cotton yield. One study evaluated the effect of four different foliar K products against a control treatment on cotton yield (Howard et al., 1998). The application resulted in significantly higher yields in all plots receiving foliar treatments than control plots not receiving any foliar K products (Howard et al., 1998). A 1990 study found that foliar K (applied as KNO_3), when used in combination with soil applied K, increased seedcotton yield by 7 percent (Oosterhuis et al., 1990). However, a later study conducted in Arkansas to compare the yield effects of foliar application of 5 salts of K resulted in more inconsistent findings (Miley and Oosterhuis, 1994). In only one year of the three-year, single-location study did foliar treatments affect total cotton yield. It was also noted that the year that the differences due to foliar K application were noticed was the highest yielding year of the study's duration. Furthermore, another study's findings resulted in the conclusion that foliar fertilization with a blended product containing N, K, and B could not be consistently expected to increase cotton yield (Pettigrew, 2010).

CONCLUSIONS

In our foliar K uptake study, there was never any consistent difference in K uptake due to K source at either of the foliar K study locations. At only one sampling time and location did any foliar K products (K sulfate, K thiosulfate, K formate) significantly increase leaf K content when compared to the control plots. Therefore, claims that any product included in this study is consistently more readily taken up by plants than other foliar K sources was unsubstantiated.

In 2018, cotton yield in the soil and foliar K study at the EVS location increased as rate of soil-applied K increased, up to an applied K level of 176 kg K_2O ha^{-1}. This matched current soil-test recommendations. At this same location in 2018, foliar K increased cotton lint yield. This was the highest yield test, with almost double the yield of the other two harvested plots. In 2019, cotton yield at EVS showed no response to increasing rates of soil-applied K. At the WREC location in 2019, there was no yield response to any added K.

It can be concluded that when critical soil K levels are met that cotton yield response, if there is any, will be slight. More research is needed to determine if Auburn University K rate recommendations need to be updated. Given the findings of these projects, we cannot with confidence recommend the incorporation of foliar K fertilizers into standard cotton production practices, nor can we suggest that Auburn’s K rate recommendations need to be modified.

LITERATURE CITED

Ashworth, L.J.J., A.G. George, and O.D. McCutcheon. 1982. Disease-induced potassium deficiency and verticillium wilt in cotton. Calif. Agric.:18–20.

Baker, W.H., P.F. Bell, C.R. Campbell, F.R. Cox, S.J. Donohue, G.J. Hascho, E.A. Hanlon, L.E. Hinesley, G.J. Hochmuth, J.L. Kovar, G.M. Lessman, R.M. Lippert, G.S. Miner, C.C. Mitchell, C.O. Plank, W.E. Sabbe, H.J. Savoy, W.O. Thom, M.R. Tucker, and L. Unruh. 2013. Reference Sufficiency Ranges for Plant Analysis in the Southern Region of the United States. Southern Cooperative Series Bulletin #394 (C.R. Campbell, editor).

Bassett, D.M., W.D. Anderson, and C.H.E. Werkhoven. 1970. Dry matter production and nutrient uptake in irrigated cotton (*Gossypium hirsutum*). Agron. J. 62:299–303.

Bennett, O., R. Rouse, D. Ashley, and B. Ross. 1965. Yield, fiber quality, and potassium content of irrigated cotton plants as affected by rates of potassium. Agron. J. 57:296–299.

Cassman, K.G., T.A. Kerby, B.A. Roberts, D.C. Bryant, and S.L. Higashi. 1990. Potassium nutrition effects on lint yield and fiber quality of Acala cotton. Crop Sci. 30:672–677.

Clarkson, D.T., and J.B. Hanson. 1980. The mineral nutrition of higher plants. Annu. Rev. Plant Physiol. 31:239–298.

Clement-Bailey, J., and C.O. Gwathmey. 2007. Potassium effects on partitioning, yield, and earliness of contrasting cotton cultivars. Agron. J. 99:1130–1136.

Coker, D.L., D.M. Oosterhuis, and R.S. Brown. 2000. Potassium partitioning in the cotton plant as influenced by soil and foliar potassium fertilization under water deficit stress. Spec. Rep. Arkansas Agric. Exp. Stn. 198:81-88 ST-Potassium partitioning in the cotton p.

Cope, J.T. 1981. Effects of 50 years of fertilization with phosphorus and potassium on soil test levels and yields at six locations. Soil Sci. Soc. Am. J. 45:342–347.

Dhindsa, R.S., C.A. Beasley, and I.P. Ting. 1975. Osmoregulation in cotton fiber. Plant Physiol. 56:394–398.

Dong, H., W. Tang, Z. Li, and D. Zhang. 2004. On potassium deficiency in cotton – disorder, cause and tissue diagnosis. Agric. Conspec. Sci. 69:77–85.

Gerardeaux, E., L. Jordan-Meille, J. Constantin, S. Pellerin, and M. Dingkuhn. 2010. Changes in plant morphology and dry matter partitioning caused by potassium deficiency in gossypium hirsutum (l.). Environ. Exp. Bot. 67:451–459.

Guertal, E.A., A.O. Abaye, B.M. Lippert, G.S. Miner, and G.J. Gascho. 1996. Sources of boron for foliar fertilization of cotton and soybean. Commun. Soil Sci. Plant Anal. 27:2815–2828.

Gwathmey, C.O., and D.D. Howard. 1998. Potassium effects on canopy light interception and earliness of no-tillage cotton. Agron. J. 90:144–149.

Gwathmey, C.O., C.L. Main, and X. Yin. 2009. Potassium uptake and partitioning relative to dry matter accumulation in cotton cultivars differing in maturity. Agron. J. 101:1479–1488.

Halevy, J. 1975. Growth rate and nutrient uptake of two cotton cultivars grown under irrigation. Agron. J. 68:701–705.

