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# Cotton Response to Foliar Potassium Application in South Texas Dryland

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**Abstract:** Potassium (K) deficiency is common in cotton (*Gossypium hirsutum* L.)-growing areas. This study aims to investigate the effects of different rates of foliar K fertilizer application on three cotton varieties: NG 5711 B3XF (V1), PHY 480 W3FE (V2), and FM 1953GLTP (V3). Potassium fertilizer was dissolved in water and was foliar-applied at 34, 50, and 67 kg ha$^{-1}$. Cotton plant height (CH) and canopy width (CW) were monitored throughout the growing season. The results showed that foliar K fertilizer application significantly impacted the CH and CW in dry years. Although insignificant, the cotton lint yield increased by 15% and 20% with 34 and 50 kg ha$^{-1}$ in 2020 and by 9% and 7% with 50 and 67 kg ha$^{-1}$ in 2021, indicating the potential for improved lint yield with foliar K application in rainfed production systems. Similarly, variety V3 had significantly greater lint and seed yields than V1 in 2020. The average lint yield among the varieties was 32%, and the seed yield was 27% greater in 2020 than in 2021. The cotton fiber color grade was significantly greater at 50 kg ha$^{-1}$ in 2020 and 67 kg ha$^{-1}$ in 2021. Cotton variety significantly affected color grade, uniformity, staple length, Col, RD, and Col-b contents in 2020 and 2021. The results suggest that foliar K application can enhance cotton production in rainfed production systems. However, more research is required to quantify varietal and foliar K application rates for improved lint yield and quality.

**Keywords:** cotton quality; cotton yield; potassium; foliar application; dryland production systems



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## 1. Introduction

Cotton (*Gossypium hirsutum* L.) production is concentrated in 17 southern states, including Texas, which accounts for ~40% of the total production in the United States [1]. Potassium (K) is a crucial macronutrient necessary for optimal growth, energy metabolism, stomatal regulation, enzyme activation, resistance against abiotic and biotic stresses, fiber secondary wall deposition, fiber strength, and yield [2–8]. A simple schematic model showing how foliar K application enhances cotton growth, development, and yield is presented in Figure 1. Despite these advantages, K fertilization in cotton is often overlooked, mainly because soil tests indicate adequate K concentrations. However, K deficiency remains widespread in cotton-growing regions and has been reported above the required soil test K threshold levels [2,4]. Cotton requires an average of 110 to 250 kg K ha$^{-1}$ during the growing season, with a daily demand of 3–5 kg ha$^{-1}$ day$^{-1}$ during the boll-filling phase [9–12]. High-yielding new cotton varieties may require additional K for optimum yield, and a re-evaluation of current fertilizer requirements is necessary [12]. Furthermore, soil testing may indicate adequate K concentrations, but slow-release rates, high K fixation capacity, and weathering of K in soils developed from mica minerals may influence the K availability and outpace the soil supply during the growing season [13–15], warranting additional K application for optimum yield and quality.

South Texas's semi-arid climate during the cotton growing season, characterized by high temperatures, humid conditions, and scarce rainfall, can challenge the availability, movement, and absorption of K nutrients, leading to a shortage during the reproductive growth stages of cotton, especially in rainfed production systems [16]. In addition, K management difficulties arise for growers due to complex K chemistry and its interaction with soil and environmental variables in semi-arid climates [2]. One possible solution to this problem is to provide potassium (K) directly to the leaves during the boll-filling stages by foliar application [17]. Directly applying fertilizers to the foliage can be feasible to fulfill the potassium requirements. Foliar K application can correct nutrient deficits, supplement nutrient requirements under unfavorable conditions, help plants retain more bolls per plant, and increase yield and quality [14,18,19]. This is especially true in areas with unfavorable soil and climatic conditions in rainfed production systems, as cotton plants can move and absorb nutrients through their roots and leaves [14,16].

