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Potassium doses in previous crops and effect on soybean in succession

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Glycine max (L.) Merrill

ABSTRACT
Early potassium fertilization in previous crops may be beneficial to the main crop in succession. The objective of this study was to investigate the behavior of the soybean crop as a function of potassium (K) doses in the previous crops, associated or not with K application in soybean. The experiment was carried out from 2012 to 2015 in an experimental area of the Faculty of Engineering, UNESP, Campus of Ilha Solteira-SP, located in Selvíria-MS, Brazil. For the previous crops, a randomized block design was used in a 3 x 4 factorial scheme with four replications, i.e., three previous crops (maize, sorghum and millet) and four K doses (0, 35, 70 and 120 kg ha^{-1} of K_2O). For soybean in succession, a randomized complete block design was used in the split-plot scheme. The treatments were arranged in a 3 x 4 x 2 factorial scheme with four replicates, i.e., soybean sowing on three types of straw (maize, sorghum and millet), residual of the four K doses and with or without top-dressing K fertilization in the soybean. Millet accumulated higher K content in comparison to maize and sorghum. The return of K to the system by millet is similar to that by maize. Potassium doses in the previous crops do not alter their dry matter production and K content. Potassium fertilization in the soybean crop in succession to millet allows higher yields.

Palavras-chave:
adubação de sistemas
ciclagem de nutrientes
Glycine max (L.) Merrill

Doses de potássio em culturas antecessoras e efeito na soja em sucessão

RESUMO
A antecipação da adubação potássica em culturas antecessoras pode ser benéfico para a cultura principal em sucessão. Assim, objetivou-se investigar o comportamento da cultura da soja em função de doses de potássio antecipada nas culturas antecessoras, associadas ou não à aplicação de K em cobertura na soja. O experimento foi desenvolvido no período de 2012-2015 em área experimental pertencente à Universidade Estadual Paulista (UNESP), Faculdade de Engenharia, Ilha Solteira, SP. Nas culturas antecessoras, adotou-se o delineamento em blocos casualizados em um esquema fatorial 3 x 4 com quatro repetições, ou seja, três culturas antecessoras (milho, sorgo e milheto) e quatro doses de potássio (0, 35, 70 e 120 kg ha^{-1} de K_2O). Para a soja em sucessão, foi empregado o delineamento em blocos casualizados no esquema de parcelas subdivididas, estando os tratamentos dispostos em um esquema fatorial 3 x 4 x 2 com quatro repetições, ou seja, semeadura da soja sobre três tipos de palhada (milho, sorgo e milheto), residual das quatro doses de potássio e com ou sem adubação potássica em cobertura na soja. O milheto acumulou maior teor de K em relação ao milho e o sorgo. O retorno de K ao sistema pelo milheto é semelhante ao milho. As doses de K nas culturas antecessoras não alteram a produção de massa de matéria seca e teor de K das mesmas. Adubação potássica na cultura da soja em sucessão ao milheto permite maiores produtividades.

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Introduction

Most of the Brazilian territory exploited with soybean cultivation is in areas with high degree of weathering, highlighting an important program of potassium fertilization (Assis et al., 2013). Along with nitrogen (N), potassium (K) is the second nutrient most required by the soybean crop along its cycle; however, N can be supplied by biological fixation, whereas K needs to be applied in the soil via fertilizers, because Brazilian soils have low contents of this element (Silva & Lazarini, 2014).

In addition, K in plant residues is not incorporated to the carbon chains and, after plant harvest or senescence, it rapidly returns to the soil in the form readily available to the crops (Rosolem et al., 2007). Therefore, crop residues are a readily available reserve, allowing an early K fertilization in the previous crops.

Studies on fertilizer application and forms in the agronomic field are very common, especially in order to reduce losses and increase efficiency. Potassium chloride (KCl), which is the most used K fertilizer in agriculture, has high solubility in water and the K^+ ions exhibit high mobility in the system. Thus, at high doses, fertilization must be split, especially in sandy soils (Foloni & Rosolem et al., 2008).

In this context, following the concept of modern agriculture, farmers have adopted a practice called “fertilization of systems” (Segatelli, 2008). This technique consists in the partial or total early fertilization of the autumn/winter crop, aiming at the residual effect and cycling of nutrients to the crop sown in the spring/summer period (Cibotto et al., 2016).

Hence, the present study aimed to evaluate the productive behavior of soybean as a function of K doses applied in the previous crops, associated or not with top-dressing K fertilization in soybean.