Howard, D.D., C.O. Gwathmey, and C.E. Sams. 1998. Foliar feeding of cotton: evaluating potassium sources, potassium solution buffering, and boron. Agron. J. 90:740–746.

Isaac, R.A., and W.C. Johnson. 1985. Elemental analysis of plant tissue by plasma emission spectroscopy: collaborative study. J. Assoc. Off. Anal. Chem. 68:499–505.

Kafkafi, U. 1990. The functions of plant K in overcoming environmental stress situations. In: Development of K-fertilizer recommendations. 22nd Colloquium of the International Potash Institute. p. 81–93

Kafkafi, U. 1992. Foliar feeding with potassium nitrate in cotton. Proceedings 22nd Colloquim. Potash and Phosphate Institute, Norcross, GA. p. 16–17

Kerby, T.A., and F. Adams. 1987. Potassium nutrition of cotton. In: Munson, R.D., editor, Potassium in Agriculture. ASA, CSSA, SSSA, Madison, WI. p. 843–860

Leffler, H.R., and B.S. Tubertini. 1976. Development of cotton fruit II. accumulation and distribution of mineral nutrient. Agron. J. 68:858–861.

Maples, R.L., W.R. Thompson Jr., and J. Varvil. 1988. Potassium deficiency in cotton takes on a new look. Better Crop. 73:6–9.

Marschner, H. 1995. Mineral nutrition of higher plants. Second Ed. Acdemic Press, San Diego.

Miley, W.N., and D.M. Oosterhuis. 1994. Three-year comparison of foliar feeding of cotton with five potassium sources. Proceedings of the Beltwide Cotton Production Conference. National Cotton Council, Memphis, TN. p. 1534–1536

Mitchell, C.C., and G. Huluka. 2016. Potassium dynamics in us coastal plain soils. Commun. Soil Sci. Plant Anal. 47:54–63.

Mullins, G.L., and C.H. Burmester. 2010. Relation of growth and development to mineral nutrition. In: Stewart, J.M., Oosterhuis, D.M., Heitholt, J.J., and Mauney, J.R., editors, Physiology of Cotton. Springer Netherlands, Dordrecht. p. 97–105

Mullins, G.L., G.J. Schwab, and C.H. Burmester. 1999. Cotton response to surface applications of potassium fertilizer: a 10-year summary. J. Prod. Agric. 12:434–440.

Mylavarapu, R., and R. Miller. 2014. Mehlich-1. In: Sikora, F.J. and Moore, K.P., editors, Soil Test Methods From the Southeastern United States. p. 95–100

Oosterhuis, D.M. 1989. Potassium management of cotton. In: Pasricha, N.S. and Bansal, S.K., editors, Potassium for Sustainable Crop Production. International Potash Institute, Basel, Switzerland and Potash Research Institute of India, Gurgaon, Haryana,. p. 321–346

Oosterhuis, D.M. 2001. Physiology and nutrition of high yielding cotton in the USA. INFORMAÇÕES AGRONÔMICAS 95:18–24.

Oosterhuis, D.M., O. Abaye, D.W. Albers, W.H. Baker, C.H. Burmester, J.T. Cothren, M.W. Ebelhar, D.S. Guthrie, M.G. Hickey, S.C. Hodges, D.D. Howard, R.L. Huthinson, L.D. Janes, G.L. Mullins, B.A. Roberts, J.C. Silvertooth, P.W. Tracy, B.L. Weir,. 1994. A summary of a three-year beltwide study of soil and foliar fertilization with potassium nitrate in cotton. Proceedings of the Beltwide Cotton Production Conference. p. 1532–1533

Oosterhuis, D.M., D.A. Loka, and T.B. Raper. 2013. Potassium and stress alleviation: physiological functions and management of cotton. J. Plant Nutr. Soil Sci. 176:331–343.

Oosterhuis, D.M., and B.L. Weir. 2010. Foliar fertilization of cotton. Physiology of Cotton. p. 272–288

Oosterhuis, D.M., S.D. Wullschleger, R.L. Maples, and W.N. Miley. 1990. Foliar-feeding of potassium nitrate in cotton. Better Crop. 74:8–9.

Pettigrew, W.T. 2008. Potassium influences on yield and quality production for maize, wheat, soybean and cotton. Physiol. Plant. 133:670–681.

Pettigrew, W.T. 2010. Effects of foliar fertilizer and mepiquat pentaborate on early planted cotton growth and lint production crop management. Online. Crop Manag.

Pettigrew, W.T., and W.R. Meredith. 1997. Dry matter production, nutrient uptake, and growth of cotton as affected by potassium fertilization. J. Plant Nutr. 20:531–548.

Raper, T. 2018. Cotton and potassium: background and the potential of placement to increase efficiency. Crop Soils 51:16–19.

Rosolem, C.A., R.H. Da Silva, and J.A. De Fátima Esteves. 2003. Potassium supply to cotton roots as affected by potassium fertilization and liming. Pesqui. Agropecu. Bras. 38:635–641.

Snider, J.L., and D.M. Oosterhuis. 2015. Physiology. In: Fang, D.D. and Percy, R.G., editors, Cotton, Second Edition. Second Edi. ASA, CSSA, SSSA, Madison, WI. p. 339–400

Volk, N.J. 1946. Nutritional factors affecting cotton rust. Agron. J. 38:6–12.

Waddle, B.A. 1984. Crop growing practices. Cotton, Agronomy Monograph no. 24. ASA-CSSA-SSSA, Madison, WI. p. 233–263

White, P.J., and A.J. Karley. 2010. Potassium. In: Hell, R. and Mendel, R.R., editors, Cell Biology of Metals and Nutrients. Springer, Heidelberg, Dordrecht, London, New York. p. 199–224

Zhou, Z., W. Zhao, M. Abid, Y. Wang, H. Dong, and R. Zahoor. 2017. Potassium fertilizer improves drought stress alleviation potential in cotton by enhancing photosynthesis and carbohydrate metabolism. Environ. Exp. Bot. 137:73–83.

