RESIDUAL EFFECTS OF POTASSIUM AND MAGNESIUM ON SOYBEAN YIELD AND ON DISEASE INCIDENCE IN A CERRADO DARK-RED LATOSOL[1]

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ABSTRACT - Soybean cultivar Paraná was grown in 1981-81 at EMBRAPA/CPAC, at Planaltina, Brazil, to determine the residual effects of levels of K and Mg applied in 1975, upon the yield and seed quality and the severity of diseases caused by *Phomopsis* spp. and *Colletotrichum truncatum* on soybean stems. Decreasing yields and seed quality were associated with decreasing soil K and/or Mg levels. Foliar K levels were directly related to soil K levels while foliar Mg levels were inversely related to soil K. Foliar K content of 1.3% was sufficient for maximum seed production. Annual return of crop residue increased soil K and Mg, foliar K and Mg, and cation exchange capacity but not soil organic matter. There was no difference among K treatments in amount of fruiting structures of *C. truncatum* and *Phomopsis* spp. on soybean stems.

Index terms: *Glycine max*, *Phomopsis*, *Colletotrichum truncatum*, critical foliar K, critical foliar Mg level, crop residue.

EFEITO RESIDUAL DE POTÁSSIO E MAGNÉSIO NA PRODUÇÃO DE GRÃOS E NAS DOENÇAS DE SOJA NUM LATOSSOLO VERMELHO-ESCURO DE CERRADO

RESUMO - A cultivar de soja Paraná foi cultivada em 1981-82 no CPAC, em Planaltina, Brasil a fim de se determinar os efeitos residuais dos níveis de K e Mg, aplicados em 1975, sobre a produção e qualidade das sementes, assim como o grau das doenças causadas pelo *Phomopsis* spp. e pelo *Colletotrichum truncatum* nos caules das plantas de soja. A redução verificada na produção e na qualidade das sementes foi associada à redução dos níveis de K e/ou Mg no solo. Os teores foliares de K foram diretamente correlacionados aos níveis de K no solo, enquanto que os teores foliares de Mg foram inversamente correlacionados aos níveis de K no solo. O teor foliar de 1,3% de K foi suficiente para máxima produção de semente. O retorno anual dos restos culturais aumentou os níveis de K e Mg do solo e das folhas e a capacidade de troca de cátions, mas não da matéria orgânica do solo. Não houve diferenças entre tratamentos de K nas quantidades de estruturas de frutificação de *C. truncatum* e *Phomopsis* ssp. nos caules das plantas de soja.

Termos para indexação: *Glycine max*, *Phomopsis*, *Colletotrichum truncatum*, nível crítico foliar de K, nível crítico foliar Mg, restos culturais.

INTRODUCTION

There is a high potential for leaching losses of nutrients such as potassium and magnesium in highly weathered soils with low cation exchange capacity (CEC), such as those of the Cerrado. The evaluation of the residual effects of these elements is important because of their low initial levels in the soil (Lopes 1975) and because of their very low reserves in the soil, clay fraction which consist predominantly of kaolinite and gibbsite (Rodriguez 1977).

The effective CEC (2.29 meq/100 g), the negative charge (2.66 meq/100 g) and the potassium buffering capacity of Cerrado soil are very low (Souza et al. 1979). Consequently, low retention of cations and high leaching losses are expected. These authors showed that the application of 300 kg of K_2O/ha caused leaching of K to a depth of 60 cm in the first cropping. However, Silva & Ritchey (1982) showed that maize recycles potassium such that the potassium absorbed from

[1] Accepted for publication on April 7, 1987.
This study was supported in part by the United States Agency for International Development under research contracts with North Carolina State University, csd-2806, ta-c-1236, and with Cornell University, csd-2490, ta-c-1104, ta-c-1441, and grants-in-aid from the Potash Institute (Atlanta) and the International Potash Institute (Berne).

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the soil is carried to the leaves, and from there is washed by the rain and returned back to the soil, thus reducing markedly the potential losses by leaching. If crop residues are incorporated into the soil rather than harvested, a considerable amount of potassium is recycled (Vilela & Ritchey 1985).

Magnesium leaching in cerrado soils has not been studied extensively, however this element bonds to the sulfate anion to form a neutral ion pair which probably makes magnesium as susceptible to leaching losses as potassium.

Nutrient-stressed plants may be more vulnerable to disease than plants with an optimum nutritional level. One example is the effect of potassium decreasing the severity of many diseases (Huber 1980). Soybean pathogens such as *Colletotrichum truncatum* (Schw.) Andrus & Moore (anthracnose) and *Phomopsis* spp. (pod and stem blight, stem canker, and seed decay) are major problems on stems, pods and seeds in tropical regions and can result in reduced yield (Sinclair & Shurtleff 1975). Low soybean seed quality due to *Phomopsis* spp. was associated with potassium deficiency by Crittenden & Svec (1974), Camper & Lutz Junior (1977) and Mascarenhas et al. (1977), while Jeffers et al. (1982), Spilker et al. (1981) and Svec et al. (1976) showed that the degree of soybean seed infection with fungi was not affected by potassium fertilization.