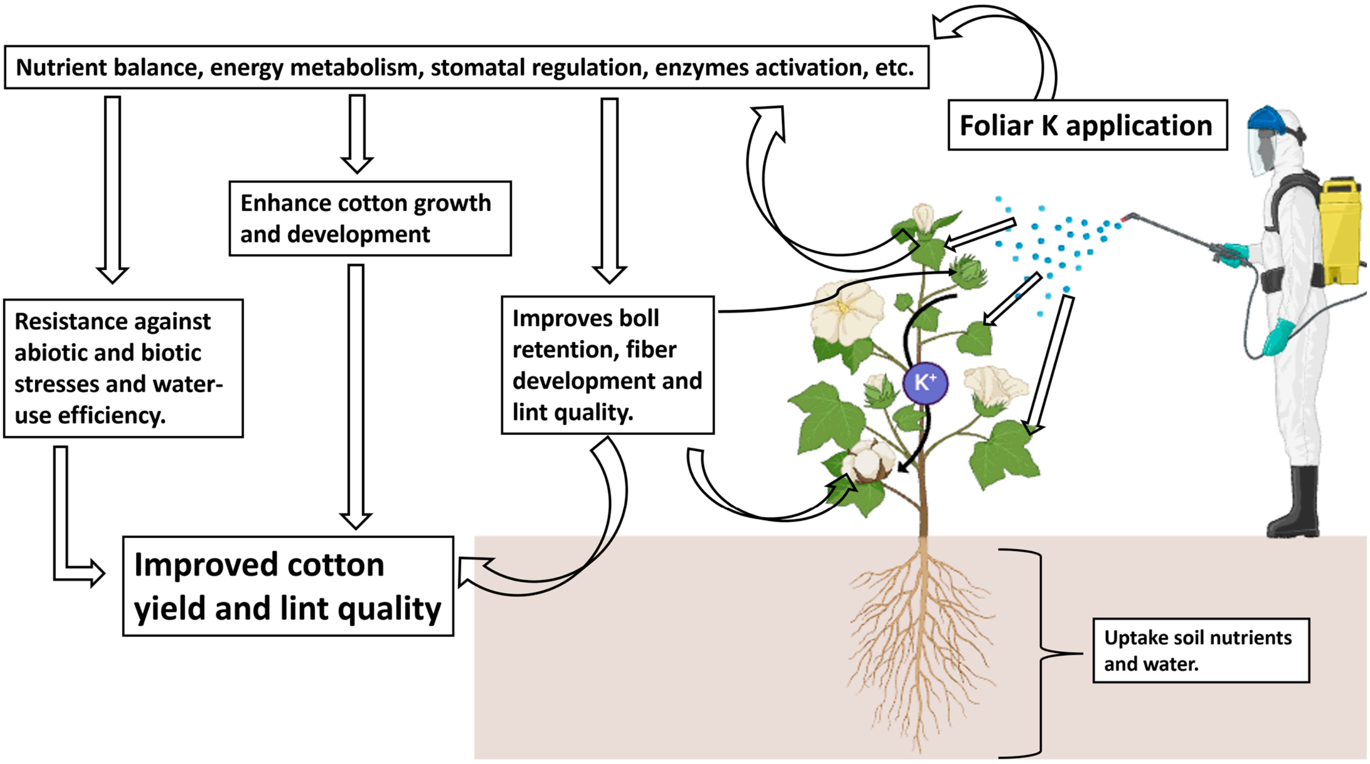


**Figure 1.** Schematic model showing how foliar K application enhances cotton growth, development, and yield.

However, inconsistent results of foliar K application on cotton yield and quality indicate the need for further investigation to accurately assess the effects of foliar K application [9,14,18,20–22]. Furthermore, field studies that quantify the effect of foliar K application on cotton yield and quality are limited [14]. Consequently, it is crucial to address this gap with additional field research. This study aims to evaluate the effects of varying rates of foliar K fertilizer on plant height, canopy, yield, and fiber quality in rainfed production systems in southern Texas.

## 2. Materials and Methods

### *2.1. Site Characteristics*

The study was conducted in 2020 and 2021 at the Texas A&M University-Kingsville (TAMUK), Texas (27°32′50.3″ N 97°52′57.3″ W, 18 m above sea level) farm. Soil samples were collected from 0 to 15 cm in depth using a core probe (50 mm diameter) in both years. The sampling procedures, soil series names, and test results were also reported by [15]. Briefly, the soil had an average organic matter content of 1.36%, a pH of 6.8, a nitrate–nitrogen ($NO_3$-N) concentration of 6 mg $kg^{-1}$, a phosphorous ($P_2O_5$) concentration of 134 mg $kg^{-1}$, and a potassium ($K_2O$) concentration of 370 mg $kg^{-1}$. The soil pH and soluble salts were measured using a selective hydrogen electrode and conductivity probe [23,24]. $NO_3$-N was extracted using the method explained by [25]. Olsen-P was analyzed using the method explained by [26]. Potassium was extracted using Mehlich-3 solution and determined by inductively coupled plasma (ICP).

Long-term climate data (50 years) for the study site from 1969 to 2019 show an average annual precipitation of 799 mm and a mean temperature of 23 °C [27]. The average temperature was 24 °C and 23 °C in 2020 and 2021, respectively (Figure 2a). The total precipitation was 685 mm in 2020 and 1077 mm (~392 mm greater than that in 2020) in 2021 (Figure 2b). Most of the increase in rainfall occurred in May, when the crops received approximately 532 mm of rainfall in Kingsville (Figure 2b).

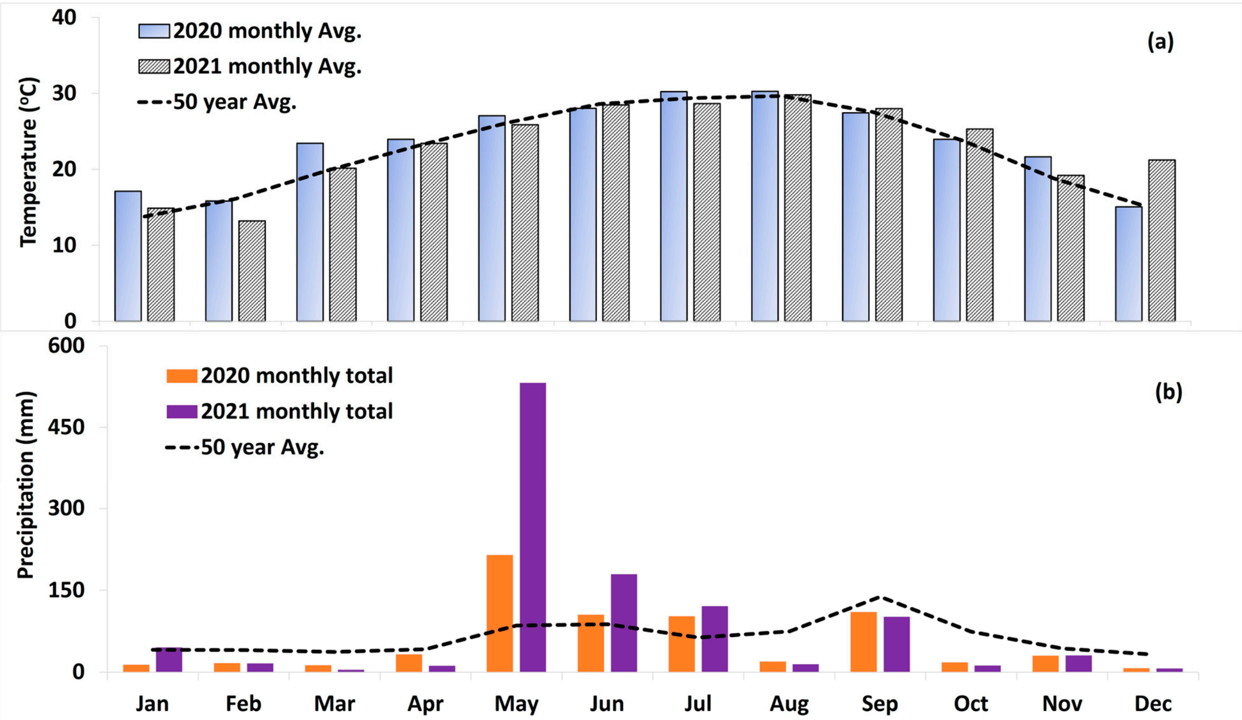


**Figure 2.** Comparisons of long-term (50 years) weather variables with those observed during the experiment in 2020 and 2021: (**a**) monthly average daily air temperatures and (**b**) monthly total precipitation.

## *2.2. Management Practices, Planting, and Foliar Fertilizer Application*

Three cotton varieties, NG 5711-B3XF (V1), PHY 480-W3FE (V2), and FM 1953-GLTP (V3), recommended for South Texas, were planted at the TAMUK farm on 10 April 2020 and 30 March 2021, using a 4-row, 36-inch planter (1705 Planter) at an approximate rate of 88,000 seeds per hectare. The management practices, plot sizes, tillage, and planting were described in [15]. Briefly, the plots measured 7.62 m by 0.91 m, with a 1.52 m alley between plots and a 2.44 m alley between replications. The study used a randomized split-plot design with three replications with foliar potassium (K) fertilizer rate (FKAR) as the whole-plot factor and cotton variety as the split-plot factor. The cotton varieties and FKAR were randomized. Nitrogen fertilizer was applied after planting (UAN; knifed) at a recommended rate of 118 kg $ha^{-1}$. The potassium chloride (KCl) was used as foliar K fertilizer at rates of 0, 34, 50, and 67 kg K $ha^{-1}$ (Table 1).