Material and Methods

The experiment was carried out from 2012 to 2015 in an experimental area of the São Paulo State University (UNESP), Faculty of Engineering, Ilha Solteira-SP, located in the municipality of Selvíria-SP, Brazil (55° 22’ W; 20° 22’ S; 335 m). The soil of the experimental area is classified as dystroferric Red Latosol, clay texture, according to EMBRAPA (2013a). Prior to experiment installation in the field, soil samples were collected in the 0–0.20 m layer for chemical analysis, according to the methodology described by Raij (2011), and the results were: P (resin): 22 mg dm^{-3}, OM: 21 g dm^{-3}, pH ($CaCl_2$): 5.5, K: 1.8 $mmol_c$ dm^{-3}, Ca: 22 $mmol_c$ dm^{-3}, Mg: 19 $mmol_c$ dm^{-3}, H+Al: 22 $mmol_c$ dm^{-3}, SB: 42,8 $mmol_c$ dm^{-3}, CEC: 64.5 $mmol_c$ dm^{-3} and V%: 66.

Mean annual rainfall, temperature and relative humidity of the last 15 years are 1313 mm, 25 °C and 70-80%, respectively (Portugal et al., 2015). The climate of the region is Aw, according to Köppen’s classification, defined as humid tropical, with rainy season in the summer and dry season in the winter. The experiment was carried out under rainfed conditions. Meteorological data relative to the experimental period are presented in Figure 1.

For the previous crops, the experimental design was randomized blocks with four replicates, and treatments were arranged in a 3 x 4 factorial scheme, i.e., three previous crops (maize, sorghum and millet) and four K doses: 1 – control, 2 – half the dose recommended for the previous crops (35 kg ha^{-1} of K_2O), 3 – dose recommended for the previous crops (70 kg ha^{-1} of K_2O) and 4 – dose recommended for the previous crops plus the doses demanded by the soybean crop in the summer cultivation (120 kg ha^{-1} of K_2O), in the form of KCl (58% of K_2O).

In succession to autumn/winter crops, soybean was planted in a completely randomized design in split-plot scheme and treatments were arranged in a 3 x 4 x 2 factorial scheme, i.e., soybean planted on three types of straw (maize, sorghum and millet), residual of the four K doses and K fertilization to meet the soybean requirement, at dose of 50 kg ha^{-1} of K_2O in the form of KCl (58% of K_2O), applied broadcast.

Plots were 7.0 m wide and 10 m long. In the summer period, crops were subdivided into 3.50-m-wide 10-m-long plots.

Autumn/winter crops (maize, sorghum and millet) were sown always from May to April of each year. The early maize

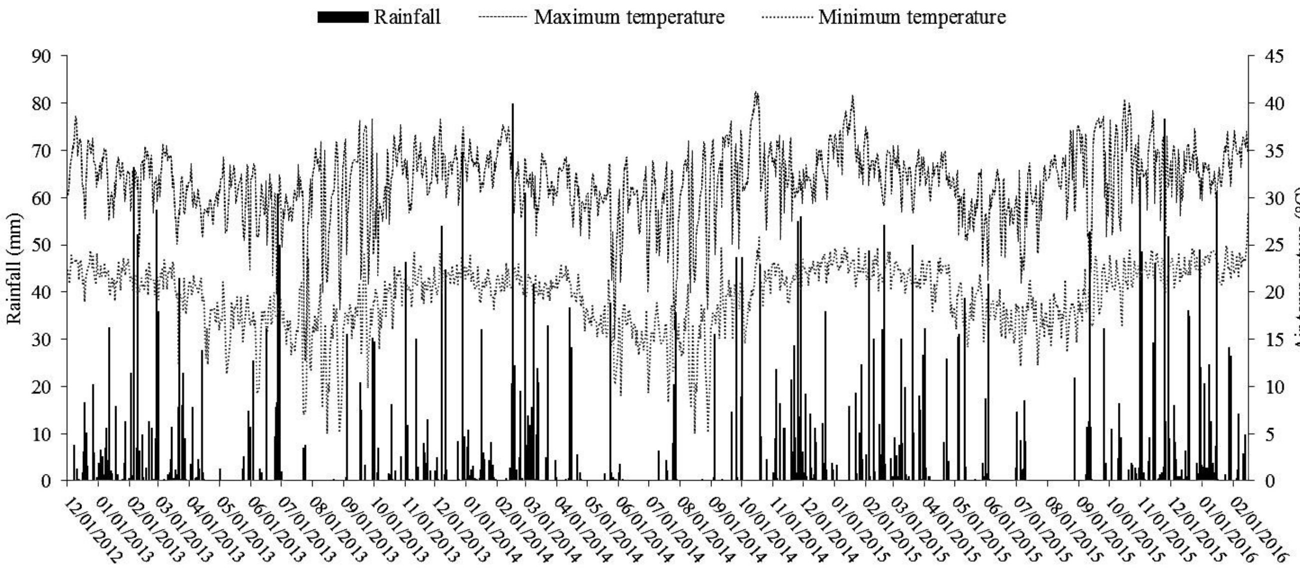

Figure 1. Rainfall, and maximum and minimum temperature data relative to the experimental period

