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Research Findings

Alfalfa (*Medicago sativa*). Photo by A.C.C. Bernardi. 2017.

Polyhalite Compared to KCl and Gypsum in Alfalfa Fertilization

Bernardi, A.C.C.(1)***, G.B. de Souza**(1)**, and F. Vale**(2)

Abstract

Poor acidic soils significantly challenge potassium (K) availability for crop production in Brazil. Therefore, huge amounts of K fertilizers, mostly KCl, are applied yearly. Nevertheless, KCl agronomic efficiency in those soil is often insufficient, hence alternative K donors are sought. In the present study, polyhalite, a natural mineral with potential as a multi-nutrient (11.7, 19, 3.6, and 12.1% of K, sulfur (S), magnesium (Mg), and calcium (Ca), respectively) fertilizer, was examined in a pot-grown (local topsoil) alfalfa (*Medicago sativa* L.) experiment vs. KCl together with gypsum. Four K application rates (equivalent to 0, 50, 100, and 200 kg K_2O ha^{-1}) were tested with seven fertilizer combinations: KCl; KCl + gypsum1; KCl + gypsum2; polyhalite + KCl (1:7); polyhalite + KCl (1:1); polyhalite + KCl (7:1); and polyhalite. The results of seven successive harvests indicated that K application was essential to obtain considerable plant biomass in a K-rate dependent pattern. Polyhalite application, in combination with KCl or exclusively, gave rise to significantly higher biomass yields than KCl application, with or without gypsum. Polyhalite significantly enhanced K, S, Ca, and Mg uptake, particularly when applied alone at the highest dose. Indications of K-Mg or Cl-S competition seen under KCl application diminished under polyhalite. In conclusion, under the terms of a pot-grown experiment, polyhalite appeared as a promising alternative among K fertilizers for alfalfa grown on Brazilian acidic soils. Polyhalite may be considered as a replacment to KCl as a K source, as well as a donor of Ca, Mg, and S. Broad scale field experiments are

(1)Embrapa Pecuária Sudeste, São Carlos, SP, Brazil
(2)IPI Coordinator for Latin America, International Potash Institute (IPI), Zug, Switzerland
*Corresponding author: alberto.bernardi@embrapa.br

required, however, to further confirm this conclusion under practical terms.

Keywords: Acidic soil; calcium; magnesium; *Medicago sativa*; nutrient uptake; polyhalite; potassium; slow release; sulfur.

Introduction

Brazil is the fourth largest fertilizer consumer in the world (ANDA, 2016). In 2016, the estimated consumption of fertilizers was approximately 32.8 million tons, of which 28% was related to potassium (K) fertilizer (IPNI, 2017). The primary K source in the Brazilian fertilizer market is KCl (58-62% K_2O) (ANDA, 2016). Local KCl production comprises 5.3% of total consumption, and the rest is imported (IPNI, 2017).

The minerals commonly explored as K sources are sylvite (KCl), sylvinite (KCl + NaCl), and carnallite ($KMg_2Cl_3 \cdot 6H_2O$). However, there are other minerals composed of sulfates that may be considered of economic interest owing to their K content and easy solubilization, e.g. langbeinite, kainite, and polyhalite (Prud'homme and Krukowski, 2006; Vale and Sério, 2017). Polyhalite ($K_2MgCa_2(SO_4)_4 \cdot 2H_2O$) is a natural mineral occurring in large deposits, which has potential to be a multi-nutrient (ratio of 11.7% K, 19% sulfer (S), 3.6% magnesium (Mg), and 12.1% calcium (Ca)) fertilizer for forage crop production (Barbarick, 1991; Vale and Sério, 2017).

Supplying nutrients at balanced and adequate levels is a critical factor for alfalfa (*Medicago sativa*) production and is essential to maintain high quality and efficient yields. An alfalfa crop is extremely demanding on soil fertility (Moreira *et al.*, 2008; Bernardi *et al.*, 2013b). According to Werner *et al.* (1996) alfalfa nutrient uptake from soil could reach 20, 6.65, and 33.9 kg N, P_2O_5, and K_2O Mg^{-1} dry biomass.

Potassium fertilization is essential for alfalfa production and is the most common nutrient input for this crop, especially when grown on the highly weathered infertile acidic soils of Brazil (Moreira *et al.*, 2008). Therefore, imbalanced fertilization and ineffective soil management might lead to loss of alfalfa vigor and reduced longevity (Bernardi *et al.*, 2013a).

However, little information is available on the response of alfalfa to polyhalite. Acid, low-fertile, high-weathered soils are expected to benefit from the addition of K, Ca, Mg, and S nutrients. Therefore, polyhalite may provide an alternative to KCl, with the advantage of providing a slow-release source of these nutrients (Barbarick, 1991; Vale and Sério, 2017).