The objective of this study was to evaluate the residual effect of rates of potassium and magnesium applied six years previously (1975) on yield and disease incidence in Paraná soybeans in 1981-82.

MATERIALS AND METHODS

The soybean crop was grown in an allic clayey Dark-Red Latosol (Oxisol), with pH 4.6 (soil: water = 1:2.5), 1.1 meq/100 ml exchangeable Al, 0.34 meq/100 ml Ca + Mg, and aluminum saturation approximately 72% of the effective CEC. Originally the soil had 0.061 meq/100 ml K. The original cerrado vegetation of the area had been cleared some years previously and it was used as a natural pasture until the dry season of 1975 when it was cleared, plowed and levelled as reported by Ritchey et al. (1979).

In the first year, the K and Mg treatments listed in Table 1 were applied to 7.2 m by 14 m plots grouped in completely randomized blocks with four replications. The rates of magnesium were obtained from mixtures of

TABLE 1. Effect of magnesium content in limestone and potassium fertilization on extractable soil magnesium and potassium in 1981/1982 and on Paraná soybean grain yield in a Dark-Red Latosol.

Treatment	Mg added		K_2O added							Total K_2O applied	Soil K	Soil Mg	Grain yield
	1975/ 1976	1980/ 1981	1975/ 1976	1976/ 1977	1977/ 1978	1978/ 1979	1979/ 1980	1980/ 1981	1981/ 1982				
	kg/ha					kg/ha					meq/100 g		kg/ha
1R[1]	345	3	-	-	-	-	-	-	-	0	0.041	0.32	699
1M	345	3	-	100	-	-	-	-	-	100	0.039	0.40	819
2R	345	3	75	-	-	-	-	-	2F 75[4]	150	0.121	0.34	2.231
2M	345	3	75	100	-	-	-	-	2C 75[4]	250	0.154	0.33	2.357
3R	345	3	150	-	-	-	-	-	-	150	0.046	0.31	1.070
3M	345	3	150	100	-	100	100	100	100	650	0.226	0.32	2.497
4R	345	3	300	-	-	-	-	-	-	300	0.047	0.40	1.079
4M	345	3	300	100	-	-	-	-	-	400	0.054	0.28	1.293
5R	345	3	600	-	-	-	-	-	-	600	0.070	0.42	1.921
5M	345	3	600	100	-	-	-	-	-	700	0.072	0.34	2.193
6R	345	3	150[3]	-	100	-	-	-	6F 75[4]	225	0.136	0.38	2.393
6M	345	3	150[3]	100	-	-	-	-	6C 75[4]	325	0.140	0.30	2.319
7R[2]	345	3	150	-	-	-	-	-	-	150	0.090	0.51	2.466
7M[2]	345	3	150	20	-	-	-	-	-	170	0.088	0.50	2.428
8	7	3	150	100	-	100	100	100	100	650	0.217	0.08	234
9	27	3	150	100	-	100	100	100	100	650	0.226	0.10	326
10	97	3	150	100	-	100	100	100	100	650	0.219	0.10	1.293
3M	345	3	150	100	-	100	100	100	100	650	0.226	0.32	2.497
F-protected lsd											0.020	0.14	326

[1] Based on a completely randomized design with 4 replications
[2] Crop residues were returned and incorporated annually
[3] Band applied
[4] The subplots were redivided perpendicularly to the previous division and 75 kg/ha K_2O as kalsilite or KCl were applied. Treatments 2F and 6F received kalsilite, and 2C and 6C received KCl.

calcitic and dolomitic limestone as shown in Table 2. In 1980, 3 t/ha of calcitic limestone (Total Relative Neutralizing Capacity 67%) were applied to the experiment. In 1981, the soil pH, measured in water, averaged 5.5 in all the treatments. The basic broadcast fertilizer application consisted of 320 kg/ha P_2O_5 (ordinary superphosphate), 9 kg/ha Zn (zinc sulfate), 1.1 kg/ha B (borax), and 0.2 kg/ha Mo (ammonium molybdate). The potassium treatments (as potassium chloride) were applied at the same time and mixed with the soil to a depth of 15 cm by Rotòvator. Subsequent applications of 400, 320, 80, 80 and 160 kg/ha P_2O_5 as ordinary superphosphate were made in 1975, 1976, 1978, 1979 and 1981, respectively.

TABLE 2. Quantities of calcitic and dolomitc limestone used for the various magnesium treatments.

Magnesium	Calcitic limestone[1]	Dolomitic limestone[2]
7	3.756	32
27	3.541	172
97	2.765	791
345	0	3000

[1] 32.1% Ca, 0.2% Mg, CCE = 78.87%; 2% was retained on the 10 mesh sieve, 8% on the 20 mesh and 45% on the 60 mesh.

