Acta Scientiarum

http://www.periodicos.uem.br/ojs/
ISSN on-line: 1807-8621
Doi: 10.4025/actasciagron.v46i1.65712

CROP PRODUCTION

Enhanced potassium use by colored cotton cultivars in the semiarid region of Brazil

Gisele Lopes dos Santos[1*], Manoel Galdino dos Santos[1], Flávio Pereira da Mota Silveira[2], Ênio Gomes Flôr Souza[3], Welder de Araújo Rangel Lopes[1], José Artur Silva[1], Anna Kézia Soares de Oliveira[1] and Aurélio Paes Barros Júnior[1]

[1]Departamento de Ciências Agronômicas e Florestais, Universidade Federal Rural do Semi-Arido, Rua Francisco Mota, 572, 59625-900, Presidente Costa e Silva, Mossoró, Rio Grande do Norte, Brazil. [2]Universidade Federal do Rio Grande do Norte, Macaíba, Rio Grande do Norte, Brazil. [3]Instituto Federal de Alagoas, Piranhas, Alagoas, Brazil. *Author for correspondence. E-mail: gisele1612@gmail.com

ABSTRACT. Proper potassium (K) fertilization management is crucial for optimizing yield and minimizing environmental impacts in colored fiber cotton cultivars, particularly in semiarid regions. This study aimed to assess the efficiency of K use by colored cotton cultivars under K fertilization in a semiarid region. Two experiments were conducted in 2019 and 2021, representing two agricultural seasons. The experimental design employed randomized blocks with split plots and four replications. The main plots consisted of five randomized K doses (0, 60, 120, 180, and 240 kg ha^{-1} of K_2O), while subplots included four cultivars of colored cotton (BRS Rubi, BRS Safira, BRS Topázio, and BRS Verde). The results revealed that BRS Rubi exhibited superior agronomic efficiency with a dose of 60 kg ha^{-1} of K_2O in both agricultural seasons. The maximum efficiency of K use by colored cotton cultivars was achieved with a dose of 240 kg ha^{-1} of K_2O in the semiarid region of Brazil. The cultivars BRS Rubi and BRS Topázio demonstrated the highest use efficiency. Furthermore, BRS Topázio displayed the highest K accumulation in plant shoots during both seasons.

Keywords: *Gossypium hirsutum* L.; potassium fertilization; colored fiber; nutritional efficiency.

Received on November 3, 2022.
Accepted on June 22, 2023.

Introduction

Naturally colored fiber cotton has emerged as a significant alternative for the textile industry in Brazil, particularly in the northeastern semiarid region where its cultivation is currently limited to a small scale. To further develop this production chain, it is crucial to introduce cultivation techniques that facilitate the expansion and establishment of colored cotton (Carvalho, Borin, Staut, & Ferreira, 2014), with a particular focus on proper crop nutritional management.

Among the essential nutrients, potassium (K) plays a critical role in cotton performance. Its deficiency can lead to early senescence and reduced photosynthetic efficiency, ultimately resulting in decreased productivity (Yang et al., 2016b). Additionally, Zahoor, Zhao, Abid, Dong, and Zhou (2017) highlighted that adequate K availability ensures improved crop yield. According to Oosterhuis, Loka, and Raper (2013), the choice of cultivar is another crucial factor influencing efficient nutrient use, as cultivars with higher yield potential and precocity tend to be more susceptible to K deficiency.

Although K is considered abundant in the Earth's crust, its availability for plant growth can be limited under specific conditions, including soil factors (such as soil type, clay content, and competition with other nutrients) and climate conditions (Zörb, Senbayram, & Peiter, 2014). It should be noted that K levels and forms in the soil (non-exchangeable K, exchangeable K, and soluble K) vary with the degree of pedogenetic development of the soils, with less developed soils often found in the semiarid region (Saraiva et al., 2021). Consequently, K supplementation via fertilizer becomes necessary in such regions.

The concept of nutritional efficiency refers to a plant's ability to achieve greater growth and productivity with application of less fertilizers. However, the plant's ability to absorb and accumulate available nutrients is crucial for the success of the crop. Various indexes, including agronomic efficiency, physiological efficiency, physiological efficiency, recovery efficiency, and use efficiency, are used to determine the most efficient doses of mineral fertilizer and cultivars for nutrient use (Tartaglia et al., 2020).

In this context, it is essential to identify cultivars and doses that enable efficient use of K fertilizer, minimizing losses, reducing economic and environmental impacts, and promoting advancements in the colored cotton industry in Brazil. Therefore, the objective of this study was to evaluate the efficiency of K use by colored cotton cultivars in the semiarid region of Brazil.

Material and methods

The experiments were conducted at the Rafael Fernandes Experimental Farm, which is part of the *Universidade Federal Rural do Semi-Árido*, located in Mossoró, Rio Grande do Norte State, Brazil (latitude 5°03'31.00" S, longitude 37°23'47.57" W, and altitude of 80 m). Crops were evaluated during two agricultural seasons, namely 2019 and 2021, both from July to November.

A split plot design was employed, with a randomized block arrangement and four replications. The main plots consisted of five potassium (K) doses (0, 60, 120, 180, and 240 kg ha^{-1} of K_2O), while the subplots included four colored cotton cultivars (BRS Rubi, BRS Safira, BRS Topázio, and BRS Verde). The selection of doses was based on the responsive range found in the literature for cotton crops (ranging from 0 to 300 kg ha^{-1}). The interval between doses was determined using the reference dose of 60 kg ha^{-1} of K_2O, considering the soil's K levels (Gomes & Coutinho, 2008). The selected cultivars were among the most commonly cultivated ones in the region.

The climate in the region is characterized as BSh (warm semiarid tropical), with an average temperature of 27.4°C and an irregular annual rainfall of approximately 673.9 mm (Alvares et al., 2013). Meteorological data during the experimental period were obtained from the Automatic Meteorological Station at Rafael Fernandes Farm (Figure 1). The soil in the experimental area is classified as a typical dystrophic Red Argisol (Rêgo, Martins, Silva, Silva, & Lima, 2016).

