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Sources and Application Methods of Potassium Fertilizer for Cotton Cultivation in Cerrado Soil of Western Bahia

Paulo César Teixeira[1*], *Jorge Makhlouta Alonso*[1], *Lino Furia*[2] *and Maria da Conceição Santana Carvalho*[3]

[1] Embrapa Solos, Jardim Botânico, Rio de Janeiro, Brazil. paulo.c.teixeira@embrapa.br; j_makh@hotmail.com

[2] Anglo American Crop Nutrients. Ponta Grossa, Paraná, Brazil. linofuria@gmail.com

[3] Embrapa Arroz e Feijão, Santo Antônio de Goiás, Goiás, Brazil. maria.carvalho@embrapa.br

*Corresponding author: paulo.c.teixeira@embrapa.br

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Henrique Souza
Teogenes Senna de Oliveira

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ABSTRACT

Potassium (K) fertilization strategies are crucial for maximizing cotton yield and fiber quality in Brazil's Cerrado region. This study evaluated the effects of K source and application timing on cotton performance in Western Bahia. The experiment followed a randomized block design with four replications. Treatments included pre-planting applications of muriate of potash (MOP), polyhalite (Poly4), and a 50/50 MOP/Poly4 blend; post-planting (topdressing) applications of MOP and Poly4; and a control without K. Seed yield, fiber yield, fiber quality parameters, and macronutrient concentrations were assessed. Potassium fertilization significantly increased seed and fiber yields compared to the control. Among the fertilized treatments, yields and fiber quality were statistically similar. The highest leaf K concentration was observed in the post-planting Poly4 treatment, while both this treatment and the control had the highest Mg concentrations. Sulfur concentrations were higher in all fertilized treatments than in the control. Fiber quality did not differ significantly among treatments, except for the yellowing grade (+b), which was lower in the control. Additionally, cotton classification grades were higher in all fertilized treatments. These results indicate that Poly4 is a viable alternative to MOP for cotton cultivation in Western Bahia, offering additional macronutrients and flexibility in application timing.

Keywords: *Gossypium*, cotton nutrition, fertilization, polyhalite, fertilizer management, cotton quality.

INTRODUCTION

Brazil produced 3232 thousand tons of cotton lint and was the world's third-largest producer and second-largest exporter in the 2022/23 season.[1] Over 90% of the cotton produced in Brazil comes from the Cerrado region, specifically from two areas: Southwest Mato Grosso and Western Bahia.[2] The Western Bahia area has soils ideal for cotton production, but they require the application of lime and fertilizers to correct pH, aluminum toxicity, and nutrient deficiencies.[3]

Cotton requires a significant supply of potassium (K) to support optimal growth, enhance plant resilience, and improve fiber quality.[4,5] Another important nutrient that cotton requires is sulfur (S), which in Brazil is mainly supplied with N and P through ammonium sulfate, single superphosphate, or an annual application of phosphogypsum.[6] However, the growing use of higher-concentration N and P fertilizers, such as triple superphosphate or mono ammonium phosphate, demands new methods for S supply.[7]

Agronomic practices to apply existing mineral fertilizers, primarily containing N, P, and K, at the right time, the right place, in the right amount, and of the right composition can improve the use efficiency of fertilizers.[8] An effective K fertilization strategy should consider the interrelationship between the plant, soil, and environment; such strategies involve the appropriate timing and placement of fertilizers.[9] The K application strategy is critical to ensure the nutrient is available to plants during high-demand periods while minimizing losses.[10] In Western Bahia, K and all other nutrients are usually applied on the soil surface by top-dressing, except for P, which is applied in the furrow. However, there is currently no official or tested recommendation for the K application strategy for cotton in the region. Therefore, further studies are needed to confirm or modify current practices.

The muriate of potash (MOP) or potassium chloride (KCl) accounts for over 95% of the K fertilizers produced worldwide, but alternative sources can also be effective.[11] One alternative is polyhalite, a soluble geological mineral that also contains calcium (Ca), magnesium (Mg), and sulfur (S), all of which are considered macronutrients for plants.[12] Polyhalite is particularly promising for cotton and other crops when S is not supplied alongside nitrogen (N) or P fertilizers. Therefore, this study aims to evaluate the effect of different potassium fertilizer sources and application methods on cotton crops in Western Bahia.

