SOYBEAN (*Glycine max* (L.) Merril) RESPONSE TO SOIL FERTILITY TREATMENTS, WITH A DARK RED LATOSOL (TYPIC EUTRUSTOX) FROM JAIBA, MINAS GERAIS, BRAZIL

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CHAPTER I

INTRODUCTION

Improved agricultural and industrial development of the northern part of Minas Gerais state in Brazil is a government objective. The Agricultural and Industrial District of Jaiba was established in order to accomplish this goal in utilizing the high potential of this area.

At present the more important agricultural production enterprises of this region are cotton, castor beans, and beef cattle. Other important crops of this area include rice, corn, beans, cassava, and sugar cane. Other less important crops for commercial production include bananas, peanuts, tobacco, sweet potatoes, oranges and a variety of yams (17).

Although the farmers living in the region are generally poor with limited resources, the soils have good productive potential and are well adapted to mechanized agriculture, irrigation, and the installation of industries for processing and marketing agricultural production.

The region is well located geographically between the southern and northeastern part of the country. Soybeans produced within the area will have many important uses. This crop can supply the poor people of the region with a high protein food. Utilizing the fluvial navigation of the São Francisco River, the soybeans production that is not consumed or industrialized in the area can be exported to the northeastern area of the country efficiently, Figure 1. Surplus pro-

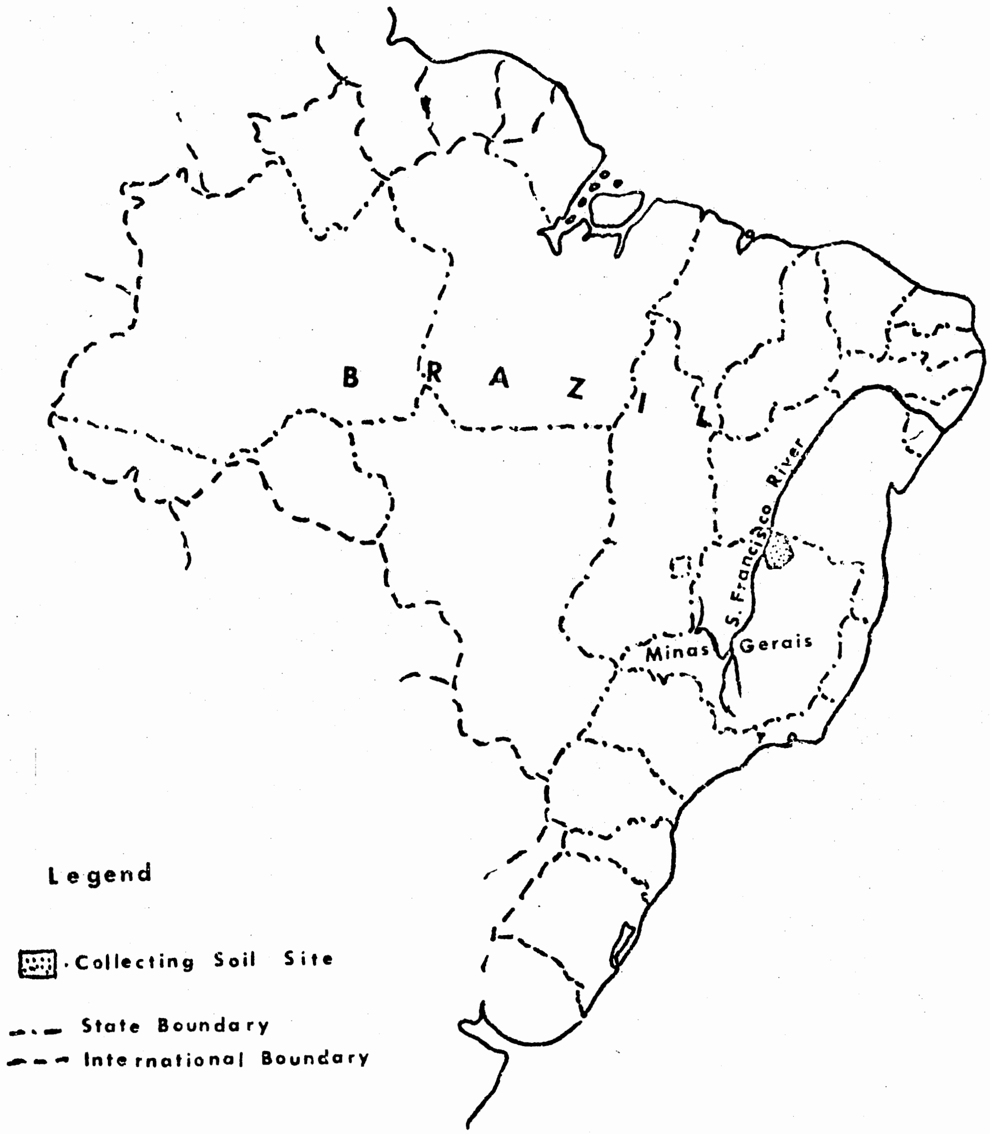

Figure 1. Map Showing Brazil and Soil Collecting Site

duction can be exported contributing greatly to a favorable international trade balance necessary to the economy of the country.

World production of soybeans for recent years is shown in Table I, and Brazilian production of soybeans by states from 1968 to 1974 is shown in Table II. The Minas Gerais state production was very low and for this reason the state government has been making a great effort in order to improve the soybean culture by using better technology and management with a more productive type of cultivation.

The objective of this study was to determine the effects of principal base cations Ca^{++}, Mg^{++}, and K^{+} with and without P on soybean growth, nodulation and to determine some indicator enzyme characteristics of nodules related to nitrogenase activities with a dark red latosol (Oxisol) of the region.

Hopefully, this information will contribute to the knowledge of establishment and improvement of soybean culture in the region.

TABLE I

WORLD PRODUCTION OF SOYBEAN, 1969 TO 1977

Calendar year / Country	1969	1970	1971	1972	1973	1974	1975	1976	1977
				(Thousand Metric Tons)					
USA	26,575	30,127	30,839	30,675	32,006	33,062	41,406	34,012	34,425 *
CHINA	9,500	9,100	9,200	9.700	9,200	9,600	10,000	9,500	9,000 *
BRAZIL	1,057	1,508	2,169	3,523	5,009	7,400	9,600	11,227	12,429
ARGENTINA	22	32	27	59	272	540	485	695	950 *
MEXICO	106	218	266	280	375	510	663	244	370 *
RUSSIA	543	528	434	595	258	423	780	781	640 *
CANADA	220	246	209	283	375	280	367	291	312 *
RUMANIA	41	47	51	91	186	200	330	344	387 *
SOUTH KOREA	201	245	229	232	224	257	263	269	285 *
OTHERS	1,048	1,145	1,176	1,283	1,443	1,509	4,426	4,833	4,200 *
TOTAL	39,313	43,196	44,600	46,721	49,348	53,781	68,320	62,196	62,998 *

* Estimates by USDA
Sources: Up to 1974 - Oil World Weekly
From 1975 to 1977 - USDA and FAO - Monthly Bulletin of Agricultural and Statistics. Rome. October, 1976.

TABLE II

BRAZILIAN PRODUCTION OF SOYBEAN BY STATES, 1968 TO 1974

	Production (1000 m. tons)						
	1968	1969	1970	1971	1972	1973	1974 *
Rio Grande do Sul	432.58	744.47	979.81	1,386.00	2,140.00	2,872.06	3,970.00
Santa Catarina	14.83	31.65	53.00	54.02	65.00	253.51	391.70
Paraná	163.20	213.58	368.01	567.10	966.20	1,323.34	2,024.10
São Paulo	39.33	61.01	90.09	93.60	222.00	331.19	522.00
Minas Gerais	0.36	0.56	1.81	14.00	27.09	36.32	44.20
Mato Grosso	3.39	4.30	8.99	12.40	43.00	103.23	218.00
Goiás	1.50	1.89	9.82	41.95	60.00	89.70	81.20
Bahia	0.78	0.02	0.02	...	...	0.03	...
Total	655.97	1,057.48	1,508.48	2,169.07	3,523.29	5,009.38	7,151.20
	Percent of Total Production						
Rio Grande do Sul	65.9	70.4	64.8	63.9	60.7	57.3	54.1
Santa Catarina	2.3	3.0	3.5	2.5	1.9	5.1	5.5
Paraná	24.9	20.2	24.4	26.1	27.1	26.4	28.3
São Paulo	6.0	5.8	6.0	4.3	6.3	6.6	7.3
Minas Gerais	.1	.0	.1	.7	.8	.7	.6
Mato Grosso	.5	.4	.6	.6	1.2	2.1	3.1
Goiás	.2	.2	.6	1.9	1.7	1.8	1.1
Bahia	.1	.0	.0	.0	.0	.0	.0
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0

* = Preliminary data

Source: IEA, EAGRI/SUPLAN - Ministry of Agriculture and IBGE Foundation

CHAPTER II

LITERATURE REVIEW

Literature reviews concerning soybean response to soil fertility conditions and factors influencing nodulation were recently published (11, 68). However, much of the important research concerning soybean fertilization studies in Brazil was not included in the American Society of Agronomy Monograph 16 and some of them will be summarized in this chapter.

Mikkelsen et al. (49), using soybean, corn and cotton for responses and working with a deep regosol, a dark red latosol, and a red-yellow latosol, concluded that with the application of dolomitic limestone, the yields of all crops were increased. The excessive soil acidity was corrected by limestone, which supplied magnesium and calcium, enhanced the uptake of native sulfur, nitrogen, and phosphorus. When fertilizers were used with limestone, responses were obtained with phosphorus, nitrogen, potassium, sulfur and the micronutrients molybdenum, boron and zinc. The specific requirement for each nutrient was dependent on the crop being grown and upon the liming level.

Nelson and Hartwig (54), with soybean fertilization studies found that when phosphorus was applied alone the increases in soybean yields was small, but where potassium, phosphorus and lime were applied the yields obtained were much higher.

Freitas et al. (23), after conducting a two-year lime and fertilizer research at five places in the "Cerrado" areas of the Federal District of Brazil, using corn and soybeans as test crops and nitrogen, phosphorus, potassium, sulphur, zinc, boron and molybdenum as fertilizers, found that application of lime and fertilizer influenced high production levels of both tested crops. The two-year average annual increases for liming were 821 Kg. per hectare and 415 Kg per hectare for corn and soybean respectively. Complete fertilization resulted in annual increases of 4,950 Kg. per hectare and 1,810 Kg. per hectare for corn and soybean respectively. The researchers concluded that the costs of applying very high rates of phosphorus and zinc during initial application should be apportioned over several years, similar to the costs of lime.

