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Enhanced Efficiency Potassium Fertilizer in Soybean and Cotton Crop

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Abstract: Adequate plant nutrition is very important to soybean and cotton crops to express its potential production. Among plant nutrients, potassium (K) plays an important role in plants to achieve high yields. Potassium fertilization is an important tool for soybean and cotton high yields achieving because K absence reduces foliar K content and plant growth. Several strategies have been used to increase the efficiency of K fertilization. Among them, the use of enhanced efficiency K fertilizers has been studied more often recently. Owing to the lack of information related to the use of enhanced K fertilizers, the present study aimed at evaluating potassium leaching and soybean and cotton K foliar content, yield and agronomic efficiency in response to K rates and sources. To evaluate K leaching, a factorial 3×10 (three K sources and 10 irrigations levels) was carried out, under greenhouse conditions. Three soybean field trials and one cotton field trial were carried out to evaluate soybean K foliar content, soybean 100-grain weight, cotton 10-balls weight, K agronomic efficiency and yield. Increasing irrigation levels increased potassium leaching, which was mitigated by the Policote coated K fertilizer. Potassium fertilization increased soybean and cotton yields. Higher potassium agronomic efficiency index with Policote coated KCl explained higher yields obtained with this enhanced efficiency K fertilizer. Results show that Policote coated fertilizer is a more efficient way to deliver required potassium to plants. The use of enhanced efficiency fertilizers is an emerging technology to increase the potassium use efficiency of crops in the field. The observed changes in potassium use efficiency among potassium fertilizers increased our understanding of enhanced efficiency fertilizers.

Keywords: Slow-Release, Agronomic K Efficiency, Policote

Introduction

Soybean (EMBRAPA, 2019) and cotton (Freire, 2011) are important crops in Brazil, the world's second-largest soybean producer (EMBRAPA, 2019) with significantly increasing cotton exports (Freire, 2011). Adequate plant nutrition is very important for these crops to express their potential production. Among plant nutrients, potassium (K) plays an important role allowing plants to achieve high yields. K is involved in enzymatic activation, stomach regulation and tissue osmotic control (Malavolta, 2006) since it is important for water balance, metabolism and plant growth (Rosolem *et al*., 2010).

Most of the K found in soil is not available to plants and can fall into four pools: soil solution K, exchangeable K, non-exchangeable K and structural K (Moody and Bell, 2006). The fraction of plant available

K in a soil solution is 0.1 to 0.2% of total soil K, exchangeable K is 1 to 2%, non-exchangeable K is 1 to 2% (fixed in 2:1 clays) and the soil-unavailable K is 96 to 99% (Sparks 1987; Wang *et al*., 2007; Britzke *et al*., 2012; Sardans and Peñuelas, 2015). Low K use efficiency about 20-60% (Baligar and Bennet, 1986), 38-51% (Dobermann, 2007), 25-32% (Jin, 2012) are reported. Potassium can be lost by leaching, transported by water to depths beyond those occupied by plant roots (Oliveira and Villas Bôas, 2008). Increasing potassium fertilizer use in Brazil is important because Brazilian agricultural market is highly dependent on the foreign market of this fertilizer, importing about 95% of all K consumed (Mantovani *et al*., 2017).

World population is expected to rise from 7.2 billion at present to 9.1 billion by 2050 and food demand is estimated to double over this period (Fink *et al*., 2016). The increasing demand for food has raised the need for efficient use of fertilizer in order to meet the demands for increased agricultural production while ensuring environmental sustainability.

Several strategies have been used to increase K fertilization efficiency. Among them, the use of enhanced efficiency K fertilizers has been studied more often recently. Those fertilizers contain aggregate technologies that control the release of nutrients, increasing their availability to plants. Such characteristics minimize the potential for nutrient losses to the environment when compared to conventional fertilizers (Association of American Plant Food Control Officials - AAPFCO, 1997).

Due to the lack of information related to the use of enhanced efficiency potassium fertilizers, the present study aimed at evaluating the productivity, nutritional characteristics and agronomic efficiency in cotton and soybean crops using KCl coated with polymers.

