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Potassium Doses and Frequency of Application to Alfalfa Growing on a Brazilian Tropical Soil: Influence on Dry Matter Yield and K Content of the Harvested Crop and Exchangeable Soil K

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General view of the experimental plot at Embrapa Cattle Southeast, Sao Carlos, Brazil. Photo by A. Bernardi.

Introduction

Providing an adequate supply of nutrients is an important requirement for alfalfa production for maintaining high quality and profitable yields. On highly weathered, low-fertile and acids soils of tropical regions, potassium fertilization is essential (Rassini and Freitas, 1998) and is the most common nutrient input for this crop. High-yielding alfalfa removes large amounts of potassium from the field at each cutting (Smith, 1975; Lanyon and Smith, 1985), extractions range from 1,500 to 1,700 kg ha^{-1} associated with a productivity of 21.5 mt ha^{-1} DM being reported by Lloveras *et al*. (2001) on a soil of high fertility.

Potassium (K) is taken up by plant roots in ionic form. Diffusion to the roots accounts for the major form of K acquisition, with mass flow contributing only a small fraction of total plant K (Mengel and Kirkby, 2001). K salts in general are highly soluble and, when applied to soils low in K-fixing capacity, relatively high K concentrations may occur in soil solution, which in turn may lead to leaching of potassium from the soil and excessive absorption by plants (Havlin *et al*., 1999).

Experimental Studies

A two-year field study made over two growing seasons was carried out at Embrapa Cattle Southeast, in Sao Carlos (22°01'S and 47°54'W; 856m above sea level), Brazil. The climate is a Cwa (Köeppen), with yearly average of low and high temperatures of 16.3 and 23.0°C respectively, and a total precipitation of 1,502 mm falling mostly in summer. Soil type is a Typic Hapludox with chemical properties as presented in Table 1.

Table 1. Soil analysis of a Typic Hapludox at 0-0.2, 0.2-0.4 and 0.4-0.6m layers.

Chemical property	Depth (m)		
	0-0.2	0.2-0.4	0.4-0.6
pH_{CaCl2}	5.9	5.3	5.1
Organic matter (g dm^{-3})	21	11	10
P_{resin} (mg.dm^{-3})	42	10	3
K ($mmol_c$ dm^{-3})	1.3	0.9	0.5
Ca ($mmol_c$ dm^{-3})	29	14	11
Mg ($mmol_c$ dm^{-3})	13	5	2
CEC ($mmol_c$ dm^{-3})	69	50	48
Base saturation (%)	63	39	28
Clay (g kg^{-1})	253	273	302
Sand (g kg^{-1})	730	710	689
Silt (g kg^{-1})	17	17	9

Potassium is involved in essential physiological and metabolic roles within the alfalfa plant including photosynthesis, ATP production, sugar translocation, starch production, nitrogen fixation, and protein synthesis. A deficiency of K in plants has a major impact in disrupting plant water status, as well as decreasing photosynthetic activity, increasing respiration, slowing growth, and suppressing yields which, in agricultural practice, is expressed as a loss in income for the farmer (Lanyon and Smith, 1985).

Map of Brazil showing the experimental site.

The objective of this study was to evaluate the effect of doses and frequency of application of potassium fertilizer on alfalfa dry matter yield and plant-soil interaction of potassium as measured by alfalfa shoot content and exchangeable soil K.

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Irrigated alfalfa (*Medicago sativa* cv. Crioula) was sown with a planting density of 20 kg ha^{-1} of seed inoculated with *Sinorhizobium meliloti*. Before planting, dolomite lime was applied to increase the base saturation of the soil to 80 per cent. Plots were uniformly fertilized at planting with 120 kg ha^{-1} P_2O_5 (single superphosphate; SSP) and 30 kg ha^{-1} of FTE BR-12 (a micronutrient source; 1.8% of B, 0.8% Cu, 3% Fe, 2% Mn, 0.1% Mo, 9% Zn). Soil liming, phosphorus and micronutrient fertilization were repeated when soil testing indicated any decrease in fertility. The experiment was carried out in 3.2 m^2 plots, formed by eight sowing 2 m-length rows, with a 0.2 m-interlinear space.