Jones and de Freitas (34), studying the response of four tropical legumes to phosphorus, potassium and lime, with red-yellow latosols of the "campo cerrado", and using <u>Stylosanthes gracilis</u>, <u>Centrosema pubescens</u>, <u>Glycine javanica</u> and <u>Phaseolus stropurpureus</u> found that all the legumes responded to P, attaining near maximum yields between 100 and 200 Kg. per ha. Applied in small increments, lime gave marked increases in yield. The response of the tropical legumes to potassium applications was not statistically significant.

França and Carvalho (21), used greenhouse experiment to study nutrient deficiencies that restrict the development of some legumes. They studied <u>Glycine javanica</u> L. (var. comman), <u>Glycine javanica</u> (var. tinaroo), <u>Phaseolus atropurpureus</u> D.C. (siratro, <u>Pueraria javanica</u> Benth (tropical kudzu) and <u>Centrosema pubescens</u> Benth, for responses and a red latosol "fase cerrado" soil. They found that plant nutrient deficiencies of this soil resulted in decreasing nodule weight, nitrogen content, and dry matter yields of all legumes. Potassium and sulfur failed to cause negative effects on dry matter yield and nitrogen fixation. Omitting lime affected all legumes, resulting in decreases in both dry matter yield and nitrogen fixation, with an increase of ineffective nodules production.

Bahia Filho and Braga (5), in greenhouse experiments with 12 oxisols of Minas Gerais, Brazil, and using oats (Avena sativa) for responses, concluded that there was a direct correlation between the quantity of phosphorus fixed and phosphorus buffer capacity. They also found that the maximum yield was obtained when applying between .79 to .98 of the maximum capacity, for phosphorus absorption.

McClung et al. (47), conducted pot culture experiments using six "Campo Cerrado" soils from Goiás and São Paulo states, Brazil. Responses were obtained from grass and legume growth that indicated severe phosphorus deficiency. The minus-phosphorus treatment in most cases yielded only 5 to 10% as much growth as the complete treatment. Dry matter production of Pangola grass, with all four soils from Goiás was lower when the elements boron, copper, iron, molybdenum, sulfur and zinc were omitted from the fertilizer mixture and the yield of alfalfa from one of the Sáo Paulo state soil was similar. It was not possible to determine which of these elements were involved in this response from these data. Potassium omission did not affect dry matter production, with either grasses or legumes, but liming omission resulted in growth reduction of both soybeans and alfalfa.

Martini et al. (46), working with some oxisols from Rio Grande do Sul state in Brazil, and using soybean for response in a soybean-wheat double cropping experiment concluded that optimum yield was obtained when lime application reduced Al from .1 to .5 meq/100 g (1-5% Al saturation), and when the pH was raised from 5.2 to 5.7 and Ca + Mg from 5.7 to 8.5 meq/100 g. Yield responses to lime application were highly significant due to exchangeable Ca + Mg, available P, high exchangeable Al and extractable Mn found in these soils. Root nodulation was increased while P fixation and Mn Levels were reduced with the lime application.

Duque et al. (13), studying an oxisol in the Brazilian Federal District with 47 dry beans and 17 soybeans varieties, found that only four dry beans varieties gave the best result and only one soybean variety, "IAC-2", performed well and were suited for mechanical harvesting.

Bahia Filho and Braga (4), working on the phosphate buffering intensity and capacity of 20 oxisols from Minas Gerais state, topsoil samples, observed that those soils presented high P fixation capacity.

Pereira et al. (57), determined the effects of phosphorus sources and levels on soybean nodulation and nutrient absorption with an oxisol. They found that the sources and levels of phosphorus depressed the nodule weight and also the amount of phosphorus content in the leaves. They also noted a tendency for increasing the amounts of calcium and potassium, and that the decrease of magnesium when phosphate levels were increased.

Hunsaker and Pratt (31), studied calcium-magnesium exchange equilibria in soils. They found that a Brazilian oxisol showed strong Ca preference over Mg and that the oxisol had a selectivity coefficient of 6.52 at equilibrium with Ca and Mg ratio of 10:90.

Leggett and Gilbert (37), studied salt uptake by plants and using soybeans for response found that Mg uptake was inhibited by the concentrations of Ca and K in the solution, but not with Ca or K.

Souto and Döbereiner (64), using Perennial soybeans for response and working on the nodulation effects due to phosphorus fertilization, soil temperature and moisture, concluded that superphosphate increased forage yield, nodulation, and nitrogen fixation indicating high phosphorus requirements at the initial stage of plant growth. When the daily maximal temperatures were between 34 and 43°C forage yield, protein content, nodulation, and nitrogen fixation were reduced as compared with daily maxima between 29 and 32°C. When the phosphorus level was high the high soil temperature effects were less pronounced.

Eira et al. (15), working with a dark red podzolic soil from the Brazilian Federal District area under "cerrado" vegetation obtained large responses to nitrogen, phosphorus and lime applications. The responses for micronutrients and potassium were not significant.

Miller et al. (50), using dry beans for response and working with a red-yellow latosol at the "Estação Experimental de Uberaba", Minas Gerais, Brazil obtained a large response to nitrogen and phosphorus applications. They also found that when phosphorus was present, the maturity time was shortened with plots where phosphorus was not applied having 30% fewer plants at harvest.

Kamprath and Miller (35), studying the soil phosphorus level effect on soybean yields found that soybean yields were related to the soil pH and the soil phosphorus level. The soybean yields were related to soil phosphorus levels. When soil phosphorus level was low the yield was low, but yield was high if the soil phosphorus level was high.

Aprison et al. (3), working on nitrogen fixation by excised soybean root nodules found that the optimum temperature for fixation of nitrogen by soybean nodules was 25°C.

Galletti et al. (26), working on the effects of soil temperatures in soybean symbiosis found that daily maximal temperatures above 33°C decreased nódule initiation and nodule efficiency although the nodule growth was not affected.

Freitas et al. (22), utilizing corn, cotton and soybeans as test crops and working with latosols at São Paulo and Goiás states, in Brazil, noted that these soils were responsive to lime and inorganic fertilizer addition and that these soils were highly deficient in several essential plant nutrients. In São Paulo, results of soybean experiment were surprisingly good. The early response of cotton appeared to be due to lime, sulfur, alone and combined. The failure of crop response to phosphorus was unexpected because the "Campos Cerrados" are considered generally having low available soil phosphorus levels. In Goiás, the most remarkable response in the early stage of growth appeared to result with phosphorus application. Because some phosphorus deficiency characteristics were not consistent they concluded that when growth was extremely poor, calcium was the principal limiting factor. With responses obtained for nitrogen, potassium and zinc in the soybean experiment there was excellent nodulation, but nitrogen response was apparent with responses obtained to phosphorus, zinc, lime and molybdenum when lime was not applied.

Braga et al. (6), working with 17 latosols from "Triângulo Mineiro", Minas Gerais state, Brazil, and using soybean as a test crop applied different levels of phosphorus with and without lime and three levels of potassium. The analysis of results from these latosols indicated a correlation between soil and plant parameters in order to recommend soybean fertilization responses. Data obtained indicated the conclusion that the sum of bases and pH values were related to soybean yields. Relative production was related to phosphorus availability. The opposite relationship was observed in respect to exchangeable aluminum levels. There were not significant correlation coefficients between soybean and available phosphorus nor between relative production and available phosphorus according to phosphorus application levels. Potassium availability correlated significantly with soybean production and with response to phosphorus application, but did not show significant correlations between available potassium and relative production as related to potassium application levels.

Mascarenhas et al. (44), working with dry beans determined the effects of lime, nitrogen and phosphorus on dry beans planted in a strongly acid latosol area of the "Ribeira" Valley, São Paulo state, Brazil. They concluded that yield increases were induced by lime and phosphorus, principally when applied together, while no response to nitrogen was obtained.

Guimarães et al. (27), studied soybean response with three soils classified as Podzol and two as Latosols applied different levels of nitrogen and found that symbiotic nitrogen fixation was not adequate for the requirements of the plants, and suggested that some factor essential to symbiosis was deficient.

Miyasaka et al. (51), studied the effects of three levels of nitrogen, phosphorus, potassium and lime on soybean yields with two poor soils. The nitrogen and potassium responses, as well as interactions were not significant. The effect of phosphorus, however, was linear and significant with both crops, this effect was much higher in the limed areas.

Mascarenhas et al. (43), studied the effects of increasing levels of potassium, phosphorus and lime on a red latosol soil with "cerrado" vegetation and using soybean as the test crop, concluded that phosphorus increased yields considerably. The potassium effect, although positive, was small and in spite of the low soil pH (4.8), liming was not effective.

Ferrari et al. (19), studying the effects of applying potassium and phosphorus with and without liming in 14 latosol locations in Minas Gerais state, used soybean as the test crop. They found that yields increased significantly in all locations with phosphorus application. The phosphorus x calcium interaction resulted in yield increases in 9 locations when lime was applied. Potassium fertilization was beneficial in 7 locations.

Heltz and Whiting (29), studying the fertilizer effects on soybean nodule formation, found that some legumes seemed to be more benefited by fertilizer application, especially those planted on soils with phosphorus and potassium deficiency. Certain fertilizer compounds may inhibit nodule formation by increasing the soil acidity. Potassium and phosphorus increased nodulation when their levels were not inhibitory to germination.

Mascarenhas et al. (45), studied soybean responses to phosphorus, potassium and lime application on a red latosol during two nonconsecutive years (1965-1966) (1967-1968). They found that during the first, only lime increased yield, however, in the second year both lime and potassium effects were positive and linear. The response obtained from phosphorus application was not significant.

Dutra et al. (14), completed 5 experiments with dark red latosols studying soybeans and dry beans at two locations of Goiás state, Brazil. They found a significant quadratic response when phosphorus was applied. In Goiania they noted that potassium application tended to decrease yields. They concluded that potassium availability initially was below the critical level proposed for Brazilian soils. They also found that the fertilizer application responses varied among varieties of both crops.

Freitas et al. (24), working with soybeans and sweet corn on soil formerly planted in coffee culture for thirty years and with two soils under "cerrado" vegetation, applied different rates and formulas of fertilizer and lime. "Cerrado" soils of Brasília gave the highest yield responses which indicated an overall need for zinc and phosphorus. At one location in Brasília, potassium effects were apparent. It was necessary to supply an adequate level of potassium as well as magnesium and sulfur in these experiments. Soybean yields were increased when planted after corn crop, showing a high residual effect of the fertilizers used, especially phosphorus.