Materials and Methods

The experiment was conducted in a greenhouse and in four field trials. Three soybean trials were carried out, in MS Foundation experimental area (located in Naviraí, MS, Brazil), in Goiás State University experimental area (located in Ipameri, GO, Brazil) and in Chapadão Foundation experimental area (located in Água Clara, MS, Brazil). A cotton trial was carried out in Chapadão Foundation experimental area (located in Chapadão do Sul, MS, Brazil) and one greenhouse trial was carried out in IAPAR experimental installation (located in Londrina, PR, Brazil). Naviraí is located in the state of Mato Grosso do Sul, Brazil, with average altitude, temperature and precipitation of around 338 m, 22.4°C and 1517 mm, respectively. Ipameri is located in the state of Goiás, Brazil, with average altitude, temperature and precipitation of around 767 m, 23.9°C and 1437 mm, respectively. Água Clara is located in the state of Mato Grosso do Sul, Brazil, with average altitude, temperature and precipitation of around 325 m, 24.4°C and 1370 mm, respectively. Chapadão do Sul is located in the state of Mato Grosso do Sul, Brazil, with average altitude, temperature and precipitation of around 791 m, 22.7°C and 1598 mm, respectively. Londrina is located in the state of Paraná, Brazil, with average altitude, temperature and precipitation of around 603 m, 20.9°C and 1429 mm, respectively. According to Köppen international classification, Naviraí, Ipameri, Água Clara, Chapadão do Sul and Londrina climate are Am, Aw, Aw, Aw and Cfa, respectively. Soils' chemical characteristics from Naviraí, Ipameri, Água Clara and Chapadão do Sul are presented in Table 1.

Greenhouse Trial

A factorial 3×10 [three K sources: Control, KCl (58% K_2O) and Policote Kallium coated KCl (55% K_2O) and 10 irrigations levels: 0; 60; 120; 180; 240; 300; 360; 420; 480; 540; 600 mm] was carried out in a complete randomized design, with four replications. Policote Kallium, an additive marketed by Wirstchat Polímeros do Brasil, is a partially water-soluble copolymer used to slow KCl solubilization. Each experimental plot consisted of one Polyvinyl Chloride (PVC) tube measuring 300 mm (height) by 150 mm (diameter), filled with sand (250 mm height). The K sources, in a rate of 147 kg $K_2O.ha^{-1}$, were applied on the top of the soil surface, followed by irrigation (60 mm, each time) levels application. The leached soil solution was collected after each irrigation to evaluate K content and quantify the accumulated percentual of leached K (%LK) after each irrigation.

Table 1: Soils' chemical characteristics (0-20 cm depth) from Naviraí, Ipameri, Água Clara, Chapadão do Sul and Londrina.

	pH ($CaCl_2$)	O.M. $g.dm^{-3}$	P $mg.dm^{-3}$	K	Ca	Mg	Al	H+Al	Sand	Silt	Clay
				$mmol_c.dm^{-3}$					$g.kg^{-1}$		
Naviraí	4.48	17.7	7.94	0.70	11.5	6.0	3.9	30.0	740	60	200
Ipameri	5.20	29.0	1.20	0.97	7.0	2.0	1.0	28.0	375	50	575
Água Clara	5.25	18.9	7.67	1.00	8.9	2.8	0.8	21.4	847	41	112
Chapadão do Sul	5.10	27.9	14.30	1,70	28.0	6.0	0.0	27.0	415	50	535

