PEANUT RESPONSE TO LIME AND MOLYBDENUM APPLICATION IN LOW pH SOILS[1]

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SUMMARY

Liming acid soils is considered to assure the availability of Mo in crops. Additionally, in peanuts (*Arachis hypogaea* L.) the positive response to liming is associated to a better supply of Ca^{+2}, Mo for the nitrogenase-complex activity, and other non-nitrogen fixing activities of the crop. This study was thus undertaken to assess the effect of lime, Mo, and the lime-Mo interaction on peanut crop, on an acid Ultisol at the Mococa Experimental Station, Instituto Agronômico, São Paulo State, Brazil, from 1987 to 1990. A randomized complete block design with four replications, in a 4 x 4 factorial arrangement, was used in the study. The factors included four lime rates (0, 2, 4, and 6 t ha^{-1}) broadcast and incorporated into the soil, and Mo (0, 100, 200, and 300 g ha^{-1}) as $(NH_4)_2MoO_4$ applied as seed dressing. Lime was applied once at the beginning of the study while Mo was applied at every planting. Peanut seed cv 'tatu' was used. Significant increase in peanut kernel yield with liming was only evident in the absence of Mo, whereas the peanut response to Mo was observed in two out of the three harvests. A higher yield response (28 % increase) was found when Mo was applied without liming. Soil molybdenum availability, as indicated by plant leaf analysis, increased significantly when lime was applied. Molybdenum fertilization led to higher leaf N content, which in turn increased peanut yield in treatments with smaller lime doses.

Index terms: *Arachis hypogaea*, liming, molybdenum, nitrogen fixation

[1] Recebido para publicação em junho de 2002 e aprovado em junho de 2004.
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RESUMO: *RESPOSTA DO AMENDOIM À CALAGEM E AO MOLIBDÊNIO EM SOLO ÁCIDO*

A calagem em solos ácidos tem sido considerada prática suficiente para garantir a disponibilidade de molibdênio para as culturas. Adicionalmente, seu efeito positivo na cultura do amendoim tem sido associado ao melhor fornecimento de cálcio, maior disponibilidade de molibdênio para o complexo nitrogenase, e outros processos na planta não relacionados com a fixação biológica de N. Esse trabalho foi realizado, com vistas em estudar os efeitos de doses de calcário e de molibdênio e suas interações na cultura do amendoim, num Argissolo ácido da Estação Experimental de Mococa do IAC durante três safras (1987 a 1990). Foi empregado o delineamento em blocos, com quatro repetições, num esquema fatorial 4 x 4. Os tratamentos constituíram das doses de 0, 2, 4 e 6 t ha^{-1} de calcário calcinado e de 0, 100, 200 e 300 g ha^{-1} de Mo, aplicadas como tratamento de sementes, na forma de molibdato de amônio. O calcário foi aplicado uma única vez no início do ensaio, enquanto o Mo foi aplicado anualmente por ocasião do plantio. Foi utilizado o amendoim cv. Tatu. Houve resposta significativa da produção de grãos à calagem apenas na ausência de Mo, enquanto a resposta do amendoim ao Mo foi observada em duas das três safras estudadas. Foi encontrado um maior ganho de produção (28 %) quando o Mo foi aplicado na ausência de calagem. A disponibilidade de Mo no solo, avaliada por meio da análise de folhas, aumentou significativamente com a calagem. A aplicação de Mo proporcionou maior concentração de nitrogênio nas folhas, o que aumentou a produtividade do amendoim nos tratamentos com doses mais baixas de calcário.

Termos de indexação: Arachis hypogaea*, calagem, molibdênio, fixação de nitrogênio.*

INTRODUCTION

Peanuts (*Arachis hypogaea* L.), a legume, is an important crop for oil production and also a protein source (Krishna, 1997). It is grown on many soil types including those that are highly weathered and acidic (Gascho et al., 1993). Studies in such soils suggest a deficiency of available molybdenum (Mo) (Adams et al., 1990). Molybdate is sorbed by the soil (Goldberg & Forster, 1998); however, molybdate sorption is highly sensitive to the soil pH and decreases with increases in soil pH (Adams et al., 1990; Goldberg & Forster, 1998). Therefore, liming is an effective means of increasing the available molybdenum in such soils (Rosolem & Caires, 1998; Quaggio et al., 1998; Hodges et al., 1994).