[2] 22.1% Ca, 11.6% Mg, CCE = 100.4%; 1% was retained on the 10 mesh sieve, 30% on the 20 mesh and 45% on the 60 mesh.

The plots receiving different K rates (Table 1) were split lengthwise during 1976 to form "residual" and "maintenance" treatments designated as R and M, respectively. The M treatments received an additional application of 100 kg/ha K_2O in 1976, except for the 7 M treatment which received only 20 kg/ha. The crop residues of treatments 7 M and 7 R were returned annually and incorporated before the next planting season. Treatments 2C, 2F, 6C, and 6F were created in 1981 to compare the effects of kalsilite and KCl. Plots from the old 2 M and 2 R and 6 M and 6 R treatments were redivided crossways and 75 kg/ha K_2O of the two sources applied in 1981.

An early-maturing soybean variety, Paraná, was planted on 5 Nov. 1981 in 60 cm rows. The stand was thinned to 20 plants/meter. Soil samples (20 per plot at 0 cm 15 cm depth) were collected at time of planting an leaves were collected at early flowering stage. Sample were analyzed as described by Vettori (1969).

Plants were removed one week after harvest maturity from an area of 12 or 12.6 m^2 in the central part of each plot, and yields were corrected to 13% moisture content. Details of earlier yields are given by Souza et al. (1979), Ritchey et al. (1979) and Vilela & Ritchey (1985).

Seed germination was evaluated by maintaining seeds for three days on moist absorbent paper in a germination chamber maintained at 25.5°C and approximately 70% relative humidity. Damaged seeds were defined as those broken, chaffy or otherwise physically defective.

In order to evaluate disease incidence, ten 8 cm long stems per plot were cut from the mid-region of plants at harvest maturity and were rated for the presence of acervuli of *C. truncatum* and pycnidia of *Phomopsis* spp. as described previously (Cerkauskas et al. 1983) where 1 = 0%, 2 = 1% - 5%, 3 = 6% - 25%, 4 = 26&- 50%, and 5 = more than 50% of the stem covered by the fruiting bodies of the fungi. Values were square root transformed before statistical analysis.

Ratings for incidence and severity of marginal chlorosis and necrosis on foliage in the center two rows of each plot were made at full-pod growth stage using a Horsfall & Barratt rating system where a rating score from 0 to 11 was used which corresponded to the following respective intervals for percent foliar necrosis: 0, 0 to 3, 3 to 6, 6 to 12, 12 to 25, 25 to 50, 50 to 75, 75 to 88, 88 to 94, 94 to 97, 97 to 100 and 100. Ratings were converted with the Elanco conversion tables (ELANCO Products Co., Indianapolis, IN 46140 USA) to obtain mean percent values for all replicates. Higher numbers indicate more damage. All results were analyzed using the Statistical Analysis System (Barr et al. 1979), and differences were considered significant at the 5% level of probability.

RESULTS AND DISCUSSION

Trends in plant response to potassium were clearly visible 55 days after emergence (Fig. 1), and where soil K was 0.069 meq/100 ml (22 ppm) or less, plant dry weight was lower. Symptoms of potassium deficiency began to appear about 75 days after emergence with the outer one to two thirds of the margins of the upper leaves developing a bronze color (Plate 1). The development of symptoms in the upper part of the plant was described by Nelson & Barber (1964), although other authors state that potassium deficiency symptoms predominate in the lower part of the plant (Scott & Aldrich 1970). By 82 days after emergence the upper parts of the potassium deficient plants were necrotic.

The grain yield increased significantly as a function of the increase in soil K in the treatments

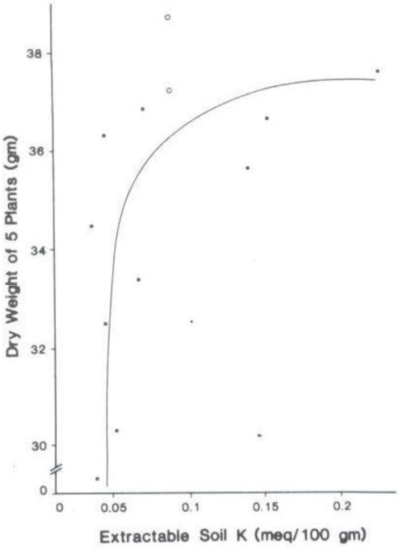
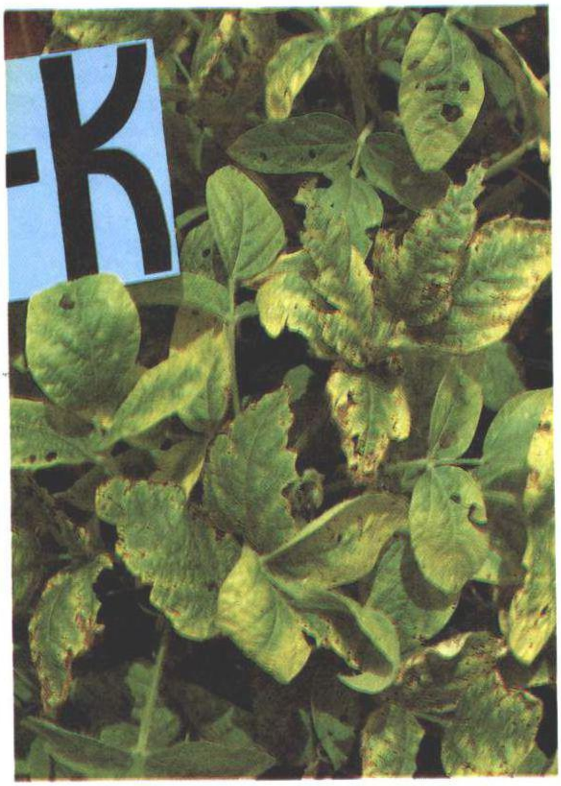