**Table 1.** Planting and management practices performed in 2020 and 2021 with dates and days after planting (DAP).

| 2020 | | 2021 | | Activities |
|---|---|---|---|---|
| Date | Days After Planting (DAP) | Date | Days After Planting | |
| 04/10/2020 | 1st day | 03/30/2021 | 1st day | Seeds planted |
| 05/10/2020 | 30 DAP | 04/30/2021 | 30 DAP | 1st measurement |
| 05/15/2020 | 35 DAP | 05/04/2021 | 35 DAP | 1st foliar spray |
| 05/20/2020 | 40 DAP | 05/09/2021 | 40 DAP | 2nd foliar spray |
| 05/25/2020 | 45 DAP | 05/14/2021 | 45 DAP | 2nd measurement |
| 05/30/2020 | 50 DAP | 05/19/2021 | 50 DAP | 3rd foliar spray |
| 06/04/2020 | 55 DAP | 05/24/2021 | 55 DAP | 4th foliar spray |
| 06/09/2020 | 60 DAP | 05/29/2021 | 60 DAP | 3rd measurement |
| 06/14/2020 | 65 DAP | 06/03/2021 | 65 DAP | 5th foliar spray |
| 06/19/2020 | 70 DAP | 06/08/2021 | 70 DAP | 6th foliar spray |
| 06/24/2020 | 75 DAP | 06/14/2021 | 75 DAP | 4th measurement |
| 06/29/2020 | 80 DAP | 06/18/2021 | 80 DAP | 7th foliar spray |
| 07/04/2020 | 85 DAP | 06/23/2021 | 85 DAP | 8th foliar spray |
| 07/09/2020 | 90 DAP | 06/28/2021 | 90 DAP | 5th measurement |
| 07/24/2020 | 105 DAP | 07/13/2021 | 105 DAP | 6th measurement |

The total K required for each plot was calculated based on the plot size and divided into eight applications. During each application, the KCl fertilizer was dissolved in a 1 L glass beaker using a magnetic stirrer in the laboratory with reverse osmosis (RO) water. A ULINE solo (H-7986) backpack sprayer was calibrated, and the dissolved K fertilizer was added with addental RO water to dilute the K concentration before foliar application. K fertilizer was diluted to minimize leaf burn after application. Recommended pre-emergence and post-emergence herbicide applications were followed to manage weeds.

### *2.3. Data Collection*

The data collection procedure was explained in detail by [15]. Briefly, eight plants in the middle two rows were randomly tagged 25 days after planting (DAP). Measurements for cotton plant height (CH) and canopy width (CW) were obtained from the tagged plants using a measuring stick throughout the growing season as described in [15]. Data were collected at 30, 45, 60, 75, 90, and 105 DAP (Table 1). Cotton was hand-harvested from a 1.82 m row length in the middle two rows. The sample was ginned to determine the seed and lint weights.

The lint quality was assessed using high-volume instruments (HVIs) at the United States Department of Agriculture (USDA) Cotton Division, Corpus Christi, TX. The fiber quality parameters included color grade, micronaire, staple length, fiber strength as force (g $tex^{-1}$) necessary to break the fiber bundle, fiber uniformity, fiber whiteness expressed as % reflectance (Rd), and fiber yellowness (+b).

### *2.4. Statistical Analysis*

Analysis of variance was performed using the PROC GLIMMIX procedures in SAS version 9.4 [28]. For each analysis, the cotton varieties and FKAR were considered fixed effects. The least square mean and standard error (SE) of the mean were considered in all the analyses, and the mean value was separated using Fisher's protected least significant difference (LSD) test at $p < 0.05$.

## 3. Results

### *3.1. Analysis of Variance (ANOVA)*

The ANOVA results showed a significant interaction between year and FKAR ($p = 0.0447$) and year and variety ($p = 0.0400$) for CH but not for CW (Table 2). Likewise, there was a significant interaction between variety and FKAR ($p = 0.0035$), and year, variety and K application rate ($p = 0.0009$) for CW but not for height (Table 2).

**Table 2.** Analysis of variance (ANOVA) with three-way interaction on measured cotton (growth, yield, and quality) parameters.

| Treatments | Height | Canopy Width | Seed Yield | Lint Yield | Color Grade | Micronaire | Staple Length | Strength | Uniformity | Col-Rd | Col-b |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | * | * | * | * | NS | * | * | * | * | * | * |
| K rate | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS |
| Year * K rate | * | NS | NS | NS | * | NS | NS | NS | NS | NS | NS |
| Variety | * | NS | * | NS | * | NS | * | NS | * | * | * |
| Year * Variety | * | NS | NS | NS | * | NS | NS | NS | NS | NS | * |
| Variety * K rate | NS | * | NS | NS | NS | NS | NS | NS | NS | NS | NS |
| Year * Variety * K rate | NS | * | NS | NS | NS | NS | NS | NS | NS | NS | NS |

* Significant at the 0.05 probability level. NS: not significant.

### 3.2. Cotton Plant Height (CH) and Canopy Width (CW)

In 2020, the cotton variety did not significantly impact CH, and mixed results were observed. Varieties V1 and V2 had slightly greater heights (3%) than V3. In 2021, V1 and V3 had a significantly greater CH ($p < 0.001$) than V2 (Table 3). Variety V1 had 14% and V3 had 8% taller height than V2.

The foliar potassium application rate (FKAR) significantly influenced ($p \leq 0.001$) CH in 2020 (Table 3). The FKARs of 34 and 50 kg ha$^{-1}$ resulted in significantly greater CH compared to the control and 67 kg ha$^{-1}$ ($p \leq 0.001$). However, this effect was not observed in 2021. In 2020, the CH increased by 8% and 13% at the 34 and 67 kg ha$^{-1}$ FAPR, respectively, compared to the control. In 2021, the CH increased by 2%, with a 50 kg application rate. However, the 34 and 67 kg ha$^{-1}$ FKAR treatments decreased plant height by 2% and 4%, respectively, compared to the control. (Table 3). Overall, cotton plant height was 12% greater with variety and application rate in 2021 than in 2020.