The objective of this study was to compare the effects of different K fertilizer doses on alfalfa dry matter yield and nutritional status.

Materials and methods

A greenhouse experiment was conducted at Embrapa Pecuária Sudeste, in São Carlos (22°01'S; 47°54'W, 856 m above sea level), State of São Paulo, Brazil. Alfalfa (cv. Crioula) plants were grown in 2-L pots filled with 3 kg topsoil (layer of 0-20 cm) of a Typic Hapludox (red yellow latosol), the properties of which are given in Table 1.

Pots were uniformly limed to raise soil base saturation (V%) to 80% with dolomitic lime (32% CaO, 19% MgO) 30 days before planting. At planting, all pots were applied with P (458 mg P_2O_5 kg^{-1}) as triple superphosphate (45% P_2O_5 and 15% Ca), and with 25 mg kg^{-1} micro-nutrient fertilizer FTE-BR12 (1.8% boron (B), 0.8% copper (Cu), 3% iron (Fe), 2% manganese (Mn), 0.1% molybdenum (Mo), and 9% zinc (Zn)). Four doses of K_2O, equivalent to field quantities of 0, 50, 100, and 200 kg ha^{-1}, were applied before planting and following each of the seven harvests during the season, using two K sources - polyhalite and KCl - in combination or alone. Additional treatments evaluated two gypsum doses (Table 2), as an alternative Ca and S donor, combined with KCl as the K donor. The gypsum doses were calculated to have equivalent levels of Ca and S of the treatments KCl+polyhalite (1:7), and KCl+polyhalite (1:1). A detailed description of the treatments is given in Table 2. Thus, the experiment consisted of 22 treatments (7x3+1) in a fractionated factorial design with four replications. The total quantities supplied at the crop cycle were equivalent to 0, 350, 700 and 1,400 kg K_2O ha^{-1}, respective to the dose asigned to each treatment.

Shoot dry matter yield was periodically determined when the crop reached 10% flowering and the 10 cm above-ground biomass was harvested. The samples were dried and dry matter yield was

Table 1. Texture and chemical properties of the local topsoil (depth of 0-20 cm) used as a growth medium in the alfalfa pot experiment.

Soil property	Quantity	Units
Sand	265	g kg^{-1}
Silt	198	g kg^{-1}
Clay	537	g kg^{-1}
pH ($CaCl_2$)	5.2	
Organic matter	24	g dm^{-3}
Cation exchange capacity (CEC)	52	$mmol_c$ dm^{-3}
Basic saturation	55	V%
Phosphorus, as P_{resin}	2	mg dm^{-3}
K	1.6	$mmol_c$ dm^{-3}
Ca	19	$mmol_c$ dm^{-3}
Mg	8	$mmol_c$ dm^{-3}
S, as SO_4	12	mg dm^{-3}
B	0.37	mg dm^{-3}
Cu	6.3	mg dm^{-3}
Fe	13	mg dm^{-3}
Mn	1.5	mg dm^{-3}
Zn	0.5	mg dm^{-3}

determined. Dry matter samples were used to determine total K, Ca, Mg and S concentrations.

Results and discussion

Alfalfa shoot biomass response to K application dose displayed an optimum curve, with a maximum of 67 g plant^{-1} at K_2O ranging from 145 to 165 kg ha^{-1} (Fig. 1A). However, the nature of the data do not allow to definite conclusion of whether plant biomass decreased beyond that rate, or actually obeyed a saturation curve. Alfalfa growth was severely restricted under no K application, obtaining less than 30 g dry matter (DM) plant^{-1}, while an application of 50 kg K_2O ha^{-1} gave rise to 80% biomass increase. These results are consistent with those observed by Smith (1975), Rassini and Freitas (1998), and Bernardi *et al.* (2013b), who found an alfalfa DM yield surge in response to increasing K application dose.

Nevertheless, yield response to K dose was significantly affected by K origin - KCl or polyhalite (Fig. 1B). As an exclusive K source, polyhalite was significantly more effective than KCl, obtaining higher biomass yields under all K doses, with an average peak of 82 g DM plant^{-1} under 200 kg K_2O ha^{-1}, 191% greater than in the no fertilizer control (Fig. 1B; Fig. 2). The KCl-polyhalite combinations also indicated a slight advantage to the higher polyhalite proportion, however, these differences were not always significant. Gypsum co-application with KCl did not result in any significant advantages.

Potassium concentration in shoots of the non-fertilized control was 6.5 g kg^{-1} DM, much lower than in all other treatments (Fig. 3). KCl application, with or without gypsum, significantly increased leaf K concentrations, however, in all treatments where polyhalite was involved, the higher K dose (200 kg ha^{-1}) gave rise

Table 2. A detailed description of the fertilization treatments and the rates of K, S, Ca, and Mg applied in each treatment per growth cycle (transformed into kg ha^{-1}).