MATERIAL AND METHODS

The experiment was conducted at Novo Milênio Farm in Luís Eduardo Magalhães, Bahia, Brazil, on a plot with flat relief. The region's climate is classified as Aw (tropical with a dry season in winter) according to the Köppen classification, with a mean annual temperature of 24 °C and a mean annual precipitation of 1,200 mm. This region has two distinct seasons: a dry season from April to September and a rainy season from November to March, which accounts for approximately 94% of the total annual precipitation. The study focused on cotton as the crop of interest, with soybean being the previous crop in the experimental area during the 2017/18 growing season under a no-tillage system.

The study evaluated six different treatments for crop fertilization. These treatments compared the application of K_2O at a rate of 160 kg ha^{-1} through different methods, such as pre-planting via muriate of potash (MOP), polyhalite (Poly4), or a blend of 50/50 of MOP/Poly4 (Blend), or post-planting (top-dressing) application of MOP and Poly4 (Table 1). The last treatment was the control without K application. The MOP used contained 60% K_2O, while Poly4 contained 14% K_2O, 19% S, 17% Ca, and 6% Mg.

The experimental design was a completely randomized block design with four replications. Each plot consisted of five six-meter-long rows of cotton (0.76 m row spacing), totaling 22.8 m^2, and the sampling area was composed of the two central planting lines, using the central 3 m length of the rows. Sowing was performed on December 14, 2018, using the upland cotton variety TMG44 at a density of 10 seeds m^{-1}. Plot marking and application of pre-planting fertilizers were carried out immediately after cotton sowing. Top-dressing fertilizer treatments were applied approximately 40 days after emergence, on January 22, 2019. In all treatments, monoammonium phosphate (MAP) was applied at a rate of 135 kg ha^{-1} and urea at 400 kg ha^{-1}, supplying 70 kg ha^{-1} of P_2O_5 and 194 kg ha^{-1} of N. MAP was applied in the planting furrow, while the urea was split into four applications of 100 kg ha^{-1} each, delivered via fertigation through a central pivot system. Weed and pest control followed the farmer's standard practices for irrigated cotton in the region, and the same management was applied across all treatments.

According to the Brazilian Soil Classification System, the experimental area soil is classified as "Latossolo Amarelo Distrófico típico",[13] which corresponds to Loamic

Table 1. K fertilizer treatments applied pre-planting and top dressing in the cotton study at Novo Milênio Farm, Luís Eduardo Magalhães, BA, Brazil, in the 2018/2019 growing season

Treatments	Pre planting		Top dressing		Total amount of applied nutrients			
	MOP	Poly4	MOP	Poly4	K_2O	S	Ca	Mg
	kg ha^{-1}							
MOP Pre	267	-	-	-	160	0	0	0
Poly4 Pre	-	1143	-	-	160	217	194	69
Blend Pre	133	571	-	-	160	108	97	34
MOP Post	-	-	267	-	160	0	0	0
Poly4 Post	-	-	-	1143	160	217	194	69
Control	-	-	-	-	0	0	0	0

[1/] MOP: Muriate of potash (60% K_2O), Poly4: Polyhalite (14% K_2O, 19% S, 17% Ca, and 6% Mg); Blend: 50/50 (K_2O) of MOP/Poly4; Pre: pre-planting application; Post: post-planting (top-dressing) application; control: with no K application

Xanthic Ferrasol in the WRB.[14] The clay fraction consists of kaolinite, gibbsite, goethite, hydroxy-Al interlayered vermiculite, and anatase. Kaolinite is the predominant mineral, followed by gibbsite, which is also abundant, while the other minerals are present in smaller proportions. Before the field trial began, soil samples were collected and evaluated at depths of 0-10 cm and 10-20 cm. The results of the soil fertility analysis are presented in Table 2. All analyses were done using methodologies described in Teixeira et al.[15]

Cotton was irrigated using a center pivot system, which also facilitated nitrogen topdressing fertilization. For nitrogen application, 200 kg ha^{-1} of urea was applied in the planting furrow, followed by an additional 200 kg ha^{-1} as topdressing through the center pivot in four equal applications of 50 kg ha^{-1} each, totaling 400 kg ha^{-1}. As topdressing, urea application followed a 100% center pivot duty cycle, with an initial irrigation depth of 3–4 mm, followed by heavier irrigation of 9–10 mm at a duty cycle of 30–40%.