FIG. 1. Dry weight of 5 soybeans plants at 55 days after emergence as a function of Mehlich-1-extractable soil K. EMBRAPA-CPAC.



where the different rates of potassium fertilizer had been applied (Table 1).

Below 0.07 meq/100 ml (27 ppm) yields were markedly depressed, while little yield increase was observed where extractable soil K was above the critical level of 0.128 meq/100 ml Relatório Técnico Anual (1979) (Fig. 2).

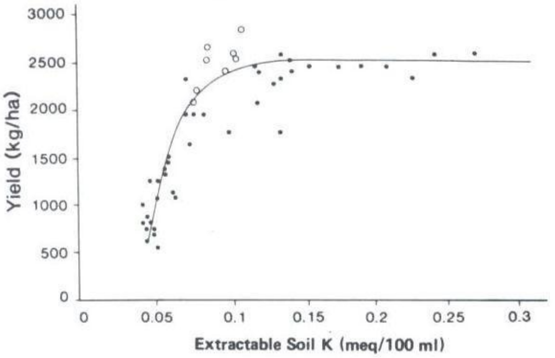


FIG. 2. Grain yield of Paraná soybeans as a function of Mehlich-1-extractable soil K. Open circles indicate plots where crop residues were returned and incorporated. EMBRAPA-CPAC.

There was no difference in yield between the treatments of 75 kg/ha K_2O applied in 1981 as KCl or applied as kalsilite, indicating that the two sources were equally efficient, at least for the first year. The rate, however, was within the range of the response curve where small differences in K availability would not affect yield.

Decreased yields were observed where leaf K contents were below about 1.3% (Fig. 3). This is lower than the 1.71% minimum sufficiency value cited by Small Junior & Ohlrogge (1973) for soybeans. The yields for the treatments receiving crop residues were higher than would have been predicted from the foliar K content. Foliar Mg decreased as soil K increased, falling from near 0.55 to 0.30 (Fig. 4). There was a major change in the ratio of foliar K to foliar Mg in consequence of the concurrent increase in foliar K (Fig. 5) foliar K/Mg ratio increased linearly with soil K, from 1 to 9 (data not shown).

Soil residual K in the top 15 cm as a function of fertilizer K applied in 1975/1976 and 1976/1977 is shown in Fig. 6. Mehlich-extractable-K increased by 0.0049 meq/100 ml for each 100 kg/ha K_2O added as fertilizer for the treatments where

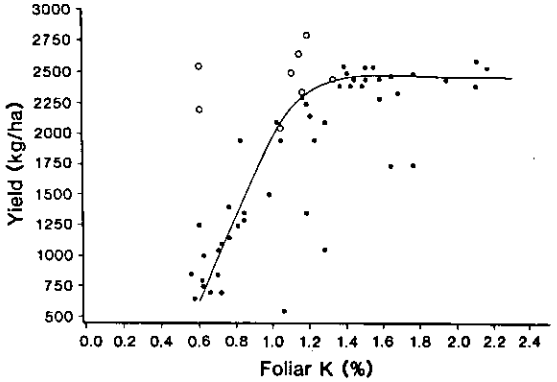


FIG. 3. Grain yield of Paraná soybeans as a function of foliar K. Open circles indicate plots where crop residues were returned and incorporated. EMBRAPA-CPAC.