Molybdenum is one of the micronutrients required for plant growth and development. It is essential for the reduction of nitrate in plants (Sedbeery et al., 1993). Symptoms of Mo deficiency have been characterized in many crops including peanuts (Sedbeery et al., 1993). More pronounced deficiencies have been observed under acid soil conditions (Adams et al., 1990).

Molybdenum, which constitutes part of the enzyme nitrogenase, is also essential for symbiotic nitrogen fixation; Mo deficiencies are therefore much more pronounced in legumes (Bailey & Laidlaw, 1999). Since peanut is a legume, it is highly susceptible to Mo deficiency when grown in acidic soils. This affects its ability to nodulate and symbiotically fix atmospheric nitrogen (Simbajon & Duque, 1987; Bailey & Laidlaw, 1999). This study, therefore, investigated the effect of lime and molybdenum and their interaction on peanut yields on a low pH soil.

MATERIAL AND METHODS

The study was conducted over three consecutive years (1987/88, 1988/89, and 1989/90) on an acidic Ultisol of the Mococa Experimental Station, Instituto Agronômico, Mococa, São Paulo State, Brazil. The following analysis results described the original soil characteristics: $pH_{(CaCl_2)}$ 4.2; exchangeable Ca, Mg, and K, in $mmol_c\ dm^{-3}$, 10, 4, and 2.1 respectively, and 21 % soil base saturation. A randomized complete block design with four replications in a 4 x 4 factorial arrangement was used in the study. The factors consisted of four lime rates (0, 2, 4, and 6 t ha^{-1}) and molybdenum (0, 100, 200, and 300 g ha^{-1}). Burnt dolomitic limestone (127 % $CaCO_3$ equivalent) and ammonium molybdate ($(NH_4)_2MoO_4$) were used as lime and molybdenum sources, respectively. The lime treatments were applied once at the beginning of the study by broadcasting and mixing with the topsoil (depth 0 to 5 cm), before deep incorporation by ploughing to the depth of 30 cm, three months prior to planting in 1987. The treatments were set up in plots of 6 rows of 6 m in a spacing of 0.6 by 0.1 m between and within the rows, respectively, and were maintained on the same plots throughout the study period. Basic fertilization (0-20-15 NPK formula at a rate of 400 kg ha^{-1}) was applied each year at planting to all plots.

One year after liming, 15 soil samples from the plough layer were randomly collected with auger, mixed, dried, ground, sieved (2 mm), and used to evaluate the soil pH, phosphorus and organic carbon contents, exchangeable bases, and exchangeable acidity as described by Raij & Quaggio (1983).

Leaf samples, composed by 100 leaves per plot, were taken every year at flowering by collecting the third leaf from the top. The samples were washed, dried at 35 °C, and ground prior to total nutrient content analyses according to methods described by Bataglia et al. (1983).

Certified peanut (*Arachis hypogaea* L.) cv. 'tatu' seeds were dressed with 0, 2.8, 5.6, and 8.4 g $(NH_4)_2MoO_4$, respectively, per 1.200 g of seeds. The seeds were then inoculated with *Bradyrhizobium sp* in each study year. No nitrogen fertilizer was applied throughout the study period. Other agricultural practices recommended for growing peanuts in Brazil were observed.

The statistical analysis of evaluated variables were based on variance and regression analyses using the Minitab Statistics Program (Minitab, 2000).

RESULTS AND DISCUSSIONS

Soil chemical analyses one year after the application of lime and molybdenum showed that liming increased exchangeable Ca and Mg and the soil base saturation linearly, while the soil pH increased from 4.2 in control plots to 5.7 in the plot under the highest liming rate (Table 1).

The peanut yield increase due to liming was not statistically significant, but the lime-Mo interaction was significant in all studied harvests (Table 2). The response of peanut to lime was quite linear in absence of Mo. This could be more related to the increase of Mo availability than to soil acidity neutralization, because no response to liming was observed where the smallest rate of Mo was applied (Figure 1).