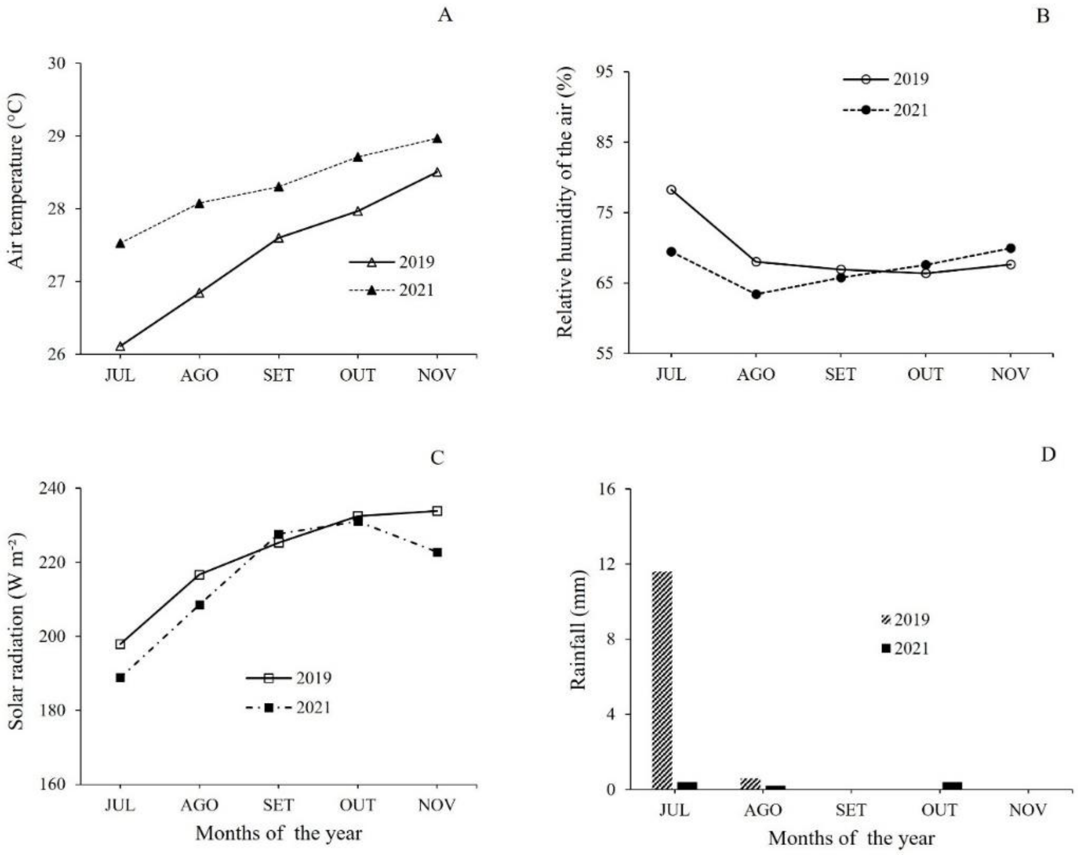

Figure 1. Average values of air temperature (A), relative humidity (B) solar radiation (C) and rainfall (D) in the two agricultural seasons 2019 and 2021, Mossoró, Rio Grande do Norte State, Brazil.

Before the installation of the experiments, the experimental area was conventionally prepared by watering and grading. Soil samples were collected at a depth of 0-0.20 m in both seasons for physical and chemical characterization, as well as for determining the balanced fertilization of nitrogen (N) and phosphorus (P) (Gomes & Coutinho, 2008). The results of the soil characterization are presented in Table 1.

Table 1. Chemical characterization and soil granulometry, at depths of 0-0.20 m of experimental areas referring to the two agricultural seasons 2019 and 2021.

Depth	pH	P*	K^+	Na^+	Ca^{2+}	Mg^{2+}	Al^{3+}	Sand	Silt	Clay
m		mg dm^{-3}			$cmol_c$ dm^{-3}				kg kg^{-1}	
					2019					
0 – 0.20	7.50	8.00	0.10	0.04	1.30	0.20	0.00	0.90	0.03	0.07
					2021					
0 – 0.20	5.60	4.20	0.11	0.01	0.78	0.30	0.00	0.90	0.03	0.07

*Extractor: $Mehlich^{-1}$.

Nitrogen was supplied in the form of urea (45% N) and monoammonium phosphate (MAP - 12% N), while P was available as MAP (61% P_2O_5). Potassium was provided as potassium chloride (KCl - 61% K_2O). Phosphorus was applied as a foundation, while N and K were applied in installments at planting and in two additional cover applications every 20 days. The first fertilization consisted of 50% of the total value, and the subsequent two applications were 25% each. A micronutrient compound, REXOLIN™ BRA (2.10% B, 0.36% Cu, 2.66% Fe, 2.48% Mn, 0.036% Mo, and 3.38% Zn), was also applied at the appearance of floral buds (Pedroso Neto, Fallieri, Silva, & Laca, 1999).

The cultivars used in the experiments were developed by the Genetic Improvement Program of the *Centro Nacional de Pesquisa de Algodão* (CNPA) by the *Empresa Brasileira de Pesquisa Agropecuária* (EMBRAPA) in Campina Grande, Paraíba State, Brazil. The seeds were provided by the company in a sample quantity for multiplication. The selected cultivars have different colors, including reddish brown (BRS Rubi and BRS Safira), light brown (BRS Topázio), and green (BRS Verde). They have an annual cycle of 120 to 140 days, an average height of 1.20 m, and average seed cotton production ranging from 2 to 3.5 t ha^{-1} under semiarid conditions with irrigation (Carvalho, Andrade, & Silva Filho, 2011).

The experimental procedures were the same in both seasons, conducted in the same area. Due to the COVID-19 pandemic, the interval between the harvests resulted in the experiment being conducted only in the second half of each year to avoid the rainy season that typically occurs in the first months of the year, which could affect the experimental results and fiber quality. Each subplot consisted of four lines, with 19 plants per line. The spacing used was 0.20 m between plants and 0.70 m between rows, resulting in a total area of 10.64 m^2 (3.8 x 2.8 m) for each subplot (Figure 2). Only the two central lines were considered as the useful area, excluding the plants at the ends (surround), totaling 34 plants in the useful area of each experimental subplot. The total area of each experiment was 851.2 m^2, with a population density equivalent to 71,428 plants ha^{-1}.

Sowing was done manually, placing three seeds per pit at a depth of 0.05 m. Thinning was performed when the plants had three definitive leaves, leaving only the most vigorous plant per pit. Three weed control operations were carried out during the crop cycle.

The irrigation system used was a drip type, with emitters spaced at 0.20 m and a flow rate of 1.6 L h^{-1}. The average daily water depth applied was 6.39 mm in the first season and 6.47 mm in the second season, based on the daily evapotranspiration of the crop using the crop coefficient (K_c) (Allen, Pereira, Raes, & Smith, 1998). The initial, middle, and final reference K_c values were 0.35, 1.10, and 0.39 for the 2019 season, and 0.36, 1.15, and 0.45 for the 2021 season. Therefore, the total water depths applied were 685 and 662 mm in the first and second season, respectively. Irrigation was suspended at 115 and 110 days after sowing for the first and second season, respectively.

The first harvests were performed at 106 days after sowing (DAS) in the first season and at 102 DAS in the second season, manually. The first harvest included the bolls from the lower third of the plants, and subsequent harvests were conducted weekly according to the boll opening. At the end, all plants in the useful area were harvested, and the yield of the cotton plume, total biological productivity (including straw, grains, and fiber), and K accumulation in shoot biomass (straw, grains, and fiber) were determined to assess nutrient use efficiency.

Feather yield (Table 2) was determined by multiplying the cotton seed yield (kg ha^{-1}) by the percentage of fiber, which was evaluated using the High Volume Instrument (HVI) equipment at the EMBRAPA laboratory in Campina Grande, Paraíba State, Brazil.

