Australian Journal of Crop Science AJCS

AJCS 13(05):709-716 (2019) ISSN:1835-2707
doi: 10.21475/ajcs.19.13.05.p1373

Productivity of soybean crop after fertilization with normal and polymer-coated potassium sources

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Abstract

The adoption of different fertilizer application methods should consider the operational, agronomic and economic aspects. The objective of this work was to study the fertilization response with potassium in the soybean crop at different times of application and different potassium sources in an Eutroferric Red Latosol. The experiment was carried out in the municipality of Formosa do Oeste-PR. The design was in a randomized block in a factorial scheme (2 × 5) +1, with 2 potassium sources: normal KCl (KCl) and polymer-coated KCl (KCl-polymer), the KCl doses were adjusted to 40 kg ha $^{-1}$ of K_2O, the second factor refers to the splitting of K_2O dose in five application times: T1, application of K_2O was nine days before sowing, T2 application split up being ½ of the dose nine days before sowing + ½ of the dose of K2O at sowing, T3 application of the total dose of K_2O at sowing, T4 ½ of the dose at sowing + ½ at the V3 phenological stage of the crop, T5 application of K_2O was total at the V3 stage of the crop. And an additional witness, without K_2O application. KCl-polymer was more efficient for application to the haul before sowing the crop. The fertilization with KCl was better when applied at the V3 stage of the crop. Fertilization with KCl-polymer resulted in higher K content in the leaf, higher efficiency of fertilizer use reflecting in higher productivity.

Keywords: Potassium fertilization, times of application, efficiency.
Abbreviations: K_2O_oxido de potassium, K_potassium, Al_aluminum, p_ phosphorus, Ca_ calcium, Mg_magnesium, KCl_ potassium chloride,V3_ phenological stage of the soybean, S_sulfur, OM_organic matter.

Introduction

The nutrients with the highest annual extraction and replenishment in the soybean crop are K and P. The potassium demand for the crop is approximately 38 kg of K_2O for each ton of grain (Oliveira Junior, et al., 2013). In the plant, potassium is a mobile element in the phloem redistributing to young meristematic tissues in case of deficiency (Malavolta et al., 1997). It is responsible for the osmotic regulation control of stomata opening, assimilate translocation, nitrogen absorption and protein and starch synthesis, important for grain filling (Taiz and Zeiger, 2004).
As source of potassium for mineral fertilization in agriculture, the potassium chloride is most used, with around 90% of the volume applied to supply the need for potassium in agriculture (Santiago and Rossetto, 2010), besides being the fertilizer with the highest concentration of potassium and also being relatively cheap (Rosolen et al., 2017).
However, pelleted fertilizers currently exist in the market, which can be coated or encapsulated by soluble compounds enveloped by a water-permeable resin that will regulate the nutrient delivery process (Vieira and Teixeira, 2004). In addition to that, factors such as thickness and the chemical nature of the coating resin, the amount of microcracks on its surface and the size of the fertilizer granule determine the release rate of nutrients over time (Girardi and Mourão Filho, 2003).
With the expansion of no-tillage system, there were changes in soybean fertilization, aiming at the availability of nutrients during the periods of greatest crop's need and optimization of sowing in extensive areas, in order to increase productivity associated with better management practices (Silva and Lazarini, 2014).
In the soybean crop, the maximum absorption of potassium occurs during the flowering period (Sfredo, 2008). However, when fertilization is carried out before sowing, the nutrient may not be available for absorption when supplied by the usual source, normal KCl, as a consequence of leaching and soil K fixation (Rosolem and Steiner, 2017). This fact becomes more worrying when the applied dose is high and carried out in a single application, since water-soluble potassic fertilizers can have deleterious effects on soil fertility and plant growth (Daliparthy et al., 1994).
In order to maximize the productivity of the soybean crop, there is a constant search for formulations and sources of

fertilizers that present less harmful dynamics to the development of the crop and that are more efficient when throwing is carried out before or after sowing and even at the moment of sowing (Caires and Fonseca, 2000). However, when applied on the line at the time of sowing, it has often led to a reduction in the germination power of the seeds (Bernardi et al., 2009). A similar result was observed by Kawavata et al. (2017), when studying the influence of doses of normal KCl and coated KCl in the maize root system and in the electrical conductivity in the soil.