TABLES

Table 1. Potassium fertilizers applied in Field Study 1, E.V. Smith Field Crop Unit and Plant Breeding Unit, AL, 2019.

Trade Name	Name/Address of Manufacturer	Analysis (N – P – K)	K sourced from:
K-Row 23	Tessenderlo-Kerley, Inc. 2255 North 44th Street, Suite 300 Phoenix, AZ 85008-3279	0-0-23-8S	Potassium sulfite/bisulfite
LoKomotive	Loveland Products 3005 Rocky Mountain Avenue Loveland, CO 80538	2-0-25	Potassium acetate
ReNforce K	Loveland Products 3005 Rocky Mountain Ave Loveland, CO 80538	5-0-20-13S	Potassium thiosulfate
Super K	Huma Gro 1331 W. Houston Ave. Gilbert, AZ 85233	0-0-40	Potassium hydroxide
Ultrasol SOP52	SQM Los Militares 4290 Las Condes Santiago, Chile	0-0-52-18S	Potassium sulfate
YaraVita Safe K	Yara North America 100 N. Tampa Street, Suite 3200 Tampa, FL 33602	3-0-34	Potassium formate

Table 2. Sampling dates and times for foliar K uptake study; Studies located at FCU and PBU, AL, 2019.

		Sampling Time (Hours)				
Location	Date	Application	Post Application Sampling			
			4 hr	12 hr	24 hr	48 hr
FCU†	7-25-19	10:00	14:00	22:00	--	--
	7-26-19	--	--	--	10:00	--
	7-27-19	--	--	--	--	10:00
PBU‡	8-1-19	9:00	13:00	21:00	--	--
	8-2-19	--	--	--	9:00	--
	8-3-19	--	--	--	--	9:00

† FCU – Field Crops Unit, E.V. Smith Research Center, Shorter, AL

‡ PBU – Plant Breeding Unit, E.V. Smith Research Center, Shorter, AL

Table 3. Soil-test information for Field Study 1, 2019. Soil extract is Mehlich-1.

FCU†					PBU‡				
pH	Ca	Mg	K	P	pH	Ca	Mg	K	P
	------------ kg ha^{-1} ------------					------------ kg ha^{-1} ------------			
6.8	1328.2	138.9	100.9	48.2	6.1	573.9	96.4	184.9	72.9

†Field Crop Unit, E.V. Smith Research Center, Shorter, AL
‡Plant Breeding Unit, E.V. Smith Research Center, Shorter, AL

Table 4. Background soil-test information for Field Study 2, 2018-2019.

Year	Location	pH	Ca	Mg	K	P
			kg ha^{-1}			
2018	EVS†	6.0	625.4	82.9	105.4	40.4
	WREC‡	6.0	548.1	38.1	97.5	30.3
2019	EVS†	7.0	1039.0	83.0	83.0	71.0
	WREC‡	6.4	687.1	31.4	84.1	108.7

†EVS – E.V. Smith Research Center, Shorter, AL

‡WREC – Wiregrass Research and Extension Center, Headland, Al

Table 5. Sampling dates for leaf tissue for subsequent K analysis, soil K fertilizer/foliar K research study, 2018 and 2019.

Leaf Tissue Sampling Dates							
	Pre	Post 1	Post 2		Pre	Post 1	Post2
	EVS† 2018				WREC‡ 2018		
Date	7/10/2018	7/24/2018	8/9/2018	Date	7/13/2018	7/24/2018	8/7/2018
	EVS† 2019				WREC‡ 2019		
Date	7/11/2019	8/8/2019	8/30/2019	Date	7/3/2019	7/18/2019	8/6/2019

†EVS - E.V. Smith Research Center, Shorter, AL
‡WREC - Wiregrass Research and Extension Center, Headland, AL

Table 6. Potassium content of cotton leaves at 0, 4, 12, 24, and 48 hours after the application of foliar K fertilizer in Field Study 1 at the E.V. Smith Field Crops Unit, 2019.

	Time elapsed after application (hours)				
K Source	0	4	12	24	48
	-------------------- percent K --------------------				
Control	1.47 ab	1.51 b	1.64 a	1.75 a	1.65 ab
K sulfite/bisulfite	1.61 ab	1.78 ab	1.82 a	1.78 a	1.64 ab
K acetate	1.65 a	1.75 ab	1.84 a	1.66 a	1.67 ab
K thiosulfate	1.59 ab	1.87 a	1.68 a	1.67 a	1.61 b
K formate	1.61 ab	1.85 a	1.82 a	1.73 a	1.83 a
K hydroxide	1.45 b	1.79 ab	1.75 a	1.78 a	1.61 b
K sulfate	1.64 ab	1.85 a	1.82 a	1.70 a	1.75 ab

† Different letters within the same column denote significant differences at $\alpha = 0.05$ as determined via means separation.

Table 7. Potassium content of cotton leaves at 0, 4, 12, 24, and 48 hours after the application of foliar K fertilizer in Field Study 1 at the E.V. Smith Plant Breeding Unit, 2019.

K Source	Time elapsed after application (hours)				
	0	4	12	24	48
	-------------------- percent K --------------------				
Control	1.23 a	1.64 a	1.35 a	1.23 b	1.31 ab
K sulfite/bisulfite	1.36 a	1.66 a	1.40 a	1.31 b	1.41 a
K acetate	1.36 a	1.58 a	1.47 a	1.42 ab	1.31 ab
K thiosulfate	1.35 a	1.60 a	1.39 a	1.43 ab	1.35 ab
K formate	0.96 b	1.53 a	1.19 a	1.26 b	1.21 b
K hydroxide	1.31 a	1.60 a	1.39 a	1.61 a	1.43 a
K sulfate	1.25 a	1.60 a	1.40 a	1.42 ab	1.21 b

† Different letters within the same column denote significant differences at α = 0.05 as determined via means separation.