**Table 3.** Least square means of cotton height (cm) and canopy width (cm) as affected by cotton variety and foliar K fertilizer application rates in 2020 and 2021.

| Measuring Unit (CM) | [1] Variety (VAR) | | | | Foliar K Application Rate, kg ha$^{-1}$ (FKAR) | | | | | Main and Interactions Effect $p$ Values | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | V1 | V2 | V3 | SE | 0 | 34 | 50 | 67 | SE | VAR | FKAR | VAR * FKAR |
| Height, 2020 | 69.4 $^{a}$ | 70.0 $^{a}$ | 67.3 $^{a}$ | 6.5 | 65.6 $^{b}$ | 71.6 $^{a}$ | 75.0 $^{a}$ | 63.4 $^{b}$ | 6.6 | 0.57 | 0.0001 * | 0.7648 |
| Height, 2021 | 64.6 $^{a}$ | 56.8 $^{b}$ | 61.6 $^{a}$ | 2.4 | 61.6 $^{a}$ | 60.3 $^{a}$ | 62.7 $^{a}$ | 59.4 $^{a}$ | 2.5 | 0.001 * | 0.55 | 0.0049 |
| Canopy width, 2020 | 38.3 $^{a}$ | 37.2 $^{ab}$ | 35.6 $^{b}$ | 2.2 | 35.2 $^{b}$ | 40.3 $^{a}$ | 38.0 $^{a}$ | 34.7 $^{b}$ | 2.2 | 0.005 * | 0.0001 * | 0.3721 |
| Canopy width, 2021 | 62.8 $^{a}$ | 62.3 $^{a}$ | 59.5 $^{a}$ | 2.0 | 61.6 $^{a}$ | 60.8 $^{a}$ | 62.2 $^{a}$ | 61.5 $^{a}$ | 2.1 | 0.14 | 0.92 | 0.0001 |

[1] Variety = V1, NG 5711 B3XF); V2, PHY 480 W3FE; and V3, FM 953GLTP. Within a row and main effect, least square means lacking a common superscript letter differ ($p \leq 0.05$), * significant; SE: standard error.

In 2020, V1 had a significantly larger canopy width than V3, but it was not statistically different from V2. The difference in canopy width was substantial, with V1 having 3% and 7% more canopy than V2 and V3, respectively (Table 3). In 2021, there was no significant difference in canopy size among the varieties. However, V1 maintained a 1% and 6% larger canopy than V2 and V3, respectively.

In 2020, there was a significant difference ($p < 0.001$) in cotton CW with 34 and 50 kg ha$^{-1}$ FKAR treatments compared to the control and 60 kg ha$^{-1}$ K treatment (Table 3). However, this significant disparity in FKAR was not observed in 2021 with FKAR. In 2020, the cotton plant CW increased by 13% and 8% with 34 and 50 kg ha$^{-1}$ FKAR, respectively, compared to the control, demonstrating the positive effect of K fertilizer. In 2021, the cotton CW increased by 2% with 50 kg ha$^{-1}$ foliar K application rate but decreased by 2% and

4% with 34 and 67 kg $ha^{-1}$ FKAR compared to the control. Overall, the cotton plant CW increased by 66% in 2021 compared to 2020 across cotton varieties and FKARs.

### 3.3. Lint and Seed Yield

The results showed a significant difference in lint production ($p \leq 0.049$) among cotton varieties in 2020 (Table 4). V3 had a significantly greater lint yield than V1. However, in 2021, the cotton lint content was statistically similar across all the varieties (Table 4). There is no interaction effect of variety and K foliar application rates in both years. In 2020, V3 had 32% and 15% greater lint yield than V1 and V2, respectively. Although not significant, in 2021, V3 had 10% and 9% greater lint yield than V1 and V2 (Table 4). The average lint yield was 32% greater in 2020 (628 kg $ha^{-1}$) than in 2021 (429 kg $ha^{-1}$).

The FKAR did not significantly affect the lint yield in 2020 and 2021 (Table 4). However, the 34 and 50 kg $ha^{-1}$ FKAR increased the lint yield by 15% and 20%, respectively, in 2020, indicating the potential for improved lint yield with foliar K application in rainfed production systems. Similarly, in 2021, foliar K applications of 50 and 67 kg $ha^{-1}$ increased the lint yield by 9% and 7%, respectively, compared to the control.

**Table 4.** Least square means of cotton seed and fiber yields as affected by cotton variety and foliar K fertilizer application rates in 2020 and 2021.

| Yield (kg $ha^{-1}$) | [1] Variety (VAR) | | | | Foliar K Application Rate, kg $ha^{-1}$ (FKAR) | | | | | Main and Interactions Effect *p* Values | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **V1** | **V2** | **V3** | **SE** | **0** | **34** | **50** | **67** | **SE** | **VAR** | **FKAR** | **VAR * FKAR** |
| Lint, 2020 | 508 [b] | 633 [ab] | 743 [a] | 128 | 578 | 678 | 722 | 533 | 133 | 0.049 * | 0.37 | 0.95 |
| Lint, 2021 | 410 | 418 | 458 | 70 | 411 | 413 | 450 | 439 | 81 | 0.87 | 0.98 | 0.61 |
| Seed, 2020 | 734 [b] | 893 [ab] | 1177 [a] | 186 | 882 | 1059 | 1021 | 775 | 195 | 0.015 * | 0.37 | 0.97 |
| Seed, 2021 | 601 | 692 | 756 | 107 | 659 | 668 | 762 | 644 | 116 | 0.57 | 0.91 | 0.50 |

[1] Variety = V1, NG 5711 B3XF); V2, PHY 480 W3FE; and V3, FM 953GLTP. Within a row and main effect, least square means lacking a common superscript letter differ ($p \leq 0.05$), * significant; SE: standard error.

In 2020, there was a significant difference in cotton seed yield among the varieties ($p < 0.05$). The seed yield of the variety V3 was significantly greater than that of V1 (Table 4). In 2020, the seed yield of V3 was 38% and 24% greater than that of V1 and V2, respectively. Despite being statistically insignificant, the seed yield of V3 was 21% and 8% greater in 2021 compared to V1 and V2, respectively (Table 4). The average seed yield was 27% greater in 2020 (934 kg $ha^{-1}$) than in 2021 (683 kg $ha^{-1}$).

Seed yield was statistically insignificant with FKAR in both 2020 and 2021. However, in 2020, the FKARs of 34 and 50 kg $ha^{-1}$ resulted in a 17% and 14% increase in cotton seed yield, while 67 kg $ha^{-1}$ resulted in a 14% decrease in seed yield compared to the control. Similarly, in 2021, 34 and 50 kg $ha^{-1}$ FKARs resulted in 1% and 14% increases in seed yield, while 67 kg $ha^{-1}$ FKAR resulted in a 2% decrease in cotton seed yield. The seed yield was decreased with a 67 kg $ha^{-1}$ foliar K application rate in both years.