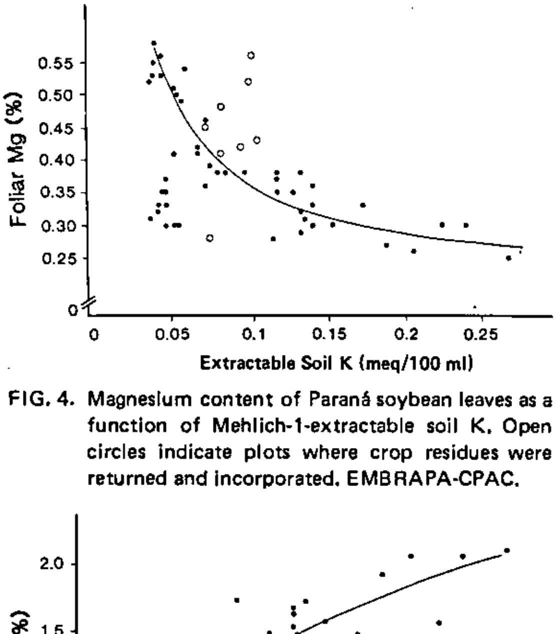


FIG. 4. Magnesium content of Paraná soybean leaves as a function of Mehlich-1-extractable soil K. Open circles indicate plots where crop residues were returned and incorporated. EMBRAPA-CPAC.

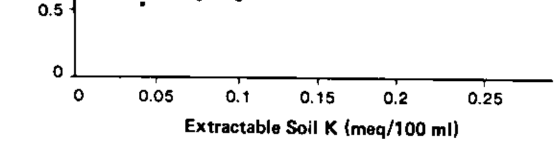


FIG. 5. Potassium content of Paraná soybean leaves as affected by Mehlich-1-extractable soil K. Open circles indicate plots shere crop residues were returned and incorporated. EMBRAPA-CPAC.

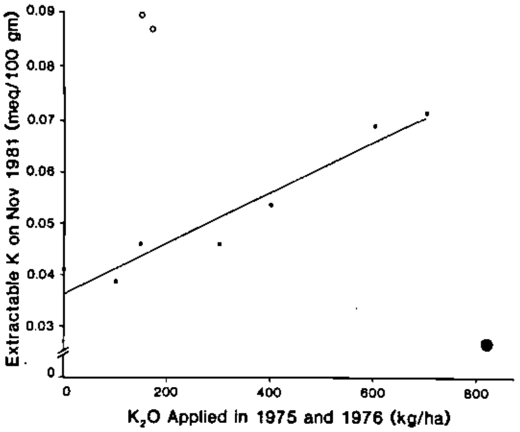


FIG. 6. Mehlich-1-extractable soil K present in the surface 15 cm on November 1981 as a function of potassium applied in 1975 and 1976. Open circles indicate plots where crop residues were returned and incorporated. EMBRAPA-CPAC.

crop residues were removed from the field. In this experiment, Souza et al. (1979) showed that exchangeable K corresponded to 124% of Mehlich--extractable-K. Calculations made using this factor showed that in the treatments where the above--ground portion of the crop was removed annually, 5.6% of the fertilizer originally applied was still present in the upper 15 cm of the soil profile after six years, for all rates of application from 0 to 700 kg/ha K_2O.

Yields as a function of fertilizer applied in 1975/1976 and 1976/1977 (Fig. 7) were higher for treatment 7, indicating that annual return of crop residue had been an important factor in the efficient use of K, as was demonstrated by Vilela & Ritchey (1985). Foliar K and Mg, and soil K and Mg were increased by this cultural practice. CEC, but not soil organic matter, was significantly higher in the residue incorporation treatments (3.88 meq/100 ml vs. grand mean of 3.41).

The 100 seed weight increased linearly from 12.5 g to 18.5 g as grain yield increased from 400 kg/ha to 2800 kg/ha in response to soil K levels. The number of seeds per m^2 increased from 400 to 1510 indicating that the increase in yields as a function of applied K was the result, principally, of the increase in the seed number.

There was more than a tend-fold increase in

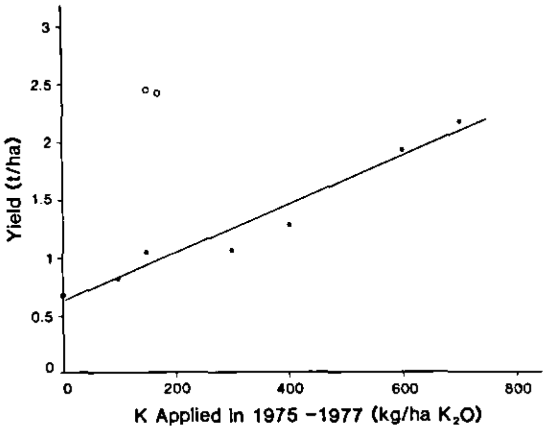


FIG. 7. 1982 grain yield of Paraná soybeans as a function of potassium fertilizer applied in 1975 and 1976. Open circles indicate plots where crop residues were returned and incorporated. EMBRAPA-CPAC.