Treatment	K_2O	S	CaO	MgO
	kg ha^{-1}			
Control (no K, S, Mg or Ca)	0	0	0	0
100% KCl	50	0	0	0
	100	0	0	0
	200	0	0	0
100% KCl+gypsum1	50	9	6	0
	100	18	13	0
	200	36	25	0
100% KCl+gypsum2	50	34	24	0
	100	68	48	0
	200	136	96	0
87.5% KCl+12.5% polyhalite (1:7)	50	9	5	2
	100	18	10	4
	200	36	20	8
50% KCl+50% polyhalite (1:1)	50	34	19	7
	100	68	38	13
	200	136	75	26
12.5% KCl+87.5% polyhalite (7:1)	50	60	38	11
	100	120	76	23
	200	240	151	46
100% Polyhalite	50	68	43	13
	100	136	86	26
	200	272	172	52

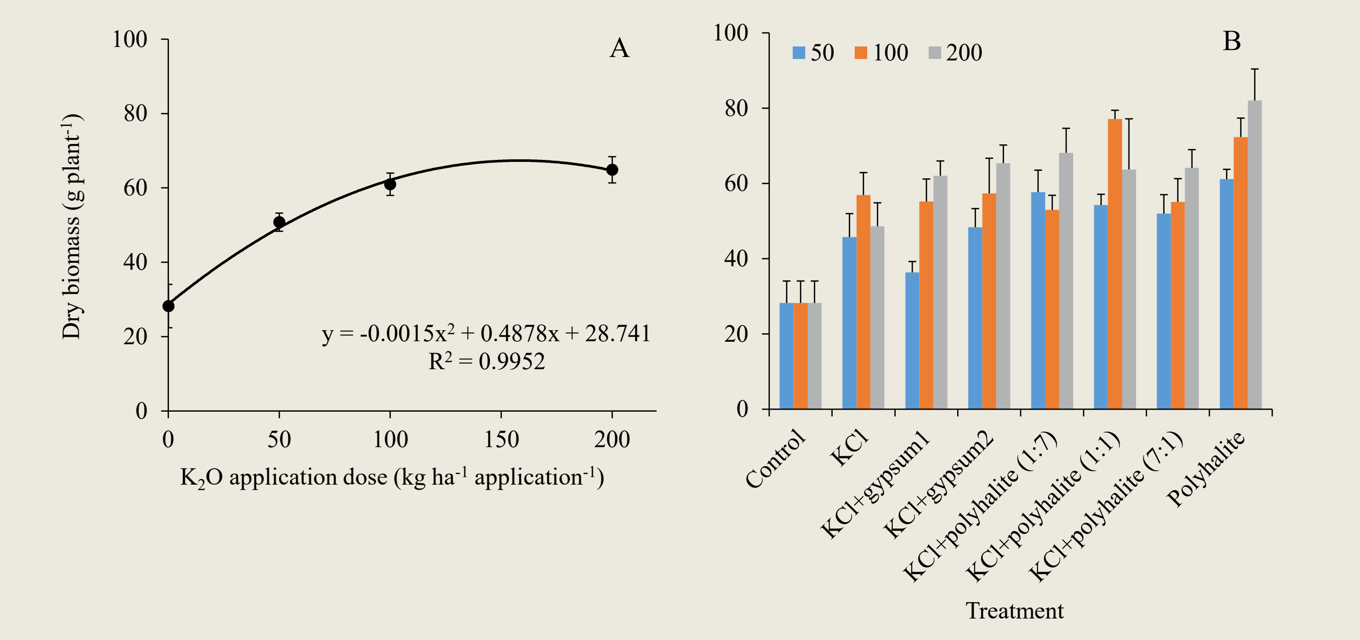

Fig. 1. Alfalfa dry biomass production in response to K application (rates of 50, 100, and 200 kg K_2O ha^{-1}) in a pot-grown experiment. Mean DM production in response to K dose (left); effects of K origin and dose on DM production (right). Bars indicate standard error (SE).