Soybean Trial

A randomized complete block design, with four replications in a (2×4)+1 factorial arrangement, composed by two K sources (KCl and Policote Kallium Coated KCl-PKCK), four K rates and a Control, was used in Naviraí, Ipameri and Água Clara. K rates used in Naviraí were 50, 100, 150 and 200 kg $K_2O.ha^{-1}$, while K rates used in Ipameri were 30, 60, 120 and 180 kg $K_2O.ha^{-1}$ and K rates used in Água Clara were 25; 50; 100; 150 kg $K_2O.ha^{-1}$. The experimental plot used in Naviraí, Ipameri and Água Clara consisted of six, five and seven lines, respectively, with 0.45 m, 0.50 m and 0.45 m row spacing, respectively. Soybean seeds of cultivar BRS 282, NS 3730 IPRO and Valiosa RR were sown in November/2010, December/2014 and November/2012, respectively, in Naviraí, Ipameri and Água Clara, respectively, with a basal application of 400 kg 00.30.10.ha^{-1}, 220 kg 00.46.00.ha^{-1} and 150 kg 00.52.00.ha^{-1}, respectively, in furrows. Treatments were applied by hand, broadcasting the fertilizers 25 days after seedling emergence. Cultural treatments were carried out following technical recommendations for soybean crops. Foliar samples (fully developed leaves, with petiole, in the top three or four nodes) were collected at reproductive (R1-R2) growth stages (EMBRAPA, 2014) to assess K content. Leaves were then washed in distilled water and oven-dried with forced air circulation at 65°C for 72 h. Leaves were then milled in Wiley type mill, with a 0.84 mm mesh sieve. Dry matter was mineralized by nitric-perchloric mixture (3:1 $v.v^{-1}$), determining the K content. Foliar K status was diagnosed based on soybean standards suggested by (EMBRAPA, 2014). Soybean yield and 100-grain weight were evaluated at soybean harvest in March/2011 (Naviraí), April/2015 (Ipameri) and March/2013 (Água Clara). Potassium agronomic efficiency index (Fageria *et al*., 2010) was calculated with average yields.

Cotton Trial

A randomized complete block design, with five replications in a (2×3)+1 factorial arrangement, composed by two K sources (KCl and PKCK), three K rates (50, 100 and 150 kg $K_2O.ha^{-1}$) and a Control, was used. The experimental plot consisted of four lines, with 0.90 m row spacing. Cotton seeds of cultivar FMT701 were sown in December/2010, with a basal application of 410 kg 08.24.12.ha^{-1}, on top soil surface. Treatments were applied by hand, broadcasting the fertilizers in January/2011. Cultural treatments were carried out following technical recommendations for cotton crops. Foliar samples ($4^{th}/5^{th}$fully mature leaves, with petiole, from the main stem of plant) were collected at first bloom stage to assess K content. Leaves were washed and milled, followed by mineralization and K content evaluation, as described above. Cotton yield and 10-balls weight were determined in June/2011, after defoliation, by hand harvesting the center rows of each experimental unit. Potassium agronomic efficiency index (KAE) was calculated with average yields (Fageria *et al*., 2010).

Data Analyses

Data were analyzed through Analysis of Variance (ANOVA). Tukey's test and regression analysis were performed whenever necessary. All statistical procedures were performed with R Studio software.

Results and Discussion

Greenhouse Trial

Fertilizer ($p<0.01$) and irrigation ($p<0.01$) managements statistically influenced the %LK. Increasing irrigation level increased %LK, as expected. %LK between potassium fertilizer sources, under different irrigation managements, is shown in Fig. 1. Approximately %LK was over 60% with a 240 mm irrigation level. PKCK resulted in lower %LK until the 9^{th} irrigation level (540 mm). PKCK reduced potassium leaching by 37.0, 34.4, 28.9, 25.2, 22,0 and 19.2% compared to KCl, after 2^{nd} (2×60 mm), 3^{rd} (3×60 mm), 4^{th} (4×60 mm), 5^{th} (5×60 mm), 6^{th} (6×60 mm) and 7^{th} (7×60 mm) irrigations, respectively. PKCK showed potassium slow release pattern, reducing K leaching and loss.

Soybean Trial

Potassium fertilizer sources did not influence potassium Foliar Content (KFC), but increasing K rates increased K foliar content in Naviraí ($p<0.01$) and Água Clara ($p<0,05$). KFC increased from 11.8 and 15.9 $g.kg^{-1}$, without K fertilization, up to 16.4 and 19.0 $g.kg^{-1}$, respectively, with 151.2 and 101.8, respectively, kg $K_2O.ha^{-1}$ (Fig. 2) in Naviraí and Água Clara, respectively. In Ipameri, KFC was not influenced by potassium fertilization, with an average value of 20.1 $g.kg^{-1}$. K foliar contents in Naviraí, Ipameri and Água Clara were classified as lower, adequate and adequate, respectively (EMBRAPA, 2014).