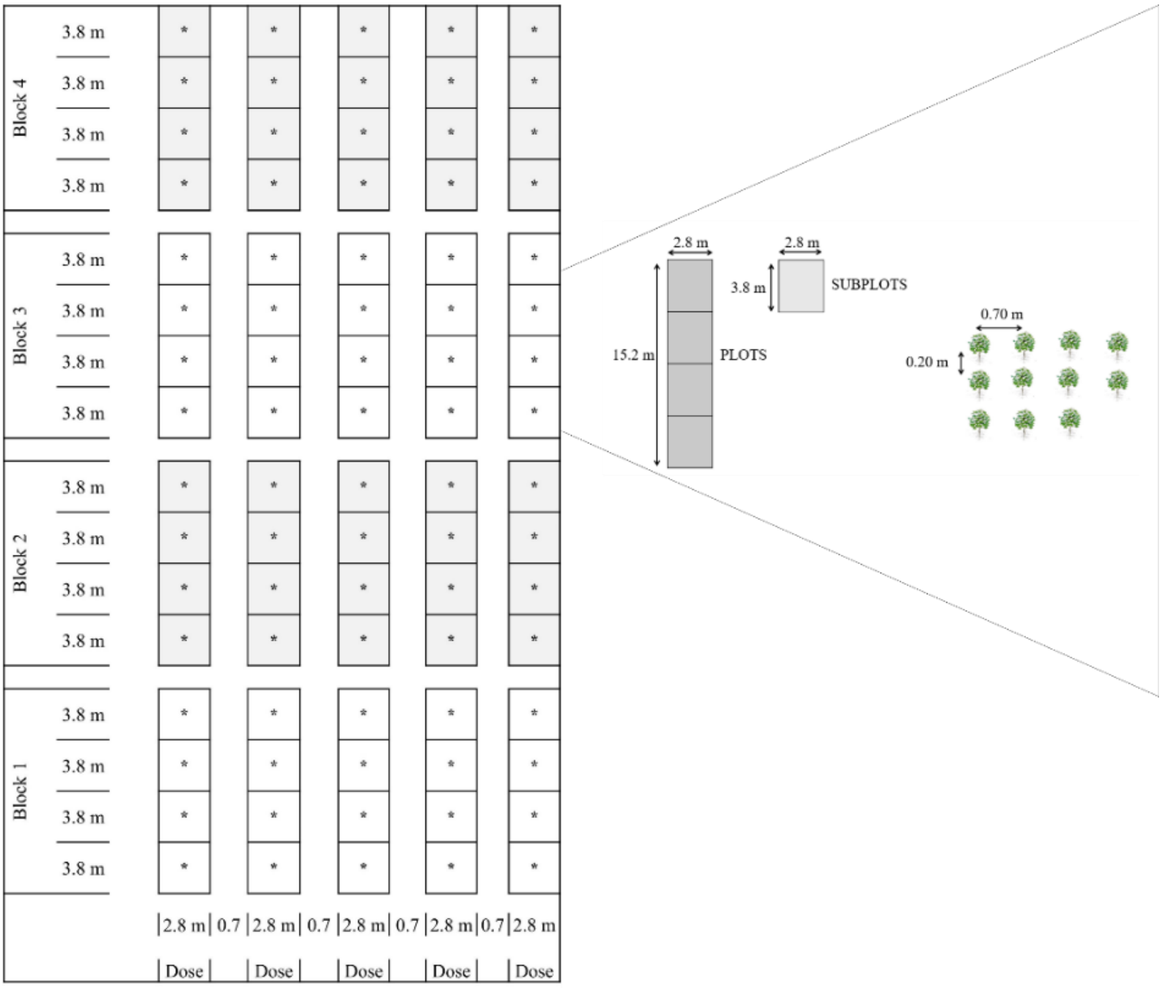

Figure 2. Illustration of experimental design in the field, Mossoró, Rio Grande do Norte State, Brazil.

Table 2. Average plume productivity in colored cotton cultivars fertilized with potassium doses in two agricultural seasons 2019 and 2021.

	Average feather weight (kg ha^{-1})*		
Doses of K	Cultivars	2019	2021
0 kg ha^{-1}	BRS Rubi	883.59	483.99
	BRS Safira	836.05	654.48
	BRS Topázio	1,557.85	986.30
	BRS Verde	674.95	445.38
60 kg ha^{-1}	BRS Rubi	1,002.81	580.12
	BRS Safira	900.95	714.59
	BRS Topázio	1,610.42	1,055.57
	BRS Verde	877.70	473.20
120 kg ha^{-1}	BRS Rubi	958.61	667.20
	BRS Safira	922.00	800.69
	BRS Topázio	1,404.70	1,105.37
	BRS Verde	814.75	515.14
180 kg ha^{-1}	BRS Rubi	798.24	707.96
	BRS Safira	932.36	880.02
	BRS Topázio	1,305.17	1,276.07
	BRS Verde	692.25	597.12
240 kg ha^{-1}	BRS Rubi	766.06	757.92
	BRS Safira	914.87	923.67
	BRS Topázio	1,214.52	1,393.93
	BRS Verde	595.84	626.96

*Input data for calculating efficiency variables, for information purposes only.

To determine the total biological productivity (including straw, grains, and fiber), two plants were collected per experimental unit on the day of the final harvest. The collected material was packed in paper bags and dried in a greenhouse with forced air circulation at 65°C until reaching constant weight. The dried material was then weighed using a semi-analytical digital scale (with three decimal places), and the average weight per plant was calculated in kilograms and estimated for a hectare using conversion factors (as provided in Table 3).

Table 3. Average values for total biological productivity in colored cotton cultivars fertilized with potassium doses in two agricultural seasons 2019 and 2021.

Total biological productivity (kg ha^{-1})*			
Doses of K	Cultivars	2019	2021
0 kg ha^{-1}	BRS Rubi	6,572.00	4,036.90
	BRS Safira	5,391.65	4,303.00
	BRS Topázio	9,089.57	5,204.07
	BRS Verde	6,278.49	3,852.98
60 kg ha^{-1}	BRS Rubi	6,684.68	4,418.66
	BRS Safira	6,528.79	4,859.78
	BRS Topázio	7,274.85	5,610.91
	BRS Verde	8,009.40	4,267.97
120 kg ha^{-1}	BRS Rubi	6,961.29	4,759.34
	BRS Safira	6,053.79	5,088.26
	BRS Topázio	5,284.63	6,019.33
	BRS Verde	4,806.47	4,886.18
180 kg ha^{-1}	BRS Rubi	4,800.94	5,274.24
	BRS Safira	6,035.50	5,490.67
	BRS Topázio	4,790.05	6,930.84
	BRS Verde	4,470.14	5,659.24
240 kg ha^{-1}	BRS Rubi	3,987.20	6,178.08
	BRS Safira	4,053.99	5,829.03
	BRS Topázio	4,463.18	7,995.56
	BRS Verde	3,031.58	6,319.32

*Input data for calculating efficiency variables, for information purposes only.