Fontes et al. (20), working at 6 sites in the Minas Gerais state, used dry beans and applied nitrogen, phosphorus, potassium and liming. They found that dry beans responded well to phosphorus application in all six locations. Response to lime was found at one site. No response was obtained from nitrogen and potassium applications and phosphorus and lime interaction was not significant. When additional plantings were made at one of six locations without lime or fertilizer application, the limed plots continued to give yield increases. Where lime was applied a large response to phosphorus was also observed.

Mascarenhas et al. (41), studying fertilizers effects on dry beans and working with poor soil in the southern section of the São Paulo state plateau concluded that dolomitic lime and phosphorus were the principal factors that influenced the yields. Lime and phosphorus were most effective when applied in combination.

Miyasaka et al. (52), using dry beans for response and working with "terra roxa" soils of São Paulo state conducted eight fertilizer experiments. They concluded that phosphorus increased the yields significantly in three experiments and potassium in one. The responses to sulfur, nitrogen and micro-nutrients (Mo, Zn, Cu, and B) were not significant.

Neme and Lovadini (55), studied the effects of liming and phosphate fertilizers applied alone or in combination, with perennial soybean on a poor type of "cerrado" soil during 7 years period. They found that liming and phosphate fertilizers increased forage production. Liming increased pH value and decreased exchangeable aluminum level. Phosphorus and liming residual effects were observed during all seven years.

Jones and Freitas (33), experimented with a strongly acid and phosphorus deficient red-yellow latosol soil and studied phosphorus, potassium, and lime effects on the behavior of four tropical legumes. They found that the responses to liming and phosphorus applications were significant. Potassium fertilization did not yield any significant response.

Hutchings (32), studied the relation of phosphorus to growth, nodulation and composition of soybean. He found that in the early growth of the soybean plant, phosphorus was not a significant factor in controlling nodulation. When the calcium needs of the young plants were satisfied, seed phosphorus and applied phosphorus were most efficient in terms of growth and plant composition. The responses indicated a relatively close interrelationship of calcium-phosphorus-nitrogen.

MacTaggart (40), studied the influence of several fertilizer salts on the nitrogen-content and growth of some legumes. He concluded that phosphorus and lime, when applied together, increased total nitrogen-content and weight of soybeans, Canada field peas and alfalfa over that of lime alone. Phosphorus alone influenced the three crops by a) increased total nitrogen; b) increased dry matter and c) increased nitrogen percentage. Potassium increased only nitrogen in all three crops. Sulfur, alone or in combination, increased alfalfa in growth and nitrogen content, but did not effect soybeans or field peas.

Mascarenhas et al. (42), working in a latosol soil formerly under "cerrado" vegetation and studying the soybeans responses to boron, copper, iron, manganese, molybdenum, zinc and sulfur found that the micronutrients effects were not significant, but sulfur did increase considerably the seed yield.

Thornton (66), studying the growth of _Glycine hispida_ and _Vicia faba_ L. under the influence of fresh straw, concluded that the incorporation of fresh chaff to the soil caused a significant increase in the number of nodules produced on inoculated plants and that this increase was due to the increase of available soil phosphate.

Calcium as a factor in soybean inoculation, was studied by Scanlan (62) and he found that limestone increased nodulation greatly in all instances where used, and that the soil type influenced significantly the results related with phosphorus fertilization.

Abrunã et al. (1), working with corn and beans on typical ultisols and oxisols of Puerto Rico found that response to lime application was highly significant. Calcium content increased with increasing yields in corn and also showed a close relationship between Ca:Mn ratio with bean yields in these studies. Liming to a soil pH of 5.0 to 5.5 was adequate for both crops with regard to Ca requirements and reduced Al and Mn toxicities.

Soares et al. (63), studied the effects of liming soils of the Brazilian Cerrado with two red-yellow latosols, and one dark red latosol using sorghum, corn, stylosanthes and soybean. For the dark red latosol they used 3.8 ton of $CaCO_3$/ha-20 cm and this rate gave a satisfactory production of all crops. In the Federal District area with dark red latosol the rate of 5 tons/ha of lime resulted in: a) aluminum saturation reduced to less than 10% with soil pH increased to a range of 5.3 to 5.6, b) Crops yields were increased for sorghum by 140%, corn by 15 to 40% and soybean by 7 to 75%. They recommended that because the soils in the cerrado area require liming for production of several crops, the limestone deposits within the cerrado area should be developed.

Freitas and Van Raij (25), experimented with corn, soybeans, cotton and peanuts in four rotation systems during a six year experiment with a red-yellow latosol and with the application of 10 tons of lime per hectare. Six years after liming, the exchangeable Ca+Mg content was about 1 meq/100 g higher than the value of Al+Ca+Mg of the unlimed soil indicating that liming was effective for several years.

Higdon and Marshall (30), using soybeans, barley and buckwheat as the experimental plants, studied the uptake of Ca and K. They found that potassium uptake was more closely related to the total amount present in the substrate than to its activity. With soybeans calcium uptaking was related to the Ca activity.

Kamprath (36), in a review of experiments in tropical areas of Latin America pointed out that phosphorus disponibility in latosols is generally very low because usually phosphorus is found in unsoluble form as iron phosphate or aluminum phosphate. Based on soil analysis, the phosphorus level for clay soils is low (0-17 ppm) and high when greater than 17 ppm. For sandy soils the phosphorus level is low from 0 to 7 ppm, medium from 7 to 14 ppm, and high more than 14 ppm.

Cox (9), reviewed experiments conducted in tropical regions of Latin America and emphasized that the potassium effect on plant growth depends on crop sensitivity.

de Mooy and Pesek (10), experimented on nodulation responses of soybeans to fertilizations with phosphorus, potassium, and calcium salts. They found large and highly significant curvilinear responses in weight, number, and leghemoglobin content of nodules of soybean to phosphorus application. Sometimes Ca x P interactions were significant for nodule number and weight. Maximum nodulation required very high levels of applied K and P salts. Phosphorus had a dominant role on optimum nodulation of soybeans.

Cheniae and Evans (8), studied the relation between nitrogen fixation and nodule nitrate reductase of soybean nodules. They found that there were positive correlation with nitrogen-fixing capacity, nitrate reductase activity of nodules, and the nodule hemoglobin content.

Fellers (18), studied composition and nodule formation of soybeans. He found that the yield of total dry matter and of seed production were substantially increased by inoculation. Small applications of lime at intervals of a few years are to be preferred to a single large application. Lime application on soybean cultures in acid soils was nearly as important as inoculation, but if applied in combination would give the best result. Nodule production on soybeans was also stimulated on limed soils by acid phosphate, but this was not so marked on acid soils. When potassium was applied, yields increased for total dry matter and seed on limed and unlimed plots by an average of 10%. Nodule production was also slightly stimulated on limed plots. Manganese sulfate stimulated germination and growth but did not increase nodule production or yields.

Perkins (58), studied mineral fertilizer effects upon the soybeans nodulation and concluded that phosphate is not essential for the nodulation of young soybean plants, potassium is not necessary for maximum nodulation while calcium is essential for obtaining a good nodulation. When lime was absent or in small amounts, it limited the nodulation greatly.

Andrew (2), experimented on nutrition influence on legumes growth and nitrogen fixation. He found that Mo, Ca, and B deficiencies limited nodule formation and physiology which reduced nitrogen fixation on acidic soils.

Döbereiner et al. (12), evaluated nitrogen fixation by some legumes determining the total plant nitrogen composition as related to nodule weight and they concluded that legumes nitrogen fixation was related more to nodule numbers or size than to the amount of fixed nitrogen per unit of nodule tissue.

Ruschel et al. (60), studying the effects of Mg, B, and Mo on symbiotic nitrogen fixation of dry beans, found that there was a pronounced effect of liming which increased nodule numbers. The effects of B were dependent on calcium applications. Mg only influenced the increasing of nodule number while molybdenum decreased the nodule numbers but increased the amount of nitrogen fixed per nodule.

Lopes (38), studied 518 soil samples collected in Central Brazil in areas under cerrado vegetation. He concluded that the soil reaction was generally highly acidic and that the levels of calcium, magnesium, potassium, phosphorus, copper and zinc were below the critical suggested levels. Aluminum saturation was found to be toxic for most crops, when the cation exchange capacity was very low. He did not identify problems caused by iron and manganese levels which were judged satisfactory. Organic matter levels were considered from medium to well supplied.

Norris (56), worked on the role of calcium and magnesium in Rhizobium nutrition and concluded that Rhizobium is not a calcium sensitive organism and minute trace amounts of calcium can satisfy Rhizobium needs, but magnesium was shown to be essential for Rhizobium.

Souto and Döbereiner (65), experimented with nitrogen fixation on two perennial soybean (Glycine javanica L.) varieties studying effects of calcium and phosphorus fertilization and manganese toxicity. They found that phosphorus fertilization increased, significantly, nodule growth and total nitrogen, but had no effect on nodule numbers of the amount of nitrogen fixed per unit of nodule weight. Calcium applied as gypsum increased nodule size but tended to decrease their number.

Ruschel and Eira (61), studied the influence of calcium and molybdenum on nitrogen fixation in soybeans (Glycine max (L.) Merril) and found that while mean nodule weight was not affected by any of the treatments, total nodule weight was higher when calcium or phosphorus were present in the pots. Nodule weight was also decreased when molybdenum was applied in the calcium absence. Calcium increased manganese uptake by plants probably due to the decrease of the pH.

Carvalho et al. (7), experimented on fertilization of six tropical legumes with a dark red latosol and found that dry matter production and nodule production increased with phosphorus fertilization. Dry matter production and nitrogen fixation were not affected by the absence of potassium, sulfur or micronutrients, but with the liming omission, both symbiotic nitrogen fixation and dry matter production decreased.

An accurate and comprehensive view of the problems concerned with the agricultural in the Cerrado areas in Brazil is given in the 1976 Annual Technical Report from the "Centro de Pesquisas Agropecuarias do Cerrado" (16), the principal concepts about soil fertility and soybean cultures is presented as follows:

The low fertility of the Cerrados soils are related to the high capacity fixation of phosphorus, high aluminum saturation, low cation exchange capacity and generalized nutrients deficiency principally phosphorus, nitrogen, potassium, magnesium and zinc.

The best results for soybean production were obtained with the application of 200 kg/ha of P_2O_5 and 3.3 ton/ha of calcium.

The low nodule numbers of soybeans planted in cerrado soils has been one of the obstacles in the success of this culture in the cerrado region.

CHAPTER III

MATERIALS AND METHODS

The place from where the soil was collected is called Jaiba. The Jaiba's Agricultural and Industrial District is located at the North part of Minas Gerais state (Figure 1). The region has an area of 3,000 Km^2 and is bounded by the following natural marks at the west part São Francisco River, at the south side Escuro Stream, at the east side Verde Grande River and at the north part by Serraria Creek, and all area is under Manga municipality jurisdiction (17).