The 100-grain weight was not influenced by potassium fertilization, with an average value of 13.3 g, 17.0 g and 15.2 g in Naviraí, Ipameri and Água Clara, respectively. Increasing seed weight with K fertilization is reported by (Gaspar *et al*., 1994; Khan *et al*., 2004; Reis Venturoso *et al*., 2009), but we did not observe it.

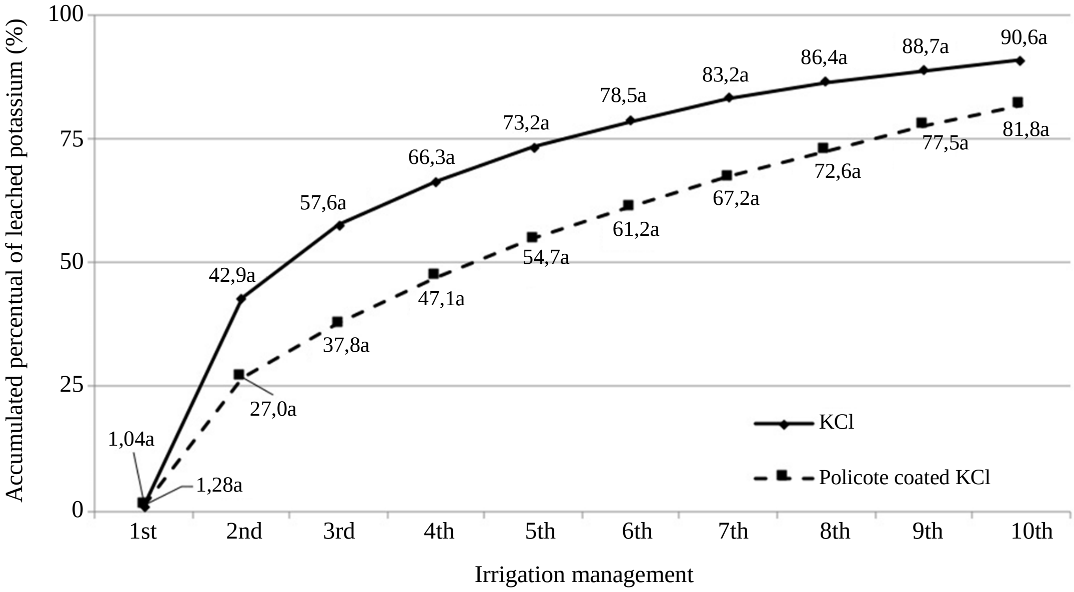

Fig. 1: Accumulated percentual of leached potassium among fertilizer and irrigation managements. Means followed by the same letter, in the same irrigation management, do not differ significantly by Tukey's test (p<0.05)

