Effects of Potassium Management on Physiological Traits, Enzyme Activity and Cotton Fiber Cellulose Content

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Abstract

Aims

Potassium (K) is prone to be washed out of plant tissues independent of mineralization since it is not strongly bound to organic structures in the plant. Therefore, cover crops can enhance K cycling in cropping systems increasing the nutrient use efficiency by taking it up deep in the soil profile and releasing it on the soil surface. However, it is not clear if this cycling would have an effect on cotton morphophysiology, enzyme activity, and eventually on fiber quality.

Methods

Potassium was applied to two cotton cultivars, either to the cover crop ruzigrass (*Urochloa ruzisiensis*), or to cotton grown after the grass or not, and split between the cover crop and cotton.

Results

Cotton leaf area index was increased late in the season by K, with small differences between fertilized treatments, but was highest at full bloom when at least part of the K was applied to cotton. Stomatal conductance was improved, mainly late in the season and when cotton was grown after ruzigrass. Consequently, the enzymatic activity and accumulation of cellulose in the cotton fiber were also increased.

Conclusion

Potassium fertilization improves cotton physiological parameters such as leaf area index and stomatal conductance, but the effect on enzyme activity depends on the enzyme and on the cotton cultivar. Early cellulose accumulation in the fiber is favored by potassium fertilization and cotton rotation with ruzigrass.

Highlights

- Cotton leaf area index was increased late in the season by K.
- Stomatal conductance was improved late in the season when cotton was grown after ruzigrass.
- Enzymatic activity (SuSy, SPS and SI) and accumulation of cellulose in the cotton fiber were increased by K fertilization.
- Early cellulose accumulation in the fiber is favored by potassium fertilization and cotton rotation with ruzigrass.
- Fiber maturity was higher when K was applied to the grass or split in the grass and sidedressed in cotton.

Introduction

Depending on crop yield, cotton K uptake ranges from 190 to 415 kg ha⁻¹ (Vieira et al. 2018; Rosolem et al. 2012; Rochester et al. 2007). The maximum uptake rate of 3.2 kg ha⁻¹ day⁻¹ was observed during boll filing stage (~115 DAE), but around 61% of the K was taken up during flowering in a high yielding field in Australia (Rochester et al. 2012). Potassium exports in fibers and seeds ranges from 15% to 21% of the total taken up, considering lint yields from 1,000 to 2,400 kg ha⁻¹ (Rochester et al. 2007). During fruit development K translocation to fruits is intense (Ali et al. 2018), resulting in high K concentration in the fruit capsules. The fruit, including its peel, is the dominant K drain in the plant (Rosolem and Mikkelsen 1991).

Potassium plays an important role in plant metabolism, growth, development and yield. It is essential for the optimal functioning of the plant's photosynthetic apparatus due to its role in stomata regulation and enzyme activation, in rubisco activity and chlorophyll concentration (Dana et al. 2016; Wang et al. 2017; Shabala 2017; Parveen et al. 2020). Potassium also activates enzymes related to sucrose and starch transformation, which is mainly responsible for carbon metabolism (Kahrizi et al. 2010; Ali et al. 2018; Parveen et al. 2020). The deficiency of K impairs leaf area expansion and CO₂ assimilation capacity (Gerardeaux et al. 2010), as well as numerous physiological functions, including water relations, enzymatic activation, charge balance, stress resistance and eventually cotton growth and yield (Oosterhuis et al. 2013). Fiber quality is paramount for cotton commercialization, and K deficiency can result in less cellulose deposition on the secondary fiber wall, harming fiber maturity, micronaire, length, and uniformity (Hu et al. 2018). The lack of K results in an early maturing plant, with shorter cycle (Silva et al. 1995), decreased seed and boll weights and fiber yield (Pettigrew et al. 1996; Yang et al. 2012). Fiber strength can be decreased by K deficiency due to the nutrient role in building "bridges" between cellulose chains in the cotton fiber (Lima and Bélot 2019). A decrease in activity of key enzymes such as sucrose synthase (SuSy), can affect cellulose deposition in the fiber, and consequently, fiber strength, short fiber index and maturity (Raphael et al. 2019). Sucrose synthase (SuSy) plays two fundamental roles: sucrose synthesis and decomposition (Tung et al. 2018). Acid invertase acts on the hydrolysis of sucrose to glucose and fructose (Hu et al. 2015) and sucrose phosphate synthase (SPS) is linked to the regulation of the carbon partition between sucrose and starch in the leaves (Huber and Huber 1996). The activity of these enzymes is dependent on K nutrition (Hafeez et al. 2019; Hu et al. 2015). Therefore, K regulates photoassimilation and translocation simultaneously with the enzyme activities (Zahoor et al. 2017). When K deficiency occurs during fiber elongation, the decrease in turgor pressure results in shorter fibers (Rosolem and Bogiani 2014). As this nutrient is associated with sugar transport in the plant, it is likely that K deficiency may affect the deposition of cellulose microfibrils on the secondary wall in cotton fibers, thus decreasing fiber resistance and micronaire.