To estimate total K accumulation, two plants were collected from each subplot and dried in a greenhouse with forced air circulation at 65°C until they reached constant weight (approximately 72 hours). Samples from different parts of the plants were ground in a stainless-steel knife mill (SOLAB™, SL-31). About 0.4 g of each ground sample was transferred to a digester tube and added to 1g of a digester mixture (K_2SO_4 + $CuSO_4$ in a 10:1 ratio), along with 2 mL of hydrogen peroxide (H_2O_2) and 4 mL of sulfuric acid (H_2SO_4) (98%). The mixture was heated in a digester block up to 350°C and maintained until a greenish viscous liquid was obtained (approximately 3 hours). After cooling, the volume was adjusted to 50 mL using Milli-q™ water, and the K content was determined by photometry using a flame photometer (DIGIMED™, DM-62), following the adapted methodology of Silva (2009). The nutrient concentration was multiplied by the dry shoot biomass mass (expressed in kg ha^{-1}) considering the population density.

Potassium use efficiency was evaluated using different indices, including agronomic efficiency (*AE*), physiological efficiency (*PE*), agro-physiological efficiency (*APE*), apparent recovery efficiency (*ARE*) and utilization efficiency (*UE*). Calculation formulas and methodologies were adapted from Fageria and Baligar (2005) and Rochester (2011).

Agronomic efficiency (*AE*) was expressed as kg kg^{-1} and estimated by the following formula:

$$AE = (CPY_{WK} - CPY_{NK}) / QK_a$$

wherein: CPY_{WK} is the cotton plume yield with K application (kg); CPY_{NK} is the cotton plume yield with no K application (kg); and QK_a is the amount of K applied (kg).

Physiological efficiency (*PE*) was estimated as the relationship between shoot biomass with and without K application and nutrient accumulation in shoot biomass with and without K application, in kg kg^{-1}:

$PE = (TBY_{WK} - TBY_{NK})/(AK_{WK} - AK_{NK})$

wherein: TBY_{WK} is the total biological yield with K application (kg); TBY_{NK} is the total biological yield without K application (kg); AK_{WK} is the accumulation of K in shoot biomass with K application (kg); and AK_{NK} is the accumulation of K in shoot biomass with no K application (kg).

Agro-physiological efficiency (*APE*) was estimated as kg kg^{-1} using the following formula:

$APE = (CPY_{WK} – CPY_{NK})/(AK_{WK} - AK_{NK})$

wherein: CPY_{WK} is the cotton plume yield with K application (kg); CPY_{NK} is the cotton plume yield with no K application (kg); AK_{WK} is the accumulation of K in shoot biomass with K application (kg); and AK_{NK} is the accumulation of K in shoot biomass with no K application (kg).

Apparent recovery efficiency (*ARE*) was estimated as the relationship between the K accumulation in shoot biomass with and without K application and the amount of K applied, and expressed as %:

$ARE = (AK_{WK} - AK_{NK}/QK_a) \times 100$

wherein: AK_{WK} (kg) is the accumulation of K in shoot biomass (straw, grains, and fibers) with K application; AK_{NK} is the accumulation of K in shoot biomass with no K application (kg); and QK_a is the amount of K applied, in kg.

Utilization efficiency (*UE*) was determined as the relationship between physiological efficiency (*PE*) and apparent recovery efficiency (*ARE*), in kg kg^{-1}:

$UE = PE \times ARE$

The data obtained were subjected to analysis of variance (ANOVA) using the F-test at a significance level of $p < 0.05$. When the assumption of homogeneity of variances was met between the seasons, a joint analysis was performed. The means of qualitative treatments were compared using the Tukey's test at a significance level of 5%. The data related to quantitative factors were subjected to regression analysis using the SISVAR program (Ferreira, 2014).

Results and discussion

In the first season, BRS Verde achieved the highest agronomic efficiency (4.08 kg kg^{-1}) with a dose of 60 kg ha^{-1} of K_2O, followed by BRS Rubi, BRS Safira, and BRS Topázio, with values of 2.03, 1.13, and 0.80 kg kg^{-1}, respectively (Figure 3A). However, higher potassium (K) doses reduced agronomic efficiency for all cultivars. In the second season, BRS Rubi showed the highest agronomic efficiency (1.92 kg kg^{-1}) with a dose of 60 kg ha^{-1} of K_2O, followed by BRS Topázio (1.74 kg kg^{-1}) with a dose of 240 kg ha^{-1} of K_2O (Figure 3B). BRS Safira reached an agronomic efficiency of 1.31 kg kg^{-1} with an estimated dose of 160 kg ha^{-1} of K_2O, and BRS Verde achieved 0.65 kg kg^{-1} with a dose of 165 kg ha^{-1} of K_2O.

Notably, while BRS Topázio had the highest fiber productivity (Table 3), it did not have the highest agronomic efficiency. This discrepancy can be attributed to the cultivar's characteristic of high lint production, which does not necessarily correlate with agronomic efficiency. The results suggest that high K doses may reduce agronomic efficiency, as observed in the first season. This finding is in line with Tariq et al. (2017), who conducted a study on K use in cotton with different application methods. However, for the second season, most cultivars showed an increase in agronomic efficiency with higher doses of K_2O.

Agronomic efficiency represents the amount of cotton plume produced in kilograms per kilogram of K applied. This parameter can help reduce production costs by determining fertilizer doses that promote better cost-benefit ratios. However, it is important to consider that agronomic efficiency is influenced not only by nutrient availability but also by various metabolic activities of the plant that can affect nutrient absorption and use. It should also be noted that fertilizer use efficiency is closely associated with the edaphoclimatic conditions of each region, which can affect K dynamics (Reetz, 2017).

In terms of physiological efficiency, BRS Rubi achieved the highest value of 90.46 kg kg^{-1} with a dose of 240 kg ha^{-1} of K_2O in the first season (Figure 3C). BRS Topázio reached a maximum value of 89.34 kg kg^{-1} with a dose of 60 kg ha^{-1} of K_2O. BRS Safira and BRS Verde showed higher values of 88.91 and 85.46 kg kg^{-1}, respectively, with doses of 167 and 185 kg ha^{-1} of K_2O. In the second season, BRS Topázio had the highest physiological efficiency of 60.04 kg kg^{-1} with a dose of 174 kg ha^{-1} of K_2O (Figure 3D). BRS Verde achieved a maximum value of 58.48 kg kg^{-1} with a dose of 182 kg ha^{-1} of K_2O, and BRS Safira reached 48.50 kg kg^{-1} with a dose of 240 kg ha^{-1} of K_2O. BRS Rubi did not show significant variation in physiological efficiency across doses, with an average of 36.15 kg kg^{-1}. It is worth noting that the physiological efficiency of the cultivars was lower in the 2021 season compared to the 2019 season. A low physiological efficiency can be attributed to nutrient deficiency, stress, or mineral toxicity (Reetz, 2017). However, in this study, high K doses did not lead to a significant decrease in this parameter, indicating that there was no toxicity due to K application. Nevertheless, higher physiological efficiency in nutrient use may indicate poor conversion of absorbed nutrients into plant biomass (Akhtar et al., 2022).