On February 18, 2019, during the flowering stage, approximately 20 samples of leaves with petioles, located in the fifth position from the apex, were collected per plot. These leaves were dried in an oven at 65°C for 72 hours and ground. After this, the leaves were analyzed to determine the levels of N, P, K, Ca, Mg, S, B, Fe, Cu, Mn, and Zn, as described by Malavolta et al.[16]

At the harvest, which took place from June 29 to July 1, 2019, 30 cotton bolls were collected from the useful area of each plot, specifically from the middle third of plants, to assess fiber quality. The remaining bolls from the plot sampling area were also collected and later added to the 30 bolls to estimate the cotton yield. The harvested material was weighed and then transported to the Bahia Cotton Producers Association (ABAPA) laboratory in Luís Eduardo Magalhães for analysis. The fibers were separated from the seeds, and their quality was evaluated using the High-Volume Instrument (HVI) machine. This system measures the strength of fiber bundles, enabling the simultaneous testing of multiple fibers and determining their average values. Several variables were analyzed to assess fiber quality, including micronaire (Mic), fiber length (Len), short fiber index (SFI), uniformity (Uni), strength (Str), and yellowing grade (+b). Productivity was evaluated by measuring the fiber and seed yields in each plot sampling area and extrapolating them to their productivity in kg ha^{-1}.

Table 2. Soil chemical characteristics before the application of the treatments and planting. Novo Milênio Farm, Luís Eduardo Magalhães, BA, Brazil. 2018/2019 growing season

Depth	pH H_2O[1/]	Al	K	Ca	Mg	Na	H+Al	CEC[2/]	SB[3/]	V[4/]	m[5/]	P	S	B	Cu	Fe	Mn	Zn
Cm		mmol$_c$ dm^{-3}								%		mg dm^{-3}						
0-10	6.33	0.0	0.73	15.3	7.0	0.1	10.67	33.8	23.2	68	0.0	76.3	8.7	0.67	0.47	20.0	6.17	3.07
10-20	5.90	0.0	0.40	14.7	5.0	0.1	10.67	30.8	20.1	65	0.0	15.1	5.7	0.51	0.40	47.0	2.40	1.87

[1/] 1:2.5 (Soil: water); [2/] CEC: Total cation exchange capacity [CEC= SB + (H+Al)]; [3/] SB: Sum of bases [SB = (Ca + Mg + K + Na)]; [4/] V: base saturation [V% = (SB x 100) / CEC]; [5/] m: aluminum saturation [m% = (Al x 100) / (SB + Al)].

The data underwent Bartlett's test to check the homogeneity of variances and the Shapiro-Wilk test to examine the normality of the residuals ($p < 0.05$). If needed, the data was transformed to meet the analysis of variance (ANOVA) assumptions using the Yeo-Johnson transformation. Then, an ANOVA was performed using the easyanova package[17] in the R software.[18] Whenever the F-test indicated a difference between treatment means ($p < 0.10$), the Scott-Knott test was used to compare them ($p < 0.10$). Part of the results were presented graphically using the ggplot2 package[19] in R. The data set and R code for the statistical analysis and results visualization are published in Alonso et al.[20]

RESULTS

In all the treatments that received potassium, the yields of cotton seeds, fiber, and the total yield (seeds + fiber) were similar. On the other hand, in the control treatment, where no K fertilization was applied, yields were lower (Figure 1A and 1B). The proportion of seeds and fiber was similar among all treatments, with an average of 54/46, varying from 52/48 to 56/44.

The concentration of nitrogen (N), phosphorus (P), and calcium (Ca) in the leaves of cotton plants during the flowering stage were similar in all treatments, including the control that received no K fertilization (Figure 2A, 2B, and 2D). For potassium (K), the post-planting application of Poly4 resulted in the highest K concentration, while the control treatment had the lowest, and the other treatments showed intermediate values (Figure 2C). For sulfur (S) the concentration was similar in all fertilized treatments and lower in the control (Figure 2F). On the other hand, magnesium (Mg) concentration was higher in the Poly4 applied post-planting (top dressing) and in the control group but lower in the other fertilized treatment groups (Figure 2E).