### 3.4. Cotton Quality

The analysis of cotton fiber quality parameters for 2020 and 2021 revealed significant effects of both cotton variety and FKAR on various quality indicators. In 2020, color grade exhibited a significant difference among varieties ($p < 0.003$), with V1 and V3 displaying significantly higher color grades than V2 (Table 5). However, among the varieties, no significant difference was observed in micronaire, staple length, or strength. Notably, uniformity was significantly greater with V2 compared to V1, and color reflectance (Col-RD) and color yellowness (Col-b) were significantly impacted by variety selection ($p \leq 0.01$ and $p < 0.0001$, respectively). Variety V3 had the highest col-Rd compared with V1 and V2, and V2 had the highest Col-b compared with V1 and V3 (Table 5), indicating the impact of varieties and variations in lint color characteristics. Likewise, in 2021, the varieties showed significant effects for the color grade ($p < 0.009$), staple length ($p < 0.001$), col-RD ($p < 0.004$), and Col-b ($p < 0.0001$) (Table 5). The V3 had a significantly greater color grade than V2, and V1 and V3 had significantly greater staple lengths than V2. Similarly, V3 had a significantly greater col-Rd than V1 and V2, but V1 and V2 had significantly greater Col-b than V3.

**Table 5.** Least square means of cotton variety and foliar K fertilizer application rates on different cotton fiber quality in 2020 and 2021.

| Quality Parameter | [3] Variety (VAR) | | | | Foliar K Application Rate, kg ha$^{-1}$ (FKAR) | | | | | Main and Interaction Effect *p* Values | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | V1 | V2 | V3 | SE | 0 | 34 | 50 | 67 | SE | VAR | FKAR | VAR * FKAR |
| 2020 | | | | | | | | | | | | |
| Color grade | 30.6 $^{a}$ | 25.3 $^{b}$ | 31.0 $^{a}$ | 1.19 | 26.1 $^{b}$ | 29.1 $^{ab}$ | 29.2 $^{ab}$ | 31.4 $^{a}$ | 1.38 | 0.003 * | 0.08 | 0.069 |
| Micronaire | 3.39 | 3.24 | 3.30 | 0.14 | 3.26 | 3.35 | 3.45 | 3.16 | 0.16 | 0.74 | 0.62 | 0.754 |
| Staple length (cm) | 1.07 | 1.07 | 1.10 | 0.02 | 1.08 $^{ab}$ | 1.08 $^{ab}$ | 1.10 $^{a}$ | 1.05 $^{b}$ | 0.02 | 0.08 | 0.05 * | 0.352 |
| Strength(g/tex) | 27.7 | 27.7 | 27.9 | 1.06 | 27.6 $^{ab}$ | 28.8 $^{a}$ | 28.3 $^{ab}$ | 26.4 $^{b}$ | 0.37 | 0.97 | 0.11 | 0.206 |
| Uniformity | 80.1 $^{b}$ | 81.7 $^{a}$ | 80.6 $^{ab}$ | 0.87 | 81.2 $^{a}$ | 80.6 $^{ab}$ | 81.8 $^{a}$ | 79.5 $^{b}$ | 0.91 | 0.08 | 0.03 * | 0.503 |
| [1] Col-RD | 75.1 $^{b}$ | 75.8 $^{b}$ | 77.7 $^{a}$ | 0.56 | 76.6 $^{a}$ | 76.7 $^{a}$ | 75.9 $^{b}$ | 75.7 $^{a}$ | 0.64 | 0.01 | 0.61 | 0.180 |
| [2] Col-b | 9.4 $^{b}$ | 10.0 $^{a}$ | 8.6 $^{c}$ | 0.23 | 9.6 | 9.2 | 9.2 | 9.3 | 0.25 | <0001 * | 0.35 | 0.898 |
| 2021 | | | | | | | | | | | | |
| Color grade | 23.6 $^{b}$ | 28.5 $^{ab}$ | 30.2 $^{a}$ | 2.10 | 31.1 $^{a}$ | 23.2 $^{b}$ | 31.0 $^{a}$ | 24.3 $^{ab}$ | 2.42 | 0.009 * | 0.049 * | 0.703 |
| Micronaire | 3.78 $^{a}$ | 3.47 $^{a}$ | 3.53 $^{a}$ | 0.10 | 3.71 $^{a}$ | 3.32 $^{b}$ | 3.76 $^{a}$ | 3.57 $^{ab}$ | 0.12 | 0.13 | 0.07 | 0.701 |
| Staple length (cm) | 1.16 $^{a}$ | 1.10 $^{b}$ | 1.16 $^{a}$ | 0.009 | 1.14 | 1.15 | 1.13 | 1.13 | 0.01 | 0.001 * | 0.45 | 0.384 |
| Strength(g/tex) | 30.4 | 30.1 | 30.6 | 0.32 | 30.1 | 30.5 | 30.7 | 30.1 | 0.32 | 0.54 | 0.64 | 0.973 |
| Uniformity | 81.7 $^{b}$ | 82.5 $^{ab}$ | 82.8 $^{a}$ | 0.37 | 82.1 | 82.5 | 82.4 | 82.3 | 0.42 | 0.12 | 0.94 | 0.258 |
| [1] Col-RD | 78.7 $^{b}$ | 77.1 $^{c}$ | 80.2 $^{a}$ | 0.44 | 77.9 $^{b}$ | 79.3 $^{ab}$ | 77.9 $^{b}$ | 79.5 $^{a}$ | 0.51 | 0.004 * | 0.06 | 0.759 |
| [2] Col-b | 8.9 $^{a}$ | 8.6 $^{a}$ | 7.2 $^{b}$ | 0.15 | 8.3 | 8.3 | 8.3 | 8.1 | 0.17 | <0001 * | 0.85 | 0.109 |

[1] Col-RD = color reflectance; [2] Col-b = color yellowness; [3] variety = V1, NG 5711 B3XF; V2, PHY 480 W3FE; and V3, FM 953GLTP. Within a row and main effect, least square means lacking a common superscript letter differ ($p \leq 0.05$), * significant ($p \leq 0.05$); SE: standard error.

In 2020, significant effects of foliar K application rates were observed for color grade ($p < 0.001$) and uniformity ($p < 0.05$) (Table 5). Specifically, higher foliar K application rates improved color grade and yellowness, with the 67 kg ha$^{-1}$ application rate showing the most pronounced effects. However, the uniformity was significantly lowest with 67 kg ha$^{-1}$ treatment compared to the control and 50 kg ha$^{-1}$ FKAR, likely because leaf burning decelerated the cotton growth at this application rate, especially in dry years. However, in 2021, the significance of foliar K application rates diminished for most quality parameters, except for color grade ($p < 0.049$), suggesting potential temporal and seasonal variation of cotton response to FKAR. However, there was no interaction effect between varieties and FKAR on cotton quality parameters in both years.