The experimental design was in 4X4-factorial randomized blocks with three replications. Treatments comprised four levels of potassium: a control without any potassium treatment; 600, 1,200 and 1,800 kg ha^{-1} of K_2O as KCl; and four frequencies of application: after each cutting (12 applications), after every two cuttings (6 applications), after every three cuttings (4 applications); and after six cuttings (2 applications per year). K doses were split equally by the number of application.

Results and Discussion

Yield

Dry matter yield of alfalfa for the first and second growing seasons, expressed as a function of K fertilizer level and frequency of application, is illustrated in Fig. 1. The highest DM yields in both years (36,890 and 24,131 kg ha^{-1}) were obtained with 1,411 and 1,432 kg ha^{-1} of K_2O respectively applied after every two cuttings (6 applications). These values are approximately 57 and 59 per cent higher than those obtained without potassium fertilizer. The results are consistent with those observed by both Smith (1975) and Rassini and Freitas (1998), who found an increase in alfalfa DM yield as potassium fertilization increased. The yield increases in this study were higher than the increases reported by Kafkafi *et al.* (1977) and Lloveras *et al.* (2001).

The results also indicate that adequate potassium supply increases the stand longevity, as already shown by Smith (1975) and Berg *et al.* (2005). The yield reduction in our experiment from first year to second was greater at the lower levels of potassium fertilization. The smallest yield reduction (-33.5%) was obtained with 1,346 kg ha^{-1} of K_2O applied approximately after two cuttings.

The large difference in yield between the years is the result of a natural decline induced by repeated cutting of the crop. Stand longevity of alfalfa is of major importance for ranchers with irrigated stands. Alfalfa longevity is limited by a decline in plant population, which results from harvesting or inappropriate grazing management. Additionally, the decline is brought about by diseases, the presence of weeds, insect damage, a fall in soil fertility, and deterioration occurring more rapidly with irrigation (Rice *et al.*, 1989). Longevity is limited and reaches no more than four-to-six years (Humphries *et al.*, 2004).

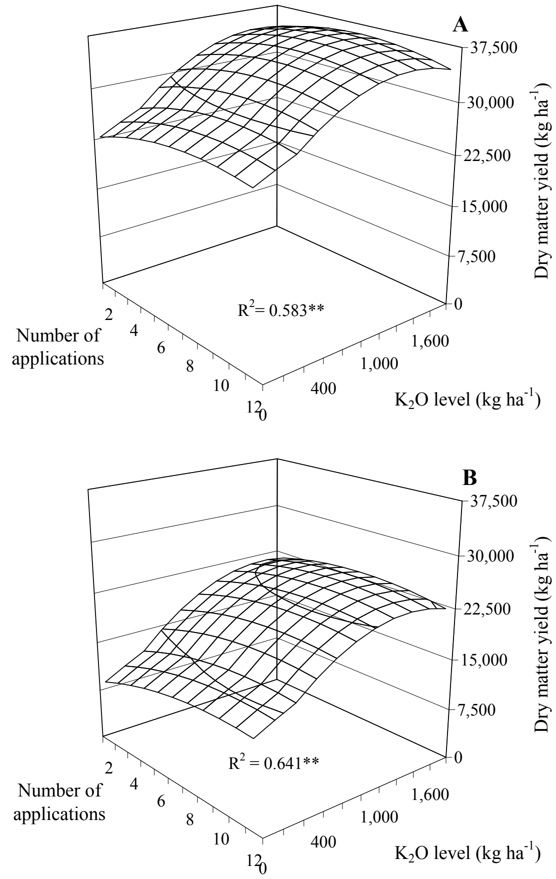

Fig. 1. Alfalfa dry matter yield for 1st (A, top) and 2nd (B, bottom) cropping season.