With the objective of comparing time sources and application rates of potassium chloride coated or not coated by polymers on the yield performance of soybean, Guareschi et al. (2011) observed higher dry mass production when using coated KCl in the anticipated fertilization in the soybean crop in relation to the conventional fertilizer.

Although fertilizers coated with controlled release polymers have been developed and used more and more in the soybean crop, when using them it is necessary to consider some factors such as soil texture, temperature, time of application and economic viability, considering that the fertilization is performed to increase production and profit (Raij, 2011).

In view of the aforementioned, this study aimed at assessing the response of the potassium fertilization in the soybean crop at different times of application and different potassium sources in an Eutrophic Red Latosol.

Results and Discussion

Plant height, height of insertion of the first pod, mass of 1000 grains and productivity

There was an increase in soybean productivity in response to potassium fertilization when compared to the control, except to the fact that when applying KCl-polymer at 100% of the dose in the crop V3 stage, the yield did not differ from the control. However, for the KCl there was no difference in relation to the control when applying 100% nine days before sowing. The results allow concluding that potassium fertilization in a soil with high potassium content can be efficient depending on the period, form of application and the source used. Serafin et al. (2012) assessed the effect of soil moisture and potassium doses in the soybean crop and found an increase in grain yield, a mass of 100 grains, K content in the grain, in addition to a viable number of pods, and concluded that K had reduced the effects of the water deficit in soybean.

The results allow concluding that potassium fertilization in a soil with high potassium content can be efficient depending on the time and form of application and the source used. Serafin et al. (2012) evaluated the effect of soil moisture and potassium doses in the soybean crop and found an increase in grain yield, mass of 100 grains, K content in the grain and number of viable pods and concluded that K reduced the effects of the deficit in soybean. The highest productivity was observed when KCl-polymer was split up, being ½ nine days before sowing + ½ at the moment of sowing. This result can be explained by the fact that this source is mainly developed for early application, a product based on potassium, based on the complexation of two molecules that reduce the salinization process and stimulate the development of radicels. In addition, the granule is protected by a resin that prevents the release of nutrients quickly, reducing the loss of K by leaching and other nutrients present in the source. These results are different from those observed by Bernardi et al. (2009), who did not find a significant response to soybean yield using doses of 0, 30, 60 and 180 kg ha-1 applied in pre-sowing (throwing) and at the moment of sowing with and without cover.

However, there are still few studies available in the literature regarding the study of potassium sources coated with different polymers. There are few studies on the soil dynamics of each product used, the coating degradation rate or its effect on the crop studied. For this reason, there are results that are contradictory to the ones seen in the present experiment. Rodrigues et al. (2014), when studying fertilization with coated-KCl in the maize crop in Brazilian savanna region showed that the type of polymer used in KCl was not efficient in the gradual release of K, probably due to the edaphoclimatic conditions of the region, high temperatures and very clay soils, which retain moisture and could have favored the rapid degradation of the coating polymer.

Considering the KCl source, the highest productivity in relation to the KCl-polymer was obtained when the fertilization was carried out in the V3 crop stage. For a better understanding of this result, it is important to consider that KCl is a very soluble source in the soil, since it is consists of sylvinite minerals (KCl) and sylvinite (KCl + NaCl), which are easily solubilized (Nascimento et al., 2008). These data are in agreement with Lana et al. (2002), who, when studying the K_2O doses split up, especially when applied at the flowering stage, showed significant responses in relation to the total dose at the moment of sowing. Corroborating with results of the present experiment, Luchese et al. (2011) verified maximum grain yield of the soybean crop when using coated polymer KCl in relation to conventional KCl.