Sandy soils show low natural fertility, water retention, and cation exchange capacity due to the low levels of organic matter and clay, and are prone to K leaching. Potassium chloride, the main source of K for agriculture, was shown to have high mobility in the soil profile, mainly in sandy soils with low CEC (Werle et al. 2008) because K adsorption to soil colloids is low (Duiker and Bleeg 2006). Since drainage is fast in

sandy soils, K percolation in the soil profile below the rooting zone can impair fertilizer use efficiency during the rainy season (Rosolem et al. 2006). To avoid K loss, it has been traditionally recommended to split rates above 50 kg ha⁻¹ of K₂O (Foloni and Rosolem 2008; Bernardi et al. 2009). Another strategy suggested to improve fertilizer use efficiency in sandy soils is applying fertilizer to cover crops such as grasses of the genera *Urochloa* grown before cotton, because the K taken up returns to the soil mimicking a slow-release fertilizer (Echer et al. 2020). Therefore, we hypothesized that K application to the cover crop grown before cotton can avoid the effects of K deficiency in cotton physiological performance and result in better fiber quality by improving the fertilizer use efficiency.

The aim of this work was to assess leaf area index, stomatal conductance, enzymatic activities of sucrose transport and cellulose contents of two cotton cultivars as affected by K fertilizer management and the use of ruzigrass as a cover crop.

Materials And Methods

Field experiments were conducted in the 2016/17 and 2017/18 cropping seasons in Presidente Bernardes, São Paulo, Brazil, 22°07'32" S and 51°23'20" W, 475 m asl. The soil is a typic Rhodustult, sandy loam (USDA 2010). The climate is tropical with dry winters and wet, hot summers. Soil samples were taken at the depths of 0 to 20 cm and 20 to 40 cm on May 05, 2016, for chemical analysis as in Raij et al. (2001). Selected chemical and particle size distribution of the soil are in Table 1. Lime (45% of CaO and 4.9% of MgO) was broadcast on the soil surface at 1,400 kg ha⁻¹ in September 2016 and 2,000 kg ha⁻¹ in October 2017. Rainfall, maximum and minimum temperatures, and vapor pressure deficit during the experiment are shown in Figure 1.

The treatments were an early (FM 913GLT) and a late (FM 983GLT) cotton cultivar and six K fertilization schemes (Table 2). Treatments were repeated in the same plots in both seasons. The experimental design was a 2 x 6 factorial in complete randomized blocks with five replicates. Each plot had four 7.0-m cotton rows spaced 0.8 m from each other. The two outer rows and 1.0 at the end of each row were considered borders and not included in evaluations.