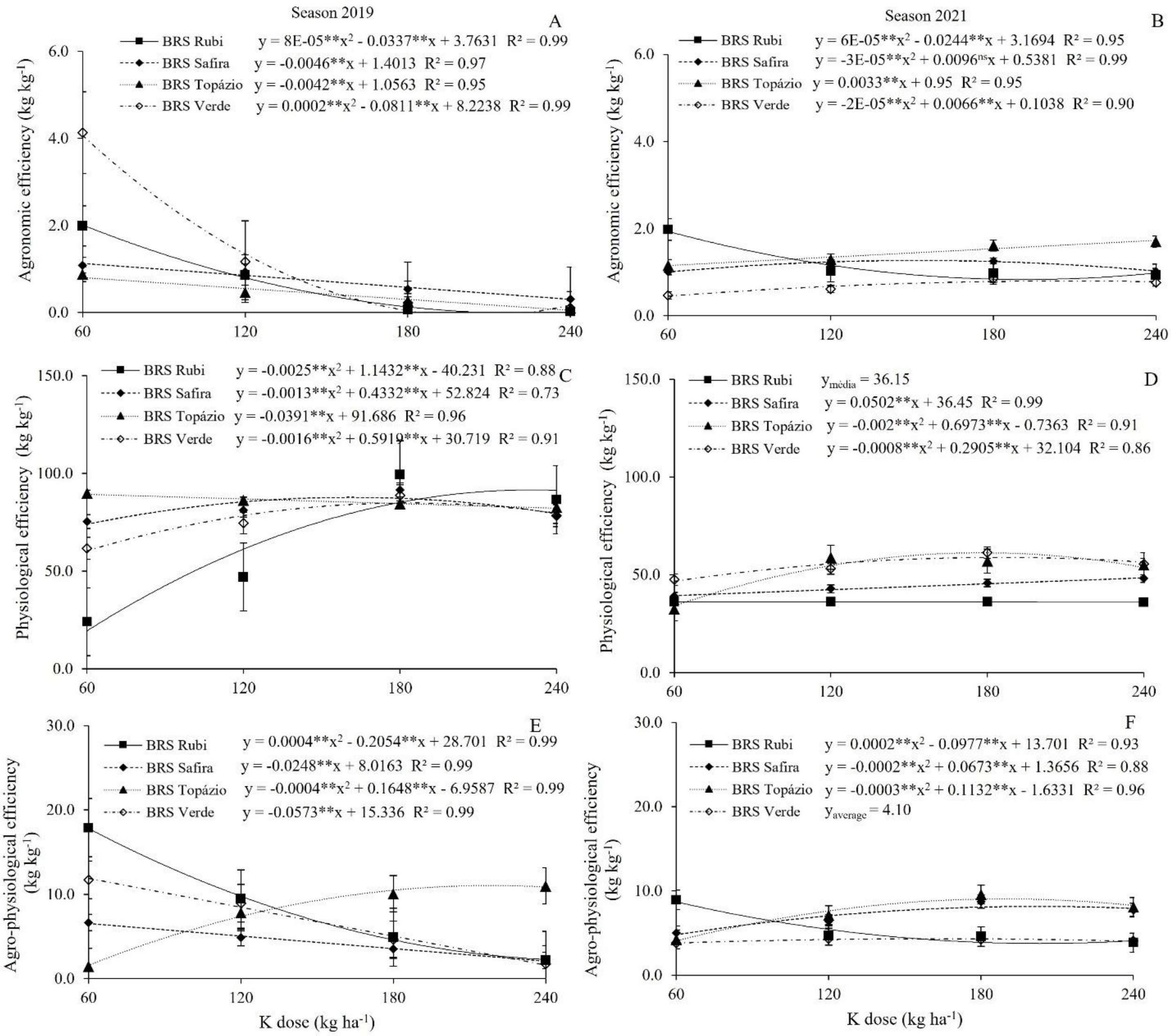

Figure 3. Agronomic efficiency (AE), physiological efficiency (PE) and agro-physiological efficiency (APE), in colored cotton cultivars under potassium doses in two agricultural seasons 2019 and 2021, Mossoró, Rio Grande do Norte State, Brazil.

Potassium plays a crucial role in various physiological processes in plants, including photosynthesis, photorespiration, and growth. The availability of K can affect these processes, and plant cells have mechanisms to monitor and regulate K concentration. However, the specific mechanisms for detecting K availability and absorbing it have not been fully elucidated (Shin, 2014). External factors to which plants are exposed can influence the efficient physiological use of K and consequently impact productivity.

In the 2019 season, BRS Rubi achieved the highest agro-physiological efficiency (17.82 kg kg^{-1}) with a dose of 60 kg ha^{-1} of K_2O. BRS Verde and BRS Topázio followed with values of 11.90 kg kg^{-1} and 10.02 kg kg^{-1}, respectively, using doses of 60 and 240 kg ha^{-1} of K_2O (Figure 3E). BRS Safira showed a higher increment (6.53 kg kg^{-1}) with the dose of 60 kg ha^{-1} of K_2O, but this value was lower compared to the other cultivars. In the 2021 season, BRS Topázio exhibited the highest agro-physiological efficiency (9.05 kg kg^{-1}) with a dose of 189 kg ha^{-1} of K_2O, followed by BRS Rubi with 8.56 kg kg^{-1} using a dose of 60 kg ha^{-1} of K_2O (Figure 3F). BRS Safira achieved a maximum value of 7.03 kg kg^{-1} with a dose of 168 kg ha^{-1} of K_2O. BRS Verde did not show significant variation across doses, with an average value of 4.10 kg kg^{-1}.

Agro-physiological efficiency represents the specific production capacity per unit of accumulated nutrient in the plant, indicating how much the plant produced in kilograms for each kilogram of accumulated K. The results suggest that there are distinct differences among cultivars in terms of their ability to absorb and accumulate K. Similar findings were reported by Hassan et al. (2014) in their evaluation of K use efficiency in white cotton genotypes in Pakistan.

It is worth noting that the values for agro-physiological efficiency were generally higher in the first season compared to the second season, except for BRS Safira. This finding is consistent with the results of Tartaglia et al. (2020), who studied nitrogen (N) use efficiency in naturally colored cotton cultivars in a semiarid region and found higher agro-physiological efficiency in the second season. The authors associated this increase with the greater amount of rainfall observed in the second year, which could lead to more nutrient leaching. In this study, although higher rainfall was observed in the first season (Figure 1), the overall rainfall percentage in the region was relatively low, suggesting a lower leaching potential.

Soil chemical and texture characteristics (Table 1) likely also influenced K use efficiency by colored cotton cultivars in both seasons. According to Yang, Du, Tian, Eneji, and Li (2016a), K losses are more common in sandy and clayey soils, which are prone to nutrient leaching. Moreover, chemical characteristics such as high sodium (Na) content in the soil can affect K absorption by plants. Sodium and K can compete for certain non-specific metabolic functions through the interionic effect between their cations (Na^+ and K^+). This competition may lead to an increased concentration of Na in plant tissues at the expense of K. Therefore, an element may be involved in vital activities, but it would not be considered a nutrient (Coelho et al., 2017).