For the KCl-polymer the lower productivity was observed when 100% of the K_2O dose was applied at the V3 stage of the crop with 3839.58 kg ha^{-1}, which did not differ at (<0.05) from the control. This fact can be explained by the protection mechanism contained in the KCl-polymer granule from which it tends to hinder the entry of water into the granule so that nutrient release does not occur quickly when the precipitation is high in a short period of time, condition that occurred in the present study (Figure 1).

Plant height is a particular characteristic of each cultivar, and the average found in this study was with DM 7166 IPRO cultivar was of 86.51cm with KCl-polymer and 85.55 with KCl (Table 2). According to Sediyama (2009), the desirable target for a more efficient harvest is that the crop should be around 70 to 80 cm. In order to highlight the importance of the variable in soybean yield, Bertolin (2010) stated that amounts next to 85 cm may favor the plant mechanical harvest. For the KCl-polymer there was higher plant height when 100% of the dose was applied at the V3 stage of the culture when lower productivity was observed. For KCl, the management that provided the highest plant height was when applied to the total dose nine days before sowing 89.07 cm, not statistically different from the other treatments, only from the control. This result is close to values found by Bertolin et al. (2010) with the cultivar Conquista and obtained higher plant heights, reaching 86.78.

Regarding the insertion height of the first pod, there was no statistical difference (Table 3). According to Finoto et

Table 1. Chemical attributes of the samples collected before the setting up of the experiment.

Depth	P	OM	H+Al	Al^{3+}	K^{+}	Ca	Mg^{2+}	SB	CEC	V
	mg dm^{-3}	g dm^{-3}	-------------------------		$cmol_c dm^{-3}$		--------------------------			%
0-10 cm	16.45	23.24	3.21	0.10	0.33	4,58	1.18	6.1	9.40	65
10-20 cm	14.12	18.12	2.80	0.30	0.3	2,30	1.30	3.83	6.63	58

P, K^{+} Mehlich-1; Ca, Mg^{2+} e Al^{+3} KCl; O.M-Walkey Black; H+Al= Exchangeable acidity, SMP buffer; CEC: Cation-exchange capacity; SB=Sum of the bases; V= Base Saturation.

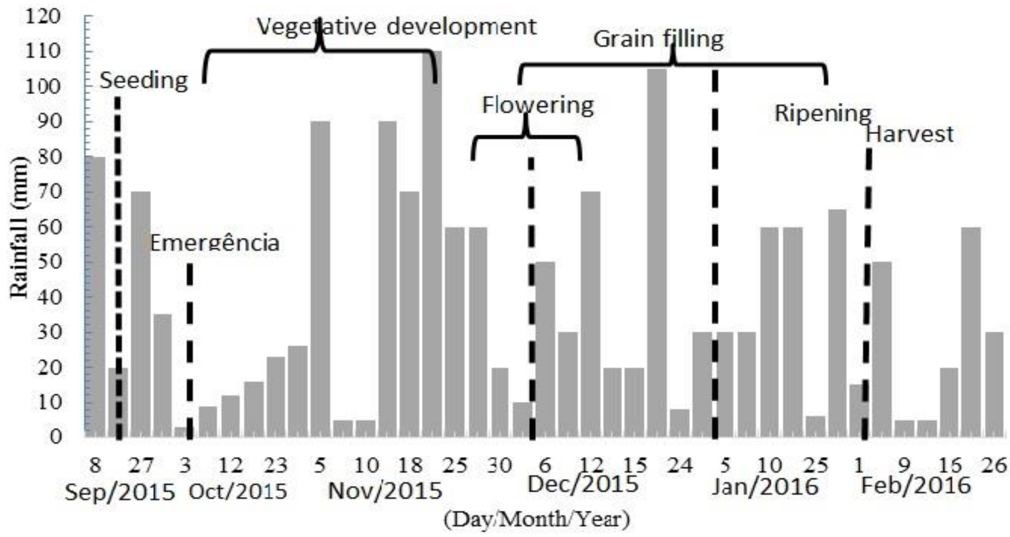

Fig 1. Daily precipitation for the experiment site during the 2015/2016 soybean harvest.