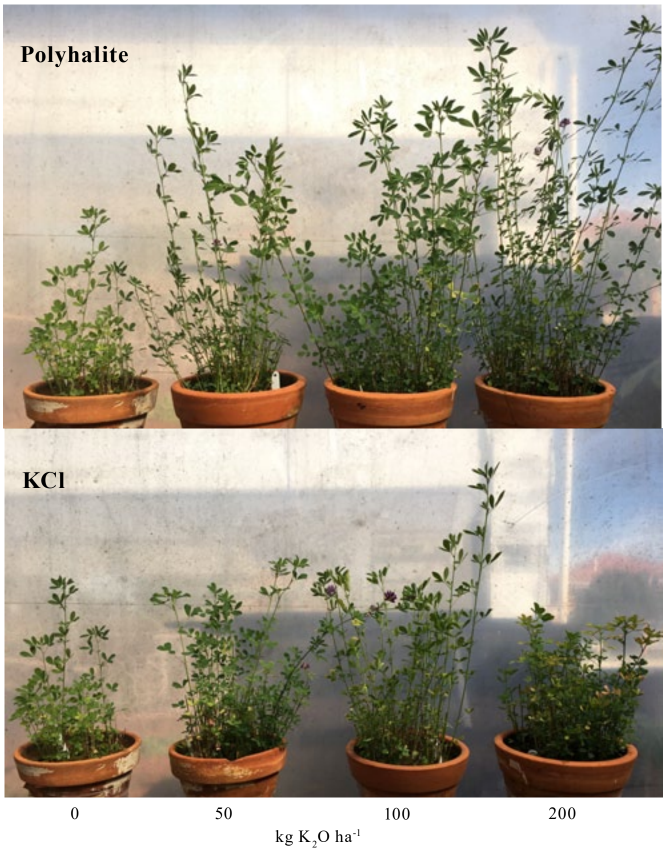

Fig. 2. Alfalfa plant performance under four K application levels using polyhalite or KCl. Photos by A.C.C. Bernardi.

to the highest leaf K concentrations, ranging from 18 to 22 g kg^{-1} (Fig. 3); three-fold greater than the control.

In Brazil, the ranges of K, Ca, Mg and S levels considered adequate for alfalfa shoots at early flowering are 20-35, 10-25, 3-8, and 2-4 g kg^{-1} for K, Ca, Mg and S, respectively (Werner *et al.*, 1996). Thus, the alfalfa shoots' K levels obtained in the present study were below the threshold and were lower than previous field results (Bernardi *et al.*, 2013b). On the other hand, Ca, Mg and S leaf concentrations were, in most cases, above the minimum thresholds (Fig. 3).

Nonetheless, a better insight into plant nutrition status may be provided by the nutrient uptake parameter, which integrates plant biomass with nutrient concentrations, resembling both soil nutrient availability and plant actual demands. The response of alfalfa K uptake to K application was dramatic, particularly where polyhalite at the highest K dose was involved (Fig. 4). The obvious advantage of polyhalite over KCl can be attributed to its stable, long-term pattern of K release, in contrast to the sudden but declining K availability that follows KCl application. Still, the mean K uptake curve suggests that K demands have not yet been fulfilled, even under the highest K dose employed in the present study (Fig. 4). Altogether, considering the low leaf K concentrations and the unsatisfied plant K demand, these results may point to another factor limiting plant performance, even under favorable K supply.

In Brazil, nitrogen (N) fertilization throughout alfalfa crop cycles is rare, since N supply relies on biological fixation performed by seed-inoculated with *Sinorhizobium meliloti* bacteria (Oliveira *et al.*, 2004). Nevertheless, balanced nutrition is essential to the maintenance of N_2 fixation activity. In plants experiencing K defficiency, this process might be negatively affected due to the decline of photosynthate's export rates from source leaves to roots (Mengel and Kirkby, 2001). The declining sugar supply to root nodules might lead to a considerable reduction in N_2 fixation and to an export of bound N (Collins and Duke, 1981). On the other hand, N supply from the biological process might not meet plant requirements under favorable K supply. The metabolic interactions between N and K are not limited to N fixation, having a broad scale of impacts on plant physiology and productivity (Fageria, 2001). Therefore, consequent to the entrance of new and more efficient K fertilizers, such as polyhalite, the need of N fertilization should be revisited.

Sulfur is another macronutrient essential to alfalfa metabolism and growth, and in combination with N, it participates in the synthesis of amino acids (methionine and cysteine) and proteins (DeBoer and Duke, 1982). Vale and Sério (2017) have pointed out that one of the advantages of polyhalite is in S delivery. Alfalfa S requirements and the positive effect of this nutrient in increasing DM production have already been demonstrated (Scherer and Lange, 1996; Moreira *et al.*, 1997). Moreira *et al.* (2008) recommended an annual application of 4 kg S Mg^{-1} DM. Considering an alfalfa yield of 20 Mg ha^{-1}, an amount of 420 kg S ha^{-1} yr^{-1} should be enough to meet this need. Sulfur concentration in alfalfa shoots remained quite constant under the macronutrient supply through either polyhalite or gypsum (Fig. 3). Under KCl as the sole K source, leaf S concentration displayed a reduction, which was further pronounced under the higher K dose. Mean S uptake increased with K dose, reflecting mainly the biomass rise (Fig. 4). Sulfur uptake was significantly greater under the higher polyhalite doses, confirming the considerable potential of the new fertilizer as an S source for alfalfa.