hybrid DKB 390 VTPRO 2 was planted at spacing of 0.45 m between rows, at sowing density of 3.4 seeds m^{-1} of furrow, considering a germination power of 85%. The experiment used the sorghum hybrid 'Ranchero', which is recommended for grain production, under low- and high-technology conditions, and adapted to sowing in the second season, at spacing of 0.45 m between rows. The millet variety was BRS-1501, adapted to biomass production in the no-tillage system and with potential for grain production, at spacing of 0.34 m between rows, using approximately 20 kg ha^{-1} of seeds. Fertilization used at sowing for the previous crops, in the planting furrow, consisted of single superphosphate (18% of P_2O_5 and 10% of S), at dose of 300 kg ha^{-1}.

For maize and sorghum, N fertilizations (top-dressing) were performed when the crops were in the phenological stage V_3, by superficially applying, 150 kg ha^{-1} of urea (45% of N). In the same occasion, K doses (30, 60 and 120 kg ha^{-1} of K_2O) were applied broadcast, using potassium chloride as source (58% of K_2O).

Always in September, all plants in the area were desiccated. Approximately seven days after, these plants were subjected to mechanical management using knife roller.

Soybean sowing in succession, in no-tillage system, was always in late October, using the variety 'BRS Valiosa RR' at spacing of 0.45 m between rows and 16.2 seeds m^{-1}.

Basal fertilization consisted of 330 kg ha^{-1} of single superphosphate (18% of P_2O_5 and 10% of S). K fertilization in the soybean crop was applied (broadcast), in the respective plots, always when the crop was in the phenological stage V_3, using 50 kg ha^{-1} of K_2O. Phytosanitary management was performed according to the need of the crop.

The mean values of the four years of experiment were used. The results were subjected to the Shapiro-Wilk normality test and to individual analysis of variance (ANOVA) by F test ($p \leq 0.05$). When there was significant difference, means were compared by Tukey test ($p \leq 0.05$) for the qualitative factors and polynomial regression analysis ($p \leq 0.05$) for quantitative factors. The analysis was performed using the software SISVAR® (Ferreira, 2014).

Results and Discussion

K doses did not influence significantly the parameters evaluated in the previous crops (Table 1). For dry matter production by the second-season crops, maize has higher potential compared with the others. Some factors influence the efficiency of phytomass production, such as leaf area index (Magalhães et al., 2002). Plants with decumbent leaves and small photosynthetic area are more limited in the process of CO_2 fixation through photosynthesis (Silva et al., 2016), which can be noted in the present study, because maize is a crop that has undergone a program of genetic improvement and selection of genotypes increasingly efficient in terms of leaf architecture, leaf area and sunlight capture, whereas millet and sorghum exhibit these same features in a more rudimentary way, which negatively reflects on the dry matter supply by these crops, compared with maize.

Table 1. F values and means for dry matter weight, K content in straw and potential return of K as a function of the treatments used

Treatments	Dry matter weight kg ha^{-1}	K content g kg^{-1}	Potential return of K kg ha^{-1}
Previous crops (PC)			
Maize	5,155 a	13.7 c	71.20 a
Sorghum	2,578 b	20.9 b	54.10 b
Millet	2,718 b	26.0 a	71.01 a
Early K dose (EKD)			
0	3,182	19.1	55.49
35	3,673	20.1	68.55
70	3,526	20.6	67.44
120	3,554	20.8	70.26
F Test			
PC	71.087 **	106.149 **	5.588 **
EKD	1.132 ^{ns}	1.179 ^{ns}	1.971 ^{ns}
PC x EKD	0.650 ^{ns}	0.302 ^{ns}	0.165 ^{ns}
CV (%)	19.73	11.80	25.39

*, ** and ^{ns} correspond, respectively, to significant at 0.05, 0.01 probability levels and not significant by F test

In general, the obtained means of dry matter are low, since the climate along the vegetative stage of the crops was not favorable to their full development, because they were grown under rainfed conditions, in a period of the year with low rainfalls and shorter light period.