The region has a good water supply available for irrigation with the general topography nearly level with moderate slopes. The altitude range is generally between 440 m and 724 m (17).

The mean temperature is about 24.5°C, October being the warmer month with a temperature of 26.4°C and July the coldest month with a temperature never less than 18°C. The annual precipitation is around 88 cm. December is the most rainy month with 21 cm while July is the least rainy with .05 cm.

Natural vegetation is composed of grass and other herbaceous plants, semideciduous broadleaf evergreen and broadleaf deciduous trees growing in small groves or individually within the grassland areas (17).

Dark Red Latosol soil used in this study is characterized by a soil profile sequence of A, B, and C horizons which were developed from clay sediments originated from Bambui Group rocks. These soils are well drained, argillous, very porous sometimes attaining 70% porosity, with low bulk density and exhibit high permeability and friability with a base saturation index greater than 50% to 80 cm depth.

The surface to subsoil transition is gradual, with a calcium content that decreases with depth. The exchangeable aluminum value is lower than the Dark Red Latosols-Distrophic.

The Dark Red Latosol-Eutrophic occupies almost level relief and the elevation range is between 450 to 470 m. The soil is not easily eroded under the natural vegetation, a tropical deciduous forest, at this specific site from where the soil came, but soil loss will occur as a type of splash or sheet erosion under cultivation (67).

Generally this soil retains a very good physical condition in which the roots can grow easily. Soil chemical characteristics appear to be the principal problem in this soil because of an aluminum, manganese and iron content that can influence essential plant nutrient uptake by plants.

This soil can also show a high content of exchangeable acidity due principally to the aluminum that is more concentrated at the A horizon with the high organic matter content of that horizon (17).

This soil type contains only traces of 2:1 silicate clay minerals as montmorillonite and illite except in the oxic horizons that are at great depth. The principal clay minerals present in the oxisol profile are kaolinite, goethite, gibbsite and a variable content of Al, Fe, and Mn oxides (67).

As the soil is an Oxisol, it can present serious agricultural risks, because this soil contains a relatively small available water holding capacity in the profile with the bulk of the available water for plants stored and released at tensions less than 1 bar. The risk associated with a variable rainfall distribution combined sometimes with limited water supplying capacity, particularly on soils where rooting depths are restricted (69).

The soil used in these greenhouse experiments presented the chemical and particle size analysis that appears in Table III.

TABLE III

SOIL AND PARTICLE SIZE ANLAYSIS

pH	BI	P #/A	K #/A	Ca ppm	Mg ppm	Fe ppm	Zn ppm	Mn ppm	% OM	CEC meq/100 g
610	6.8	15	285	2,760	300	680	1	208	3.32	25.4

% Sand	% Silt	% Clay	Texture
24.5	19.5	56.0	Clay

Soil analysis by the Soil Testing Laboratory, Agronomy Department, Oklahoma State University.

Completed at the Oklahoma State University campus in Stillwater, the experiment was designed with 16 treatments and 3 replications as a complete factorial for all possible combinations of P, Ca, Mg, and K each at single levels.

The soil was sterilized by the U. S. Quarantine Station in Miami, Fla., enroute from Brazil. The air dry soil passed through an 8 mesh screen with the large undecomposed organic debris and plant residues removed. One hundred grams of soil were thoroughly mixed with 400 grams quartz sand to total 500 g per culture in 4 inches square plastic pots for the first, second and third experiments. For the subsequent experiments, fourth and fifth, 720 g per culture were utilized with the addition of quartz sand to the soil mixture used in the first three studies.

The soil treatments utilized with the pot cultures as indicated by treatments symbols is shown in Table IV.

TABLE IV

TREATMENT COMBINATIONS AND SOURCES USED IN THE EXPERIMENT

Element symbol	Element name		Quantity (ppm)
Ca	Calcium	$CaSO_4 \cdot 2H_2O$	1,000
Mg	Magnesium	$MgSO_4 \cdot 7H_2O$	500
K	Potassium	KCl	500
P	Phosphorus	$CaH_4(PO_4)_2$	200
1- 0 -(check)	5- Mg	9- KP	13- KPMg
2- Ca	6- CaP	10- KMg	14- CaKP
3- K	7- CaK	11- PMg	15- CaKMg
4- P	8- CaMg	12- PMg	16- CaKPMg

Plant growth response to soil fertility treatments was evaluated with dry weight determinations for the above ground plant shoot and dry weight of the plant roots. Nitrogenase levels were determined with the freshly harvested root system placed in stoppered 50 ml serum bottles and incubated for 3 hrs. at 25°C to 27°C at .01 atmospheres pressure in 10% volume acetylene (C_2H_2). Acetylene (C_2H_2) reduction to ethylene (C_2H_4) was determined by the methods of Hardy et al. (28). Nodules were then removed, counted, weighed, crushed in distilled water to give a X 10 dilution; ultrasonicated for 20 seconds in an ice bath, and centrifugated at 5,000 rpm for 5 minutes. The clear nodule extract was separated and lyophilized for glutamic oxaloacetic transaminase (2.6.1.1.), GOT, by methods of Meers and Tempest (48) and protein content with the method of Lowry et al. (39).

CHAPTER IV

RESULTS AND DISCUSSION

Five experiments were conducted and selected parameters were determined as shown in Table V. In Table VI is shown the resume of significance for all parameters and measurements done in all five experiments. Only one fertilizer application was done previous to the first experiment, the subsequent experiments were completed measuring the residual effects.

First Experiment

In this experiment results were obtained only for shoot and root growth.

Shoot Growth

Results related to shoot growth, is shown in Figure 2 and Table VII.

The Ca treatment resulted in the highest yield 2.41 g of dry matter, followed by the combination of all elements Ca, K, P, and Mg with a yield of 2.32 g. The lowest yield was obtained with single application of Mg with a yield of 1.10 g.

Comparing the effects of the principal base cations Ca, Mg, and K with P combinations, K and Mg increased yields when P was present, but P decreased the yield when combined with Ca alone. The addition of P

TABLE V

RESUME OF EXPERIMENTS, VARIABLES STUDIED AND TIME OF GROWTH OF EACH EXPERIMENT

Experiment Number	Shoot	Root	Nodule Number	Nodule Weight	Nitrogenase Activity	Time of Growth Days
1	X	X	-	-	-	37
2	X	X	-	-	-	24
3	X	X	X	X	X	30
4	X	X	-	-	-	32
5	X	X	X	X	X	36

X mark means that the variable was studied in the experiment, while - means absence of variable.

TABLE VI

ANALYSIS OF VARIANCE SUMMARY FOR SHOOT, ROOT, NODULE NUMBER, NODULE WEIGHT AND NITROGENASE ACTIVITY OF SOYBEAN, FORREST VARIETY, IN A DARK RED LATOSOL - TYPIC EUTRUSTOX, FROM JAIBA, MG, BRAZIL

Source	EXPERIMENT 1		EXPERIMENT 2		EXPERIMENT 3					EXPERIMENT 4		EXPERIMENT 5				
	S	R	S	R	S	R	NN	NW	NA	S	R	S	R	NN	NW	NA
Ca	*		**		**	**	**	**	*	**	*					
K				*					*			**	**	**	**	
P	*										*	**	*		**	**
Mg									*					**	*	
CaP	*					*			**							
CaK			**							**					**	
CaMg					*			**					*			
KP					*				*			**			*	
KMg	*				**	**	**	**	**	**	**					
PMg									**	*						*
CaPMg						**	*			*						
KPMg					**	**	**			**						
CaKP								*								
CaKMg		**			*	**	*		*			**	**			
CaKPMg					**	**		*		**	**	**	*		*	

* Significant at the .05 level of significance ** Significant at the .01 level of significance
S = Shoot R = Root NN = Nodule Number NW = Nodule Weight NA = Nitrogenase Activity

TABLE VII

ORTHOGONAL EFFECTS OF VARIOUS SOIL FERTILITY TREATMENTS ON SHOOT GROWTH OF SOYBEANS, FORREST VARIETY, IN A DARK RED LATOSOL, FROM JAIBA, MINAS GERAIS, BRAZIL. EXPERIMENT 1

Treat. Symbol	Av. Yield Dry wt. (g)	Treat. Symbol	Av. Yield Dry wt. (g)	Treat. Symbol	Av. Yield Dry wt. (g)	Treat. Symbol	Av. yield Dry wt. (g)
O	1.63	K	1.72	Mg	1.10	KMg	1.31
P	2.04 *	KP	2.13	MgP	1.74	KMgP	1.91
Ca	2.41 *	CaK	1.81	CaMg	1.63	CaKMg	2.11
CaP	2.01 *	CaKP	1.60	CaMgP	2.06	CaKMgP	2.32
-P	+P	-Ca	+Ca	-K	+K	-Mg	+Mg
$\bar{\bar{x}}$ 1.72	1.98	1.70	1.99	1.83	1.87	1.92	1.78

Average yields are means of three replicate culture with 37 days of growth
$\bar{\bar{x}}$ means of composite yields with (+) and without (-) the designated element.
LSD related to the Composite mean LSD .01 = .3129 and LSD .05 = .2323
* significant at .05 ** significant at .01