Table 8. Analysis of variance for the effects and interactions for leaf K as affected by soil K fertilization, foliar K, and their interaction, 2018 and 2019.

	-----Foliar K application-----						
	Pre	Post 1	Post 2		Pre	Post 1	Post2
	--	7/11/18	7/27/18		--	7/14/18	7/25/18
	EVS† 2018				WREC‡ 2018		
Soil K Rate (R)	0.0163	0.1843	0.4856	Soil K Rate (R)	0.1614	0.2032	0.4926
Foliar K (F)	0.0002	0.0002	<.0001	Foliar K (F)	0.0053	0.1961	<.0001
RxF	0.2671	0.0557	0.6474	RxF	0.3948	0.4997	0.8592
	-----Foliar K application-----				-----Foliar K application-----		
	--	7/25/19	8/7/19		--	7/8/19	7/22/19
	EVS† 2019				WREC‡ 2019		
Soil K Rate (R)	0.0210	0.7779	0.7757	Soil K Rate (R)	0.0020	0.0072	0.7779
Foliar K (F)	0.0042	0.0039	0.0001	Foliar K (F)	0.2134	0.0033	0.0039
RxF	0.7276	0.7817	0.9206	RxF	0.2464	0.9725	0.7817

†EVS – E.V. Smith Research Center, Shorter, AL
‡WREC – Wiregrass Research and Extension Center, Headland, AL

Table 9. Analysis of variance for soil K, foliar K, and their interaction on cotton lint yield, 2018 and 2019.

	------------------------------Pr > F------------------------------		
	EVS† 2018		WREC‡ 2018††
Soil-K Rate (R)	0.1210	Soil-K Rate (R)	--
Foliar K (F)	0.0649	Foliar K (F)	--
RxF	0.1918	RxF	--
	EVS† 2019		WREC‡ 2019
Soil-K Rate (R)	0.4979	Soil-K Rate (R)	0.8409
Foliar K (F)	0.0003	Foliar K (F)	0.2432
RxF	0.4636	RxF	0.7628

†EVS – E.V. Smith Research Center, Shorter, AL
‡WREC – Wiregrass Research and Extension Center, Headland, AL
†† Yield data lost due to Hurricane Michael

Table 10. Analysis of variance for effect of fertilizer rate, sampling depth, and their interaction on soil K, Ca, and Mg levels and pH, 2018 and 2019.

	Pr > F								
	K	Ca	Mg	pH		K	Ca	Mg	pH
	EVS† 2018					WREC‡ 2018			
Soil-K Rate (R)	0.6709	0.3966	0.2296	0.0874	Soil-K Rate (R)	<0.0001	0.5517	0.9917	0.0017
Sample Depth (D)	<0.0001	<0.0001	<0.0001	<0.0001	Sample Depth (D)	<0.0001	0.0002	<0.0001	0.0214
RxD	0.5122	0.6030	0.1883	0.7940	RxD	<0.0001	0.9995	0.9970	0.9984
	EVS† 2019					WREC‡ 2019			
Soil-K Rate (R)					Soil-K Rate (R)				
Sample Depth (D)					Sample Depth (D)				
RxD					RxD				

†EVS – E.V. Smith Research Center, Shorter, AL
‡WREC – Wiregrass Research and Extension Center, Headland, AL

FIGURES

Figure 1. Potassium content of cotton leaves as affected by foliar K source, E.V. Smith Field Crop Unit, 2019. Error bars represent standard error about the mean.

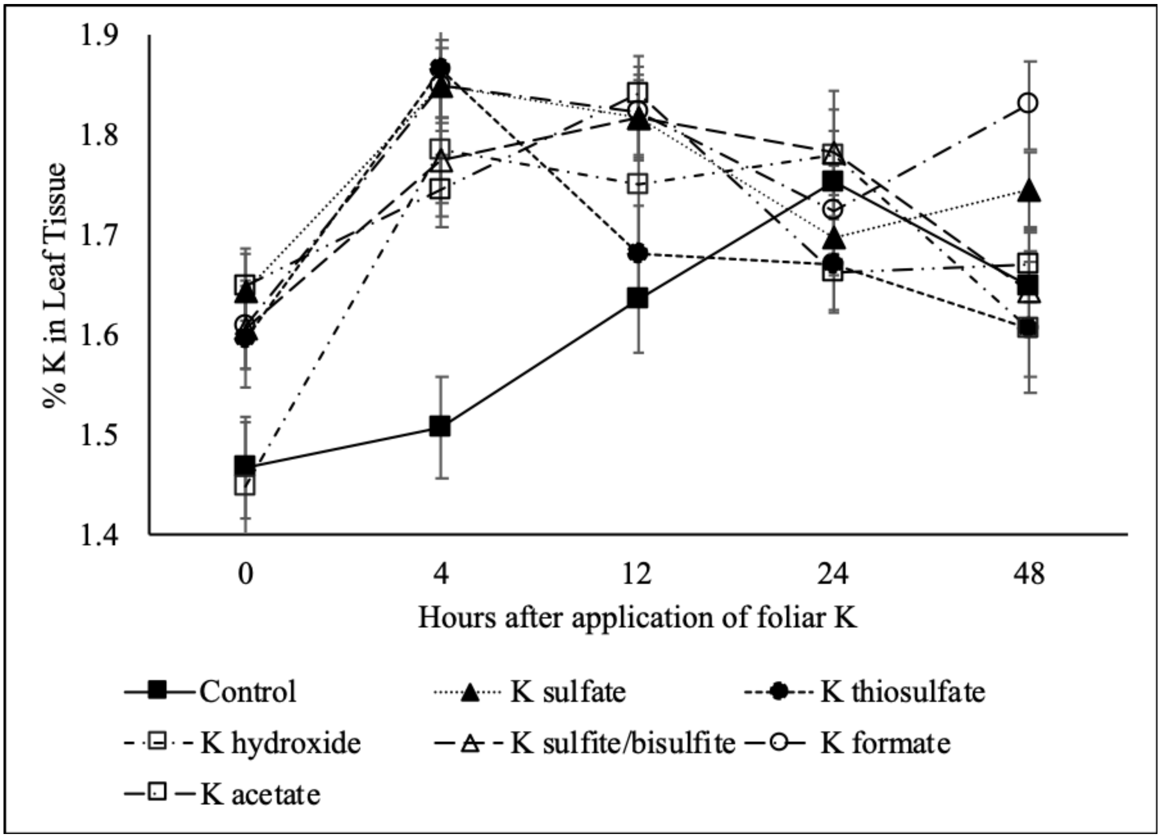

Figure 2. Potassium content of cotton leaves as affected by foliar K source, E.V. Smith Plant Breeding Unit, 2019. Error bars represent standard error about the mean.