## 4. Discussion

### *4.1. Cotton Height (CH) and Canopy Width (CW)*

Although insignificant in 2020, the cotton variety had a significant effect on cotton plant height, with V1 and V3 producing taller plants than V2 in 2021. These results align with the observations of Pervez et al. [29] and Yang et al. [30], who reported varietal differences in cotton growth responses to potassium fertilization. In 2020, foliar K fertilizer application rates significantly affected plant height, with a rate of 50 kg ha$^{-1}$ resulting in the tallest plants (75.0 cm), followed by 34 kg ha$^{-1}$ (71.6 cm). The results indicated that foliar K application might have promoted the growth and development of cotton plants in dry years. The results are consistent with [31–33], who reported positive impacts of K fertilization on cotton plant growth parameters. However, potassium fertilizer rates did not significantly influence plant height in 2021. The 67 kg ha$^{-1}$ foliar K application had the lowest height in both years, possibly due to the leaf burning we observed during the application. Therefore, a proper K concentration is vital during foliar application to avoid adverse effects on growth and development.

The contrasting effects of FKAR and variety on plant height between the two years highlight the potential impact of seasonal, temporal, and growing conditions on cotton responses to nutrient management practices. Cassman [32] and Oosterhuis [34] noted that site-specific factors, such as soil fertility levels and climatic conditions, can influence the effectiveness of potassium fertilization. Compared to 2021, 2020 was a drier year (Figure 2b), and the study site received substantially more rainfall in May (532 mm vs. 214 mm), June (180 mm vs. 105 mm), and July (120 mm vs. 103 mm) in 2021, which might have negated the impact of foliar K application in 2021.

In 2020, both cotton variety and foliar K application rate significantly affected canopy width. Variety V1 had the widest canopy, while the highest potassium rate of 34 kg ha$^{-1}$ resulted in the widest canopy. The findings are consistent with the positive effects of potassium fertilization on cotton growth parameters reported by [3,6]. However, in 2021, neither the cotton variety nor the potassium fertilizer rate significantly influenced canopy width. This lack of response could be attributed to the specific environmental conditions described earlier and nutrient dynamics during the 2021 growing season [29,35]. The variable responses observed in this study in 2020 and 2021 highlight the complex interactions between cotton varieties, nutrient management practices, and environmental factors in determining plant growth and development.

### *4.2. Lint and Seed Yield*

The results demonstrated the significant impact of cotton variety on lint and seed yields, particularly in the 2020 growing season. Variety V3 consistently outperformed V1 and V2 in terms of both lint and seed yields, indicating that variety selection should be included as part of K management in cotton. These findings align with previous research by [15,18,31–33,36], who also reported varietal differences in cotton yield across different varieties. The choice of cotton variety is a critical factor influencing yield potential, as varieties vary in their genetic makeup, growth characteristics, and adaptability to local environmental conditions. In contrast to the varietal effects, foliar application of K fertilizer at different rates did not significantly influence lint or seed yields in either year. This lack of a significant yield response to K fertilization is consistent with the findings of [31–33,37]. For example, ref. [37] reported no impact of foliar K application on lint yield and total biomass. However, these findings contrast with those of studies by [17,18,22,29,30], who reported positive impacts of K application on cotton yields.

Although statistically insignificant, foliar K application at 30 and 50 kg ha$^{-1}$ increased the lint yield by 15–30% and the seed yield by 14–17% in 2020 and by 1–16% and 0.2–9%, respectively, in 2021. Overall, the lint yield was 32%, and the seed yield was 26% greater in the dry year 2020 than in 2021, but the canopy width was 66% greater in 2021. The reduced canopy development in 2020 may have contributed to increased lint and seed yield due to better light distribution and increased photosystems within the mid-canopy layer [38]. Conversely, the greater canopy development in 2021, possibly due to substantial rainfall during May, June, and July (Figure 2b), may have negatively impacted cotton yield by shading the middle and lower parts of the plant [15], leading to reduced boll formation and yield in those areas [39]. The results also suggest that excessive canopy development should be avoided by taking precautions against the overapplication of irrigation water, which can decrease cotton yield. These discrepancies between yield in 2020 and 2021 illustrate the site-specific nature of cotton varieties' response to K fertilization, which can be influenced by factors such as soil nutrient status, rainfall, and management practices. Weather can greatly impact cotton productivity compared to foliar K application treatments [37].

### *4.3. Cotton Quality*

#### 4.3.1. Color Grade

In 2020, the cotton variety significantly affected the color grade, with V2 exhibiting a lighter color grade than V1 and V3. V3 had a 19% and V1 had a 21% greater color grade than V2. In 2021, both variety and K application rate significantly affected color grade, with V3 showing the darkest color grade and the 34 kg ha$^{-1}$ foliar K rate resulting in the lightest color grade. This is in line with the findings of [40,41], who reported that genetic factors can influence fiber color, and [42], who reported a dual influence of genetic and nutritional factors on fiber color. However, the mean color grade was 28.98 in 2020 and 27.40 in 2021, and was not statistically significant by year.

#### 4.3.2. Micronaire

Micronaire values, which indicate the fiber fineness and maturity of cotton fibers, were not significantly affected by either cotton variety or FKAR in 2020. However, the micronaire values for V1 were 5% and 3% greater than those for V2 and V3, respectively, and the application of 34 and 50 kg ha$^{-1}$ foliar K increased micronaire by 3% and 6%, respectively, compared to the control. These results align with the findings of [14,17,20], who reported that micronaires are often more influenced by environmental conditions than by genetic or fertilizer inputs. Similarly, in 2021, the micronaire values for V1 were 9% and 7% greater than those for V2 and V3, respectively, and the application of 34 kg ha$^{-1}$ foliar K increased micronaire by 1% compared to the control. However, this increase was not statistically significant.

#### 4.3.3. Staple Length

Staple length increased by 3% and 4% with V3 compared to V1 in 2020, but these differences were statistically insignificant. Staple length was significantly affected by cotton variety, with V1 and V3 producing longer fibers than V2 in 2021. This finding aligns with the research findings of [41,43,44], who reported that fiber length is a highly heritable trait influenced by cotton genotype.