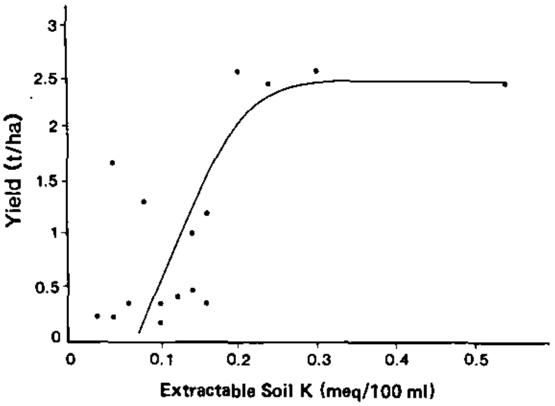


FIG. 8. Grain yield of Paraná soybeans as a function of exhangeable soil Mg. EMBRAPA-CPAC.

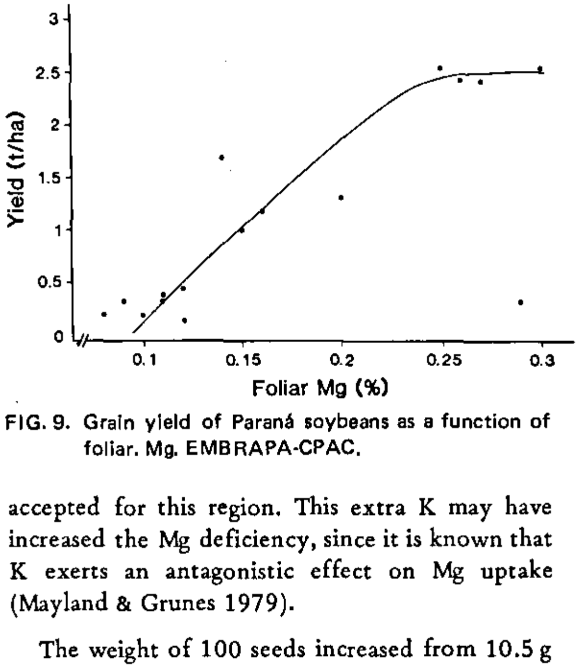


FIG. 9. Grain yield of Paraná soybeans as a function of foliar. Mg. EMBRAPA-CPAC.

grain yield associated with the use of limestone with adequate Mg (Table 1). This effect was more evident in the seventh year of the experiment than in the third year, when an increase of only 31% was observed for "Santa Rosa" soybeans (Relatório técnico anual 1979). Yield as a function of soil Mg is shown in Fig. 8. Soil Mg levels lower than 0.18 meg/100 ml were insufficient, in agreement with Doll & Lucas (1973), and Ritchey (1979). The average magnesium saturation on an equivalent basis (meq Mg/100 ml divided by effective CEC), of the three low-yielding treatments varied from 2.5% to 3.1% while the high Mg treatment was 8.9%. Magnesium saturations of less than 5 or 10% are acceptable only if soil Mg level is higher than 0.3 - 0.4 meq/100 g (Doll & Lucas 1973).

Grain yield increased linearly as a function of foliar Mg to about 0.26%, (Fig. 9) the lower limit of the sufficiency range cited by Small Junior & Ohlrogge (1973). Increases in soil K caused increases in foliar K (Fig. 5) and decreases in foliar Mg (Fig. 4). The four Mg treatments received a total of 650 kg/ha K_2O during the seven years, and, in several of the crops, removal of K was low due to low yields caused by Mg deficiency. The resulting soil K levels averaged 0.22 meq/100 ml (Table 1), which is 172% of the critical level commonly accepted for this region. This extra K may have increased the Mg deficiency, since it is known that K exerts an antagonistic effect on Mg uptake (Mayland & Grunes 1979).

The weight of 100 seeds increased from 10.5 g to 17.5 g as Mg rates and yields increased, while the number of seeds per m^2 rose from 190 to 1430 and was the principal factor responsible for the increased yield.

Increasing soil K increased seed quality (Fig. 10) and decreased K deficiency symptoms on upper leaves and pods of soybeans (Fig. 11). Foliar necrosis and soybean stem colonization by *Colletotrichum truncatum* and *Phomopsis* spp. were not significantly different between the treatments of 75 kg/ha K_2O applied in 1981 as KCl or applied as kalsilite. Similarly differences among the other

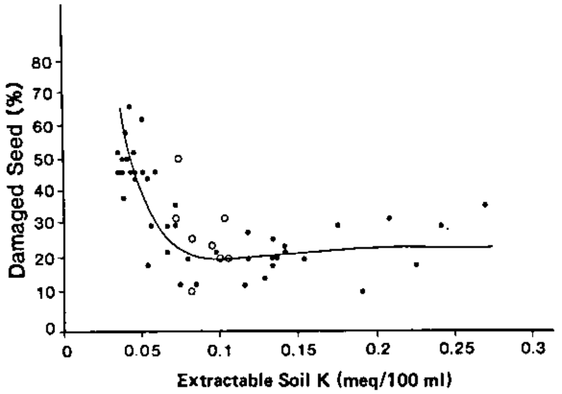


FIG. 10. Effect of Mehlich-1-extractable soil K on percentage of damaged Paraná soybean grain at harvest. Open circles indicate plots where crop residues were returned and incorporated. EMBRAPA-CPAC.