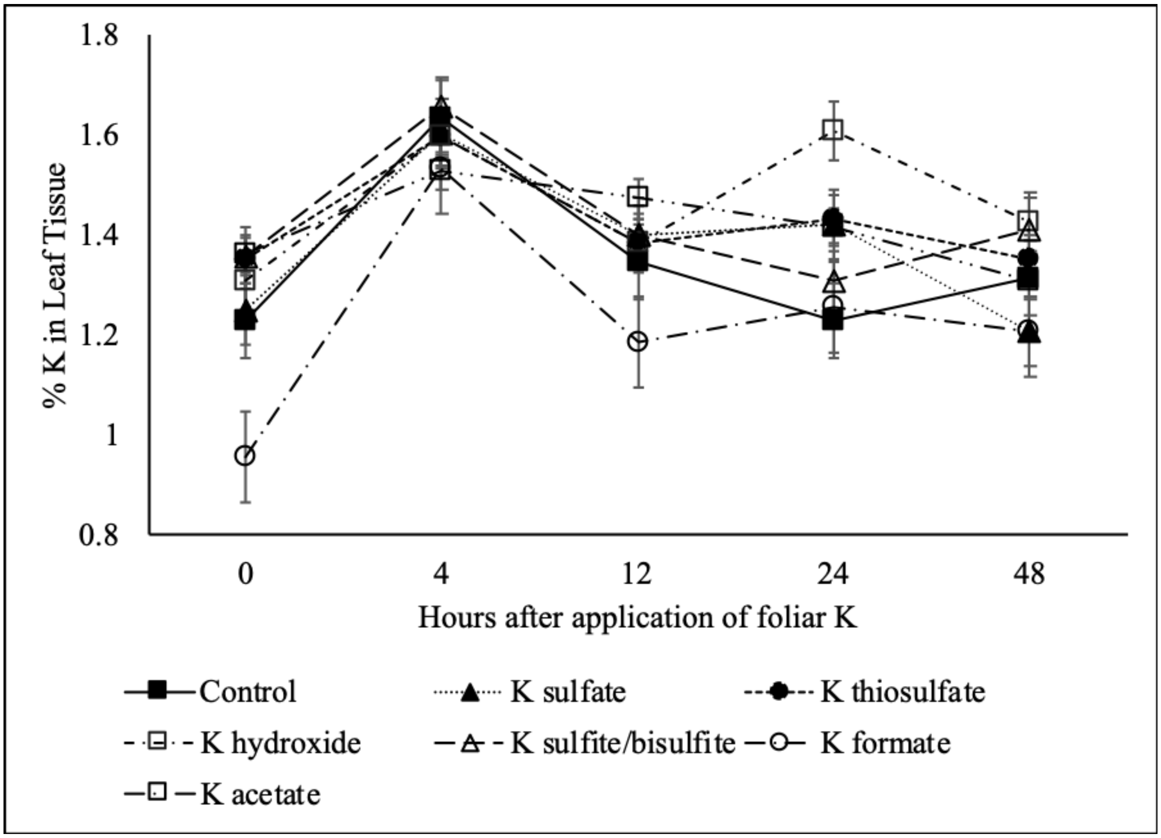

Figure 3. Cotton leaf K content after the first and second application of foliar K at E.V. Smith Research Center, 2018-2019. Different letters within the same sampling time denote significant differences at $\alpha = 0.05$ as determined via means separation.