Ruzigrass was sown on May 05, 2016, and June 06, 2017 using 14 kg ha⁻¹ pure viable seeds. Potassium fertilizer was applied to the grass in the corresponding treatments early September each year, using potassium chloride. Ruzigrass was desiccated on November 1, 2016 and November 6, 2017, using glyphosate (1.92 g ha⁻¹ a.i.), and cotton was sown on December 9, 2016, and November 23, 2017. Phosphorus was applied at 56 kg ha⁻¹ and N at 30 kg ha⁻¹ as mono ammonium phosphate at cotton planting. The rate of 140 kg ha⁻¹ of N was side dressed and equally split 35 and 45 days after plant emergence (DAE), using ammonium sulphate and urea, respectively. Boric acid was sprayed at 2.0 kg ha⁻¹ split into 4 weekly applications from the first flower. Weed, pests, and diseases were controlled according to standard farm practices in São Paulo State. Seven days before harvest plants were defoliated with

Tidiazurom (60 g ha⁻¹ a.i.) + Diuron (30 g ha⁻¹ a.i.). Cotton was handpicked 141 and 132 DAE in 2016/17 and 2017/18, respectively.

Leaf area index and stomatal conductance – 1st and 2nd season

Leaf area index was measured at 30, 60, 90, and 120 days after emergence using a ceptometer (Accupar LP-80 – Decagon Devices) in three sub-samples per plot in both seasons. Stomatal conductance was evaluated at early flowering, full flowering and early boll-opening stage (F1, F7 and C2, respectively, according to Marur and Ruano, 2001) using a porometer (SC1- Decagon Devices) from 10 AM to 2 PM in two sub-samples per plot.

Enzyme assay – 2nd season

At mid flowering (F6/F7 stage – Marur and Ruano 2001), twelve plants per plot had their first position flowers tagged, and 24 days later (24 DAA) four bolls and their leaves were collected. At 48 DAA only bolls were collected since leaves were absent. This material was ground to a fine powder in liquid nitrogen. Tissue was extracted in a ratio of 500 mg of tissue to 3.5 mL of extraction buffer. The extraction buffer contained 50 mM Hepes (pH 7.5), 10 mM MgCl₂, 1 mM EDTA (Grof et al. 2007). Extracts were centrifuged at 14,000 rpm at 4 °C for 20 minutes to remove coarse material. Extracts were then desalted using Dowex 1x4 for 10 minutes and centrifuged at 10,000 rpm at 4 °C for 10 minutes, the supernatant was collected and the Sucrose Phosphate Synthase (SPS), Sucrose Synthase (SuSy) and Soluble Acid Invertase (SAI) were analyzed. All procedures were done at 4 °C. Enzymes were assayed immediately in duplicate. Protein measurement was performed as in Bradford (1976), using bovine serum albumin as standard.

SPS - Sucrose Phosphate Synthase (EC 2.4.1.14)

Total SPS activities were assayed by measuring the synthesis of SUC-6-P (Sucrose) (and SUC) from UDP-Glc (glucose) and Fru-6-P (fructose) (Huber and Huber 1991). Each reaction contained 20 mM UDP-Glc, 5 mM Fru-6-P, 17.5 mM Glc-6-P, and 50 µL of extract in a total volume of 100 µL. The reaction was started by the addition of extract and incubated at 25 °C for 10 min. After stopping the reaction with 100 µL of 5 M KOH and 10 min of heating at 100 °C to destroy unreacted hexoses and hexose phosphates, 1 mL of 0.14% (w/v) anthrone in 80% (v/v) H₂SO₄, was added before 40 min of incubation at 40 °C. SUC-6-P (and SUC) content was determined by comparing the A₆₂₈ to that of a standard curve (0-200 nmol of SUC). The recovery of Suc was estimated by incubating 50 µL of extract with 100 nmol of Suc under the above assay conditions.