The quality of cotton fibers was similar in all treatments for all the evaluated parameters, except for the yellowing grade (+b), where the control had a lower value than the other treatments (Table 3).

DISCUSSION

The similar performance of MOP and Poly4 indicates that Poly4 can be considered a viable alternative K source in Western Bahia. In a study with cotton but in calcareous soil, Eryuce et al.[21] found that using MOP resulted in higher yields than polyhalite. However, polyhalite proved superior to MOP for some fiber quality parameters such as fiber fineness, length, and elongation. These contrasting results show the importance of studies comparing these K sources under different soil and environmental conditions.

The different K application timing and placement showed similar cotton yield and fiber quality results. This suggests that under the studied conditions, there is no difference in applying K before or after planting, likewise on the surface or in the planting furrow. Cotton requires low K levels during the seedling stage, but to achieve higher yields, this nutrient is crucial during the reproductive stage, as the demand for K drastically increases during flowering and boll formation and then decreases as the boll matures.[9] According to Muhammad et al.,[22] basal K application alone cannot fulfill cotton requirements during the critical boll formation and development period. The authors observed that splitting the annual rate into 2-4 side-dress

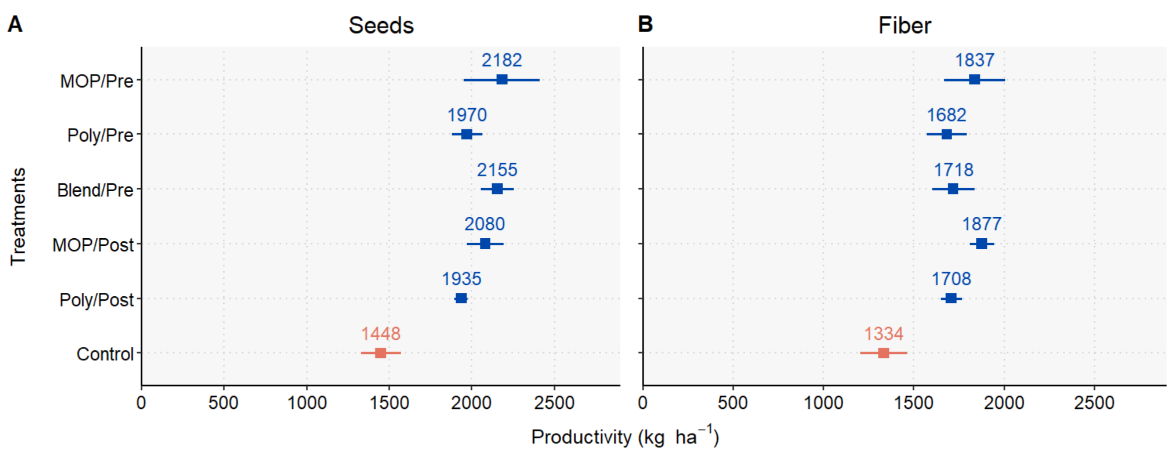

Figure 1. Cotton seed (A) and fiber (B) yield in different K fertilization treatments using muriate of potash (MOP), polyhalite (Poly4) pre- and post-planting, a 50/50 blend of both products pre-planting, and a control with no K in Luís Eduardo Magalhães, BA, Brazil. Mean values identified with the same color do not differ by the Scott-Knott test ($p < 0.10$).