Leaf Ca concentrations were quite stable under the different K fertilizers, however, values showed a clear tendency to decrease in response to the allevating K dose (Fig. 3). This tendency was more significant with leaf Mg concentrations that were very low under KCl, exclusively or with gypsum application (Fig. 3). Mean Ca uptake surged from 600 to 1,200 mg plant^{-1} in response to the lower K application dose of 50 kg ha^{-1}, but remained stable or even decreased under higher K doses (Fig. 5). While Ca uptake significantly declined under the highest KCl dose, polyhalite application maintained it at a high level in most of the combinations, and in particular when applied exclusively (Fig. 5).

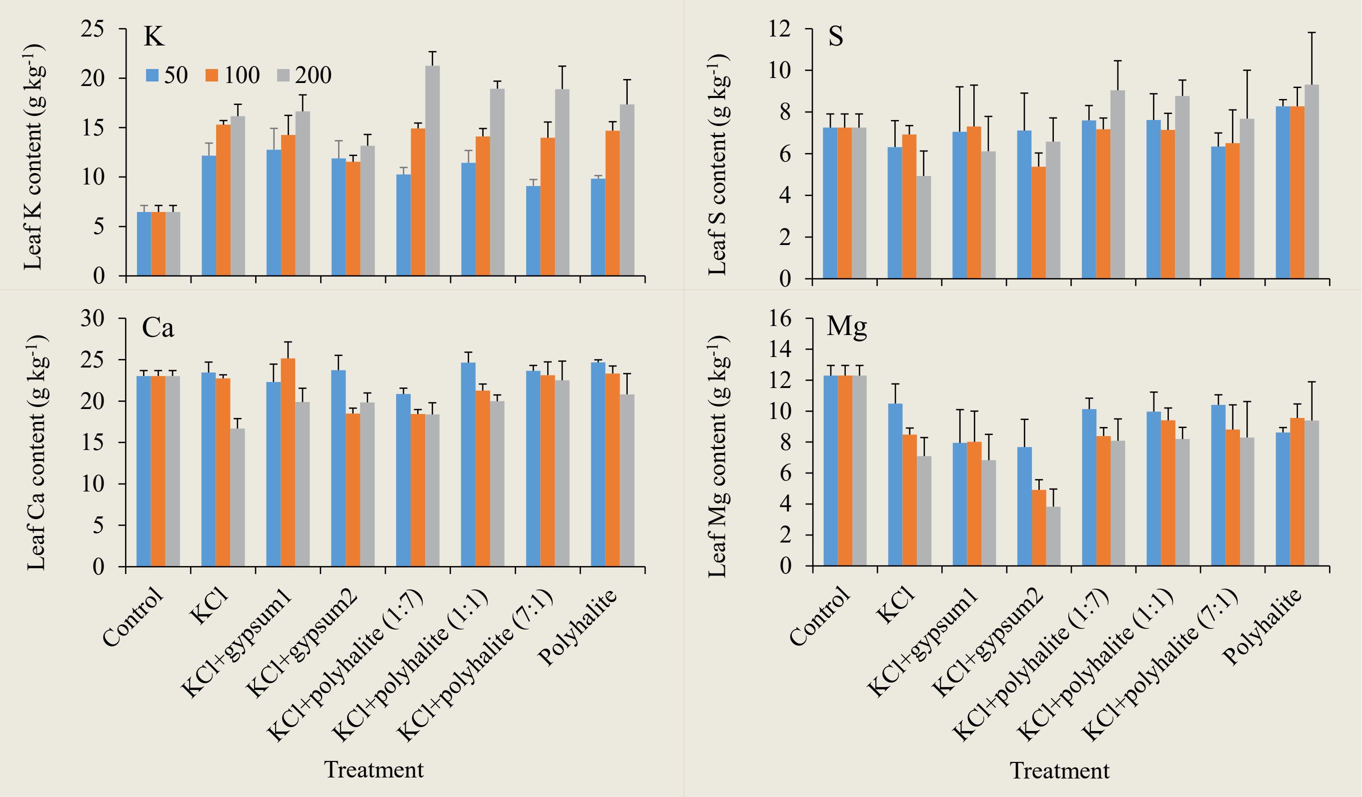

Fig. 3. Alfalfa leaf nutrient (K, S, Ca, and Mg) concentration in response to different K fertilization practices (rates of 50, 100, and 200 kg K_2O ha^{-1}) using several combinations of KCl, polyhalite, and gypsum in a pot-grown experiment. Bars indicate SE.

The response of the mean Mg uptake to increased K dose was quite moderate, compared to Ca uptake, but it displayed a similar pattern, with a clear reduction under the highest K rate (Fig. 5). While significantly lower under KCl + gypsum, Mg uptake was considerably higher under polyhalite application than the control, in most cases (Fig. 5). The phenomenon of reduced leaf Ca and Mg in response to allevated K fertilization had already been reported by Smith (1975), Lanyon and Smith (1985) and Lloveras *et al.* (2001).