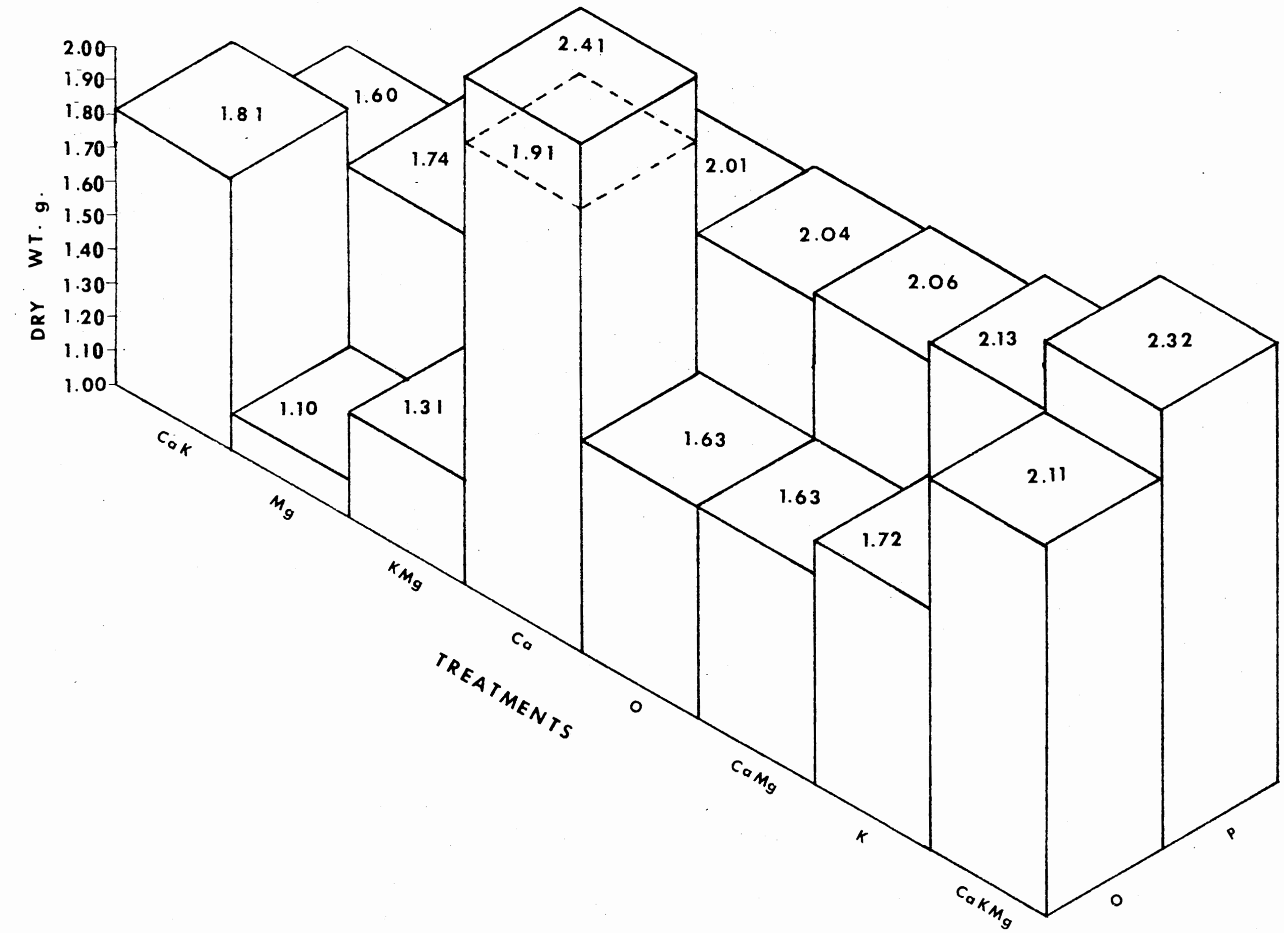

Figure 2. Effects of Various Soil Fertility Treatments on Shoot Growth of Soybean, in a Dark Red Latosol, from Jaiba, MG, Brazil. Experiment 1.

only increased the yield from 1.63 to 2.04 g. The composite mean yield of the various treatment combinations was increased with P addition. When P was omitted the composite mean yield was 1.72 g, with P addition it was 1.98 g.

The addition of Ca alone to this soil increased yield from 1.63 g to 2.41 g. An increase also occurred when Ca was added to K and Mg, but Ca depressed yield slightly when combined with P 2.04 to 2.01 g of dry matter. Overall Ca effect was noted to increase yield as can be seen by the composite mean yield 1.70 to 1.99 g.

K affected positively the yields when added to the soil alone or when combined with P and Mg, but depressed yield when combined with Ca. When a single application of K was added to the soil the yield increased from 1.63 to 1.71 g of dry shoot weight. Overall K effect over the composite mean yield was noted to increase yield from 1.83 to 1.87 g of dry matter.

The Mg effect was noted to be depressive for treatments either with the single application or when combined with Ca, P, and K. Overall effect of Mg was depressive for the composite mean where the means show a decrease from 1.92 g to 1.78 g of dry shoot weight.

By examining the Table VI, Analysis of Variance Summary, and the analysis of variance Table XXIII in the Appendix, it can be observed that the addition of Ca, P and interaction of CaP and KMg was significant at the .05 level.

Root Growth

Observing the root growth means for the first experiment that is shown in Figure 3 and Table VIII, it can be seen that the addition of

TABLE VIII

ORTHOGONAL EFFECTS OF VARIOUS SOIL FERTILITY TREATMENTS ON ROOT GROWTH OF SOYBEANS, FORREST VARIETY, IN A DARK RED LATOSOL, FROM JAIBA, MINAS GERAIS, BRAZIL. EXPERIMENT 1

Treat. Symbol	Av. Yield Dry wt. (g)	Treat. Symbol	Av. Yield Dry wt. (g)	Treat. Symbol	Av. Yield Dry wt. (g)	Treat. Symbol	Av. Yield Dry wt. (g)
O	1.13	K	1.55	Mg	1.70	KMg	1.20
P	1.44	KP	1.28	MgP	1.51	KMgP	1.37
Ca	1.55	CaK	1.00	CaMg	1.13	CaKMg	1.40 **
CaP	1.53	CaKP	1.12	CaMgP	1.20	CaKMgP	1.40
-P	+P	-Ca	+Ca	-K	+K	-Mg	+Mg
$\bar{\bar{x}}$ 1.33	1.36	1.40	1.29	1.40	1.29	1.33	1.36

Average yields are means of three replicate culture with 37 days of growth
$\bar{\bar{x}}$ means of composite yields with (+) and without (-) the designated element
LSD related to the Composite mean LSD .01 = .2871 and LSD .05 = .2132
* significant at .05 ** significant at .01

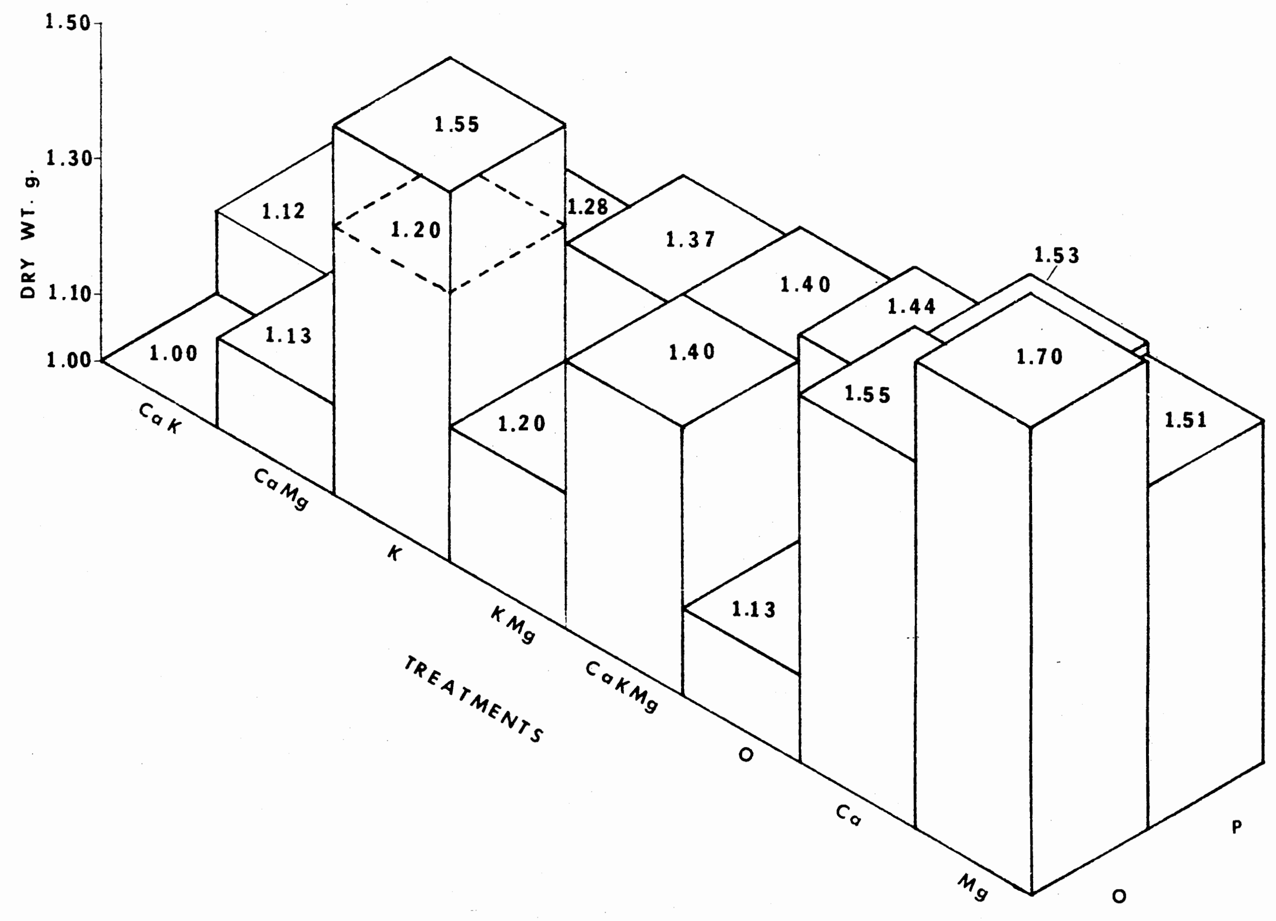

Figure 3. Effects of Various Soil Fertility Treatments on Root Growth of Soybean, in a Dark Red Latosol, from Jaiba, MG, Brazil. Experiment 1.

Mg resulted in the highest yield with a value of 1.70 g of dry matter followed by the single additions of Ca and K that gave each of them a yield of 1.55 g while the single application of P resulted in a yield of 1.44 g. The lowest yield was with the application of Ca and K applied together, that yielded 1.00 g of dry matter.

When comparing the effects of the principal base cations Ca, Mg and K with P combinations, it can be seen that all of those bases, when combined with P, increased the yields at least slightly with only one exception, CaKP.

The addition of Ca alone to the soil increased the yield from 1.13 to 1.55 g. The same yield of the control was obtained when Ca was combined with Mg, but the addition of Ca to K depressed the yield to 1.0 g while the control yielded 1.13 g. The overall Ca effect was noted to degress the yield as can be seen by the composite mean yield 1.40 g when Ca was not added and 1.29 g with the addition of Ca.

The P effect was noted to improve the yield since when the P was added 1.44 g yield was obtained while the control was 1.13 g. The P effect when combined with Ca, K and Mg respectively was noted to improve the yield and we had the following yields CaP 1.53 g, KP 1.28 g and PMg 1.51 g while the control was 1.13 g. The overall effect of P over the composite mean yield was noted to increase slightly the yield from 1.33 g to 1.36 g of dry matter.