Molybdenum application without lime in 1988/89 and with lime in 1987/88 and 1989/90 significantly increased the yields. However, the applied Mo with or without lime increased the average yields significantly in any case. In absence of liming, the calculated maximum yield was obtained with 186 g ha^{-1} Mo, corresponding to a 28 % increase in relation to the plots without Mo. Peanut response to Mo was closely related (R^2 = 0.90**) to the increase in nitrogen fixation, evaluated by the concentration of this nutrient in the leaves (Figure 2). Molybdenum deficiency symptoms were

Table 1. The effect of lime and Mo and their interactions on the soil chemical characteristics one year after liming

Lime rate	Mo rate	Resin P	Organic matter	pH $CaCl_2$	Exchangeable cations			H + Al	Sum of bases	Base saturation
					K	Ca	Mg			
t ha^{-1}	g ha^{-1}	mg kg^{-1}	g kg^{-1}		——— $mmol_c$ dm^{-3} ———					%
0	0	16	23	4.2	1.8	8	3	64	13	17
	100	9	22	4.3	1.6	8	3	62	13	17
	200	12	25	4.2	1.7	7	3	68	11	15
	300	12	22	4.2	1.8	7	3	64	12	16
2	0	14	25	4.8	1.4	14	8	45	23	35
	100	10	23	4.8	1.8	13	7	42	21	34
	200	12	26	4.6	1.7	13	6	51	21	29
	300	14	25	4.6	1.9	13	6	49	21	31
4	0	14	24	5.0	1.3	18	8	36	27	43
	100	11	24	5.2	1.6	17	9	35	28	44
	200	13	24	5.0	1.6	16	9	39	26	40
	300	12	24	5.1	1.5	15	9	38	26	41
6	0	14	26	5.6	1.3	22	12	31	36	54
	100	13	22	5.9	1.3	22	13	27	35	57
	200	16	25	5.5	1.7	22	12	32	36	51
	300	14	23	5.8	1.5	23	13	28	36	56
F-test:										
Lime		ns	ns	***	**	***	***	**	**	**
Mo		ns	ns	ns	ns	ns	ns	ns	ns	ns
Lime x Mo		ns	ns	ns	ns	ns	ns	ns	ns	ns
C.V. (%)		54	1	8	16	25	30	17	8	24

Table 2. Effect of lime and Mo and their interaction on peanuts yields

Lime rate	Mo rate	Period			Mean yi
		87/88	88/89	89/90	
t ha^{-1}	g ha^{-1}		kg ha^{-1}		
0	0	1855	2075	2188	2039
	100	2163	2633	3073	2623
	200	2113	2660	2990	2588
	300	1723	2948	2820	2497
Mean		1963	2579	2768	2437
2	0	2107	2218	2515	2280
	100	1770	2453	2723	2315
	200	2435	2393	2676	2501
	300	1635	2665	2800	2367
Mean		1987	2432	2678	2366
4	0	1733	2605	2888	2409
	100	2143	2535	2538	2405
	200	2323	2688	2853	2621
	300	2308	2632	2678	2540
Mean		2126	2615	2739	2494
6	0	2453	2310	2953	2572
	100	1895	2753	2830	2493
	200	1770	2633	2828	2410
	300	2018	2598	2873	2496
Mean		2034	2573	2871	2492
F-test:					
Lime		ns	ns	ns	ns
Mo		ns	**	*	*
Lime x Mo		**	*	**	**
C.V. (%)		15	11	9	7

* and **: statistically significant at $P < 0.05$ and $P < 0.01$, respectively.

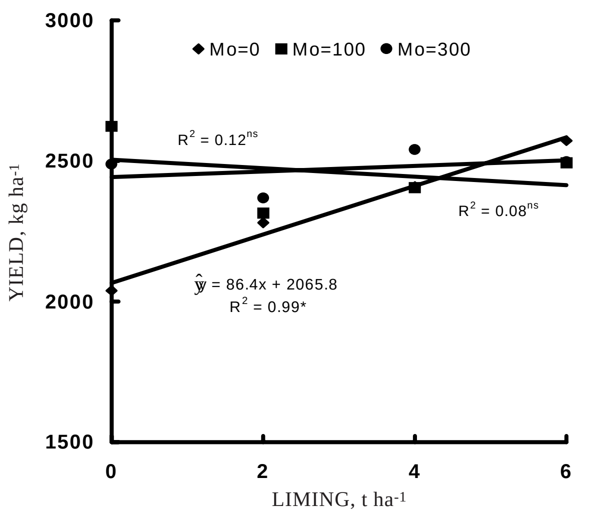

Figure 1. Lime and molybdenum interaction on peanut yield in low pH soil. Results of treatments with no lime application (averaged of three successive harvests). * and ^{ns} significant at 0.05 probability and non significant respectively.