#### 4.3.4. Strength and Uniformity

Neither the cotton variety nor the foliar K application rate significantly affected the fiber strength or uniformity in either year. V2 and V3 had 2% and 3% greater strengths than V1 in 2020. However, no varietal effect on strength was observed in 2021. Similarly, the 34 and 50 kg ha$^{-1}$ FKARs increased the fiber strength by 4% and 3% in 2020 and 1% and 2%, respectively, in 2021. This finding aligns with [45], who noted that fiber quality parameters are often more stable and less affected by management practices. In contrast, Ahmad et al. [18] suggested increased fiber strength with K application. The significant difference in uniformity between V2 and V1 in 2020 and between V3 and V1 in 2021 indicated that the performance of cotton varieties under different moisture regimes might vary, impacting lint quality. In 2020, the dry year, V2 had greater uniformity, but in 2021, the wet year, V3 had greater uniformity.

#### 4.3.5. Color Reflectance (Col-RD) and Color Yellowness (Col-b)

Significant varietal differences were observed for color reflectance and yellowness in both years. V3 had higher color reflectance and lower color yellowness, indicating brighter and less yellow fibers, which is desirable in the cotton industry. These results were supported by the findings of [46], who noted that the genetic makeup of cotton plants influences fiber brightness and yellowness.

## 5. Conclusions

This study demonstrated that cotton variety significantly impacted cotton lint and seed yields, plant height, canopy width, and fiber quality parameters such as color grade, staple length, uniformity, Col-R, and Col-b. Both lint and seed yield responded positively to FKAR, suggesting that additional foliar K application can enhance cotton growth and yield in rainfed production systems. The effects of FKAR varied across quality parameters and study years, highlighting the importance of cotton variety in determining productivity and fiber quality. However, the effectiveness of K fertilization is site-specific and can be influenced by soil fertility levels, environmental conditions, rainfall, and cotton variety characteristics. The study emphasizes the importance of tailoring nutrient management strategies to specific varieties, soil fertility levels, and climatic conditions to maximize cotton yield and fiber quality. Additional research is necessary to comprehend the fundamental mechanisms that drive these responses and develop management practices to consistently enhance cotton productivity and fiber quality in rainfed production systems.

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## References

1. USDA-ERS. Cotton Sector at a Glance. U.S. United States Department of Agriculture Economic Research Service. 2022. Available online: https://www.ers.usda.gov/topics/crops/cotton-and-wool/cotton-sector-at-a-glance/ (accessed on 25 April 2024).
2. Lewis, K.; Morgan, G.; Frame, W.H.; Fromme, D.; Dodds, D.M.; Edmisten, K.L.; Robertson, B.; Boman, R.; Cutts, T.; Delaney, D.P.; et al. Cotton yield response to soil applied potassium across the US Cotton Belt. *Agron. J.* **2021**, *113*, 3600–3614. [CrossRef]
3. Lokhande, S.; Reddy, K.R. Reproductive performance and fiber quality responses of cotton to potassium nutrition. *Am. J. Plant Sci.* **2015**, *6*, 911–924. [CrossRef]
4. Oosterhuis, D.M.; Loka, D.A.; Raper, T.B. Potassium and stress alleviation: Physiological functions and management of cotton. *J. Plant Nutr. Soil Sci.* **2013**, *176*, 331–343. [CrossRef]
5. Pettigrew, W.T. Relationships between insufficient potassium and crop maturity in cotton. *Agron. J.* **2003**, *95*, 1323–1329. [CrossRef]
6. Pettigrew, W.T.; Heitholt, J.J.; Meredith, W.R., Jr. Genotypic interactions with potassium and nitrogen in cotton of varied maturity. *Agron. J.* **1996**, *88*, 89–93. [CrossRef]
7. Römheld, V.; Kirkby, E.A. Research on potassium in agriculture needs and prospects. *Plant Soil* **2010**, *335*, 155–180. [CrossRef]
8. Tsialtas, I.T.; Shabala, S.; Baxevanos, D.; Matsi, T. Effect of potassium fertilization on leaf physiology, fiber yield and quality in cotton (*Gossypium hirsutum* L.) under irrigated Mediterranean conditions. *Field Crops Res.* **2016**, *193*, 94–103. [CrossRef]
9. Coker, D.L.; Oosterhuis, D.M.; Brown, R.S. Cotton Yield Response to Soil-and Foliar-Applied Potassium as Influenced by Irrigation. *J. Cotton Sci.* **2009**, *13*, 1–10.
10. Halevy, J. Growth Rate and Nutrient Uptake of Two Cotton Varietys Grown Under Irrigation. *Agron. J.* **1976**, *68*, 701–705. [CrossRef]
11. Mullins, G.L.; Burmester, C.H. Relation of growth and development to mineral nutrition. In *Physiology of Cotton*; Springer: Dordrecht, The Netherlands, 2010; pp. 97–105.
12. Pabuayon, I.L.B.; Lewis, K.L.; Ritchie, G.L. Dry matter and nutrient partitioning changes for the past 30 years of cotton production. *Agron. J.* **2020**, *112*, 4373–4385. [CrossRef]
13. Adeli, A.; Varco, J.J. Potassium management effects on cotton yield, nutrition, and soil potassium level. *J. Plant Nutr.* **2002**, *25*, 2229–2242. [CrossRef]