With the single addition of K the yield was increased from 1.13 g to 1.55 g. When K was combined with P and Mg the yields were improved from 1.13 for the check to 1.28 g and 1.20 g respectively, when K was combined with Ca the effect was depressive and the yield decreased from 1.13 to 1.00 g of dry matter. The effect of K over the composite mean yield was noted to decrease the yield from 1.40 to 1.29 g of dry matter.

The single application of Mg to the soil increased the production resulting in the highest yield varying from 1.13 g for the check to 1.70 g of dry matter. The Mg effect when combined with K increased slightly the yield from 1.13 to 1.51 g of dry matter while when combined with Ca the yield was not affected, being the same as the control yield. The composite mean yield with Mg was slightly higher than that with Mg omitted 1.36 to 1.33 g respectively.

By looking at the A. O. V., Table XXIV, in the Appendix, it can be seen that the only source that was highly significant was the interaction with CaKMg combination, which seems to indicate that the bases Ca, K and Mg play a big role when related to the root growth in the soil studied.

Second Experiment

In this experiment data were obtained for shoot and root growth and the effects of the treatments are residual from the soil addition of the first experiment.

Shoot Growth

The results for shoot growth are shown in Figure 4 and Table IX. The greatest yield for shoot growth in this experiment was obtained by the addition of Ca and Mg combined that resulted in 1.00 g of dry matter compared to .65 g of the control yield. The lowest yield resulted with the addition of P that depressed the yield from .65 to .50 g.

When comparing the residual effects of the principal base cations Ca, Mg and K with P combinations, it was noted that when Ca and K were

TABLE IX

ORTHOGONAL EFFECTS OF VARIOUS SOIL FERTILITY TREATMENTS ON SHOOT GROWTH OF SOYBEANS, FORREST VARIETY, IN A DARK RED LATOSOL, FROM JAIBA, MINAS GERAIS, BRAZIL. EXPERIMENT 2

Treat. Symbol	Av. Yield Dry wt. (g)	Treat. Symbol	Av. Yield Dry wt. (g)	Treat. Symbol	Av. Yield Dry wt. (g)	Treat. Symbol	Av. Yield Dry wt. (g)
0	0.65	K	0.71	Mg	0.80	KMg	0.88
P	0.50	KP	0.83	MgP	0.65	KMgP	0.83
Ca	0.90	CaK	0.81	CaMg	1.00	CaKMg	0.83
CaP	0.86	CaKP	0.95	CaMgP	0.98	CaKMgP	0.75
-P	+P	-Ca	+Ca	-K	+K	-Mg	+Mg
$\bar{\bar{x}}$ 0.82	0.79	0.73	0.89	0.79	0.82	0.78	0.84

Average yields are means of three replicate culture with 24 days of growth
$\bar{\bar{x}}$ means of composite yields with (+) and without (-) the designated element.
LSD related to the Composite mean LSD .01 = .0953 and LSD .05 = .0708
* significant at .05 ** significant at .01

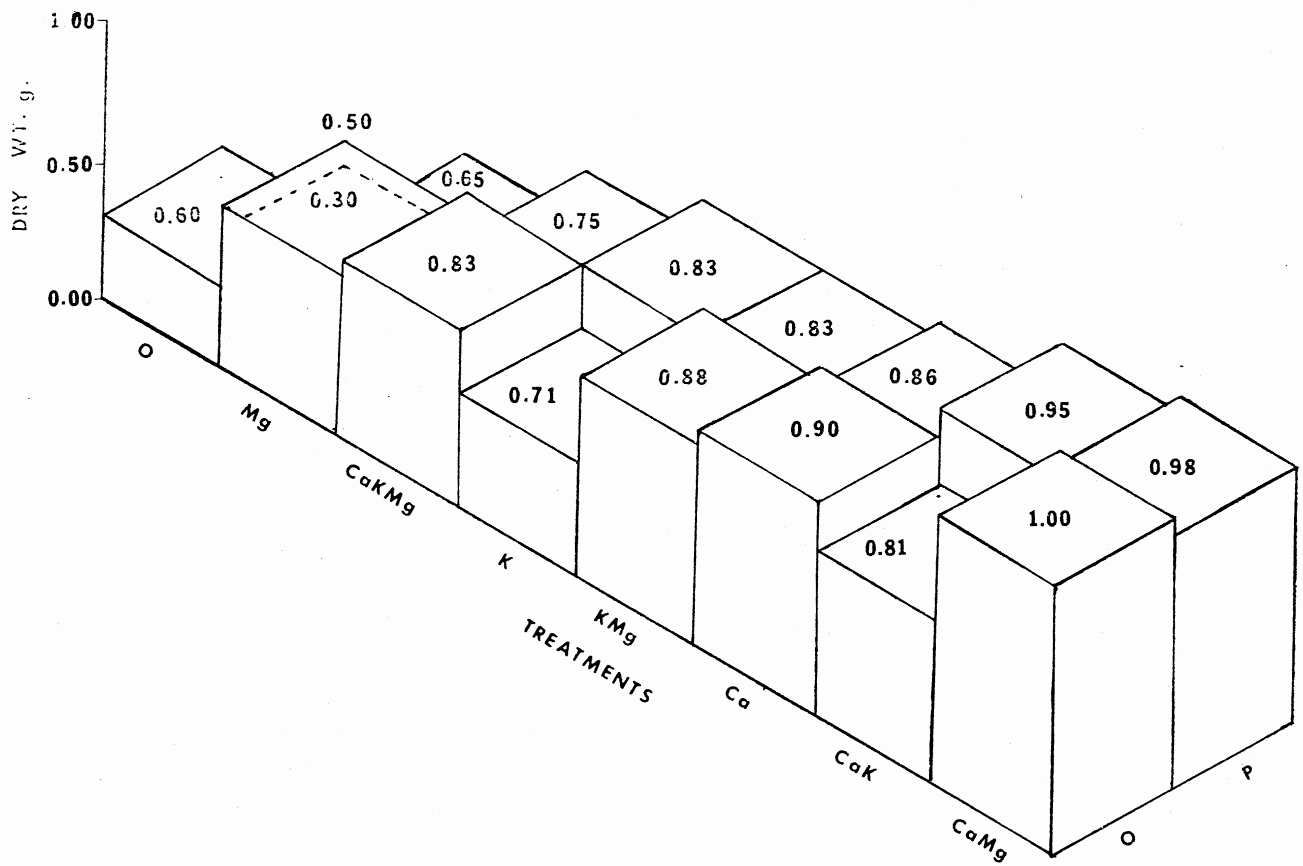

Figure 4. Residual Effects of Various Soil Fertility Treatments on Shoot Growth of Soybean, in a Dark Red Latosol, from Jaiba, MG, Brazil, Experiment 2.

combined with P they increased the yield to .86 and .83 g respectively, but the P combination with Mg maintained the same yield as that obtained with the control. The P effect when applied alone depressed the yield and the composite mean yield when P was omitted was higher, .82 g, than when P was applied, .79 g.

The addition of Ca alone to the soil increased the yield from .65 g to .90 g of dry matter. Ca combined with P, K and Mg resulted in an increase of .86, .81 and 1.0 g of dry matter respectively against the control .65 g. The composite mean yield with Ca was .89 while without yielded only .73 g.

K residual effects were positive when applied alone or when combined with Ca, P, and Mg and the yields obtained were .71 g when alone and .81, .83 and .88 g when combined with Ca, P and Mg respectively compared to control yield of .65 g. The composite mean yield was higher with K .82 g than without .79 g of dry matter.

The effect of adding Mg alone or in combination with Ca and P was positive as the yields were increased. For the single application of Mg, the yield was .80 g and for the combinations results were CaMg 1.0 g and KMg .88 g. When Mg was combined with P the yield was the same as that obtained with the control .65 g. The composite mean yield was increased when Mg was present with a yield of .84 g compared to the yield of .78 g when Mg was omitted.

From the analysis of variance, Table XXV, in the Appendix it is apparent that Ca and CaK sources were highly significant.

Root Growth

Results are shown in Figure 5 and Table X. The largest yield was

TABLE X

ORTHOGONAL EFFECTS OF VARIOUS SOIL FERTILITY TREATMENTS ON ROOT GROWTH OF SOYBEANS, FORREST VARIETY, IN A DARK RED LATOSOL, FROM JAIBA, MINAS GERAIS, BRAZIL. EXPERIMENT 2

Treat. Symbol	Av. Yield Dry wt. (g)	Treat. Symbol	Av. Yield Dry wt. (g)	Treat. Symbol	Av. Yield Dry wt. (g)	Treat. Symbol	Av. Yield Dry wt. (g)
O	1.27	K	0.97	Mg	1.48	KMg	0.97
P	0.68	KP	1.08	MgP	1.30	KMgP	0.78
Ca	1.33	CaK	1.15	CaMg	1.60	CaKMg	0.70
CaP	1.00	CaKP	0.83	CaMgP	1.40	CaKMgP	0.93
-P	+P	-Ca	+Ca	-K	+K	-Mg	+Mg
$\bar{\bar{x}}$ 1.18	1.00	1.07	1.12	1.26	0.93	1.04	1.15

Average yields are means of three replicate culture with 24 days of growth
$\bar{\bar{x}}$ means of composite yields with (+) and without (-) the designated element.
LSD related to the Composite mean LSD .01 = .3931 and LSD .05 = .2919
* significant at .05 ** significant at .01