SuSy – Sucrose Synthase (EC 2.4.1.13)

UDP-dependent cleavage of Suc into UDP-Glc and Fru was assayed (Copeland 1990). Each reaction contained 20 mM Hepes-KOH, pH 6.5, 100 mM Suc, 2 mM UDP, and 20 µL of extract in a total volume of 250 µL. Control reactions lacked UDP. Reactions were started by the addition of extract and incubated at

25 °C for 30 min. The reactions were stopped with 250 µL of 0.5 M Tricine-KOH, pH 8.3, and boiling for 10 min. Suc was measured spectrophotometrically, as described above.

SAI - Soluble Acid Invertase (EC 3.2.7.26)

SAI was measured by incubation of 20 µL of extract with 100 mM Suc in 100 mM acetic acid-NaOH, pH 5.0, in a total volume of 250 µL. Reactions were started by the addition of extract and incubated at 25 °C for 30 min. The reactions were stopped with 250 µL of 0.5 M Tricine-KOH, pH 8.3, and boiling for 10 min. Control reactions contained boiled extract, and Glc was measured spectrophotometrically, as described above (King et al. 1997).

Determination of cellulose in cotton fiber – 2nd season

Fruit samples were taken from the first position (P1) of the 10th sympodial branch 24 and 48 days after anthesis and dried in a forced-air oven at 65 °C for 96 hours. Determinations were conducted in three replications, according to Van Soest et al. (1991). The acid-detergent fiber (ADF) content was determined using an acid detergent (trimethylammonium bromide, standardized sulfuric acid. After examining the ADF content, the cellulose content was assayed in cotton samples using a standardized solution of sulfuric acid.

Statistical analysis

After testing for homogeneity and normality, data were submitted to ANOVA. The experiment was arranged in a complete randomized block design in a 2 x 6 factorial scheme (cultivars x K management) and five replicates. The data were analyzed with three-way (cultivar, K management and year) analysis of variance and Tukey test ($P < 0.05$) was used to compare treatment means. When the differences between cultivars were not significant, their averages were presented and discussed.

Multivariate analysis was performed via principal component analysis (PCA) to verify the grouping of the different responses to K fertilizer management and the use of ruzigrass in the second year (2017/2018). Considering that the measurement units differed between variables, the data were log-transformed to reduce the effect of the numeric scale (McGarigal et al. 2000). The ordination graphic (with two major components) was demarcated by two axes designated as the first (PC1) and second (PC2) principal components.

Results

Cotton leaf area index (LAI)

Cultivars had no significant effect on LAI; hence, the results in Fig 2 are averaged over cultivars FM 913GLT and FM 983GLT. In the first season, at 60 DAE LAI was higher when K was applied to cotton without ruzigrass, just to ruzigrass or split into ruzigrass and cotton as compared with the other treatments (Fig. 2a). In the second year, there was no difference between treatments at 30 DAE, but at 60 and 90 DAE

K fertilization in cotton without ruzigrass increased LAI, which was decreased in the presence of ruzigrass without K (Fig. 2b). At 120 DAE, a reduction in LAI was observed in the treatment where there was no K and ruzigrass, and it was increased when K was applied to ruzigrass.

Stomatal conductance (gs)

Stomatal conductance (g_s) at F1 (Fig. 3a) showed no difference between treatments in the first year of the study (2016/2017). In the second year (2017/2018), g_s was lower in the absence of K, irrespective of ruzigrass, or when K was applied to cotton without ruzigrass. A response to K application was observed only when there was enough rain, in the second year. At F7, g_s increased in the second year (Fig. 3b). A reduction was observed in g_s at peak flowering (F7 stage) in the absence of K and ruzigrass (0K) in 2016/17 and in the absence of K in 2017/18, irrespective of the grass. A reduction on g_s at C2 was observed in 2017/2018 in K unfertilized treatments.