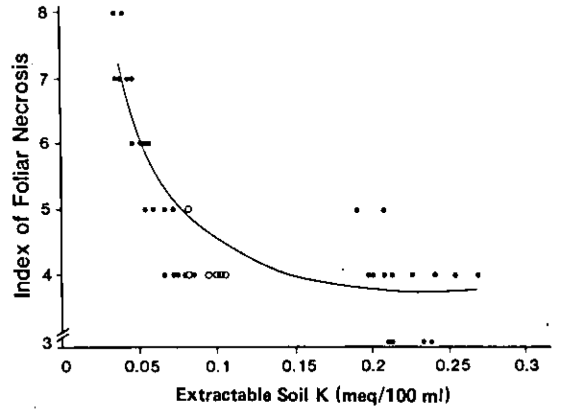


FIG. 11. Effect of Mehlich-1-extractable soil K on foliar necrosis index in Paraná soybeans. Open circles indicate plots where crop residues were returned and incorporated. EMBRAPA-CPAC.

K treatments were not significant and plots in which crop debris were incorporated did not have more disease than those where this did not occur. In comparison, Jeffers et al. (1982) and Spilker et al. (1981) found that K fertilization did not influence *Phomopsis* spp. and *D. phaseolorum* var. *sojae* infection of seed, but possibly limited fungal growth after infection had occurred. Heavy rainfall of 322 mm and warm temperatures, ideal environmental conditions for pod to seed infection by *Phomopsis* spp. (Shortt et al. 1981), occurred during the three weeks preceding harvest, and all treatments had less than 20% seed germination. No significant differences in germination were observed, although seed damage decreased as soil K increased (Fig. 10).

Seed damage increased with decreasing foliar Mg (Fig. 12) while some increase of marginal chlorosis and necrosis (F) of upper leaves occurred ($F = 3.3 + 3.09$ MGS, $R^2 = 0.36^*$, $N = 12$) as soil Mg (MGS) increased. The K supply in the magnesium treatments was adequate and yields in the high-Mg plots were adequate.

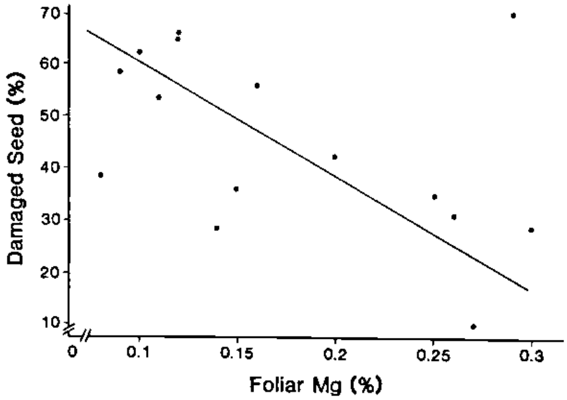


FIG. 12. Percentage of damaged Paraná soybean seeds as a function of foliar Mg. EMBRAPA-CPAC.

CONCLUSIONS

1. The higher yields and lower incidence of damaged seed associated with adequate K emphasize the importance of maintaining sufficient levels of this relatively inexpensive nutrient.

2. Yields equivalent to those on the annual maintenance treatment (TMT 3M) were still being obtained in the seventh year of cropping on plots which received 700 kg/ha K_2O in the first two years of the experiment, and in treatments where only 150 - 170 kg/ha K_2O was applied, but the crop residue was returned to the field.

3. If crop residues are not needed for other purposes, their incorporation can provide an important economy of K as well as an improvement of the soil.

4. The importance of the use of dolomitic limestone where soybeans are to be grown is evident from the ten-fold increase in yield observed where dolomitic rather than calcitic lime was applied.

REFERENCES

BARR, A.J.; GOODNIGHT, J.H.; SALL, J.P. **SAS users' guide.** Raleigh, SAS Institute, 1979. 494p.

CAMPER, H.M. & LUTZ JUNIOR, J.A. Plowsole placement of fertilizer for soybeans and response to tillage of plowsole. **Agron. J.**, 69:701-4, 1977.

CERKAUSKAS, R.F.; DHINGRA, O.D.; SINCLAIR, J.B. Effect of three desiccant-type herbicides on fruiting structures of *Colletotrichum truncatum* and *Phomopsis* spp. on soybean stems. **Plant Dis.**, 67:620-22, 1983.

CRITTENDEN, H.W. & SVEC, L.V. Effect of potassium on the incidence of *Diaporthe sojae* in soybean. **Agron. J.**, 66:696-7, 1974.

DOLL, E.C. & LUCAS, R.E. Testing soils for potassium, calcium, and magnesium. In: WALSH, L.M. & BEATON, J.D., ed. **Soil testing and plant analysis.** Madison, Soil Science Society of America, 1973. p.133-51.