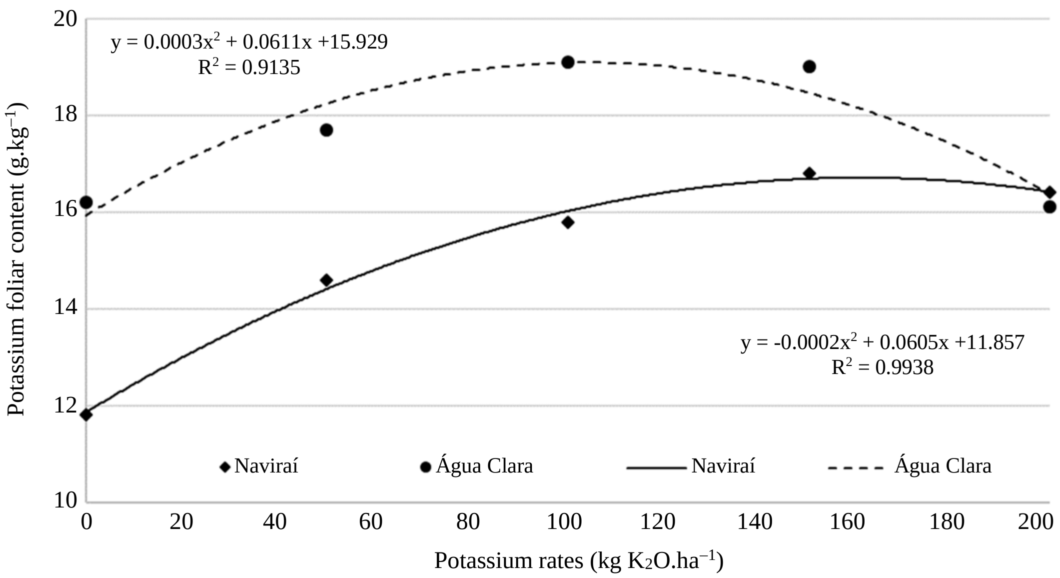

Fig. 2: Potassium foliar content in response to potassium rates in Naviraí and Água Clara

Potassium fertilization increased soybean yield in Naviraí ($p<0.01$), Ipameri ($p<0.01$) and Água Clara ($p<0.05$). In Naviraí, Ipameri and Água Clara, increasing K rates ($p<0.05$, $p<0.01$ and $p<0.05$, respectively) increased soybean yield, which had a different response ($p<0.05$, $p<0,01$ and $p<0.05$, respectively) between K sources (Fig. 3). The highest yields in Naviraí, Ipameri and Água Clara using KCl were 3,914.8, 2,880.4 and 1,307.5 kg.ha^{-1}, respectively, with 166.6, 180 and 150 kg K_2O.ha^{-1}, respectively, while using Policote coated KCl, the highest soybean yields were 4,040.0, 3,361.2 and 1,614,1 kg.ha^{-1}, respectively, with 112.6, 131,6 and 94,5 kg K_2O.ha^{-1}, respectively. The high yield observed in Control, at Naviraí, is explained by K application in soybean sowing. The highest soybean yield with Policote coated KCl in Naviraí, Ipameri and Água Clara was 3.2, 16.7 and 23.4%, respectively, higher than the highest soybean yield with KCl, with a lower K rate of 32.4, 26.9 and 37.0%, respectively. Similar results were observed by (Coppo *et al*., 2019).