Millet showed higher K accumulation in the shoots, surpassing the other previous crops. Silva & Lazarini (2014) claim that the millet crop can recycle a large amount of this nutrient, returning it to the system. The lowest K content was found in the maize crop residues. This can be explained by the fact that most K extracted by maize is exported in grain harvest, which may reach 6 to 20 kg of K t^{-1} produced (Wendling et al., 2008).

The potential returns of K by the crops were higher in maize and millet. Maize, despite having lower K content, produces a larger amount of phytomass compared with the other crops, thus being equivalent to millet regarding the capacity of K recycling to the soil when adopted in the no-tillage system.

The parameters studied in the soybean crop in succession to the residual effect of autumn/winter crops and K doses used are presented in Table 2.

Previous crops had significant influence on the final plant population. Millet led to higher establishment of soybean plants in the area, promoting larger final stand in comparison to maize and sorghum. This probably occurred because millet has high C/N ratio in its stems, which allows a long permanence of its residues in the area. Hence, the remaining straw allows the maintenance of soil moisture for a longer time compared with the other crops used, thus guaranteeing greater plant survival in the area (Foloni et al., 2016).

Although maize has higher dry matter production in comparison to the other previous crops, it shows lower number of stems compared with millet (Lemos et al., 2003). Because of this and the high C/N ratio in the stems, the mulch from millet favors soybean development in succession to millet, because crops were grown under rainfed conditions, in a region prone to dry spells. Under such conditions, the maintenance of straw on the soil becomes of great importance for soybean growth and development.

Table 2. F values and means for the final plant population, leaf K content, number of pods $plant^{-1}$, 100-grain weight and grain yield of soybean as a function of the treatments used

Treatments	Population plants ha^{-1}	K content g kg^{-1}	Number of pods $plant^{-1}$	100-grain weight g	Grain yield kg ha^{-1}
Previous crops (PC)					
Maize	258,523 b	12.8 b	51	11.44	2,182 b
Sorghum	263,423 b	13.4 b	52	11.35	2,193 b
Millet	277,157 a	16.3 a	49	11.83	2,506 a
Early K dose (EKD)					
0	268,978	13.6	50	11.74	2,245
35	267,126	14.0	54	11.10	2,294
70	262,754	14.6	51	11.56	2,355
120	266,612	14.3	48	11.76	2,281
Soybean K fertilization (SKF)					
Without	266,098	14.1	51	11.75	2,241
With	266,638	14.2	50	11.33	2,346
F Test					
PC	9.418 **	49.719 **	0.872 ^{ns}	1.734 ^{ns}	10.711 **
DKC	0.517 ^{ns}	2.013 ^{ns}	3.565 *	1.866 ^{ns}	0.498 ^{ns}
SKF	0.022 ^{ns}	0.135 ^{ns}	0.016 ^{ns}	3.600 ^{ns}	2.650 ^{ns}
PC x EKD	0.316 ^{ns}	0.590 ^{ns}	0.629 ^{ns}	0.519 ^{ns}	1.148 ^{ns}
PC x SKF	1.396 ^{ns}	0.703 ^{ns}	1.463 ^{ns}	0.882 ^{ns}	7.631 **
EKD x SKF	0.861 ^{ns}	1.574 ^{ns}	1.104 ^{ns}	0.419 ^{ns}	0.086 ^{ns}
PC x EKD x SKF	0.255 ^{ns}	1.183 ^{ns}	0.962 ^{ns}	1.064 ^{ns}	0.261 ^{ns}
CV (%)	6.68	10.54	19.06	9.44	13.82

*, ** and ^{ns} correspond, respectively, to significant at 0.05, 0.01 probability levels and not significant by F test. Means followed by different letters in the column are statistically different by Tukey test at 0.05 probability level

Leaf K content was significantly influenced by the previous crops, and values were higher in the succession with millet. In general, millet is a K-accumulating crop (Silva & Lazarini, 2014), thus it promotes greater return of this element, which may have led to greater K accumulation in the diagnostic leaf of the soybean crop. K contents in the diagnostic leaf of soybean plants, regardless of the previous crop, were below the values considered as sufficient to the crop (17-25 g kg^{-1}), according to EMBRAPA (2013b); however, millet led to values closer to the ideal one (16.3 g kg^{-1}).

The number of pods $plant^{-1}$ showed a quadratic fit to the K doses, and the dose of highest technical efficiency was equal to 45.9 kg ha^{-1} of K_2O, leading to approximately 52 pods $plant^{-1}$ (Figure 2).