KCl is the most common K fertilizer in use. Due to its high water solubility, K is immediately available for plant roots. Nevertheless, this might be a serious disadvantage in acidic soils with poor CEC. In many cases, the soil solution is K^+-saturated soon after KCl application, leading to transient stresses such as competition between K^+ and other cations (Ca, Mg, etc.) as well as between Cl^- and other anionic nutrients (NO_3^-, SO_4^{-2}), and high osmotic tension. Furthermore, due to poor soil CEC, K^+ is extremely mobile in the soil profile and might be leached away during successive irrigation (in pot experiments) or rainfall events (field conditions). Thus, the agronomic efficiency of KCl in such soils might be reduced considerably.

Some indications for competition between Cl and S or between K and Ca and Mg under exclusive KCl application, are highlighted in Figs. 4 and 5, respectively. Soil amelioration using gypsum ($CaSO_4{\cdot}2H_2O$) partially reduced the competition with Ca or S, but not with Mg. Using polyhalite fertilizer, in combination with KCl or exclusively, reduced or diminished these difficulties. As a relatively slow-release fertilizer, polyhalite brought about increased K uptake and biomass production, probably due to the consistent soil K availability it had provided. Most of the indications of competition among nutrients disappeared and nutrient uptake rates rose, including that of Mg, in a polyhalite rate-dependent pattern (Figs. 4 and 5).

In conclusion, in the present pot-grown experiment, polyhalite appeared as a promising K fertilizer alternative for alfalfa grown on Brazilian acidic soils. Polyhalite may be considered to replace KCl as a K source, as well as an important donor of Ca, Mg, and S. Broad scale field experiments are required, however, to further confirm this conclusion under practical terms.

Acknowledgement

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References

Associação Nacional para Difusão de Adubos (ANDA). 2016. Anuário estatístico do setor de fertilizantes do ano de 2016. Available at: http://www.anda.org.br/index.php?mpg=06.01.00&ver=por. Accessed 11 Dec 2017.