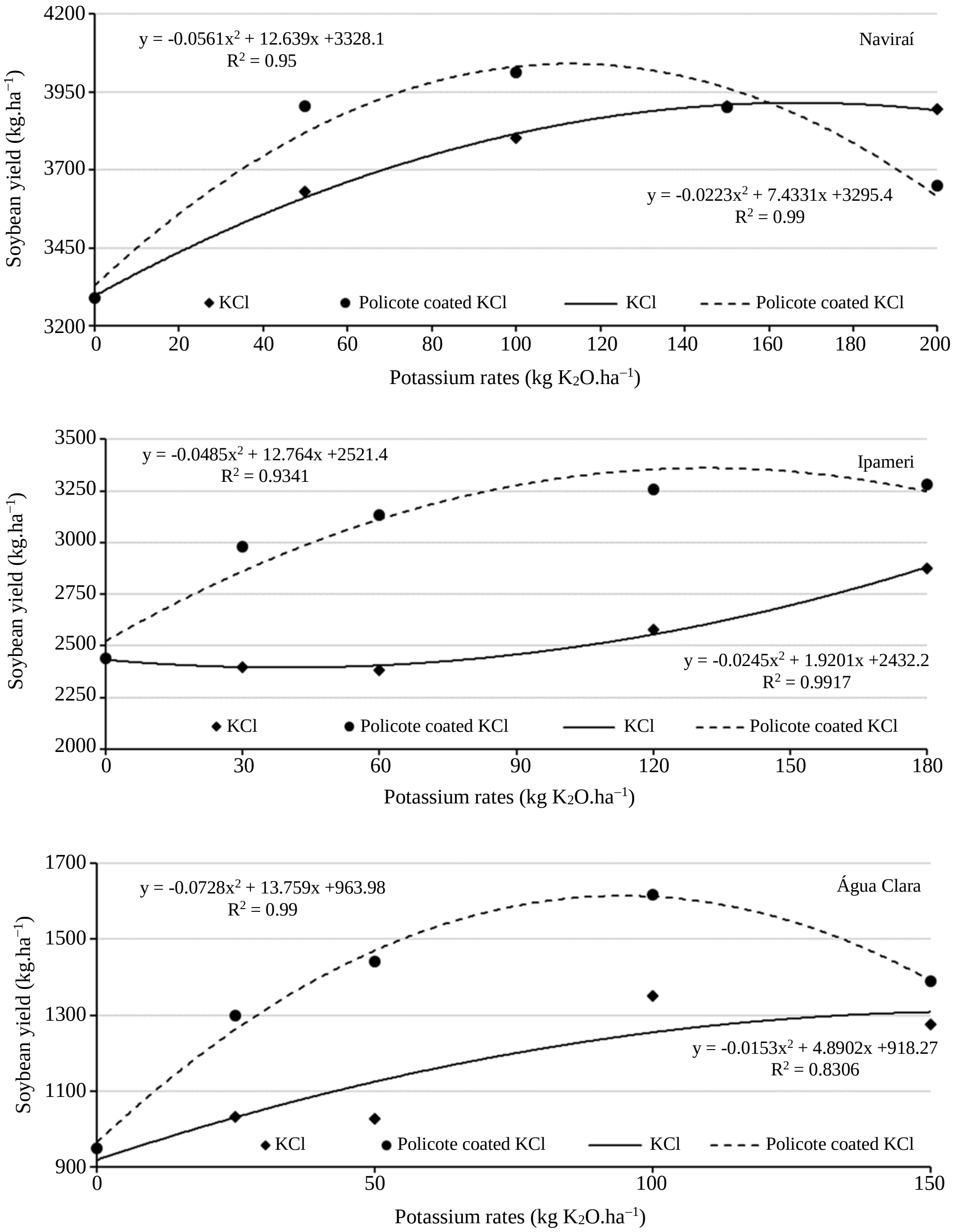

Fig. 3: Soybean yield in response to potassium rates and sources in Naviraí, Ipameri and Água Clara

Cotton Trial

Potassium Foliar Content (KFC) was not influenced by potassium rates, but it was different between potassium sources. Policote coated KCl showed higher KFC (31,6 g.kg^{-1}) than KCl (30.2 g.kg^{-1}). The 10-balls weight was not influenced by potassium fertilization, with an average value of 51.1 g. Potassium fertilization increased the cotton yield (p<0.01). Increasing K rates (p<0.01) increased cotton yield, which had a different response (p<0,01) between K sources (Fig. 4). The highest yield using KCl was 2,380.9 kg.ha^{-1} with 111.0 kg K_2O.ha^{-1}, while using Policote coated KCl, the highest cotton yield was 2,892.4 kg.ha^{-1}, with 136.9 kg K_2O.ha^{-1}. The highest cotton yield with Policote coated KCl was 21.5%, higher than the highest cotton yield with KCl, with a K rate 23.3% higher.

Agronomic K Efficiency Use

Potassium-use efficiency expressed in agronomic utilization is presented in Table 2. Potassium Agronomic Efficiency Index (KAEI) varied from -1.42 to 18.0 kg.kg^{-1} for soybean crops and from 2.31 to 9.69 kg.kg^{-1} for cotton crop. Increasing K rates reduced KAEI, except when KCl was used in Ipameri. The higher KAEI observed with Policote coated KCl explains the higher yields observed with this enhanced efficiency fertilizer. KAEI, from field trials conducted in China, for rice, wheat and maize were 8.9, 6.8, 10.4 and 45.3 kg.kg^{-1}, respectively (Jin, 2012).