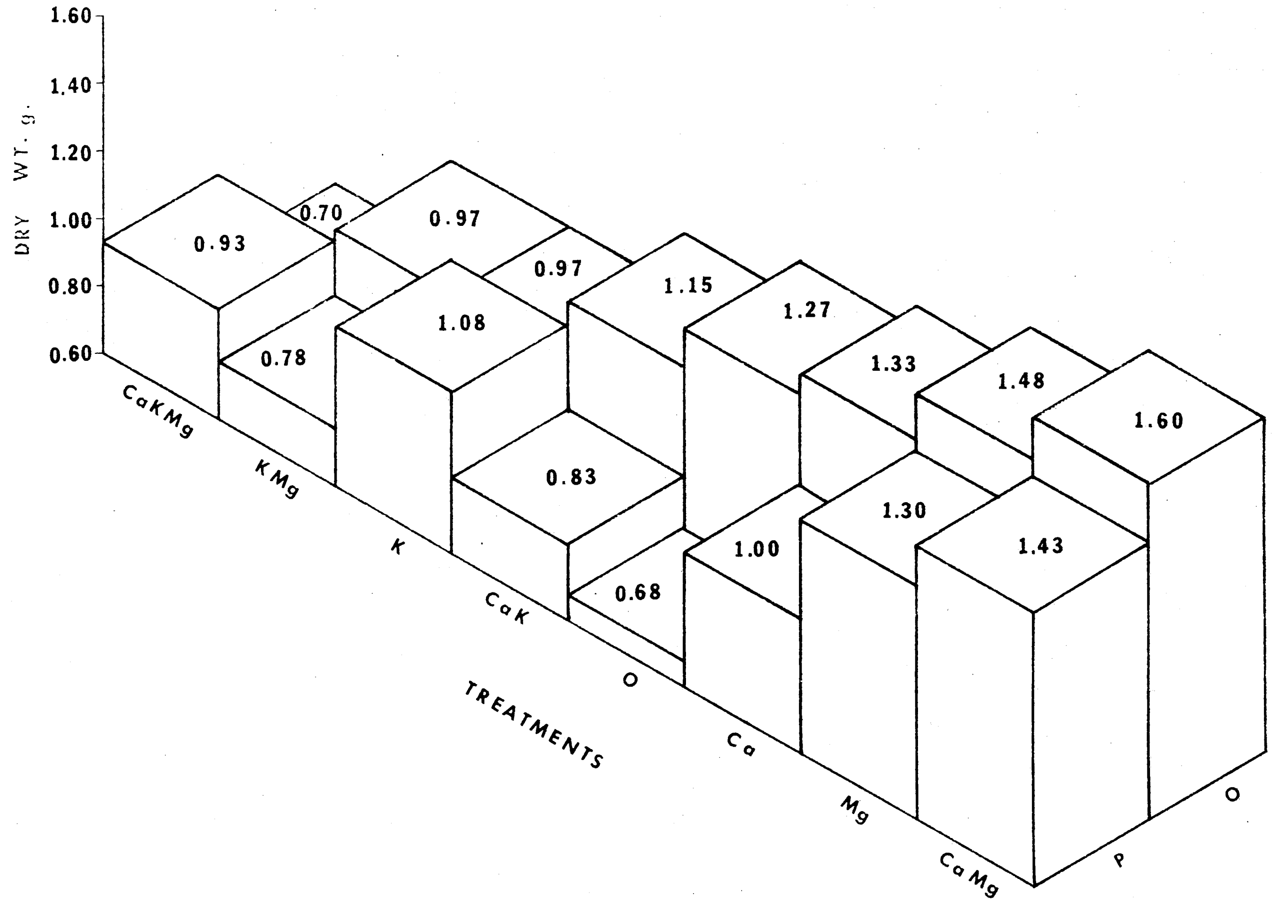

Figure 5. Residual Effects of Various Soil Fertility Treatments on Root Growth of Soybean, in a Dark Red Latosol, from Jaiba, MG, Brazil. Experiment 2

obtained with the application of Ca and Mg combined resulting in a yield of 1.60 g of dry matter, the lowest yield obtained with the application of P alone with a yield of .68 g of dry matter and the control, the soil without any treatment resulted in a yield of 1.27 g of dry matter.

Comparing the effects of the principal bases Ca, K, and Mg with and without P, it can be observed that when combined with Mg, P produced a yield of 1.30 g of dry matter but when applied alone P depressed the yield to .67 g of dry matter. When combined with Ca and K, the yields were 1.00 and 1.08 g of dry matter versus a yield of 1.27 g for the control. The composite mean yield when P was added was depressed with a yield of 1.00 g while the omission of P resulted in a yield of 1.18 g.

The effect of adding Ca to the soil increased the yield from 1.27 g for the control to 1.33 g of dry matter. When Ca was added with P, K, and Mg the results were 1.00, 1.15 and 1.60 g of dry matter respectively. Apparently the effect of Ca with P and K was depressive since the control yielded 1.27 g of dry matter. The composite mean yield when Ca was present 1.12 g was higher than with the absence 1.07 g.

The single application of K resulted in a yield of .97 g. When this element was combined with Ca, P and Mg, the results were still depressive with yields 1.15, 1.08 and .97 g respectively, and the control was 1.27 g. The composite mean yield with K depressed the yield to .93 g compared to the composite mean yield without K of 1.26 g of dry matter.

The effect of Mg when in single application increased the yield from 1.27 g in the control to 1.48 g. The combination of Mg with Ca, K and P was depressive for the KMg combination with .97 g yield. The combination with P and Ca increased the yield to 1.30 and 1.60 g respectively. The composite mean yield when Mg was present was higher than when omitted with a yield of 1.04 g without Mg and 1.15 g with Mg.

From the A. O. V., Table XXVI, in the appendix it was indicated that only the single source with K was significant at the .05 level of significance. However, it should be noted that the K influence was depressive in terms of weight of root growth and thus actual root weight may not be an indicator of the type of root growth and biological activity conducive to desirable top growth and development.

Third Experiment

This experiment was intended to study the residual effect of the fertilization from the first experiment. Data includes shoot and root growth, the number of nodules, nodule weight and nitrogenase activity.

Shoot Growth

Results for shoot growth is shown in Figure 6 and Table XI. Largest yield in shoot growth in the third experiment was observed in the pots treated with the combination of Ca, K and Mg with a yield of 2.07 g. The lowest value was K and Mg combined with P with a yield of .53 g compared with the control that yielded 1.13 g of dry matter.

The single addition of P to the soil was depressive resulting in a yield slightly lower than the control, 1.12 g for P. The P combination with Ca, K and Mg increased the yields resulting in 1.48 g for CaP, 1.63 g for KP and 1.82 g for PMg. The composite mean yield 1.46 g when P was present was lower than 1.56 g when P was omitted.

TABLE XI

ORTHOGONAL EFFECTS OF VARIOUS SOIL FERTILITY TREATMENTS ON SHOOT GROWTH OF SOYBEANS, FORREST VARIETY, IN A DARK RED LATOSOL, FROM JAIBA, MINAS GERAIS, BRAZIL. EXPERIMENT 3

Treat. Symbol	Av. Yield Dry wt. (g)	Treat. Symbol	Av. Yield Dry wt. (g)	Treat. Symbol	Av. Yield Dry wt. (g)	Treat. Symbol	Av. Yield Dry wt. (g)
O	1.13	K	1.28	Mg	1.20	KMg	1.50
P	1.12	KP	1.63	MgP	1.82	KMgP	1.73
Ca	1.52	CaK	1.80	CaMg	1.95	CaKMg	2.07
CaP	1.48	CaKP	1.55	CaMgP	1.73	CaKMgP	1.80
-P	+P	-Ca	+Ca	-K	+K	-Mg	+Mg
$\bar{\bar{x}}$ 1.56	1.46	1.28	1.74	1.49	1.52	1.44	1.58

Average yields are means of three replicate culture with 30 days of growth
$\bar{\bar{x}}$ means of composite yields with (+) and without (-) the designated element.
LSD related to the Composite mean LSD .01 = 0.2036 and LSD .05 = 0.1512
* significant at .05 ** significant at .01

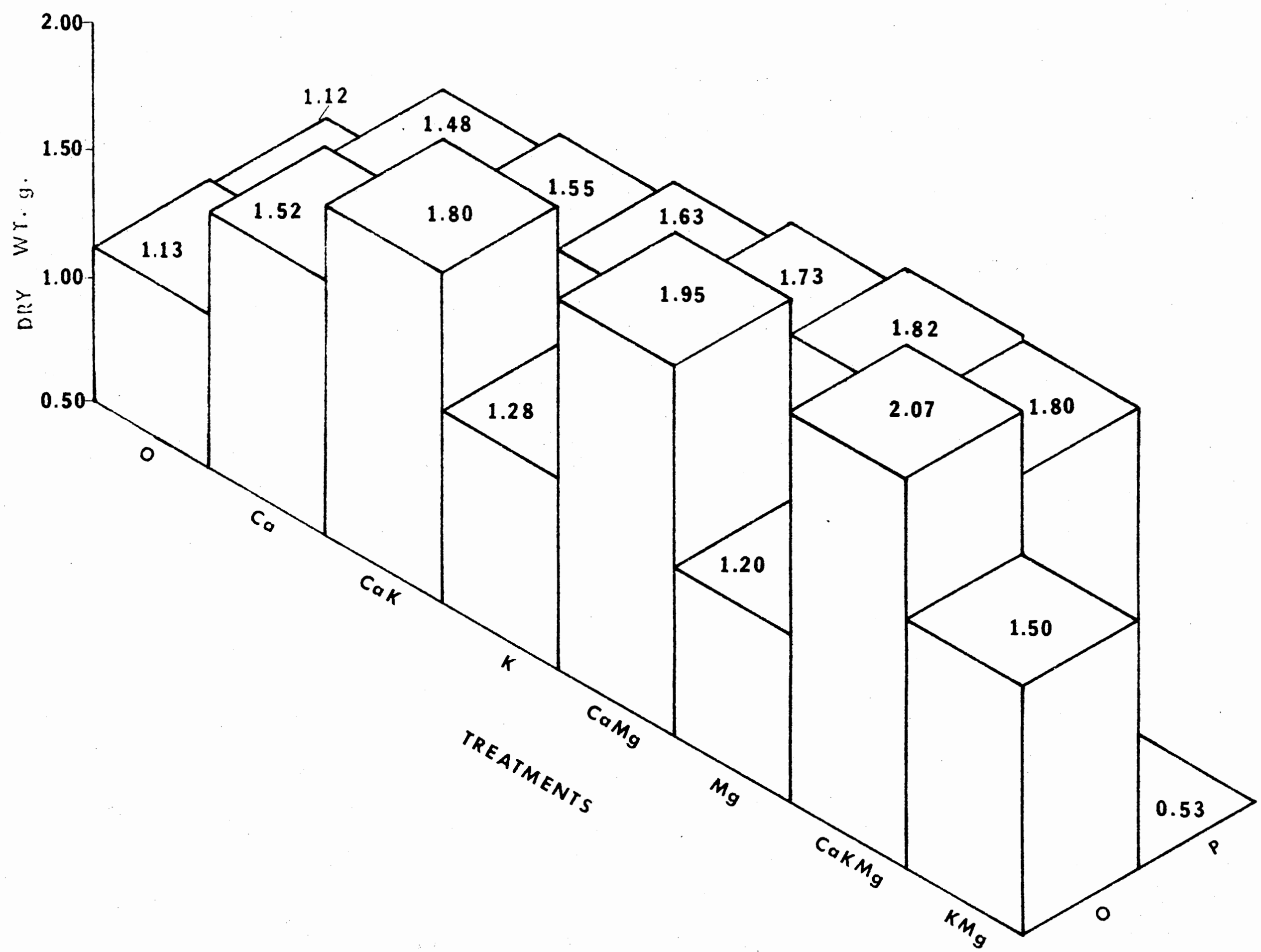

Figure 6. Residual Effects of Various Soil Fertility Treatments on Shoot Growth of Soybean, in a Dark Red Latosol, from Jaiba, MG, Brazil, Experiment 3.