Equation A: $y=-0.0053K^2+15.895K-73.474T^2+1258.5T-0.134KT+21,101$

Equation B: $y=-0.0054K^2+16.985K-60.094T^2+1207.3T-0.182KT+7,211$

Maximum K concentrations in alfalfa shoots were 35.2 g kg^{-1} DM, achieved with 1,610 kg K_2O ha^{-1} (Fig. 2). The increase in K concentration (from 20.4 to 35.2 g kg^{-1}) with increasing K fertilization is similar to the results reported by Smith (1975) and Sheaffer *et al.* (1986) on soils responsive to K fertilization. Werner *et al.* (1997), in experiments in Brazil investigating the cationic nutrient composition of alfalfa shoots at the early flowering stage, reported adequate ranges for these nutrients in terms of g kg^{-1} DM as follows: K (20-35), Ca (10-25), and Mg (3-8). Compared with these findings, all our values for K are within an adequate range. However, at higher levels of K fertilization, there is evidence that both Ca and Mg concentrations are lower than the respective adequate ranges for these two nutrients as shown below (Fig. 2). Even at a low rate of K fertilization (100 kg K_2O ha^{-1}), the concentration of Ca in the shoot dry matter was below 10 g kg^{-1} DM. The

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same was true for Mg at less than 3 g Mg kg^{-1} DM but this was at a much higher potassium fertilization level (1,800 kg K_2O ha^{-1}).

Cation competition between K, Ca and Mg uptake by plants is a very well established phenomenon (Mengel and Kirkby 2001) and has been reported in alfalfa by Smith (1975), Lanyon and Smith (1985) and Lloveras *et al*. (2001). Potassium, in contrast to the other two nutrients (in particular Ca), is taken up very rapidly by highly efficient transport systems in the roots. Even though K is usually present in the soil solution in much lower concentrations than Ca or Mg, it is preferentially absorbed by root cells. This preferential K absorption can result, as observed above, in lower concentrations of Ca and Mg in shoots especially in response to increasing K application. Only on soils which are exceptionally high in Mg is there a possibility of any restriction in K uptake by Mg competition.

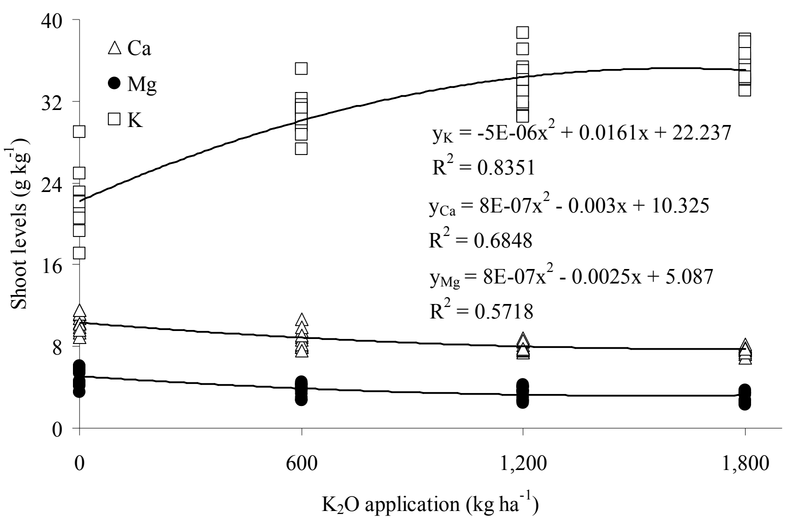

Fig. 2. Concentrations of K, Ca and Mg in alfalfa shoot in relation to potassium fertilizer application. Results from the first cropping season.

Potassium uptake in relation to exchangeable soil K

The relationship between nutrient concentration and crop yield forms the basis for using plant analysis to assess plant nutrient status. Dry matter production and K levels in the shoot showed a positive correlation (Fig. 3), where yield increased with increasing shoot K concentration. Furthermore, alfalfa plants continue to absorb K even when available K exceeds plant needs. This unique property of K plant uptake called "luxury consumption" (Havlin *et al*., 1999) was observed in which the alfalfa plants continued to absorb K in excess of needs for dry matter production so that large amounts of K were accumulated without any increase in crop yield. The reasons for this high uptake are not clear but it should be remembered that K fulfills many physiological and biochemical functions, which are not necessarily directed towards dry matter yield production.