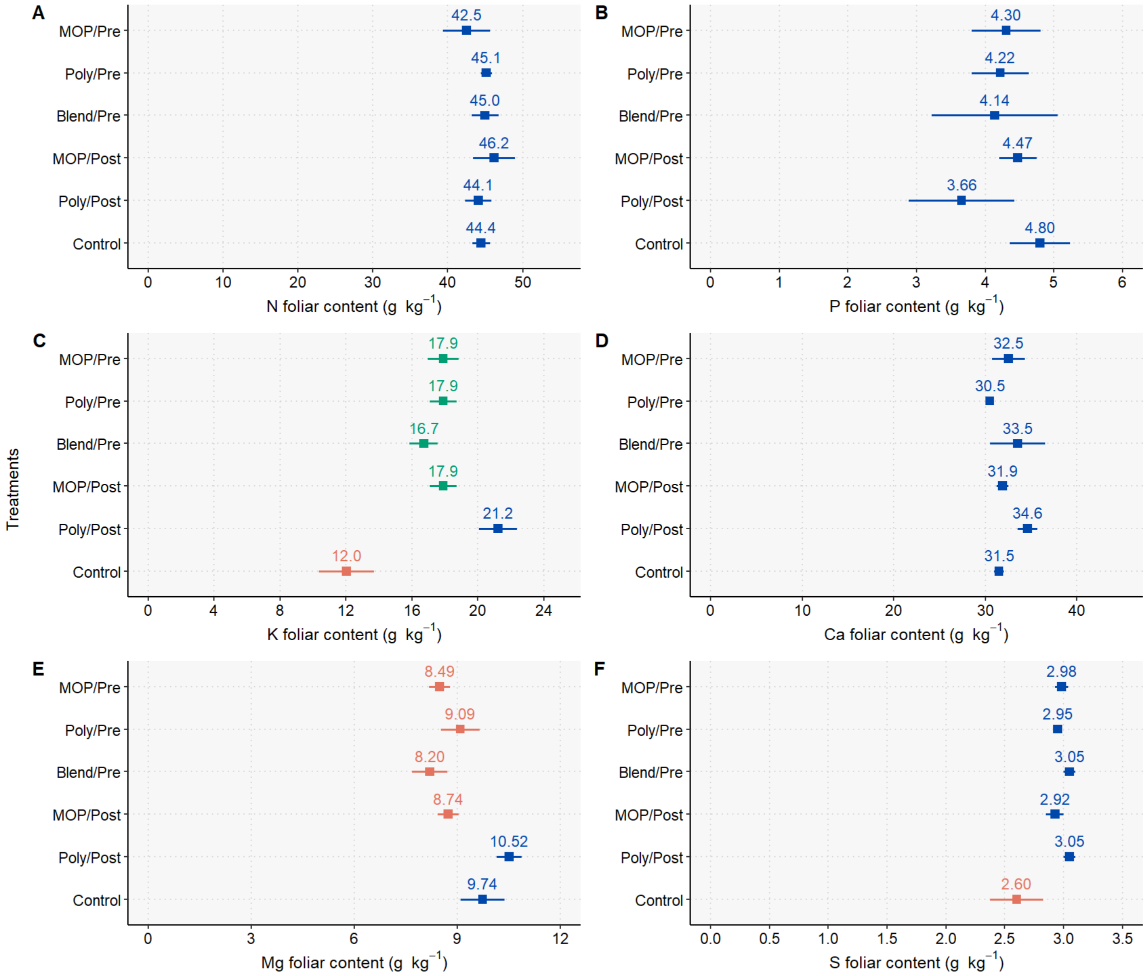

Figure 2. Concentrations of N (A), P (B), K (C), Ca (D), Mg (E), and S (F) in cotton plants during the flowering stage in different K fertilization treatments using muriate of potash (MOP), polyhalite (Poly4) pre- and post-planting, a 50/50 blend of both products pre-planting, and a control with no K, in Luís Eduardo Magalhães, BA, Brazil. Mean values identified with the same color do not differ by the Scott-Knott test ($p < 0.10$).

Table 3. Quality parameters of cotton fiber produced in different K_2O fertilization treatments using muriate of potash (MOP), polyhalite (Poly4) pre- and post-planting, a blend (50/50) of both products pre-planting, and a control with no K, in Luís Eduardo Magalhães, BA, Brazil