Table 2. Plants height, height of first pod insertion, mass of 1000 grains and soybean yield in function of the mode of application of potassium fertilizer with the source KCl-polymer and KCl in the 2015/2016 harvest.

Treatment	Plant height		Pod height	
	KCl-polymer	KCl	KCl-polymer	KCl
	----------	----------	cm ----------	
100% (9 DBS)	91.30Aab*	89.07Aa*	15.70Aa	15.90Aa
½ 9 DBS + ½ SOW	84.65Abc	88.40Aa	15.95Aa	16.75Aa
100% SOW	84.80Abc	85.64Aa	15.60Aa	15.90Aa
½ SOW + ½ V3	82.00Ac	82.52Aa	15.40Aa	16.45Aa
100%V3	96.45Aa*	87.17Ba	16.90Aa	15.55Aa
Control	80.50		15.15	
Average	87.84	86.56	15.91	16.11

Treatment	Mass of 1000 Grains		Productivity	
	KCl-polymer	KCl	KCl-polymer	KCl
	----------	----------	kg ha^{-1} ----------	
100% (9 DBS)	95.86 Ab*	93.01 Bb	4190.00 Aab*	3591.80 Bb
½ 9 DBS + ½ SOW	99.98 Aa*	95.2 Bab*	4472.77 Aa*	3953.33 Bab*
100% SOW	94.12 Ab	95.2 Aab*	4076.38 Ab*	3978.33 Aab*
½ SOW + ½ V3	94.12 Ab	96.3 Aab*	4149.44 Aab*	4051.52 Aa*
100%V3	94.14 Bb	98.69 Aa*	3839.58 Bb	4247.63 Aa*
Control	88.85		3687,77	
Average	95.64	95.68	4145.63	3964.52

The averages followed by the same capital letter in the row and lowercase in the column do not differ among them by using Tukey's test at 5% of probability. *The averages that differ from the control by using Dunnett test, at 5% probability. DBS: Day before sowing; SOW: Sowing; V3: Phenological stage of soybean crop.

Table 3. Fixed cost and variable cost of production, gross and net revenue from soybean production according to the different forms of application of KCl-polymer and KCl, in the 2015/2016 harvest.

	Fixed cost	Variable cost		Total cost		Gross revenue		Net revenue	
		KCl-polymer	KCl	KCl-polymer	KCl	KCl-polymer	KCl	KCl-polymer	KCl
	---------- R$ ha^{-1} ----------								
100 % (9 DBS)	1445.9	502.6	325.9	1948.4	1771.7	4419.0	3591.8	2231.6	1820.1
½ 9 DBS + ½ SOW	1445.9	502.6	325.9	1948.4	1771.7	4472.8	3953.3	2524.4	2181.6
100% SOW	1445.9	492.6	492.6	1938.4	1761.7	4076.4	3978.3	2138.0	2216.6
½ SOW + ½ V3	1445.9	502.6	325.9	1948.4	1771.7	4149.4	4051.5	2201.0	2279.8
100 % V3	1445.9	502.6	325.9	1948.4	1771.7	3839.6	4247.6	1891.2	2475.9
Control	1445.9			1445.9		3686.8		2019.4	

DBS: Day before sowing; SOW: Sowing; V3: Phenological stage of soybean crop. Variable cost: Operation with machines, maintenance expenses, temporary labor, seed, fertilizer, pesticides, transportation, technical assistance, pro-rage and interest. Total cost: Variable cost + cost with the fertilization of KCl and haul application operation. Gross revenue: Productivity in 60 kg bag ha^{-1} multiplied by the value of 60 kg bag quoted at the time of harvest (R$ 60.00).

Table 4. Potassium content in the leaf and in the grain with the sources KCl-polymer and KCl in soybean crop in the 2015/2016 harvest.