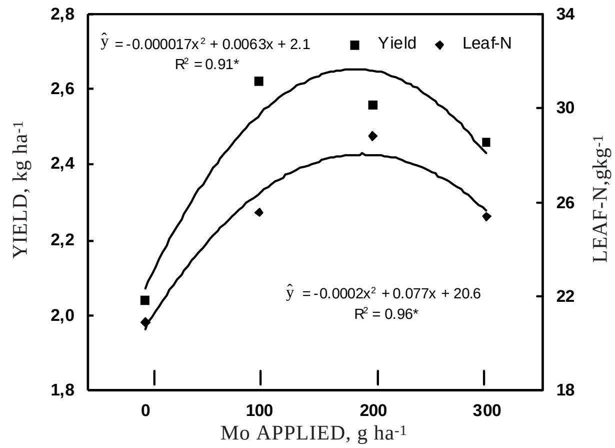

Figure 2. Effects of molybdenum rates on yield and nitrogen concentration in peanut leaves. Data of treatment without lime application. (Averaged results of three successive harvests) * significant at 0.05 probability.

only observed in control plots with a leaf Mo concentration around 2.0 mg kg^{-1}. These symptoms were characterized by a general yellowing of the foliage and tip necrosis of the young leaves (Figure 4). These symptoms were earlier described as symptoms of Mn toxicity (Nakagawa et al, 1987), but they were not observed in plots with a leaf Mo higher than 3.0 mg kg^{-1}, which was attained by both lime and molybdenum application.

Liming increased Ca and Mo significantly but decreased Mn and Zn contents in peanut leaves. Molybdenum applied with lime caused an increase in N and, without lime, an increase in N and in leaf Mo concentration (Table 3). A significant positive correlation was only found between the applied Mo and leaf N content. Leaf-N contents above 26 g kg^{-1} were associated with leaf Mo around 4.0 mg kg^{-1}. However, at the highest leaf N contents leaf Mo tended to decrease due to dilution effects (Figure 3).

The effect of lime on peanut yield depends on many factors including the initial Ca and Mo status of the soil, the time of lime application, and the peanut cultivar in use (Caires et al., 1991; Gascho et al., 1993; Hodges et al., 1994). Peanut cultivars with large seeds, as for example the Virginia and Valencia types, require considerably higher lime inputs to manifest any significant improvement in yields or grain quality. The results found in this study with soil liming are consistent with those of Rosolem & Caires (1998) on a similar soil type in Brazil. The yield increase when Mo was applied without lime could be attributed to the increase in available Mo concentration in the soil. This enabled the plant to fix atmospheric nitrogen and also incorporate the nitrate taken up from the soil. This led to an increase of vegetative growth and consequently to higher kernel per pod yield.

Table 3. Effect of lime, Mo and their interaction on peanut leaf nutrient content (Averaged results of three harvests)