Enzymatic activity

Soluble Acid Invertase - SAI

SAI activity in cotton leaves was higher when K fertilization was applied on ruzigrass + cotton (58K on RZ + 58 K on C) and when it was performed fully on cotton without ruzigrass on early cultivar (FM 913GLT) but for the late cultivar (FM 983GLT), SAI activity was increased by K fertilization on cotton without ruzigrass (Fig. 4a). In both cultivars, the lowest SAI activity was observed in the absence of K and ruzigrass. Early cultivar FM 913GLT had higher SAI activity when K was split in ruzigrass and cotton, but the full K application on ruzigrass resulted in higher SAI activity in the late cultivar (FM 983GLT).

Sucrose Phosphate Synthase - SPS

The greatest SPS activity was found in the treatment where K fertilization was applied entirely on cotton and it was slightly higher in the presence of ruzigrass for the late cultivar and the lowest in the absence of K and ruzigrass (Fig. 4b). SPS activity in the early cultivar was improved by K fertilization on cotton after ruzigrass. Furthermore, the early cultivar FM 913GLT showed greater SPS activity in most K managements, except where full K fertilization was applied to the late cultivar FM 983GLT with or without ruzigrass.

Sucrose Synthase - SuSy

The highest SuSy activity in both cultivars was found when K was applied to cotton in the absence of ruzigrass (Fig. 4c), while the lowest was observed in the absence of K fertilization and ruzigrass. Also, late cultivar FM 983GLT had higher SuSy activity in most treatments, but the early cultivar showed higher SuSy activity when receiving K in the absence of ruzigrass. In both cultivars, when K was applied on ruzigrass and cotton, SuSy activity increased.

Cellulose fiber content

Splitting K fertilization half on ruzigrass and half on cotton increased the cellulose content in the cotton fiber 24 days after anthesis (DAA). It is interesting that even applying 116 kg ha⁻¹ of K to cotton in the absence of ruzigrass, the fiber cellulose content was similar to those in the absence of K (Fig. 5a). At 48 DAE, when the cellulose contents were higher for both cultivars, there was no difference in cellulose content between treatments (Fig. 5b). However, the early cultivar (FM 913GLT) accumulated more cellulose in the fiber at 24 DAA than FM 983 GLT.

Principal Component Analysis

The principal component analysis for each cultivar showed a separation of treatments considering the analyzed variables. The PCA performed with all the data for cultivar FM 913 GLT (Fig. 6) represented 46% of the total variation of the original data by principal component 1, but PC2 was not significant. The parameters for discrimination in the main component 1(PC1) were LAI 120 (eigenvector = -0.9217), LAI 90 (eigenvector = -0.8885), and SPS (eigenvector = -0.8047) (Table 2). Plants without K and different treatments were separated at the left and right ends, respectively.

For the cultivar FM 983GLT (Figure 7) PC1 comprised 36% and PC2 was not significant. The most important parameters for discrimination in PC1 were SAI (eigenvector = -0.8911), SUSY (eigenvector = -0.8713), and LAI 120 (eigenvector = -0.7661). The ordination graph showed that groups were separated according to K fertilization. The greater distance between with and without K application indicated the sensitivity of K-treated plants compared with not K-treated plants in both cultivars.

Discussion

Potassium management did not affect LAI early in the growing cycle in both seasons (Fig 2), probably because cotton canopy growth is slow at this stage, as the plant invests most of the carbohydrates to develop its root system (Echer et al. 2019). However, at 60 and 90 DAE in the first season and 60, 90 and 120 DAE in the second season, LAI was higher when the plant was fertilized with K, as a result of the increased leaf area and life span, as the leaf's life is reduced by K deficiency (Wright 1999).