Treatment	K content in the leaf		K content in the grain	
	KCl-polymer	KCl	KCl-polymer	KCl
	---------- g kg^{-1} ----------			
100% (9 DBS)	16.66Aab*	15.67Aa	15.25Aab*	14.96Ab*
½ 9 DBS + ½ SOW	17.46Aa*	15.62Ba	15.75Aa*	13.96Bab
100% SOW	16.16Aab	16.34Aa	16.09Aa*	15.45Ba*
½ SOW + ½ V3	15.19Ab	15.50Aa	14.46Bb*	15.69Aa*
100%V3	16.50Aa*	17.34Aa*	15.17Aa*	15.50Aa*
Control	14.75		12.93	
Average	16.39	16.09	15.34	15.11

The avereges followed by the same capital letter in the row and lowercase in the column do not differ among them by using Tukey's test at 5% of probability. *The averages that differ from the control by using Dunnett test, at 5% probability. DBS: Day before sowing; SOW: Sowing; V3: Phenological stage of soybean crop.

Table 5. Potassium content in the soil in the 0-10 and 10-20 cm layer, collected after soybean harvest in the 2015/2016 harvest.

Treatment	K content in the 0-10cm soil		K content in the 10-20cm soil	
	KCl-polymer	KCl	KCl-polymer	KCl
	---------- $cmol_c dm^{-3}$ ----------			
100% (9 DBS)	0.25Ab	0.25 Aa	0.20Aa	0.22Aa
½ 9 DBS + ½ SOW	0.25Ab	0.26Aa	0.20Aa	0,18Aa
100% DBS	0.34Aab*	0.34Aa*	0.24Aa	0.28Aa
½ SOW + ½ V3	0.35Aa*	0.27Ba*	0.22Aa	0.22Aa
100%V3	0.37Aa*	0.26Ba	0.22Aa	0.21Aa
Control	0.21		0.14	
Average	0.31	0.28	0.22	0.22

The averages followed by the same capital letter in the row and lowercase in the column do not differ among them by using Tukey's test 5% of probability. *The averages that differ from the control by using Dunnett test, at 5% probability. DBS: Day before sowing; SOW: Sowing; V3: Phenological stage of soybean crop.

Table 6. Averages efficiency of the potassium use in the grain (EKUG), efficiency of the fertilizer use (EFU) and efficiency of the nutrient recovery (ENR) in soybean plants, according to the different forms of application of KCl-polymer and KCl in the 2015/2016 harvest.

	EUKG			EFU			ENR		
	KCl-polymer	KCl	Mean	KCl-polymer	KCl		KCl-polymer	KCl	
	----------Kg kg^{-1}----------						----------%----------		
100% (9 DBS)	274.75Aa	240.09 Aa	257.42	15.15 Ab	10.26Bb	12.70	45.94Aa	45.07 Aa	45.50
½ DBS (½ SOW)	283.98 Aa	283.18 Aa	283.58	23.65 Aa	12Bb	17.82	47.45 Aa	42.06 Aa	44.75
100% SOW	253,34 Aa	257.49 Aa	255.41	11.73 Ac	8.75Ab	10.24	48.47 Aa	46.55 Aa	47.51
½ SOW ½ V3	286.95 Aa	258.22 Aa	272.58	13.90 Abc	10.95Bb	12.42	43.56 Aa	47.27 Aa	45.41
100 % V3	253.10 Aa	274.04Aa	263.57	4.57 Bbc	16.86Aa	10.71	45.70 Aa	46.70 Aa	46.20
Average	270.42	262.60	266.51	34.5	11.76	12.77	46.22	45.53	45.87

The averages followed by the same capital letter in the row and lowercase in the column do not differ among them by using Tukey's test at 5% of probability. DBS: Day before sowing; SOW: Sowing; V3: Phenological stage of soybean crop.

al. (2011), the height of the first pod insertion is the most important factor in the soybean mechanized harvesting. Therefore, in order to make the crop economically viable, it is recommended that the cultivar used has an insertion height of the first pod between 10 and 20 cm high.