Therefore, the residual effect of K doses applied in the previous crops on the soybean in succession becomes evident, which may be a possibility of period to apply this nutrient. In addition, this element contributes to various metabolic and physiological processes in the plant, such as ionic balance, photosynthesis (RuBisCO enzyme synthesis), maintenance of osmotic potential and stomatal regulation (Bezerra Neto et al., 2016), very important in regions where transpiration is high and rainfall is not uniform. Potassium is also involved in meristematic growth and differentiation, since it influences the action of phytohormones (Marschner, 2012). These facts may explain the higher number of pods in the crop when well supplied with this nutrient.

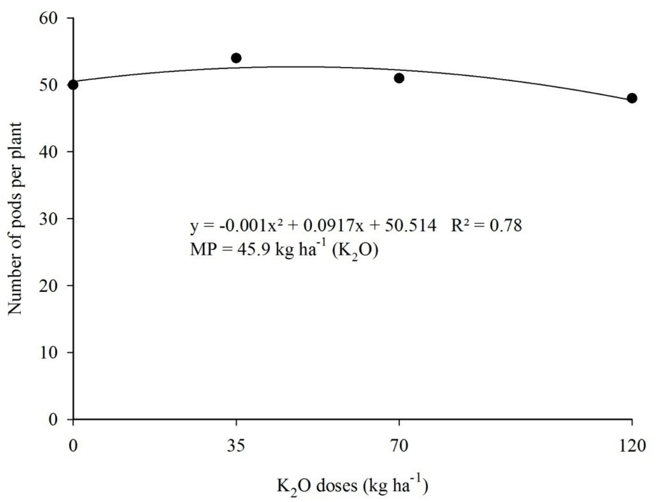

Figure 2. Number of pods per plant as a function of early K_2O doses applied in autumn/winter crops

The variable 100-grain weight was not influenced by any of the studied causal factors. Significant interaction occurred between previous crops and the top-dressing K application (or its absence) in the soybean, for grain yield (Table 3).

Soybean grown after millet with top-dressing K fertilization showed values higher than those of the other crops used, regardless of the presence or absence of top-dressing fertilization, pointing to the beneficial effect of the combination between these two factors. Millet can accumulate a considerable amount of K in its phytomass, but this fact associated with top-dressing K fertilization allows a more adequate nutrition to the crop, leading to higher yields.

This element, as previously mentioned, acts in various physiological processes that are vital to the plant, such as photosynthesis and subsequent translocation of photoassimilates, which are directly correlated with crop yield

Table 3. Follow-up analysis of the significant interaction between previous crops and top-dressing potassium fertilization in the soybean, for the parameter grain yield

Soybean K fertilization	Previous crops		
	Maize	Sorghum	Millet
Without	2,266	2,173	2,284 b
With	2,099 B	2,214 B	2,727 a A

Means followed by different letters, lowercase in the columns and uppercase in the rows, are statistically different by Tukey test at 0.05 probability level

(Bezerra Neto et al., 2016). These authors claim that, along with these beneficial effects, the water saving promoted by stomatal regulation also contributes to maintaining cell turgor and the metabolic activities of the plant, guaranteeing its productive potential even in situations of water scarcity.

The K applied in the soybean V_3 phenological stage promotes the supply of this element in the period of highest requirement by the crop, guaranteeing a balanced nutrition, which directly influences its productive performance. Foloni & Rosolem (2008) claimed that the K supply by millet after its management is fast; thus, the complementation of top-dressing K fertilization can allow a K supply at a pace more compatible with its absorption rate by the soybean crop. Hence, soybean cultivation in succession to millet does not dispense with top-dressing K fertilization, despite the large volume of K recycled in the system with the adoption of this previous crop (71 kg ha^{-1}).

Silva & Lazarini (2014) reinforce that the K content in the soil tends to stabilize over the crop cycles; however, it should be pointed out that harvest promotes high exportation of this nutrient, thus requiring fertilization at least to replace the extracted amount, in order to avoid the appearance of patches with deficiency symptoms after a few crop cycles. It is worth highlighting that the mean yield in the present study was relatively low, but this result is more associated with the edaphoclimatic conditions of the region than with the nutritional conditions.

Conclusions

1. Millet has higher K content in its straw compared with sorghum and maize.
2. The amount of K returned to the soil with millet residues is similar to that promoted by maize cultivation as previous crop.
3. K doses applied in the previous crops (maize, sorghum and millet) did not alter the amount of straw and K content in these crops.
4. Highest soybean grain yield was obtained on millet straw associated with top-dressing K fertilization recommended for the soybean crop, regardless of the K dose applied in the previous crop.
5. The use of millet prior to soybean cultivation does not dispense with top-dressing K fertilization.

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