Potassium plays a key role in stomatal regulation (Langer et al. 2004). However, in this experiment K management did not affect g_s at the F1 stage in 2016/17 (Fig 3), which may be associated with good water availability, since it rained the day before the assessment (Fig 1). This finding confirms the role of grasses such as ruzigrass in K cycling (Echer et al. 2020) and the improvement on plant physiological apparatus. When the K rate was split, cotton showed higher stomatal conductance at F7 (full flowering stage) in both seasons. The effect of K on g_s is well reported in the literature (Zhao et al. 2001; Hu et al. 2016; Hu et al. 2017), but this finding shows the benefit of splitting K fertilization in sandy soils on cotton physiology. At the latest stage C2 (1st open boll in the 2nd fruiting branch) the severe reduction in soil humidity limited treatment responses. Additionally, in the second season, K fertilization associated to ruzigrass resulted in higher g_s , showing the importance of K management on leaf life span (LAI) and activity (g_s). This may be the result of the K released from the decaying grass during cotton growth

improving K use efficiency in the system. During boll filling there is a high demand for carbohydrates from photosynthesis and proper K nutrition can support gas exchange as K is remobilized to fruits in high rates (Rosolem and Mikkelsen 1991).

SAI catalyzes the hydrolysis of sucrose into glucose and fructose (Winter and Huber 2000); SPS is directly related to sucrose synthesis from carbon fixed by photosynthesis (Mendicino 1960), and SuSy's main function is to cleave sucrose for starch synthesis and cell wall construction (Déjardin et al. 1997; Nakai et al. 1999). Our results show that potassium fertilization was essential to keep the activities of enzymes involved in carbohydrate metabolism (SAI, SPS and SuSy) at an adequate level (Fig 4). In addition, the increase in the activity of these enzymes is potentially linked to K leaf concentration (Hu et al. 2017; Zahoor et al. 2017; Tung et al. 2018, Ali et al. 2018). Studies reported changes in the leaf sucrose or starch contents and increased enzyme activity and carbohydrate metabolism by K application in cotton (Wang et al. 2012; Hu et al. 2015; Zahoor et al. 2017; Ali et al. 2018).

There is a strong relationship between cell elongation and leaf K concentration, since the hormones that stimulate cell elongation are highly dependent on adequate levels of K in plant tissues (Cakmak 2005). The qualitative characteristics of cotton fibers are positively influenced by an adequate supply of K, as this nutrient regulates the crop cycle, maintains the leaf area, and provides greater cellulose deposition on the inner walls of the fibers improving micronaire index (Carvalho et al. 2006; Hafeez et al. 2019). Indeed, during the fiber-thickening process, SAI, SPS and SuSy serve as the main enzymes for cellulose synthesis, and their activities are highly dependent upon K application rate (Zahoor et al. 2017; Tung et al. 2018; Ali et al. 2018), corroborating our results and showing that K application in cotton resulted in increased enzymatic activity concomitantly with the increase in cellulose deposition in the fibers (Fig 4 and 5).

The results of the PCAs confirmed that both cultivars were sensitive to K supply. Early cultivar FM 913GLT also showed that there was a significant correlation between carbohydrate enzymes (SAI, SPS, and SUSY) and the LAI at 90 and 120 DAE, and the reduction in g_s and LAI at 30 DAE. Also, the responses of the late cultivar (FM 983GLT) were explained by the reduction in g_s and LAI at 30 and 60 DAE. SAI, SPS and SuSy activities increased in cotton leaves under K fertilization, which explains the higher sucrose synthesis than in the absence of K (0K). However, cellulose content was affected only at 24 DAA, indicating that the application of half of the K to the grass and half to cotton can improve cellulose deposition early in the fiber development.

Conclusion

Potassium fertilization improves physiological parameters such as LAI in a year with a regular rainfall distribution, and when associated with the use of grass, improves stomatal conductance late in the season. The absence of K impairs activity of the enzymes SAI, SPS and SuSy, but the effect is cultivar dependent. Early cellulose accumulation in the fiber is favored when cotton is grown after ruzigrass.

Declarations

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Code availability: SISVAR - Statistic Program (828459851).