The composition of the soil used in this study can influence fixation and availability of nutrients, potentially compromising K use by plants, considering that this element is a highly mobile element in the soil-plant system. Additionally, in the first season, the soil had a higher number of cations compared to the soil in the second season. This suggests a potential competitive inhibition among salts such as Na, K, calcium (Ca), and magnesium (Mg), which could affect K use efficiency, particularly with higher doses of K_2O. Sodium and K, for example, may have competed for absorption sites due to their similar properties. Regarding the Ca, Mg, and K ratio, the electrical and chemical potentials of spaces external to the plasma membranes of cells may have favored greater retention of divalent cations (Ca^{2+} and Mg^{2+}) compared to monovalent cations (K^+). According to Fernandes et al. (2022), ionic competition among ions such as Na^+, K^+, Ca^{2+}, and Mg^{2+} can lead to changes in availability, absorption, transport, assimilation, and distribution of these elements in plants, resulting in lower accumulation in shoot tissues.

Regarding recovery efficiency, all cultivars achieved their maximum values in the first season at a dose of 60 kg ha^{-1} of K_2O (Figure 4A). The values were as follows: BRS Verde - 45.61%, BRS Safira - 24.63%, BRS Rubi - 7.41%, and BRS Topázio - 1.89%. Among these cultivars, BRS Verde exhibited the highest recovery efficiency. In the second season, BRS Topázio and BRS Rubi obtained the highest values (23.65% and 23.28%, respectively) with doses of 60 and 240 kg ha^{-1} of K_2O (Figure 4B). Similarly, BRS Safira and BRS Verde achieved 22.72% and 19.50% with the same doses of 60 and 240 kg ha^{-1}, respectively.

The maximum use efficiency (28.46 kg kg^{-1}) was observed in the 2019 season for cultivar BRS Verde, followed by BRS Safira (18.73 kg kg^{-1}) using a dose of 60 kg ha^{-1} of K_2O (Figure 4C). In contrast, BRS Topázio and BRS Rubi exhibited use efficiencies of 1.93 kg kg^{-1} and 1.68 kg kg^{-1}, respectively, at the same dose. During the 2021 season, the highest value (11.60 kg kg^{-1}) was obtained by cultivar BRS Topázio using the maximum dose of 240 kg ha^{-1} of K_2O (Figure 4D). Additionally, BRS Verde, BRS Safira, and BRS Rubi achieved use efficiencies of 10.43 kg kg^{-1}, 9.03 kg kg^{-1}, and 8.88 kg kg^{-1}, respectively, with doses of 207 kg ha^{-1}, 60 kg ha^{-1}, and 240 kg ha^{-1} of K_2O.

This index calculates the efficiency of fertilizer recovery, which represents the amount of nutrient accumulated per unit of nutrient applied. It indicates the plant's ability to absorb and acquire nutrients from the soil. Based on these results, it is evident that a higher amount of available nutrients does not necessarily result in greater absorption by the plant, as observed in the 2019 season. Furthermore, the recovered K content was found to be low, measuring less than 50% in both studied seasons. However, Akhtar, Tsadilas, Samaras, Schepers, and Eskridge (2022), in their study on K application combined with N under different humidity conditions, obtained an average apparent K recovery efficiency of 46% with K application, suggesting that this range may be considered typical.

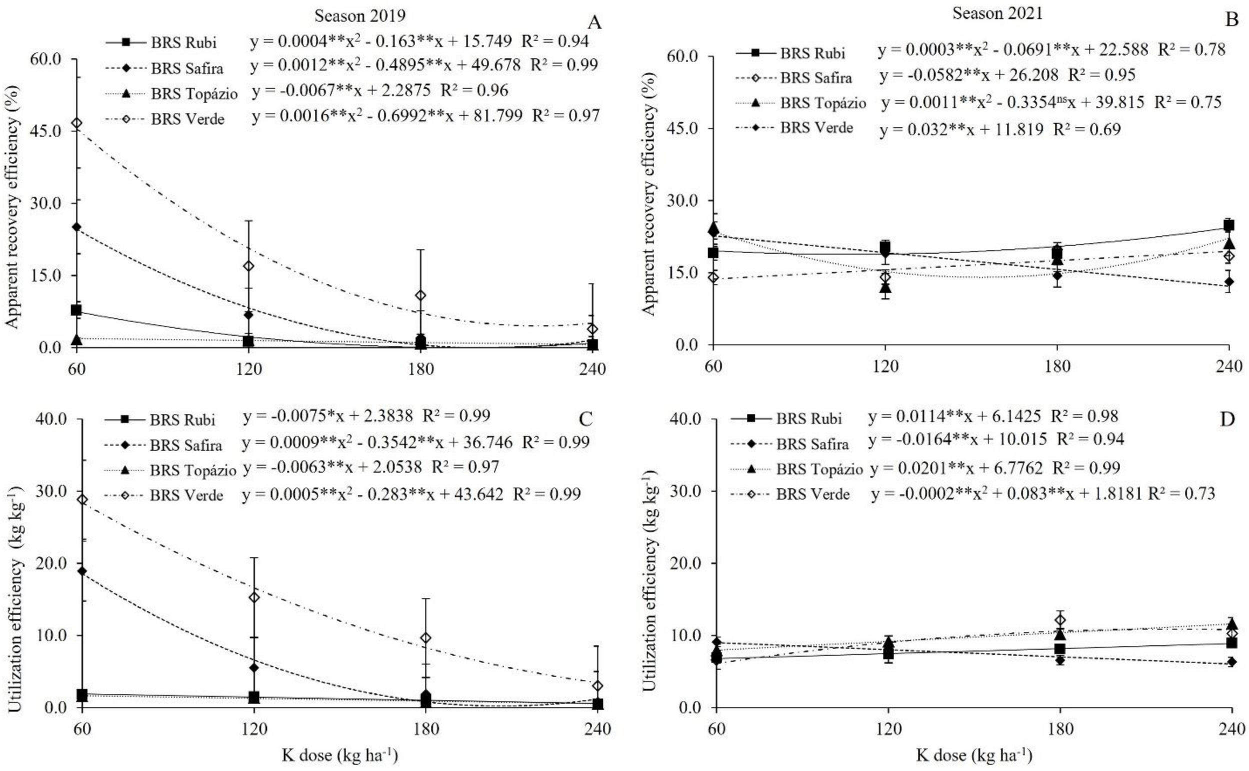

Figure 4. Apparent recovery efficiency (ARE) and utilization efficiency (UE), in colored cotton cultivars under potassium doses in two agricultural seasons 2019 and 2021, Mossoró, Rio Grande do Norte State, Brazil.