Parameters (unit)	Treatments					
	MOP/Pre	**Poly4/Pre**	**Blend/Pre**	**MOP/Post**	**Poly4/Post**	**Control**
Micronaire (ug pol^{-1})	4.36 (0.11)	4.47 (0.26)	4.57 (0.17)	4.42 (0.24)	4.56 (0.26)	4.53 (0.23)
UHML (inches)	1.20 (0.01)	1.22 (0.02)	1.21 (0.03)	1.21 (0.04)	1.19 (0.06)	1.18 (0.03)
UHML (mm)	30.4 (0.2)	31.0 (0.5)	30.6 (0.8)	30.7 (1.1)	30.3 (1.4)	30.0 (0.7)
Strength (Gf tex^{-1})	28.5 (1.3)	28.9 (1.7)	28.3 (1.9)	27.3 (1.3)	28.3 (1.3)	27.5 (0.9)
LUI (%)	84.0 (1.4)	84.1 (1.4)	84.3 (0.6)	83.8 (1.2)	83.6 (1.9)	83.0 (1.0)
Elongation (%)	5.62 (0.10)	5.72 (0.25)	5.65 (0.17)	5.65 (0.24)	5.85 (0.13)	5.60 (0.26)
Reflectance (%)	81.4 (1.4)	82.4 (1.4)	81.9 (1.1)	81.2 (0.7)	81.9 (1.1)	80.7 (2.0)
b+	7.5 (0.5) a	7.2 (0.3) a	7.2 (0.4) a	7.2 (0.2) a	7.1 (0.4) a	6.3 (0.5) b
SFI (%)	6.30 (0.65)	5.40 (1.61)	5.90 (0.95)	5.75 (0.97)	5.53 (0.99)	6.90 (0.98)
Maturity (%)	0.87 (0.01)	0.87 (0.01)	0.87 (0.01)	0.87 (0.01)	0.87 (0.01)	0.87 (0.01)
SCI	140 (6.1)	142 (7.0)	140 (8.4)	135 (5.7)	136 (14.0)	129 (7.1)
CSP	2344 (45)	2388 (39)	2353 (58)	2344 (52)	2332 (101)	2319 (17)

* UHML: upper half mean length, LUI: length uniformity index, +b: yellowing grade, SFI: short fiber index, SCI: spinning consistency index, CSP: count strength product. Mean values with the same letter in rows do not differ by the Scott-Knott test ($p < 0.10$). Values in parentheses correspond to the standard deviation of the mean.

applications improved the cotton yield for light soil in an arid region of Pakistan. Adeli & Varco[23] observed similar results in silt soil from Yazoo City, Mississippi, USA, and recommended combining band and broadcast application of K for cotton. It is important to note that the optimal timing and placement for applying K fertilizer may vary depending on site characteristics (soil type and moisture, seasonal climate conditions, and irrigation) and crop genotypes.[10] Additionally, the results of this study may have been affected by the no-tillage system used in the area under investigation, which can impact the K dynamics in the soil and increase root density in upper soil horizons.[9]

According to Murrell and Pitchay,[24] a deficiency of K in plants can lead to an increase in the leaf concentration of Mg. This may explain the results obtained in the control treatment where no K was applied. For Poly4, the result suggests that this input has the potential to supply both K and Mg without antagonistic effects between these nutrients. An increase in K supply inhibits root uptake and shoot transport of Mg in plants, so balancing fertilization with these nutrients is crucial to achieving high crop productivity and quality.[25] It is possible that the timing and placement of the Poly4 application affected the results, as K and Mg levels were higher when Poly4 was applied after planting compared to when it was applied before planting. However, it is crucial to note that the leaf analysis was performed closest to the topdressing application rather than the application in the planting furrow.

Although Poly4 contains S and Ca, the analysis showed that their levels in plant tissues were comparable across most treatments. Poly4 has a lower K_2O concentration than MOP, meaning it needs to be applied at higher rates. Therefore, the cost and logistics of its application can be considered higher. Other benefits besides similar cotton yield and K supply would be necessary to justify using this input. The present study shows that using Poly4 as a K fertilizer is technically feasible as an alternative to MOP. However, before using this material in the studied region and crop, it is essential to carefully consider and evaluate its economic viability.

It is important to note that the present study only covered a single harvest. This is because cotton is not commonly grown in the same site for two consecutive years in the Western Bahia region. Moreover, cotton is a high-investment crop usually grown in areas where other crops have been produced for several years. In such areas, soil fertility has already been established through several years of fertilization. It is possible that the study did not find any differences between treatments, which could have been observed if the same site had been studied for several years, including the assessment of other crops planted in rotation with cotton. According to Yermiyahu et al.,[26] polyhalite has a higher residual effect on subsequent crops than equivalent Ca, Mg, and S fertilizers. Therefore, it is recommended that future studies assess potassium sources and application methods for consecutive harvests at the same site to obtain more conclusive results for the Western Bahia region.