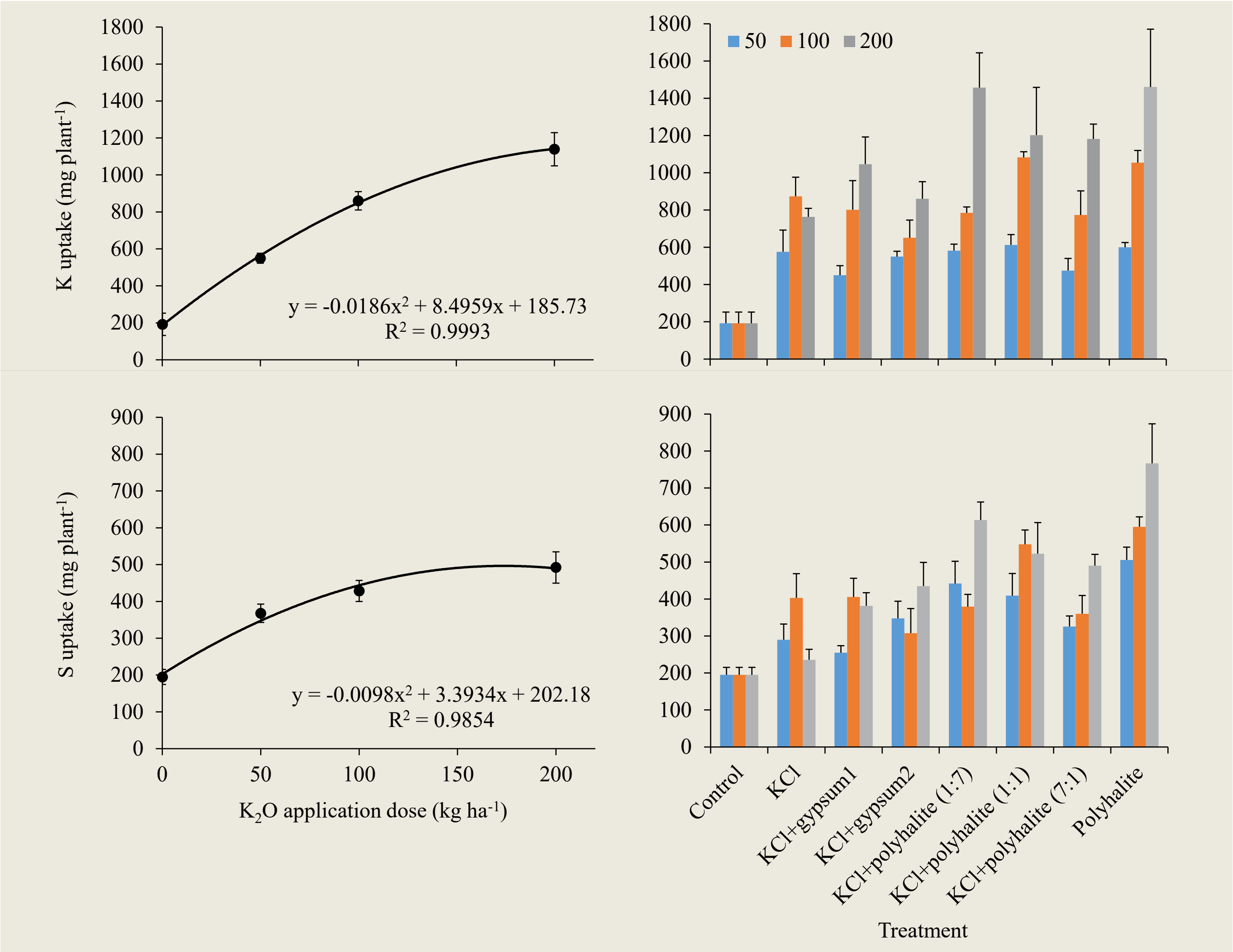

Fig. 4. Alfalfa K and S uptake in response to K application (rates of 50, 100, and 200 kg K_2O ha^{-1}) in a pot-grown experiment. Mean K or S uptake in response to K dose (left); effects of K origin and dose on K or S uptake (right). Bars indicate SE.

Barbarick, K.A. 1991. Polyhalite Application to Sorghum-Sudangrass and Leaching in Soil Columns. Soil Sci. 151:159-166.

Berg, W.K., S.M. Cunningham, S.M. Brouder, B.C. Joern, K.D. Johnson, J. Santini, and J.J. Volenec. 2005. Influence of Phosphorus and Potassium on Alfalfa Yield and Yield Components. Crop Sci. 45(1):297-304.

Bernardi, A.C.C., R.D. Cardoso, E.P. Mota, and R.P. Ferreira. 2013a. Produção, estado nutricional e qualidade da alfafa sob pastejo e ocorrência de plantas daninhas em resposta à calagem, gessagem e adubação potássica. Boletim de Indústria Animal 70:67-74.

Bernardi, A.C.C., J.B. Rassini, F.C. Mendonça, and R.P. Ferreira. 2013b. Alfalfa Dry Matter Yield, Nutritional Status and Economic Analysis of Potassium Fertilizer Doses and Frequency. International Journal of Agronomy and Plant Production 4(3):389-398

Collins, M., and S.H. Duke. 1981. Influence of Potassium Fertilization Rate and Form on Photosynthesis and N_2 Fixation of Alfalfa. Crop Science 21:481-485.

DeBoer, D.L., and S.H. Duke. 1982. Effects of Sulphur Nutrition on Nitrogen and Carbon Metabolism in Lucerne (*Medicago sativa* L.). Physiologia Plantarum 54(3):343-350.

Fageria, V.D. 2001. Nutrient Interactions in Crop Plants. J. Plant Nutr. 24:1269-1290.

International Plant Nutrition Institute (IPNI). 2017. Estatísticas: Fertilizantes, 2016. Available at: http://brasil.ipni.net/article/BRS-3132. Accessed 11 Dec 2017.

Lanyon, L.E., and W.K. Griffith. 1988. Nutrition and Fertilizer Use. *In:* Hanson, A.A., D.K. Barnes, and R.R. Hill Jr. (ed.). Alfalfa and Alfalfa Improvement. Agron. Amer. Soc. p. 333-372.

Moreira, A., A.C.C. Bernardi, and J.B. Rassini. Correção do solo, estado nutricional e adubação da alfafa. 2008. *In:* Ferreira,