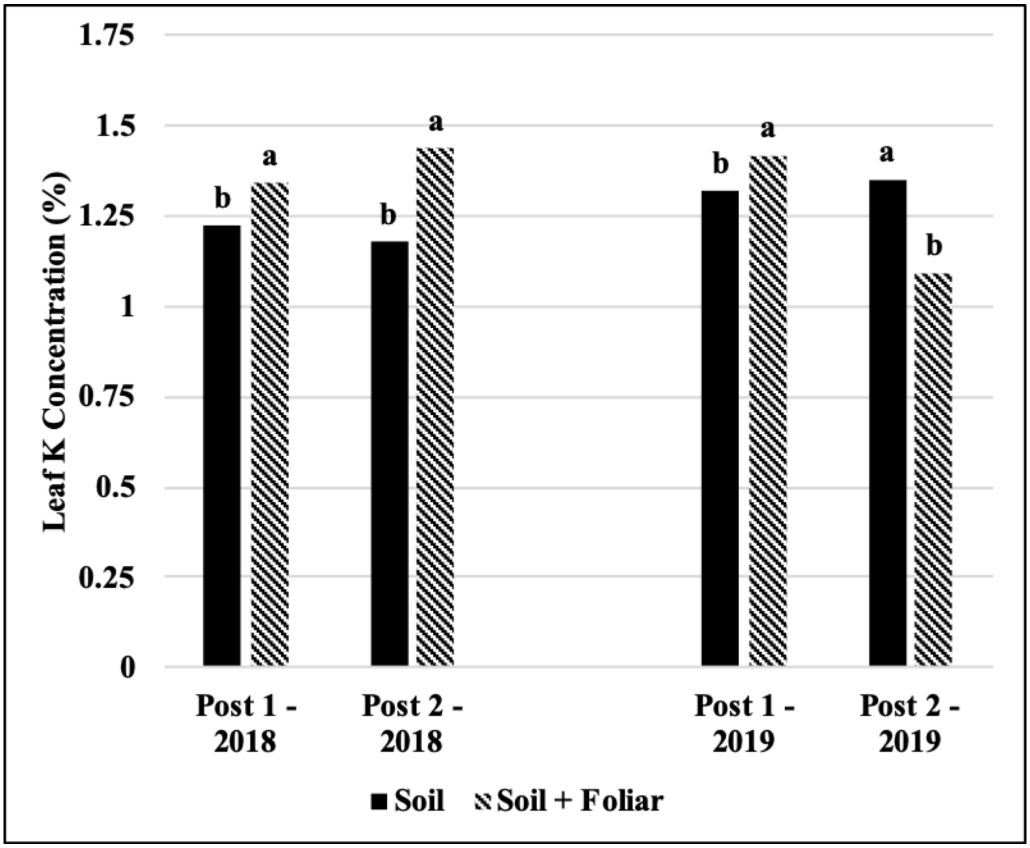

Figure 4. Cotton leaf K content after the first and second application of foliar K at Wiregrass Research and Extension Center, 2018-2019. Different letters within the same sampling time denote significant differences at $\alpha = 0.05$ as determined via means separation.

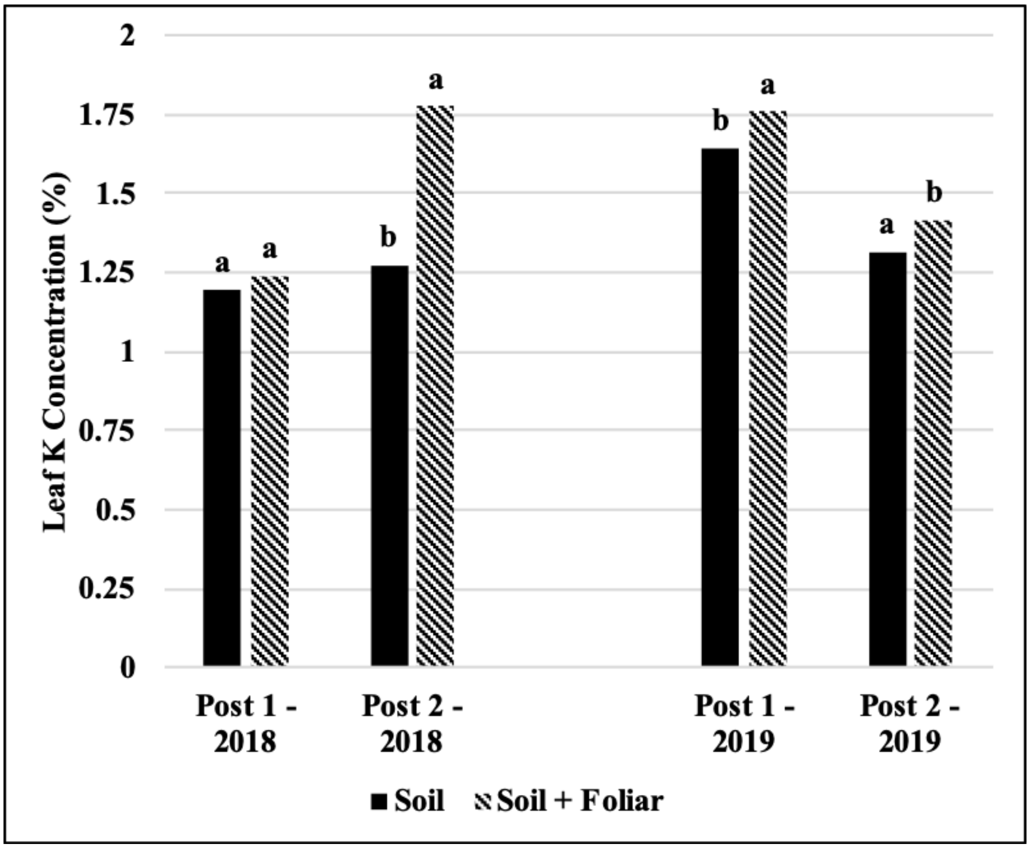

Figure 5. Average cotton lint yields as affected by foliar K and soil-applied K_2O rate at E.V. Smith Research Center in 2018. Error bars represent standard error about the mean.