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Tables

Table 1. Selected chemical properties and particle size distribution of the soil

depth	pH	SOM	P	S	Al ³⁺	H+Al	K ⁺	Ca ²⁺	Mg ²⁺	CEC
	(CaCl ₂)		(Resin)							
cm		g dm ⁻³	mg dm ⁻³							
0-20	4.7	13.6	2.8	4.0	0.6	17.6	0.8	7.3	5.1	30.7
20-40	4.8	11.6	2.0	3.3	2.3	18.6	0.8	6.5	4.4	30.3
	B	Cu	Fe	Mn	Zn	m	BS	sand	Silt	clay
		mg dm ⁻³				—%—		g kg ⁻¹		
0-20	0.34	2.0	26.0	0.9	0.4	4.3	42.6	848	36	116
20-40	0.41	1.4	31.5	1.0	0.3	16.4	38.6	841	23	137

Table 2. Eigenvalues of all variables analyzed of FM 913GLT and FM 983GLT under different K management and the use of ruzigrass

Total variance explained (%)	FM 913GLT	FM 983GLT
LAI 30	-0.6417	-0.0285
LAI 60	-0.4406	-0.3578
LAI 90	-0.8885	-0.7625
LAI 120	-0.9217	-0.7661
Gs F1	-0.4848	-0.0170
Gs F7	-0.0224	-0.5170
Gs C2	-0.6766	-0.2506
SAI	-0.7899	-0.8911
SPS	-0.8047	-0.6714
SUSY	-0.7150	-0.8713
Cellulose	-0.6132	-0.5821

Table 2. Scheme of cotton K fertilization

DAE: days after emergence

Figures

Treatments	Ruzigrass (RZ)	K rate	Time of K fertilization
0K	no	0	-
116K	no	116 kg ha ⁻¹	58 kg ha ⁻¹ applied 30 DAE and 58 kg ha ⁻¹ at 45 DAE
0K+RZ	yes	0	-
116K on RZ	yes	116 kg ha ⁻¹	applied on RZ vegetative stage (90 DAE)
58K on RZ+58K on C	yes	116 kg ha ⁻¹	58 kg ha ⁻¹ applied on RZ vegetative stage and 58 kg ha ⁻¹ on cotton 30 DAE
116K on C + RZ	yes	116 kg ha ⁻¹	58 kg ha ⁻¹ 30 DAE and 58 kg ha ⁻¹ 45 DAE

Figure 1

Rainfall, maximum and minimum temperatures, and vapor pressure deficit during the experiment.

Figure 2

Cotton leaf area index (LAI) as affected by K management in the 2016/17 (a) and 2017/18 (b) seasons. Vertical bars show the least significant difference (Tukey test, $P < 0.05$).

Figure 3

Stomatal conductance of cotton leaves (averaged across two cultivars) at phenological stages F1 (1st flower), F7 (peak flowering) and C2 (2nd cracked boll). Uppercase letters compare K managements and lowercase letters compare years in each K management. (Tukey test, P < 0.05).

Figure 4

Activity of soluble acid invertase (SAI), sucrose phosphate synthase (SPS), and sucrose synthase (SuSy) as affected by K fertilization management and cotton cultivars. Uppercase letters compare K management, and lowercase letters compare cultivars in each K management. (Tukey test, $P < 0.05$).

Figure 5

Cellulose content in cotton fibers in the middle third of the plants (10th node) at 24 and 48 days after anthesis (DAA) as affected by K fertilizer management (a) and cotton cultivar (b). Uppercase letters compare K management (DAA) and lowercase letters compare boll age in each K management (a) or cultivar (b). (Tukey test, $P < 0.05$).

Figure 6

Principal Component Analysis for early cultivar (FM 913GLT). Percentage of data variation in PC1 = 46%; PC2 was not significant.

Figure 7

Principal Component Analysis for late cultivar (FM 913GLT). Percentage of data variation in PC1 = 36%; PC2 was not significant.