Lime rate	Mo rate	Foliar content										
		N	P	K	Ca	Mg	Cu	Fe	Mn	Mo	Zn	Al
t ha^{-1}	g ha^{-1}	——— g kg^{-1} ———					——— mg kg^{-1} ———					
0	0	20.9	1.7	17.4	15.3	5.0	6.8	300	212	2.0	31.4	598
	100	25.6	1.6	18.4	14.1	5.1	8.7	418	223	3.0	30.4	807
	200	28.8	1.6	21.0	14.6	5.1	9.6	308	256	3.6	37.0	598
	300	25.4	1.5	19.9	12.1	4.9	8.3	369	243	2.7	31.0	750
2	0	23.7	1.9	18.4	16.8	6.4	8.2	371	189	3.4	33.1	782
	100	26.8	1.6	18.2	16.5	5.3	8.7	290	126	4.7	26.5	586
	200	25.5	1.7	19.5	12.8	5.0	8.3	373	142	4.7	25.3	763
	300	27.6	1.7	19.6	15.4	6.1	9.1	443	197	4.6	31.9	913
4	0	22.7	1.8	19.2	17.6	5.5	8.5	296	136	3.6	27.2	635
	100	28.9	1.6	18.3	16.1	5.4	8.2	441	71	3.6	21.8	895
	200	28.6	1.6	18.8	14.8	5.8	8.9	315	133	4.6	24.9	618
	300	27.4	1.6	17.8	13.9	5.3	8.5	311	119	4.1	30.1	629
6	0	28.4	1.7	17.1	17.5	6.0	8.5	357	113	2.5	29.6	718
	100	30.4	1.6	20.0	17.8	5.9	9.1	324	88	3.7	21.4	643
	200	24.8	1.6	17.4	14.1	5.3	8.5	429	99	4.9	20.5	939
	300	26.2	1.7	18.3	15.0	6.2	8.8	370	133	4.1	25.5	776
F test:												
Lime		ns	ns	ns	**	ns	ns	ns	**	*	**	ns
Mo		**	ns	ns	**	ns	ns	ns	*	*	*	ns
Lime x Mo		*	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
C.V. (%)		10.5	11.1	9.2	13.9	11.8	12.9	26.3	26.9	38.2	20.6	26.6

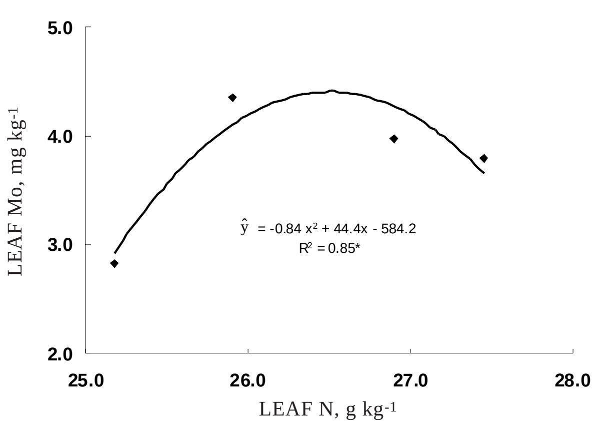

Figure 3. Relationship between leaf N and Leaf Mo in peanut crop established in four lime rates, averaged in three successive harvests. (Data for Mo rates were averaged) * significant at 0.05 probability.

In absence of liming, a significant quadratic relationship was found between leaf nitrogen content and the amount of Mo applied to the soil (Figure 2). Gascho et al. (1993), Sahu et al. (1998),

Figure 4. Molybdenum deficiency symptoms in peanut crop.

and Rosolem & Caires (1998) also found consistent results and attributed the increase in peanut yields to increased growth and development to Mo application. The yield increase when lime and Mo were applied could be explained by several reasons including that the increasing soil reaction increased available Mo, as a result of liming. The increase in soil Mo concentration due to liming is well documented (Goldberg & Forster, 1998).

The yield increase could also be related to an increased concentration of basic cations in the soil solution (Table 1), particularly Ca, that could have complemented the effect of Mo on the nutrition of the peanut plant. Calcium plays a fundamental role in the peanut nutrition, especially at the pod development; Ca deficiency at this stage would have a negative effect on yields (Hodges et al., 1994; Fernandez et al., 2000). The ameliorating effect of lime on Al and Mn toxicity and the increase in available N, P, and Mo could also have contributed to the yield increase. These effects could have improved the soil conditions for plant growth (Table 1), and reduced the adsorption of the applied Mo to the soil. Sahu et al. (1995; 1998) studied peanut response to lime and Mo on acidic soil environment and furthermore observed that the yield increase was due to the increased efficiency of Mo associated to the lime application.

CONCLUSIONS

1. Although liming significantly reduced the soil acidity, its effect on peanut yields was only significant in absence of Mo.

2. The peanut yield was more limited by molybdenum deficiency than by soil acidity in this low pH soil.

3. In absence of lime, a seed-dressed Mo rate of 186 g ha^{-1} produced maximum peanut yields.

4. The molybdenum rate for a maximum peanut yield decreased as the lime rate increased.

ACKNOWLEDGMENTS

The authors thank the CNPq (Conselho Nacional de Desenvolvimento Científico e Tecnológico) and the Third World Academy of Science for research fellowship and support.

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