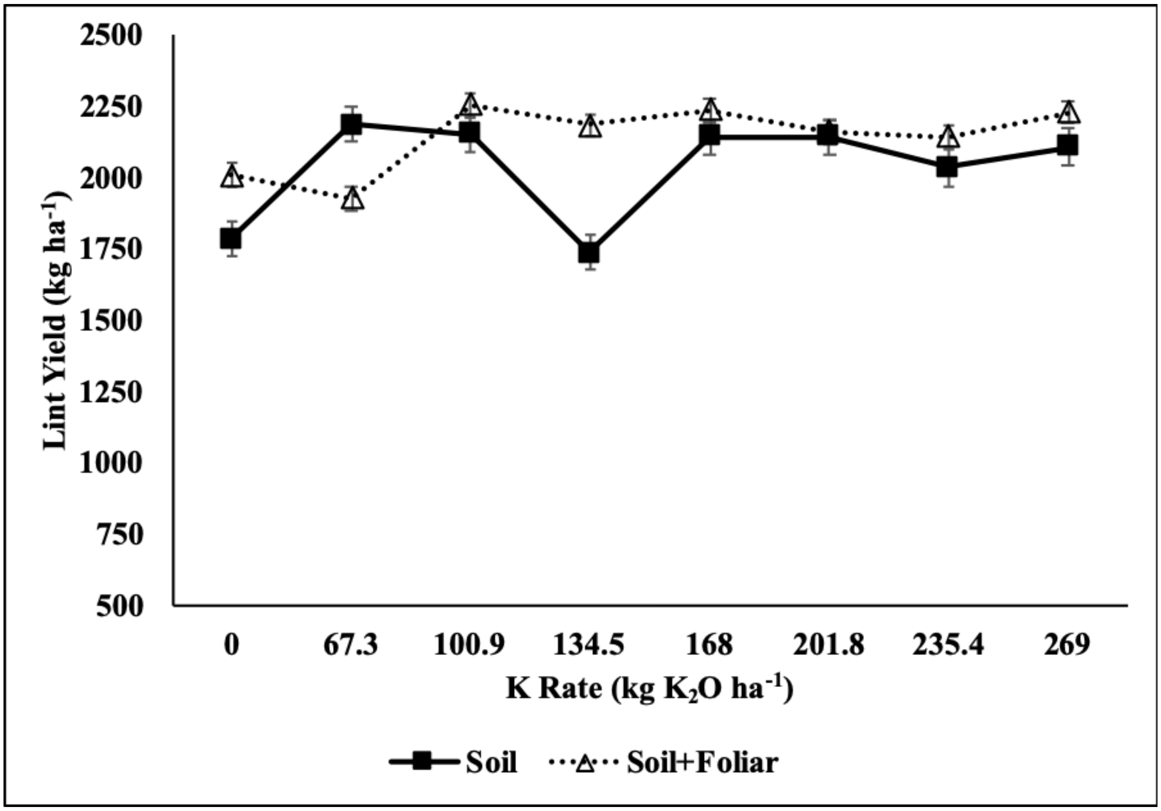

Figure 6. Average cotton lint yields as affected by foliar K and soil-applied K_2O rate at E.V. Smith Research Center in 2019. Error bars represent standard error about the mean.

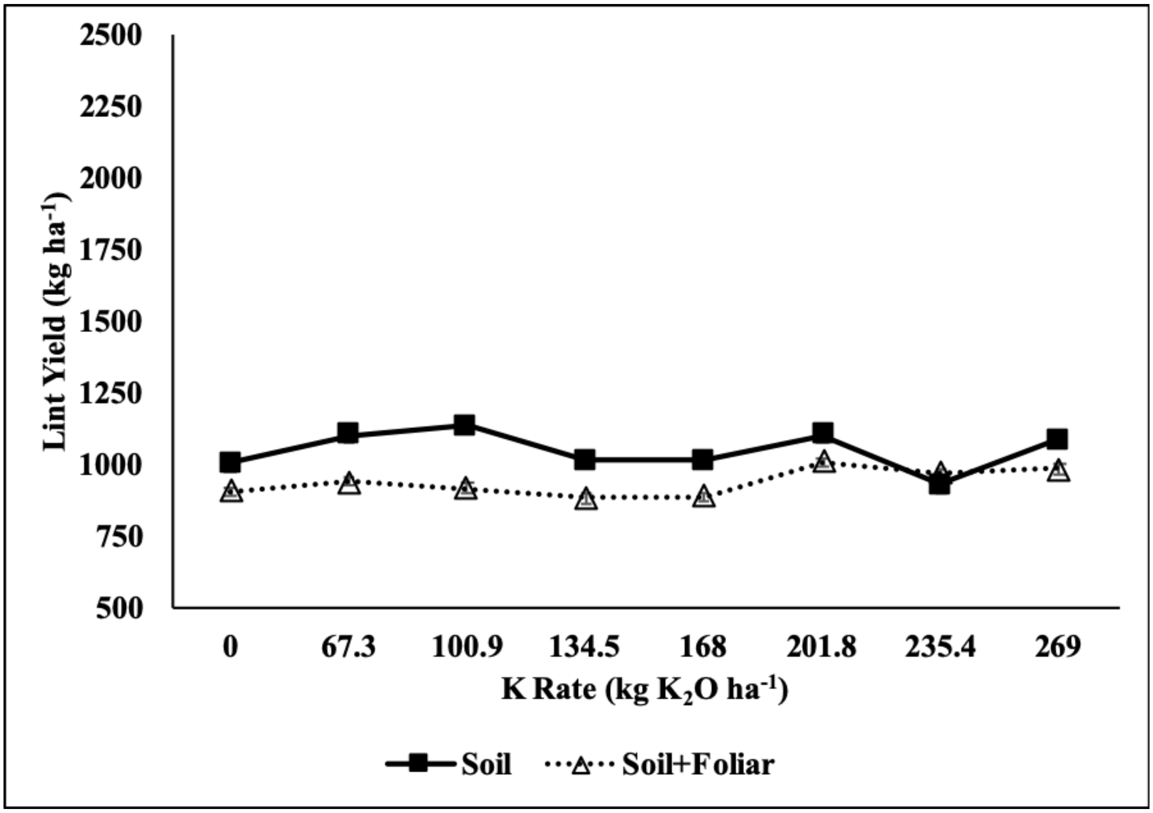

Figure 7. Average cotton lint yields as affected by foliar K and soil-applied K_2O rate at Wiregrass Research and Extension Center in 2019. Error bars represent standard error about the mean.