The efficiency of nutrient use refers to the maximum economic yield achieved per unit of nutrient applied, absorbed, or used by plants for biomass and production. It is a crucial factor in evaluating the effectiveness of applied chemical fertilizers and their impact on crop yield (Stamatiadis et al., 2016). Generally, plant species with higher use efficiency can maintain their water relations, photosynthetic activity, and yield even in low K supply environments (White, 2013).

According to White, Bell, Djalovic, Hinsinger, and Rengel (2021), genotypes with higher K use efficiency can redistribute K from older tissues to younger tissues, thereby supporting growth and photosynthesis. They also exhibit reduced vacuolar K concentration by maintaining an appropriate concentration in metabolically active subcellular compartments, either through anatomical adaptations or increased substitution of K with other solutes in the vacuole. Therefore, genetic variation plays a significant role in K absorption and use efficiency.

In the 2019 season, BRS Topázio had the highest K accumulation (102.28 kg ha^{-1}) in the absence of K fertilization (Figure 5A). It was followed by cultivars BRS Verde (85.27 kg ha^{-1}), BRS Rubi (79.45 kg ha^{-1}), and BRS Safira (69.71 kg ha^{-1}) at estimated doses of 43, 38, and 84 kg ha^{-1} of K2O, respectively. Similarly, in the 2021 season (Figure 5B), all cultivars exhibited higher accumulation at the maximum dose (240 kg ha^{-1} of K2O), resulting in 122.34 kg ha^{-1} (BRS Topázio), 119.83 kg ha^{-1} (BRS Rubi), 103.45 kg ha^{-1} (BRS Verde), and 92.02 kg ha^{-1} (BRS Safira). Thus, it is evident that among the studied cultivars and seasons, BRS Safira had the lowest capacity to accumulate K in its shoot. Hu et al. (2016) reported an increase in total K accumulation with K supply treatments for both studied cultivars. Their findings also indicated that K application influenced the pattern of K accumulation and impacted photosynthesis processes, which is consistent with the observations in our study.

BRS Topázio exhibited a higher capacity to accumulate K even in the absence of mineral fertilization during the first season, suggesting its efficient extraction of K from the soil. This efficiency may be attributed to the cultivar's effective mechanisms for controlling K absorption, even under low soil solution concentrations. The resulting strong chemical gradient from the external (soil) to the internal (plant) environment contributes to its higher production, even under conditions of limited nutrient availability. It is worth noting that the higher cation content in the soil during the first season could have influenced K absorption through ion competition, leading to lower K accumulation by the cultivars, particularly in higher nutrient concentrations in the soil.

The increased K accumulation in plants due to higher K_2O doses in the second season can be attributed to an abundant availability of K in the soil. The nutrient can be stored in various plant cell organelles such as chloroplasts, mitochondria, and vacuoles. Additionally, greater nutrient export by the plant may contribute to the observed accumulation. In summary, the greater efficiency of K use in colored cotton can be attributed to the higher accumulation of the nutrient in the aboveground parts of the plant. Therefore, this factor is proposed as an important criterion for determining fertilizer doses and selecting cultivars.

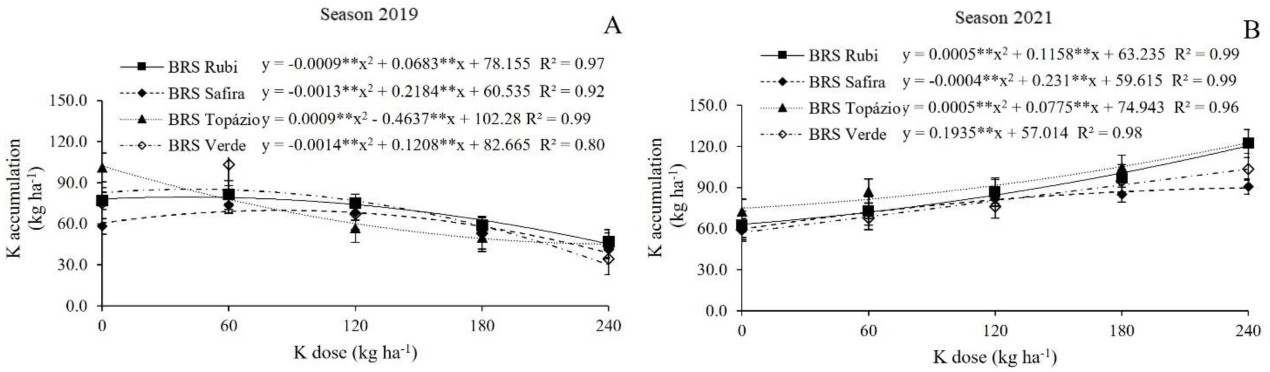

Figure 5. Potassium accumulation in shoot (AK) of colored cotton cultivars under potassium doses in two agricultural seasons 2019 and 2021, Mossoró, Rio Grande do Norte State, Brazil.

Conclusion

In the semiarid region of Brazil, the colored cotton cultivars BRS Rubi and BRS Topázio showed the highest efficiency in using potassium, with a maximum efficiency achieved at a dose of 240 kg ha^{-1} of K_2O. Additionally, BRS Topázio exhibited greater K accumulation in plant shoots in both seasons studied.

Acknowledgements

We to thank for their financial support from the *Coordenação de Aperfeiçoamento de Pessoal de Nível Superior* (CAPES) and *Instituto Federal de Alagoas* (IFAL).

References

Akhtar, M. N., Ul-Haq, T., Ahmad, F., Imran, M., Ahmed, W., Ghaffar, A., ... Ali, S. (2022). Application of potassium along with nitrogen under varied moisture regimes improves performance and nitrogen-use efficiency of high- and low-potassium efficiency cotton cultivars. *Agronomy*, *12*(2), 1-15. DOI: https://doi.org/10.3390/agronomy12020502

Allen, R. G., Pereira, L. S., Raes, D., & Smith, M. (1998). *Crop evapotranspiration: guidelines for computing crop water requirements.* Rome, IT: FAO.

Alvares, C. A., Stape, J. L., Sentelhas, P. C., Moraes, G., Leonardo, J., & Sparovek, G. (2013). Köppen's climate classification map for Brazil. *Meteorologische Zeitschrift*, *22*(6), 711-728. DOI: https://doi.org/10.1127/0941-2948/2013/0507

Carvalho, L. P., Andrade, F. P., & Silva Filho, J. L. (2011). Cultivares de algodão colorido no Brasil. *Revista Brasileira de Oleaginosas e Fibrosas*, *15*(1), 37-44.

Carvalho, M. C. S., Borin, A. L. D. C., Staut, L. A., & Ferreira, G. B. (2014). Nutrição, calagem e adubação. In A. Borém, & E. C. Freire (Eds.), *Algodão do plantio à colheita* (1. ed). Viçosa, MG: UFV.