Economic analysis

When economically analyzing, the highest yield obtained from each source in relation to the production cost per hectare, for the KCl-polymer source, was when it produced 4472.77 kg/ha and obtained a production cost of approximately R$ 1948.41 ha^{-1}, which allowed a net revenue of R$ 2524.3 ha^{-1}, compared to the highest productivity of the KCl of 4247.63 kg ha^{-1} with a net revenue of R$2475.36 (Table 3). The net revenue of the control was of R$ 2019.36 when compared to the total dose application at sowing, whose net revenue was of R$ 2137.36 and R$ 2216.60 for KCl-polymer and KCl, respectively. Considering the condition of the present study, it was seen that the application of 100% KCl at the time of sowing obtained a superior profit of R$ 78.63 in relation to the KCl-polymer source. The high cost actually seems to be the main limitation for using KCl-polymer, since agronomically the product has surpassed the source of K_2O commonly used.

As for the KCl-polymer, the lower productivity was found when 100% of the dose of K2O was applied in the V3 stage of the crop, with a net revenue of R$ 1891.17 which was R$ 128.19 lower than the control. In view of this result, it is important to consider at the time of application of the fertilizer its agronomic efficiency and its financial return, either in the reduction of the volume used, in the acquisition cost per nutrient point, or in the productivity gain.

When KCl was applied 100% nine days before sowing, it obtained net revenue of R$ 1820.07, being the net revenue lower than the control in R$ 199.29. Therefore, it can be affirmed that under the conditions of the present study, with the soil potassium content of 0.33 cmolc dm-3 the anticipated application of normal KCl is not economically feasible.

Potassium content in the leaf and in the grain

In relation to the nutrient content in the leaf tissue, when applying the KCl-polymer source ½ nine days before sowing + ½ at the moment sowing, the potassium content in the leaf was higher (17.46 g kg^{-1}), coinciding with the higher mass of 1000 grains and productivity (Table 4). The gradual potassium release from KCl-polymer, when applied in advance into the soil, provided the amount of K available in the soil compatible with the soybean crop demand, with a less possibility of losing potassium by leaching, and keeping the supply of K necessary to meet the plant demand. The same occurred with the KCl source when applied 100% in the crop V3 stage, where it could be observed the highest potassium content in the leaf of 17.34 g kg^{-1} and the highest yield. A similar result was obtained by Keogh et al. (1972) when comparing nutrient foliar concentrations of ten different maturation group varieties grown under two levels of soil fertility. The authors obtained higher potassium leaf concentrations in the most productive variety tested (22.0 g kg^{-1}).

The assessment of the data concerning the potassium content in the grain showed that when using the KCl split up by ½ nine days before sowing + ½ at sowing, 100% at sowing and 100% at the crop V3 stage, the potassium contents for these treatments were higher than those seen for the control. Still referring to KCl, the lowest yields of soybean in this work were observed when the lowest potassium contents were observed in the grain, contrary to those observed by Zambiazi (2014) who, when studying the application of potassium fertilization in the soybean crop, did not observe effect of the season of potassium application in soybean crop cover for grain yield, agronomic characteristics and potassium content in the grain.

Potassium content in the soil

According to the results shown in table 5, it is observed that when fertilizing is carried out with the KCl spit up ½ at the moment of sowing + ½ at the soybean crop V3 stage and 100% at the crop V3 stage, the residual potassium content in the soil was lower than that observed with KCl-polymer; however, for the KCl-polymer these treatments provided a higher residual potassium content in the soil but yield was lower, indicating that the potassium release from this fertilizer occurred more slowly and was not compatible with the requirement of the crop when applied at a later stage of the crop development.

However, when both sources were applied nine days before sowing and split up ½ nine days before sowing + ½ at the moment of sowing, they provided a lower potassium content available in the soil. Considering KCl, lower yields were seen in these periods and forms of application, whereas KCl-polymer obtained a higher yield, which makes evident the efficiency of the throwing application of KCl-polymer, because when this polymer was applied before sowing, it allowed the release of the available potassium to meet the period of greatest demand of the nutrient by the crop.