14. Tariq, M.; Afzal, M.N.; Muhammad, D.; Ahmad, S.; Shahzad, A.N.; Kiran, A.; Wakeel, A. Relationship of tissue potassium content with yield and fiber quality components of Bt cotton as influenced by potassium application methods. *Field Crops Res.* **2018**, *229*, 37–43. [CrossRef]
15. Kommineni, V.; Bhandari, A.B. Effects of potassium application on growth, yield, and quality of dryland cotton. *Agron. J.* **2024**, 1–9. [CrossRef]
16. Shahzad, A.N.; Rizwan, M.; Asghar, M.G.; Qureshi, M.K.; Bukhari, S.A.; Kiran, A.; Wakeel, A. Early maturing Bt cotton requires more potassium fertilizer under water deficiency to augment seed-cotton yield but not lint quality. *Sci. Rep.* **2019**, *9*, 7378. [CrossRef]
17. Blaise, D.; Singh, J.V.; Bonde, A.N. Response of rainfed cotton (*Gossypium hirsutum*) to foliar application of potassium. *Indian J. Agron.* **2009**, *54*, 444–448. [CrossRef]
18. Ahmad, Z.; Anjum, S.; Iqbal, M.A.; Saeed-ur-Rehman, H. Foliar applied potassium enhances fiber quality, water relations and yield of cotton. *J. Agric. Res.* **2018**, *56*, 17–25.
19. Channakeshava, S.; Goroji, P.; Doreswamy, C.; Naresh, N. Assessment of foliar spray of potassium nitrate on growth and yield of cotton. *Karnataka J. Agric. Sci.* **2014**, *26*, 316–317.
20. Aladakatti, Y.R.; Hallikeri, S.S.; Nandagavi, R.A.; Naveen, N.; Hugar, A.Y.; Blaise, D. Yield, and fiber qualities of hybrid cotton (*Gossypium hirsutum*) as influenced by soil and foliar application of potassium. *Karnataka J. Agric. Sci.* **2011**, *24*, 133–136.
21. Dewdar, M.D.; Rady, M.M. Influence of soil and foliar applications of potassium fertilization on growth, yield and fiber quality traits in two *Gossypium barbadense* L. varieties. *Afr. J. Agric. Res.* **2013**, *8*, 2211–2215.
22. Sekhon, N.K.; Singh, C.B. Plant nutrient status during boll development and seed cotton yield as affected by foliar application of different sources of potassium. *Am. J. Plant Sci.* **2013**, *4*, 1409–1417. [CrossRef]
23. Schofield, R.K.; Taylor, A.W. The measurement of soil pH. *Soil Sci. Soc. Am. J.* **1955**, *19*, 164–167. [CrossRef]
24. Rhoades, J.D. Soluble salts. In *Methods of Soil Analysis: Part 2. Chemical and Microbiological Properties*, 2nd ed.; Page, A.L., Ed.; ASA and SSSA: Madison, WI, USA, 1982; pp. 167–178.
25. Kachurina, O.M.; Zhang, H.; Raun, W.R.; Krenzer, E.G. Simultaneous determination of soil aluminum, ammonium-and nitrate-nitrogen using 1 M potassium chloride extraction. *Commun. Soil Sci. Plant Anal.* **2000**, *31*, 893–903. [CrossRef]
26. Olsen, S.R. *Estimation of Available Phosphorus in Soils by Extraction with Sodium Bicarbonate*; US Department of Agriculture: Washington, DC, USA, 1954.
27. National Oceanic and Atmospheric Administration (NOAA). Climate Data Online. 2023. Available online: https://www.ncdc.noaa.gov/cdo-web/search (accessed on 30 March 2024).
28. SAS (Statistical Analysis Systems). *The SAS System for Windows*; SAS Institute Inc.: Cary, NC, USA, 2023.
29. Pervez, H.; Ashraf, M.; Makhdum, M.I. Effects of potassium rates and sources on fiber quality parameters in four Varietys of cotton grown in aridisols. *J. Plant Nutr.* **2005**, *27*, 2235–2257. [CrossRef]
30. Yang, J.S.; Hu, W.; Zhao, W.; Meng, Y.; Chen, B.; Wang, Y.; Zhou, Z. Soil potassium deficiency reduces cotton fiber strength by accelerating and shortening fiber development. *Sci. Rep.* **2016**, *6*, 28856. [CrossRef] [PubMed]
31. Cassman, K.G. Soil, crop management and plant factors which influence cotton potassium nutrition on vermiculitic soils of the San Joaquin Valley. *J. Fertil. Issues* **1986**, *3*, 38–45.
32. Cassman, K.G.; Kerby, T.A.; Roberts, B.A.; Bryant, D.C.; Higashi, S.L. Potassium nutrition effects on lint yield and fiber quality of Acala cotton. *Crop Sci.* **1990**, *30*, 672–677. [CrossRef]
33. Stromberg, L. Need for potassium fertilizer on cotton determined by leaf and soil analyses. *Calif. Agric.* **1960**, *14*, 4–5.
34. Oosterhuis, D.M. Yield response to environmental extremes in cotton. *Spec. Rep.-Univ. Ark. Agric. Exp. Stn.* **1999**, *193*, 30–38.
35. Gormus, O.; Yucel, C. Different planting date and potassium fertility effects on cotton yield and fiber properties in the Cukurova region, Turkey. *Field Crops Res.* **2002**, *78*, 141–149. [CrossRef]
36. Kusi, N.Y.; Lewis, K.L.; Morgan, G.D.; Ritchie, G.L.; Deb, S.K.; Stevens, R.D.; Sintim, H.Y. Cotton Variety response to potassium fertilizer application in Texas' southern high plains. *Agron. J.* **2021**, *113*, 5436–5453. [CrossRef]
37. Menefee, D.; Smith, D.R.; Zwonitzer, M.; Collins, H.P. Effects of row spacing and potassium foliar applications on yield of cotton. *Agrosystems Geosci. Environ.* **2023**, *6*, e20432. [CrossRef]
38. Zhan, D.; Zhang, C.; Yang, Y.; Luo, H.; Zhang, Y.; Zhang, W. Water deficit alters cotton canopy structure and increases photosynthesis in the mid-canopy layer. *Agron. J.* **2015**, *107*, 1947–1957. [CrossRef]
39. Zhang, D.; Luo, Z.; Liu, S.; Li, W.; Dong, H. Effects of deficit irrigation and plant density on the growth, yield and fiber quality of irrigated cotton. *Field Crops Res.* **2016**, *197*, 1–9. [CrossRef]
40. Meredith, W.R., Jr.; Bridge, R.R. Genetic contributions to yield changes in upland cotton. *Genet. Contrib. Yield Gains Five Major Crop Plants* **1984**, *7*, 75–87.
41. Meredith, W.R., Jr.; Culp, T.W.; Robert, K.Q.; Ruppenicker, G.F.; Anthony, W.S.; Williford, J.R. Determining future cotton variety fiber quality objectives. *Text. Res. J.* **1991**, *61*, 715–720. [CrossRef]
42. Hafeez, M.N.; Sadique, S.; Hassan, S.; Sarwar, M.B.; Rashid, B.; Ali, Q.; Husnain, T. Physiological, morphological, biochemical and molecular basis of drought tolerance in cotton. *Int. J. Biol. Pharm. Allied Sci.* **2015**, *4*, 1091–1112.
43. Asif, M.; Mirza, J.I.; Zafar, Y. Genetic analysis for fiber quality traits of some cotton genotypes. *Pak. J. Bot.* **2008**, *40*, 1209–1215.
44. Sahar, A.; Zafar, M.M.; Razzaq, A.; Manan, A.; Haroon, M.; Sajid, S.; Rehman, A.; Mo, H.; Ashraf, M.; Ren, M.; et al. Genetic variability for yield and fiber related traits in genetically modified cotton. *J. Cotton Res.* **2021**, *4*, 19. [CrossRef]

45. Pettigrew William, T. Potassium influences on yield and quality production for maize, wheat, soybean and cotton. *Physiol. Plant.* **2008**, *133*, 670–681. [CrossRef]
46. Liu, J.; Meng, Y.; Chen, J.; Lv, F.; Ma, Y.; Chen, B.; Wang, Y.; Zhou, Z.; Oosterhuis, D.M. Effect of late planting and shading on cotton yield and fiber quality formation. *Field Crops Res.* **2015**, *183*, 1–13. [CrossRef]