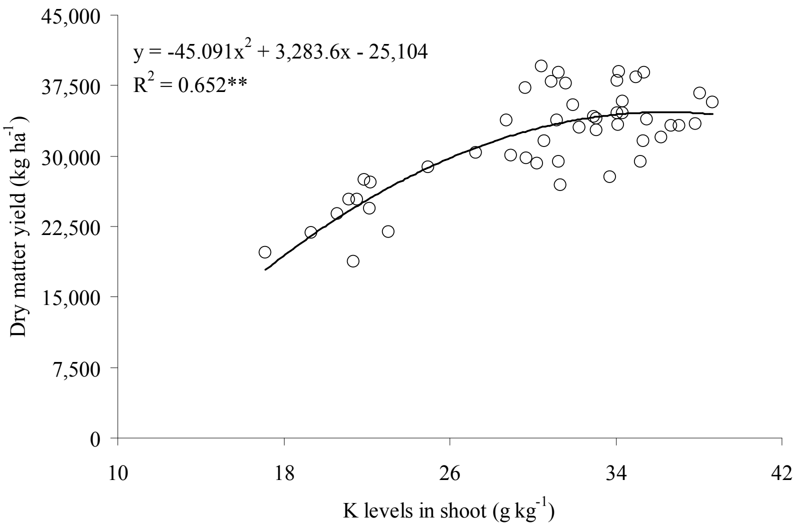

Fig. 3. K concentration in alfalfa shoots in relation to dry matter yield. Results from the first cropping season.

The total amount of K removed with the aboveground herbage increased with applied K and frequency of application (Fig. 4), as was observed for dry matter yield. Removal of K_2O reached 704 kg ha^{-1} per year with the application of 1,623 kg K_2O ha^{-1}, as compared with 205 kg K_2O ha^{-1} for the control treatment. Lloveras *et al*. (2001) found linear increases in potassium removal with increased K fertilization.

Potassium fertilization increased the exchangeable K of the soil in all three soil layers measured; the higher the application rate, the higher the exchangeable K value observed (Fig. 5). No difference in soil K_{ex} was found in relation to the number of K applications. Alfalfa has a lower root density than most grasses and generally a deeper rooting zone where soil moisture is available. Despite this deep root system, Peterson *et al*. (1983) reported that alfalfa absorbed K to the

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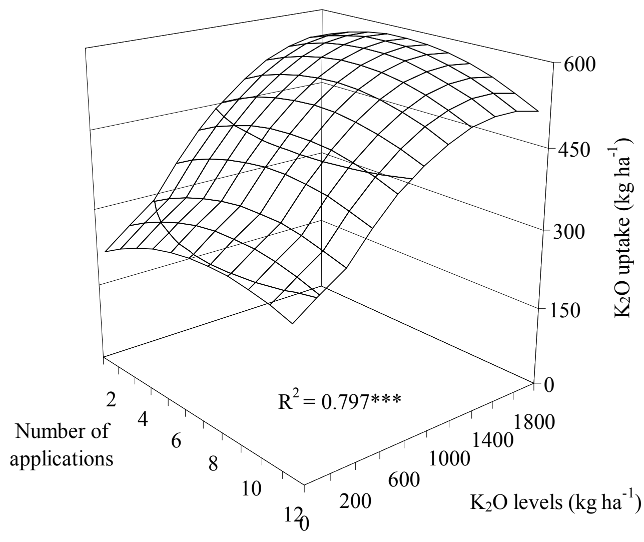

Fig. 4. Alfalfa total K uptake (K_2O units) in aboveground biomass in response to level of K and number of applications. Results from the first cropping season.