It is important to highlight that the coated KCl provided greater potassium enrichment in the 0-10 cm soil layer. These results are consistent with those reported by Duarte et al. (2013) when studying potassium leaching coming from thermopotassium and KCl, the authors found that thermopotassium increased potassium content in relation to KCl only in the 0-10 cm soil layer,

In the 10-20 cm soil layer, there was no difference between the sources and the managements for the available potassium content, being all of them considered medium. In the present study, it can be seen that there is a decrease in the potassium contents even in clay soils, since this nutrient is exported by the grain production (Oliveira Junior, et al., 2013).

The reduction of the available potassium contents in areas under successive soybean crop has occurred even when amounts from 33 to 66 kg ha^{-1} of potassium have been applied annually (Borkert et al., 1997a).

Efficiency of potassium use in the grain, efficiency of fertilizer use and nutrient recovery efficiency

Table 6 shows that there was no difference in the efficiency of the potassium use in the grain (EKUG), which represents the grain yield obtained per unit of accumulated nutrient and efficiency of the nutrient recovery (ENR), both between sources, or between different managements within each source.

For fertilizer use efficiency (EFU) when using the KCl-polymer source applied ½ nine days before sowing and ½ at sowing, EFU was higher than the other treatments, which corroborated with the higher productivity. The same occurred with normal KCl when applied at stage v3 of the culture. When comparing the two sources, the KCl-polymer showed higher EFU than conventional KCl when applied 100% nine days before sowing and also 100% at the V3 stage of the culture. Some studies indicate superior efficiency of encapsulated potassic fertilizers as in Luchese et al. (2011), who observed higher efficiency of potassium fertilization in sandy textured soils when using polymer-coated KCl compared to normal KCl.

Materials and Methods

The experiment was installed in a property of the municipality of West Formosa, with the following geographical coordinates: Longitude: 53º18'45" W and latitude: 24º17'34" S at 420 m of altitude. The soil of the experiment site is classified as Eutroferric Red Latosol (EMBRAPA, 2013). The granulometric characteristics of the soil are: 660 g kg^{-1} of clay, 130 g kg^{-1} of sand and 210g kg^{-1} of silt. The chemical attributes of the soil are shown in Table 1.

Experimental design

A randomized block design in a factorial scheme (2x5)+1 was used, with 2 sources of potassium, conventional KCl (00-00-60) and polymer-coated KCl (KCl-polymer) in the formula (40% K2O, 3% Ca and 3% S). The polymer used for coating the fertilizer is an amphiphilic compound, which favors an immediate reaction of repulsion of the water in high concentration in the soil around the fertilizer granule resulting from its hydrophobic character, although it maintains some permeability due to its hydrophilic character (Urrutia et al., 2018). Also included in the composition of this fertilizer, there are two ACP COMPLEX molecules, with the function of promoting lower salinity and reducing potassium and residual leaching in the soil, as well as AZAL 5, which is used in order to promote the protection of radicels. Five forms of subdivision of the potassium fertilization are described below.

In the first treatment the application of K_2O was carried out nine days before sowing (T1), in the second treatment the application was split up, being ½ of the dose nine days before sowing + ½ of the dose of K_2O at the moment of sowing (T2). In the third treatment (T3), the application of the complete dose was carried out, while in the fourth treatment (T4) ½ of the dose at sowing + ½ in the V3 phenological stage of the crop. In the fifth treatment (T5), the application of K_2O was carried out totally in the V3 stage of the crop and there was also an additional witness without K_2O application.

The sowing was carried out on 26th September, 2015, by sowing 13 seeds per meter of arly cycle DM7166 IPRO cultivar. The plots had dimensions of 4m wide and 7m long, each plot consisted of 4 spaced rows of 0.45 m, from which 5m of the two central rows of each plot were used for the assessments. For the treatments in which the fertilization was carried out in the planting groove, a line was manually opened next to the sowing line for the addition of the fertilizer to the depth of 5 cm below the seed. Considering the treatments with potassium fertilizers before sowing and at the crop V3 stage, a broadcast application was carried out.