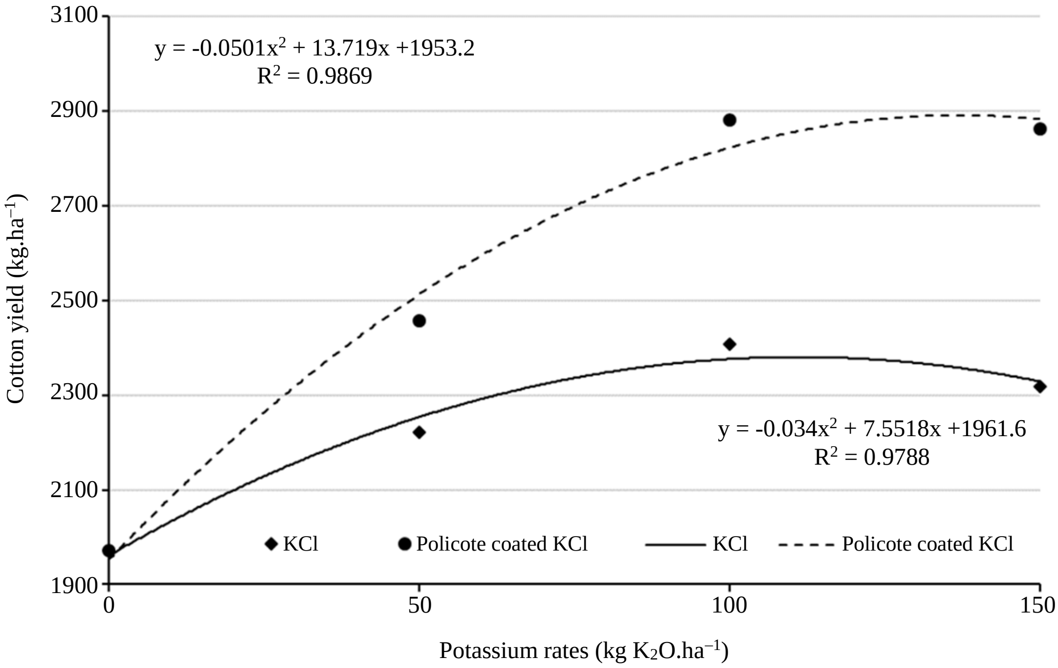

Fig. 4: Cotton yield in response to potassium rates and sources in Chapadão do Sul

Table 2: Agronomic K efficiency use (AKE) in response to K sources and rates

	K_2O Kg.ha^{-1}	AKE (kg of cotton.kg K_2O^{-1}) KCl	Policote coated KCl
Naviraí	50	6.86	12.46
	100	5.20	7.31
	150	4.15	4.11
	200	3.04	1.81
Ipameri	30	-1.42	18.0
	60	-1.00	11.5
	120	1.16	6.83
	180	2,40	4.68
Água Clara	50	3,28	14,0
	100	1,55	9,83
	150	4,01	6,67
	200	2,17	2,93
Chapadão do Sul	50	5.00	9.69
	100	4.36	9.08
	150	2.31	5.94
Naviraí		4.81	6.42
Ipameri		0.28	10.2
Água Clara		2.75	8.36
Chapadão do Sul		3.89	8.24
	Average	2.93	8.30

Conclusion

Potassium fertilization is an important tool for soybean and cotton high yields achieving because K absence reduces foliar K content and plant growth. Increasing irrigation levels increased potassium leaching, which was mitigated by the Policote coated K fertilizer. Potassium fertilization increased soybean and cotton yields. Higher potassium agronomic efficiency index with Policote coated KCl explained higher yields obtained with this enhanced efficiency K fertilizer. Results show that Policote coated fertilizer is a more efficient way to deliver required potassium to plants. The use of enhanced efficiency fertilizers is an emerging technology to increase the potassium use efficiency of crops in the field. The observed changes in potassium use efficiency among potassium fertilizers increased our understanding of enhanced efficiency fertilizers.

Author's Contributions

Adilson Pelá: Designed research plan and supervised this work.

Mário Miyazawa: Designed research plan and coordinated greenhouse work.

Luciano Gil: Designed research plan and coordinated greenhouse work.

Dirceu Broch and Marcelo Arf: Designed research plan and coordinated field work.

Roberto dos A. Reis Jr: Designed research plan and coordinated data analysis.

Iris Tiski: Designed research plan and coordinated greenhouse work.

Ethics

This article is original and contains unpublished material. The corresponding author confirms that all other authors have read and approved the manuscript and no ethical issues involved.

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