HUBER, D.M. The role of mineral nutrition in defense. In: HORSFALL, J.G. & COWLING, E.B. **Plant disease**; an advanced treatise. New York, Academic, 1980. v.5, p.381-406.

JEFFERS, D.L.; SCHMITTHENNER, A.F.; KROETZ, M.E. Potassium fertilization effects on Phomopsis seed infection, seed quality, and yield of soybeans. **Agron. J.**, 74:886-90, 1982.

LOPES, A.S. **A survey of the fertility status of soils under "cerrado" vegetation in Brazil.** Raleigh, North Carolina State University, 1975. 138p. Tese Mestrado.

MASCARENHAS, H.A.A.; MIRANDA, M.A.C.; BATAGLIA, O.C.; TISSELLI JUNIOR, O.; BRAGA, N.R.; SOAVE, J. Effect of potassium fertilization on the incidence of attack on the soya bean by *Diaporthe phaseolorum* (Cke. & Ell.) Sacc. var. *sojae* (Lehman) Wehm. **Potash Rev.** Subj. 23, 53rd Suite, no. 10, 1977.

MAYLAND, H.F. & GRUNES, D.L. Soil-climate-plant relationships in the etiology of grass tetany. In: RENDIG, V.V. & GRUNES, D.L., ed. **Grass tetany.** Madison, American Society of Agronomy, 1979. p.123-75. (Special publication, 35)

NELSON, W.L. & BARBER, S.A. Nutrient deficiencies in legumes for grain and forage. In: SPRAGUE, H.B., ed. **Hunger signs in crops.** Washington, D. McKay, 1964. p.143-80.

RELATÓRIO TÉCNICO ANUAL DO CENTRO DE PESQUISA AGROPECUÁRIA DOS CERRADOS 1977-1978. Planaltina, EMBRAPA-CPAC, 1979.

RITCHEY, K.D., ed. **Potassium fertility in Oxisols and Ultisols of the humid tropics.** Ithaca, Cornell University, 1979. 45p. (Cornell International Agriculture Bulletim, 37)

RITCHEY, K.D.; SOUZA, D.M.G. de; LOBATO, E. Potássio em solo de cerrado. I. Resposta à adubação potássica. **R. bras. Ci. Solo**, 3(1):29-32, 1979.

RODRIGUES, T.E. **Mineralogia e gênese de uma seqüência de solos dos Cerrados, no Distrito Federal.** Porto Alegre, UFRGS, 1977. 101p. Tese Mestrado.

SCOTT, W.O. & ALDRICH, S.R. **Modern soybean production.** Cincinnati, The Farm Quarterly, 1970. 192p.

SHORTT, B.J.; GRYBAUSKAS, A.P.; TENNE, F.D.; SINCLAIR, J.B. Epidemiology of Phomopsis seed decay of soybean in Illinois. **Plant Dis.**, 65:62-4, 1981.

SILVA, J.E. & RITCHEY, K.D. Acumulação diferencial de potássio em Oxissolos devido à lavagem do nutriente das plantas de milho para o solo. **R. bras. Ci. Solo**, 6:183-8, 1982.

SINCLAIR, J.B. & SHURTLEFF, M.C. **Compendium of soybean diseases.** St. Paul American Phytopathological Society, 1975. 69p.

SMALL JUNIOR, H.G. & OHLROGGE, A.J. Plant analysis as an aid in fertilizing soybeans and peanuts. In: WALSH, L.M. & BEATON, J.D., ed. **Soil testing and plant analysis.** Madison, Soil Science Society of America, 1973. p.315-27.

SOUZA, D.M.G. de; RITCHEY, K.D.; LOBATO, E.; GOEDERT, W.J. Potássio em solo de cerrado. II. Equilíbrio no solo. **R. bras. Ci. Solo**, 3(1):33-6, 1979.

SPILKER, D.A.; SCHMITTHENNER, A.F.; ELLETT, C. W. Effects of humidity, temperature, fertility, and cultivar on the reduction of soybean seed quality of *Phomopsis* sp. **Phytopathology**, 71:1027-9, 1981.

SVEC, L.V.; ANDREWS, A.K.; CRITTENDEN, H.W. Soybean (*Glycine max* (L.) Merr.) yield and disease incidence with potassium fertilization. **Commun. Soil Sci. Plant Anal.**, 7:727-41, 1976.

VETTORI, L. **Métodos de análise de solo.** Rio de Janeiro, MA-Escritório de Pesquisas e Experimentação, 1969. 24p. (Boletim técnico, 7)

VILELA, L. & RITCHEY, K.D. Potassium in intensive cropping systems on highly-weathered soils. In: MUNSON, R.D., ed. **Potassium in agriculture.** Madison, American Society of Agronomy, 1985. p.1155-76.