In total, the experiment consisted of 44 plots, being all the treatments fertilized with 60 kg of P_2O_5 on the base with simple superphosphate (18% of P_20_5, 16% of Ca and 5% S), and the potassium dose was of 40 kg of K_2O, as a result of the soil analysis and in accordance with the fertilizing recommendation for the crop (SBSC, 2017). For both sources, the potassium and phosphorus doses were the same for all the treatments involving the factorial; however, in the treatments in which the potassium application was split up, the dose of 40 kg of K_2O was also split up, that is, 20 kg of K_2O in the first application plus 20 kg of K_2O in the second application. The precipitation recorded at the experiment site during the period of the study is shown in Figure 1.

Assessed characteristics

After the harvest, some soil samples were collected at 0-10 and 10-20 cm depth in order to determine the soil potassium content. Productivity, mass of a thousand grains, plants height, insertion height of the first pod, foliar potassium content, and potassium content in the grain were evaluated. For the chemical analysis of the K content, the methodology described by Malavolta et al. (1997) was used. And lastly it was accomplished the economic viability of each treatment.

Economic evaluation

The economic evaluation of each treatment was performed by considering the fixed cost, variable cost, total cost, and the gross and net revenue. The fixed cost of each treatment was considered for estimating the amount of R$1445.86 (SEAB, 2016). In order to determine the costs of the plots, the cost with super simple fertilizers (00-19-00) was determined at R$ 980.00 per ton, with an applied dose of 222.22 kg ha^{-1}, that is, R$ 217.77 per hectare.

Considering the treatments that received potassium supplementation in soybean crop, the amount of R$ 2700.00 per ton of the polymer-coated KCl fertilizer (40% K_2O 3% Ca 3% S) was adopted, with a total estimated cost of R$274.78. This cost corresponds to the applied dose of 100 kg ha^{-1}.

Regarding the treatments with KCl 00-00-60, the amount of R$ 1400.00 per ton was adopted, with a total estimated cost of R$ 98.10. This cost corresponds to 66.66 kg ha^{-1}. The treatments that received application of KCl-polymer and broadcast KCl had the addition of R$ 10.00 per hectare in relation to the operation cost. Therefore, considering a calculation basis, a variable cost from R$ 502.55 to R$325.87 was considered for the treatments that received KCl-polymer and thrown KCl and from R$ 492.55 to R$ 325.97 for those receiving KCl-coated and KCl at sowing. The total revenue cost for each treatment that received KCl-polymer and thrown KCl was of R$ 1948.41 and R$ 1771.73. These are the costs for the treatments that received the sources at the time of sowing: R$ 1938.41 and R$ 1761.73 for the KCl-polymer and KCl, respectively.

Finally, the efficiency of the use of potassium nutrient were calculated according to the rates proposed by Moll et al. (1982) and Siddiqi and Glass (1981).

a) Efficiency of the use of the nutrient in the grain (EUNg) = grain production (Y) in relation to amount of nutrient in grains (ANg).

$$EUNg(kg\ kg^{-1}) = \frac{y}{ANg}$$

b) Efficiency of the fertilizer use (EFU) = grain producton (Y) – grain production of the control (Yc) in relation to the amount of nutrient applied (ANa).

$$EFU(kg\ kg^{-1}) = \frac{y - yc}{ANa}$$

C) Efficiency of the nutrient recovery (ENR) = Nutrient absorbed in the grain (ANg) in relation to the amount of nutrient applied (ANa).

$$ENR(\%) = \frac{ANg}{ANa} * 100$$

Conclusion

The potassium fertilization management for soybean crop with normal KCl and KCl-polymer influenced the productivity and the yield components, and it depends on the plots and period of application. The fertilization with KCl-polymer split up ½ nine days before sowing + ½ at the moment of sowing provided a greater mass of 1000 grains, potassium content in the leaf and also a higher productivity. Normal KCl fertilization before sowing in the present experiment was not agronomically or economically feasible. The efficiency of fertilizer use is influenced by the peculiar characteristics of each source to decide when and how to apply it, in order to maximize productivity.

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