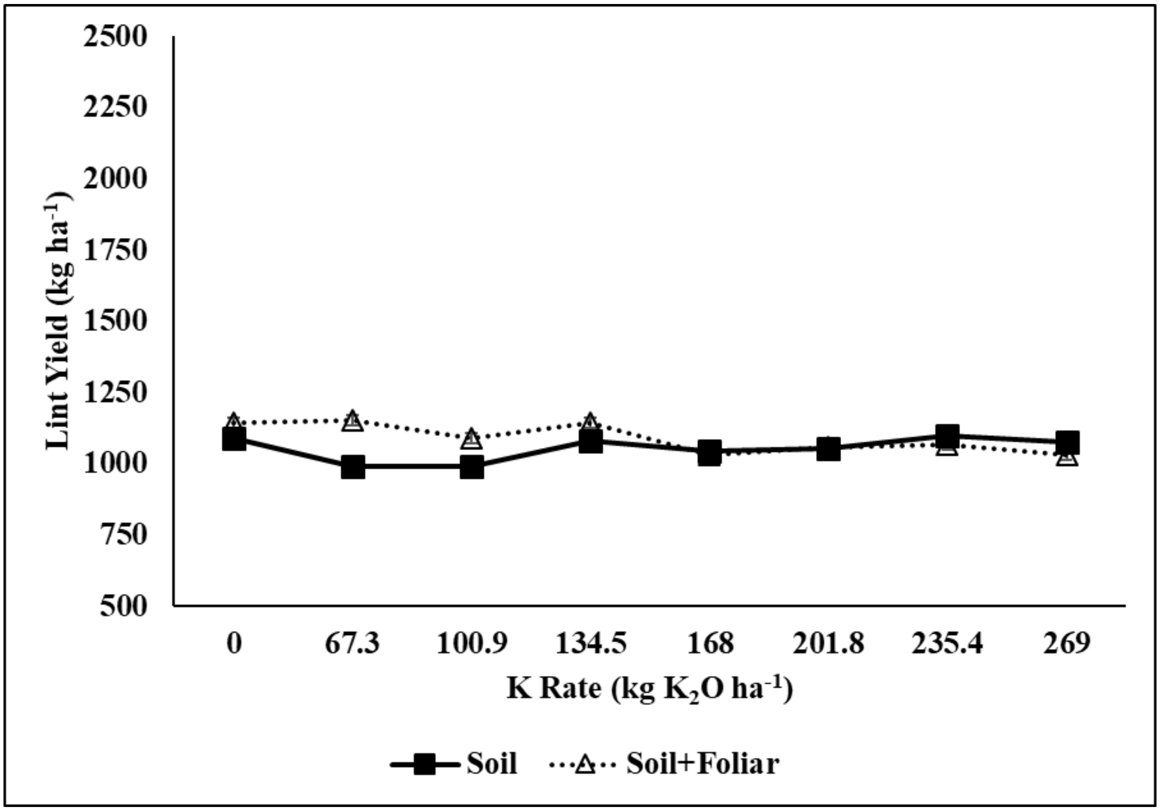

Figure 8. Mehlich-1-extractable soil K levels as affected by sampling depth and K rate, E.V. Smith Research Center, 2018. Error bars represent standard error about the mean.

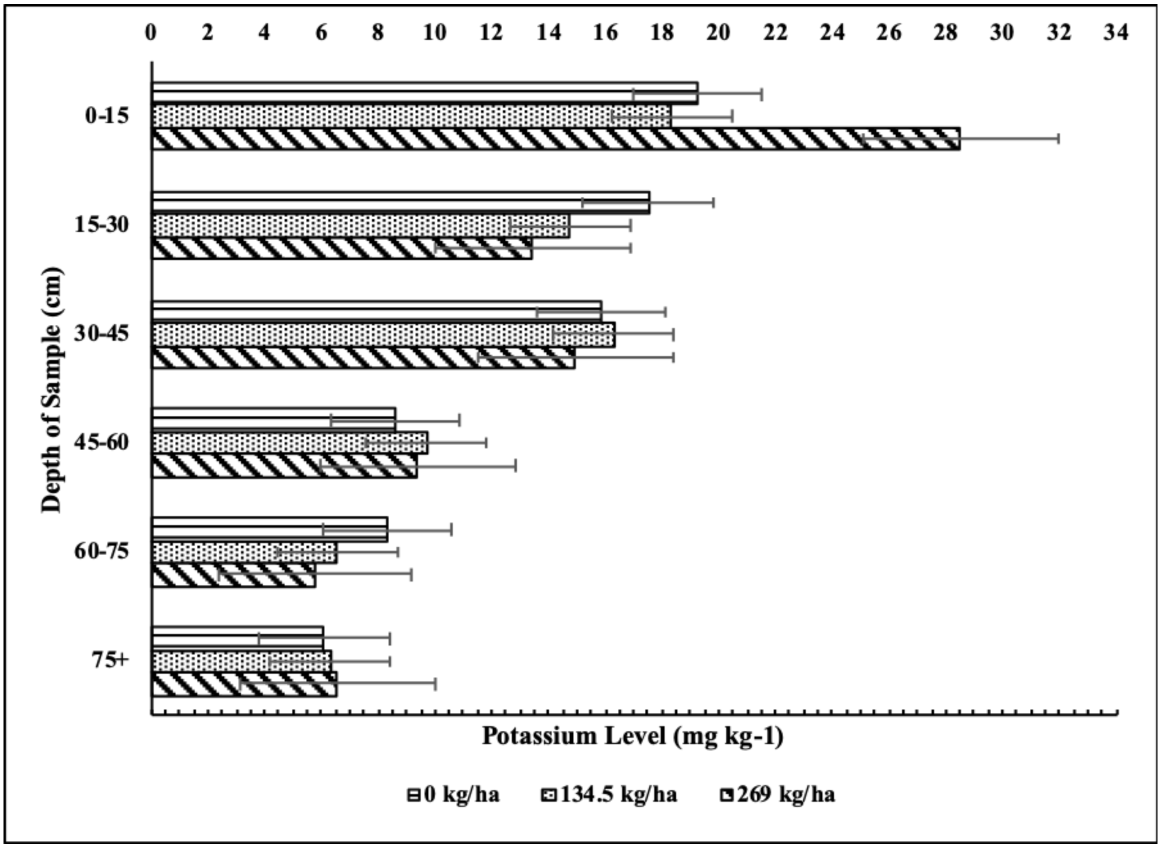

Figure 9. Mehlich-1-extractable soil K levels as affected by K rate and sampling depth at Wiregrass Research and Extension Center, 2018. Error bars represent standard error about the mean.