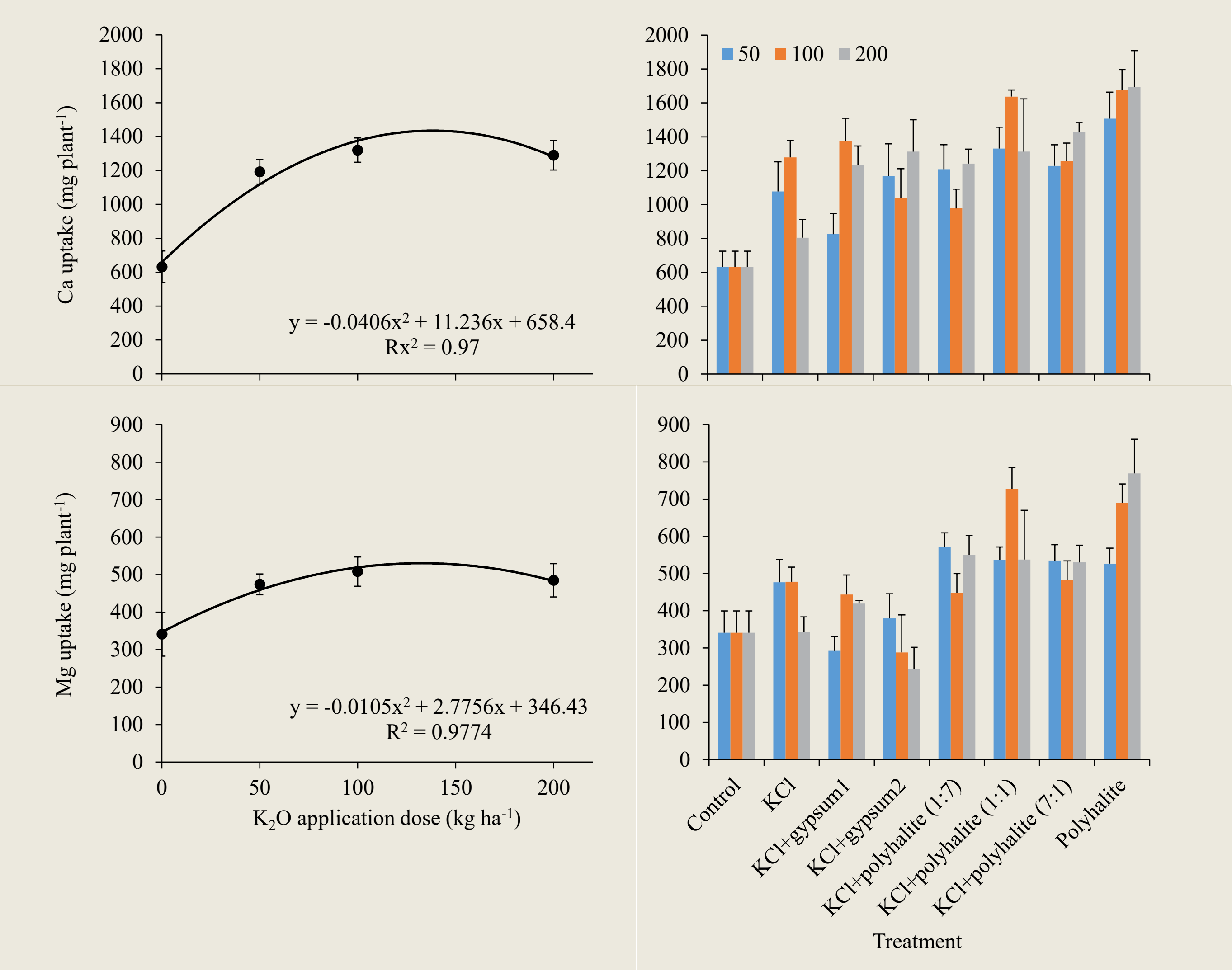

Fig. 5. Alfalfa Ca and Mg uptake in response to K application (rates of 50, 100, and 200 kg K_2O ha^{-1}) in a pot-grown experiment. Mean Ca or Mg uptake in response to K dose (left); effects of K origin and dose on Ca or Mg uptake (right). Bars indicate SE.

R.P., J.B. Rassini, A.A. Rodrigues, A.R. Freitas, A.C. Camargo, and F.C. Mendonça. (eds.). Cultivo e utilização da alfafa nos trópicos. São Carlos, Embrapa Pecuária Sudeste. p. 95-137.

Moreira, A., J.G. Carvalho, and A.R. Evangelista. 1997. Efeito de doses de enxofre na produção e composição mineral da alfafa. Pesquisa Agropecuária Brasileira 32(5):533-538.

Oliveira, W.S.D., P.P.A. Oliveira, M. Corsi, F.R.S. Duarte, and S.M. Tsai. 2004. Alfalfa Yield and Quality as Function of Nitrogen Fertilization and Symbiosis with *Sinorhizobium meliloti*. Scientia Agricola 61:433-438.

Prud'homme, M., and S.T. Krukowski. 2006. Potash. *In:* Kogel, J.E. (ed.). Industrial Minerals and Rocks: Commodities, Markets, and Uses. Society for Mining, Metallurgy, and Exploration, Englewood, CO, USA. p. 723-741.

Rassini, J.B., and A.R. Freitas. 1998. Desenvolvimento da alfafa (*Medicago sativa* L.) sob diferentes doses de adubação potássica. Revista Brasileira Zootecnia 27(3):487-490.

Vale, F., and D.R. Sério. 2017. Introducing Polyhalite to Brazil: First Steps of a New Fertilizer. IPI *e-ifc* 48:3-11.

Werner, J.C., V.T. Paulino, H. Cantarella, N.O. Andrade, and J.A. Quaggio. 1996. Forrageiras. *In:* Raij, B., H. Cantarella, J.A. Quaggio, and A.M.C. Furlani. Recomendação de adubação e calagem para o Estado de São Paulo. Campinas: Instituto Agronômico de Campinas. Boletim IAC, 100). p. 245-258.

The paper "Polyhalite Compared to KCl and Gypsum in Alfalfa Fertilization" also appears on the IPI website at:

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