$y = -0.0001K^2+0.395K-1.877T^2+30.818T-0.005KT+170.9$

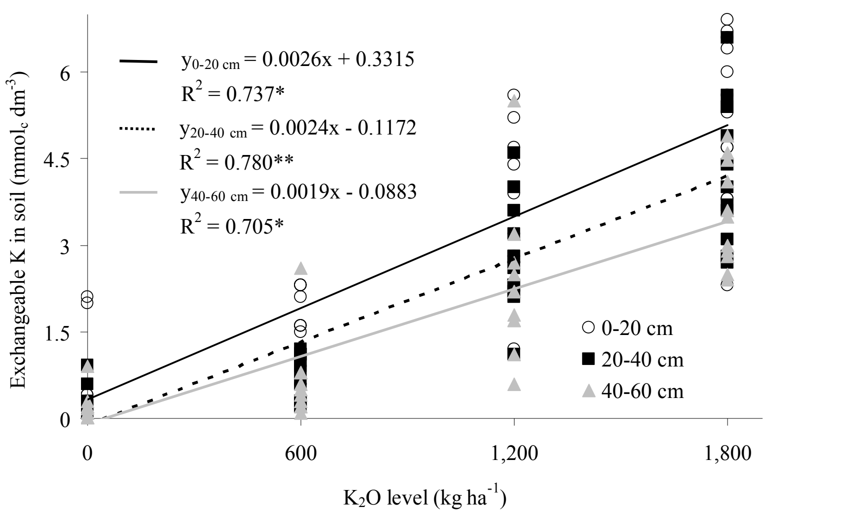

Fig. 5. Exchangeable potassium of the soil measured at three depths in relation to potassium fertilizer application.

greatest extent from the surface soil as compared with the Ap (cultivated soil) and deeper horizons. This finding supports the efficacy of topdressing K fertilizer onto existing stands of alfalfa when needed, as is commonly practiced.

Potassium leaching depends on the concentration of K in the soil solution, the amount of water moving through the soil, and the ability of the soil to bind K (Havlin *et al.*, 1999; Wilcke and Lilienfein, 2005). Considering the high levels of potassium fertilizer used in this experiment and the low ability of tropical soil to adsorb and hold K (due to low cation exchange capacity CEC) it is not surprising that K movement was observed in the soil profile leading to values which are considered high by Raij *et al.* (1997) (>3,1 mmol$_c$.dm^{-3} at 0.2-0.4 and 0.4-0.6m-depths). In our experiment, values of exchangeable K in the soil for achieving the maximum two years-average yield (30.5 mt ha^{-1}) as calculated from equations in Fig. 6 were 3.4; 1.9 and 1.6 mmol$_c$.dm^{-3} K at 0-20, 20-40 and 40-60 cm, respectively.

Conclusions

For both crop seasons, the use of 1,420 kg ha^{-1} per year of K_2O applied after every two cuttings (6 applications per year) markedly increased alfalfa dry matter yield.

Soil exchangeable K increased with increasing K rates to 0.6m depth. The number of applications had no effect on this and at all K rates, the 0-20 cm layer was enriched to a greater extent than the 20-40 cm, which in turn was enriched to a greater extent than the 40-60 cm layer.

Results from the first cropping season indicate that total alfalfa shoot K removal reached 704 kg ha^{-1} of K_2O with the application of 1,623 kg ha^{-1} of K_2O per year. Potassium fertilizer recommendations should take into account the high removal rates at harvest, as well as potential leaching.

References

Havlin, J, J.D. Beaton, S.L. Tisdale, and W.L. Nelson. 1999. Soil fertility and fertilizers: an introduction to nutrient management. Upper Saddle River: Prentice Hall.

Humphries, A, G. Auricht, and E. Koblet. 2004. Lucerne variety – Sardi Ten. South Australian Research and Development Institute. Available at: www.sardi.sa.gov.au.

Kafkafi, U, R. Gilat, and D. Yoles. 1977. Studies on fertilization of field-grown irrigated alfalfa. Plant Soil. 46:165–173.

Lanyon, L.E., and F.W. Smith. 1985. Potassium nutrition of alfalfa and other forage legumes: Temperate and tropical. *In*: Munson, R.D. (ed.) Potassium in Agriculture. ASA, Madison, WI, USA.