Coelho, V. A. T., Dias, G. M. G., Ferreira, M. M., Rodas, C. L., Silva, M. L. S., & Pasqual, M. (2017). Potássio e sódio na composição mineral e crescimento em plantas de *Zingiber spectabile*. *Revista Brasileira de Ciências Agrárias*, *12*(1), 35-40. DOI: https://doi.org/10.5039/agraria.v12i1a5417

Fageria, N. K., & Baligar, V. C. (2005). Enhancing nitrogen use efficiency in crop plants. *Advances in Agronomy*, *88*, 97-185. DOI: https://doi.org/10.1016/S0065-2113(05)88004-6

Fernandes, C. S., Sá, F. V. S., Ferreira Neto, M., Dias, N. S., Reges, L. B. L., Gheyi, H. R., ... Melo, A. S. (2022). Ionic homeostasis, biochemical components and yield of Italian zucchini under nitrogen forms and salt stress. *Brazilian Journal of Biology*, *82*, 1-10. DOI: https://doi.org/10.1590/1519-6984.233567

Ferreira, D.F. (2014). Sisvar: A guide for its bootstrap procedures in multiple comparisons. *Ciência e Agrotecnologia*, *38*(2), 109-112. DOI: https://doi.org/10.1590/S1413-70542014000200001

Gomes, R. V., & Coutinho, J. L. B. (2008). Algodão herbáceo/Algodão herbáceo irrigado. In: F. J. A. Cavalcanti (Coord.), *Recomendações de adubação para o Estado de Pernambuco*: 2ª aproximação (3. ed). Recife, PE: IPA.

Hassan, Z. U., Kubar, K. A., Rajpar, I., Shah, A. N., Tunio, S. D., Shah, J. A., & Maitlo, A. A. (2014). Evaluating potassium-use-efficiency of five cotton genotypes of Pakistan. *Pakistan Journal of Botany*, *46*(4), 1237-1242.

Hu, W., Jiang, N., Yang, J., Meng, Y., Wang, Y., Chen, B., ... Zhou, Z. (2016). Potassium (K) supply affects K accumulation and photosynthetic physiology in two cotton (*Gossypium hirsutum* L.) cultivars with different K sensitivities. *Field Crops Research*, *196*, 51-63. DOI: https://doi.org/10.1016/j.fcr.2016.06.005

Oosterhuis, D. M., Loka, D. A., & Raper, T. B. (2013). Potassium and stress alleviation: physiological functions and management of cotton. *Journal of Plant Nutrition and Soil Science*, *176*(3), 331-343. DOI: https://doi.org/10.1002/jpln.201200414

Pedroso Neto, J. C., Fallieri, J., Silva, N. M., & Laca, J. B. (1999). Algodão. In A. C. Ribeiro, P. T. G. Guimarães, & V. V. H. Alvarez (Eds.), *Recomendações para o uso de corretivos e fertilizantes em Minas Gerais* - 5ª aproximação. Viçosa, MG: Comissão de Fertilidade do Solo do Estado de Minas Gerais.

Reetz, H. F. (2017). *Fertilizantes e seu uso eficiente*. São Paulo, SP: Associação Nacional para Difusão de Adubos - ANDA.

Rêgo, L. G. S., Martins, C. M., Silva, E. F., Silva, J. J., & Lima, R. N. S. (2016). Pedogenesis and soil classification of an experimental farm in Mossoró, state of Rio Grande do Norte, Brazil. *Revista Caatinga*, *29*(4), 1036-1042. DOI: https://doi.org/10.1590/1983-21252016v29n430rc

Rochester, I. J. (2011). Assessing internal crop nitrogen use efficiency in high-yielding irrigated cotton. *Nutrient Cycling in Agroecosystems*, *90*, 147-156. DOI: https://doi.org/10.1007/s10705-010-9418-9

Saraiva, S. M., Fraga, V., Araujo Filho, J. C., Santos, R. F., Felix, E. S., Campos, M. C., ... Carneiro, K. A. A. (2021). Caracterização de Planossolos nátricos em um gradiente pluviométrico no Semiárido brasileiro. In J. C. Ribeiro (Org.), *Educação em solos e meio ambiente*. Ponta Grossa, PR: Atena Editora.

Shin, R. (2014). Strategies for Improving Potassium Use Efficiency in Plants. *Molecules and Cells*, *37*(8), 575-584. DOI: https://doi.org/10.14348/molcells.2014.0141

Silva, F. C. (2009). Amostragem, acondicionamento e preparo de amostras de plantas para análise química. In *Manual de análises químicas de solos, plantas e fertilizantes* (2. ed). Brasília, DF: Embrapa Informação Tecnológica.

Stamatiadis, S., Tsadilas, C., Samaras, V., Schepers, J. S., & Eskridge, K. (2016). Nitrogen uptake and N-use efficiency of Mediterranean cotton undervaried deficit irrigation and N fertilization. *European Journal of Agronomy*, *73*, 144-151. DOI: https://doi.org/10.1016/j.eja.2015.11.013

Tariq, M., Muhammad, D. B., Afzal, M. N., Ahmed, M., Wakeel, A., & Khan, M. A. (2017). Potassium use efficiency of cotton as affected by application methods. *Frontiers of Potassium Science Conference*, *1*, 195-200.

Tartaglia, F. L., Souza, A. R. E., Santos, A. P., Barros Júnior, A. P., Silveira, L. M., & Santos, M. G. (2020). Nitrogen utilization efficiency by naturally colored cotton cultivars in semi-arid region. *Revista Ciência Agronômica*, *51*(4), 1-9. DOI: https://doi.org/10.5935/1806-6690.20200061

White, P. J., Bell, M. J., Djalovic, I., Hinsinger, P., & Rengel, Z. (2021). Potassium use efficiency of plants. In T. S. Murrell, R. L. Mikkelsen, G. Sulewski, R. Norton, & M. L. Thompson (Eds.), *Improving potassium recommendations for agricultural crops*. Cham, SW: Springer.

White, P. J. (2013). Improving potassium acquisition and utilisation by crop plants. *Journal of Plant Nutrition and Soil Science*, *176*(1), 305-316. DOI: https://doi.org/10.1002/jpln.201200121

Yang, F., Du, M., Tian, X., Eneji, A. E., & Li, Z. (2016a). Cotton yield and potassium use efficiency as affected by potassium fertilizer management with stalks returned to field. *Crop Science*, *56*(1), 740-746. DOI: https://doi.org/10.2135/cropsci2015.03.0136

Yang, J. S., Hu, W., Zhao, W., Meng, Y., Chen, B., Wang, Y., & Zho, Z. (2016b). Soil Potassium deficiency reduces cotton fiber strength by accelerating and shortening fiber development. *Scientific Reports*, *6*(28), 1-11. DOI: https://doi.org/10.1038/srep28856

Zahoor, R., Zhao, W., Abid, M., Dong, H., & Zhou, Z. (2017). Potassium application regulates nitrogen metabolism and osmotic adjustment in cotton (*Gossypium hirsutum* L.) functional leaf under drought stress. *Journal of Plant Physiology*, *215*, 30-38. DOI: https://doi.org/10.1016/j.jplph.2017.05.001

Zörb, C., Senbayram, M., & Peiter, E. (2014). Potassium in agriculture-status and perspectives. *Journal of Plant Physiology*, *171*(9), 656-669. DOI: https://doi.org/10.1016/j.jplph.2013.08.008