The mean values of fiber quality parameters did not differ significantly across treatments, but discrepancies were observed when considering the values for quality classification. The results of all the fertilized treatments (Table 1) were classified as middling (grade M, type 31) in terms of color (reflectance and yellowing grades). In contrast, the control was classified as strict low middling (grade SLM, type 41), based on the HVI color diagram for upland cotton of the USDA Agricultural Marketing Service.[27] The color of cotton affects its capability to retain and absorb dyes and finishes, and typically, very white cotton is more valuable.[28] During Brazil's 2023/2024 and 2024 harvest, based solely on color grades, the price of grade M for white upland cotton with seeds was over 2% higher than SLM's price.[29]

In accordance with the Brazilian cotton technical regulation,[30] the analysis for other quality parameters revealed that the length uniformity index (LUI) was high for all treatments. However, all treatments' elongation at break was low, as well as the strength and micronaire obtained a medium category for all treatments. Different categories among treatments were observed for the short fiber index (SFI) that was low for the MOP/pre and the control and very low for the other treatments. According to CONAB's report on market prices during 2023/2024 and 2024 harvests in Brazil,[29] the observed parameter variations would not result in different market values across treatments for cotton fiber with seeds.

For the upper half mean length (UHML), MOP/Pre, Poly4/Post, and control were classified as Classer 1.3/16, code 38. Poly4/pre, Blend/pre and MOP/ post were classified as Classer 1.7/32 code 39. The length of cotton fibers is considered the most reliable indicator of their quality, as it is a crucial factor in determining yarn quality and processing efficiency.[27] Therefore, cotton marketers place great importance on fiber length, with longer fibers typically receiving a price premium.[31] For instance, during Brazil's 2023/2024 and 2024 harvests, the market prices for upland white cotton with a length code of 36 or above increased by R$0.0220 per kilogram.[29] All treatments received codes above 36 and can be considered of similar quality, although some received a slightly better classification.

When considering all parameters, it can be observed that all fertilized treatments produced similar quality cotton fiber and performed better than the control group. The control group had the lowest color grade and length code. These results confirm the importance of K fertilization in achieving better fiber quality, as observed in studies conducted in different soils and regions.[32-34] It is important to note that quality parameters should be evaluated based on established quality standards and classifications, rather than only statistical analysis. Although the variables in this study had similar means across treatments based on the ANOVA F test, some were different when rated on the classification scale.

In summary, this study highlights the practical importance of ensuring an adequate K supply to meet the high nutritional demands of cotton in Western Bahia's intensive production systems. From an agronomic perspective, producers can benefit from the flexibility of Poly4 as a viable alternative to MOP. The comparable cotton yields and fiber quality obtained with both K sources suggest that fertilizer selection can be based on local availability, cost-effectiveness, and the need for supplemental nutrients, such as sulfur, calcium, and magnesium. Furthermore, the absence of yield differences among application methods allows farmers to adjust timing and placement strategies according to operational constraints or equipment availability without compromising productivity.

CONCLUSION

This study reinforces the importance of potassium fertilization in improving cotton yield and fiber quality in the Western Bahia region. Polyhalite (Poly4) proved to be an agronomically viable alternative to conventional muriate of potash (MOP), delivering comparable results in terms of yield and fiber quality. No significant differences were observed between pre- and post-planting applications of K fertilizers. These findings support the use of Poly4 as a strategic K source in intensive cotton systems and highlight the potential for further studies to explore its long-term effects.

AUTHOR CONTRIBUTIONS

Conceptualization: Maria da Conceição Santana Carvalho, Paulo César Teixeira.

Data curation: Jorge Makhlouta Alonso.

Formal analysis: Jorge Makhlouta Alonso.

Funding acquisition: Lino Furia, Maria da Conceição Santana Carvalho, Paulo César Teixeira.

Investigation: Paulo César Teixeira.

Methodology: Maria da Conceição Santana Carvalho, Paulo César Teixeira.

Project administration: Lino Furia, Maria da Conceição Santana Carvalho, Paulo César Teixeira.

Resources: Lino Furia, Maria da Conceição Santana Carvalho, Paulo César Teixeira.

Supervision: Lino Furia, Paulo César Teixeira.

Visualization: Jorge Makhlouta Alonso.

Writing – original draft: Jorge Makhlouta Alonso, Paulo César Teixeira.

Writing – review & editing: Jorge Makhlouta Alonso, Lino Furia, Maria da Conceição Santana Carvalho, Paulo César Teixeira.

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