Lloveras, J, J. Ferran, J. Boixadera, and J. Bonet. 2001. Potassium

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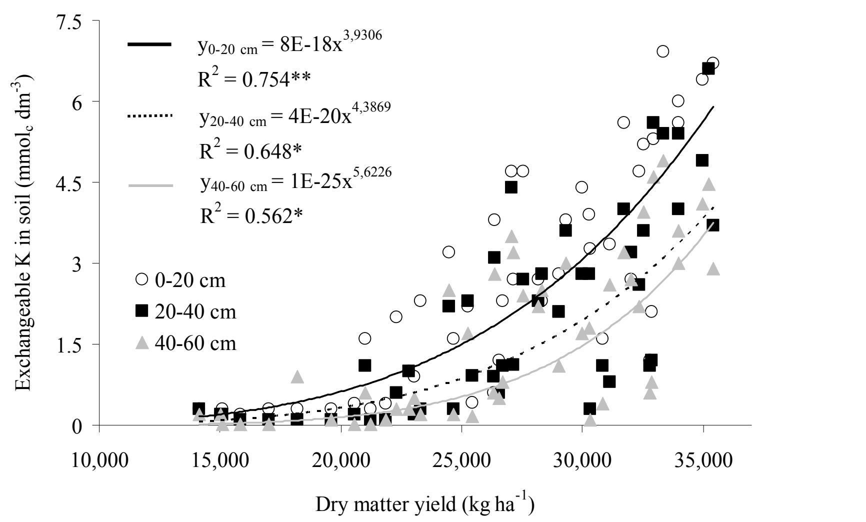

Fig. 6. Alfalfa dry matter yield as a function of exchangeable K of the soil at three soil depths.

fertilization effects on alfalfa in a Mediterranean climate. Agron. J. 93:139-143.

Mengel, K., and E.A. Kirkby. 2001. Principles of Plant Nutrition. Kluwer, 5th edition. p. 848.

Nogueira, A.R.A., A.O. Matos, C.A.F.S. Carmo, D.J. Silva, F.L. Monteiro, G.B. Souza, G.V.E. Pitta, G.M. Carlos, H. Oliveira, J.A. Comastri Filho, M. Miyazawa, and W. Oliveira Neto. 2005. Tecidos vegetais. *In*: Nogueira, A.R.A, and G.B. Souza (eds.) Manual de laboratórios: Solo, água, nutrição vegetal, nutrição animal e alimentos. São Carlos: Embrapa Pecuária Sudeste. p. 151-199.

Peterson, L.A., D. Smith, and A. Krueger. 1983. Quantitative recovery by alfalfa with time of K placed at different soil depths for two soil types. Agron. J. 75:25-30.

Raij, B. Van., H. Cantarella, J.A. Quaggio, and A.M.C. Furlani. 1997. Interpretação de resultados de análise de solo. *In*: Raij B. Van, H. Cantarella, J.A. Quaggio, and A.M.C. Furlani. Recomendação de adubação e calagem para o Estado de São Paulo. Campinas: IAC. p. 8-13.

Rassini, J.B., and A.R. Freitas. 1998. Desenvolvimento da alfafa (*Medicago sativa*) sob diferentes doses de adubação potássica. Rev Bras Zoot. 27:487-490.

Rice, J.S., V.L. Quinsenberry, and T.A. Nolan. 1989. Alfalfa Persistence and Yield with Irrigation. Agron. J. 81:943-946.

Sheaffer, C.C., M.P. Russelle, O.B. Hesterman, and R.E. Stucker. 1986. Alfalfa response to potassium, irrigation and harvest management. Agron. J. 78:464-468.

Smith, D. 1975. Effects of potassium topdressing a low fertility silt loam soil on alfalfa herbage yields and composition and on soil K. Agron J. 67:60–64.

Werner, J.C., V.T. Paulino, H. Cantarella, N.O. Andrade, and J.A. Quaggio. 1997. Forrageiras. *In*: Raij B Van, Cantarella H, Quaggio JA, Furlani AMC. Recomendação de adubação e calagem para o Estado de São Paulo. Campinas: IAC. p. 263-273.

Wilcke, W., and J. Lilienfein. 2005. Nutrient leaching in oxisols under native and managed vegetation in Brazil. Soil Sci. Soc. Am. L. 69:1152-1161.

The paper "Potassium Doses and Frequency of Application to Alfalfa Growing on a Brazilian Tropical Soil: Influence on Dry Matter Yield and K Content of the Harvested Crop and Exchangeable soil K" appears also at:

Regional Activities/Latin America

Cattle feeding on fertile alfalfa fields. Photo by A. Bernardi.