The application of Ca either alone or combined resulted in increased yields when compared to the control 1.13 g, with 1.52 g for Ca, 1.48 g for CaP, 1.80 g for CaK and 1.95 g for CaMg. The composite mean yield with the presence of Ca was 1.74 g of dry matter while only 1.28 g was obtained without Ca.

The effect of K on yields of shoot growth in this experiment was positive when alone or when combined with one exception KPMg. The single application of K increased the yield from 1.13 g for the control to 1.28 g, and when combined with Ca the yield was 1.80 g. The combination with P resulted in 1.63 g yield and when applied with Mg was 1.50 g of dry matter. The composite mean yield when K was present was slightly higher 1.52 g than when it was omitted 1.49 g.

When Mg was applied to the soil the yield increased from 1.13 g for the control up to 1.20 g of dry matter. The Mg effect when combined with Ca, K and P appeared to be beneficial since it increased the yields to the following values when compared to the control, CaMg 1.95 g, KMg 1.50 g and PMg 1.82 g against 1.13 g for the soil without any treatment. The composite mean yield with the presence of Mg was 1.58 g while the absence of Mg decreased yield to 1.44 g of dry matter.

The A. O. V., Table XXVII, in the Appendix indicated that Ca, KMg, KPMg and CaKPMg sources were highly significant while CaMg, KP, and CaKMg were significant at .05 level of significance. This significance shows good evidence of the residual effects of the cation bases Ca, K and Mg on the shoot growth in this soil. The significance due to P addition should be noted as depressive.

<u>Root Growth</u>

the root growth yields with the residual effects from the fertilization applied before the first experiment is shown in Figure 7 and Table XII.

The treatment that resulted in the highest yield was one where K and P were applied together .57 g and the lowest yield .12 g was obtained where the combination of K, P and Mg was applied.

The single application of P to the soil increased the yield from .20 g for the control up to .28 g. Comparing the effects of principal cation bases Ca, Mg and K when in the presence or absence of P, P combined with Ca yielded .40 g, P combined with K yielded .57 g and the P and Mg combination yielded .48 g of dry matter with the control yield .20 g. The composite mean yield was not affected by the presence or omission of P yielding .39 g of dry matter for both.

With the single application of Ca, the yield increased to .47 g with the control .20 g. The effect of combining Ca with K, P and Mg resulted in the following yields respectively, .47 g, .40 g, and .48 g of dry matter. The composite mean yield with Ca was .46 g while the omission of Ca resulted in the composite mean yield of .31 g.

The effect of applying K to the soil increased the yield to .38 g of dry matter. The K combination with Ca, P and Mg increased the yields when they were applied together and the yields obtained were CaK .47 g, KP .57 g and KMg .38 g of dry matter. The composite mean yield with K presence was .40 g and with K omission was .38 g.

When Mg alone was applied to the soil the yield raised from .20 g up to .28 g of dry matter. The effect of Mg combined with Ca, K and P increased the yield as follows; caMg .48 g, KMg .38 g and PMg .43 g.

TABLE XII

ORTHOGONAL EFFECTS OF VARIOUS SOIL FERTILITY TREATMENTS ON ROOT GROWTH OF SOYBEANS, FORREST VARIETY, IN A DARK RED LATOSOL, FROM JAIBA, MINAS GERAIS, BRAZIL. EXPERIMENT 3

Treat. Symbol	Av. Yield Dry wt. (g)	Treat. Symbol	Av. Yield Dry wt. (g)	Treat. Symbol	Av. Yield Dry wt. (g)	Treat. Symbol	Av. Yield Dry wt. (g)
O	0.20	K	0.28	Mg	0.28	KMg	0.38
P	0.23	KP	0.57	MgP	0.43	KMgP	0.12
Ca	0.47	CaK	0.47	CaMg	0.48	CaKMg	0.53
CaP	0.40	CaKP	0.38	CaMgP	0.53	CaKMgP	0.45
-P	+P	-Ca	+Ca	-K	+K	-Mg	+Ma
$\bar{\bar{x}}$ 0.39	0.39	0.31	0.46	0.38	0.40	0.38	0.40

Average yields are means of three replicate cultures with 30 days of growth
$\bar{\bar{x}}$ means of composite yields with (+) and without (-) the designated element.
LSD related to the Composite mean LSD .01 = 0.0619 and LSD .05 = 0.0459
* significant at .05 ** significant at .01

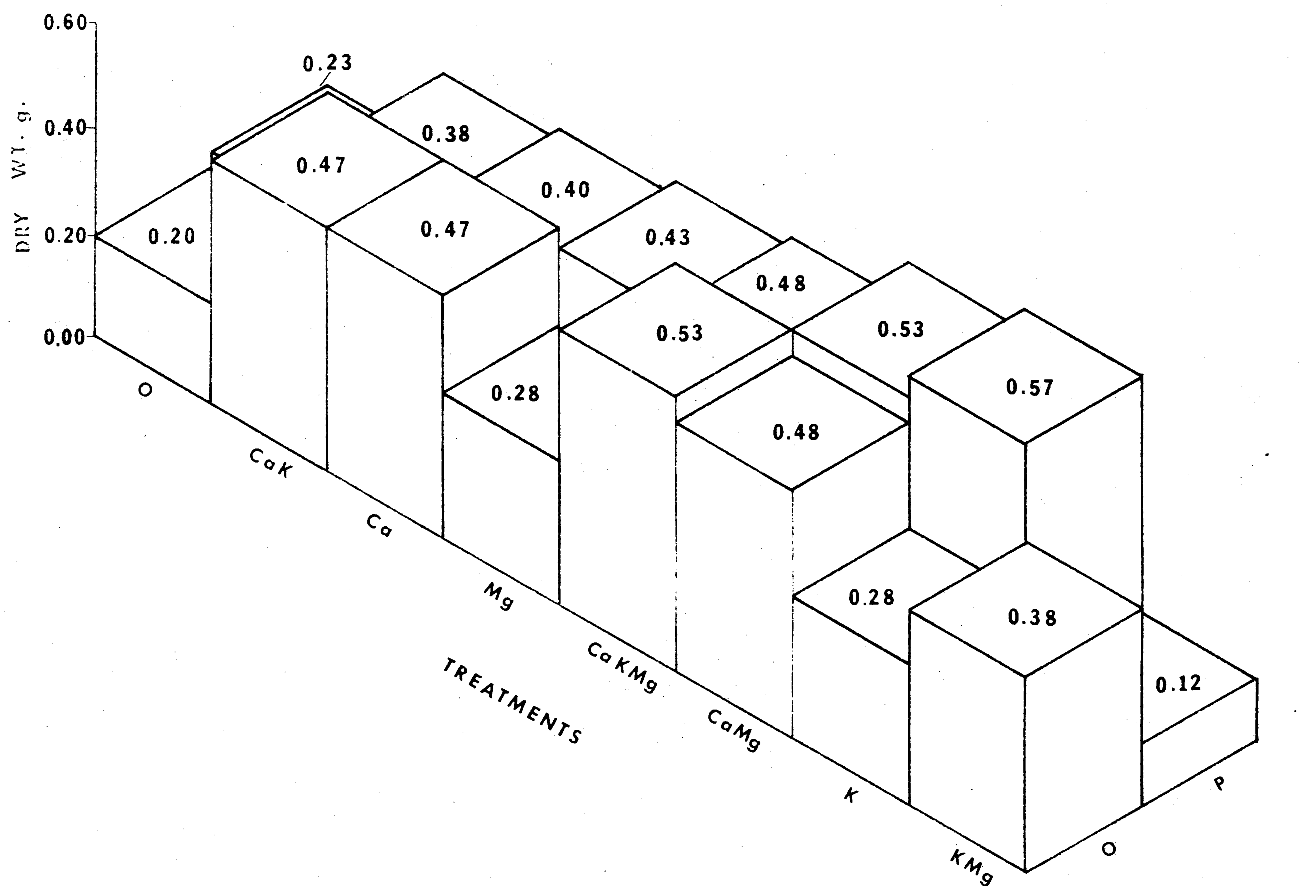

Figure 7. Residual Effects of Various Soil Fertility Treatments on Root Growth of Soybean, in a Dark Red Latosol, from Jaiba, MG, Brazil. Experiment 3.

The composite mean yield had the same pattern as the effect of K, with the Mg composite mean yield .40 g while the absence of Mg caused the composite mean yield to be .38 g of dry matter.

The A. O. V., Table XXIII, in the Appendix indicates that the effect of Ca, KMg, CaPMg, KPMg, CaKMg and CaKPMg sources were highly significant at .01 level of significance while CaP was significant only at .05 level.

Nodule Number

The data in Figure 8 and Table XIII presents nodule numbers under the residual effects of the treatments applied in the first experiment.

The largest nodule number per pot plant culture was obtained with the application of CaKP with the nodule numbers of 61 followed by CaK 56, and Ca 54. The lowest nodule number was obtained with the KPMg treatment, 1 per pot plant culture.

The single application of P to the soil slightly increased the nodule number from 21 for the control to 25 with the P addition, this increase is well below that caused by the single addition of Ca 54, K 36 and Mg 42. When observing the effects of principal cation bases Ca, K and Mg combined with P, results were 37 nodules for CaP, 39 for KP and 48 for PMg. The effect of P on the composite mean nodule number was depressive when P was present since 37 nodules were obtained compared to 41 with P omission.

Ca affected positively the nodule number response with its application increased the number of nodule from 21 for the check up to 54. The effect of Ca in combination with the other elements was beneficial in all treatments. For the combination CaP 37 nodules were obtained and

TABLE XIII

ORTHOGONAL EFFECTS OF VARIOUS SOIL FERTILITY TREATMENT ON NODULE NUMBER OF SOYBEANS, FORREST VARIETY, IN A DARK RED LATOSOL, FROM JAIBA, MINAS GERAIS, BRAZIL. EXPERIMENT 3

Treat. Symbol	Nodule Number	Treat. Symbol	Nodule Number	Treat. Symbol	Nodule Number	Treat. Symbol	Nodule Number
O	21	K	36	Mg	42	KMg	40
P	25	KP	39	MgP	48	KMgP	1
Ca	54	CaK	56	CaMg	34	CaKMg	45
CaP	37	CaKP	61	CaMgP	44	CaKMgP	42
-P	+P	-Ca	+Ca	-K	+K	-Mg	+Mg
$\bar{\bar{x}}$ 41	37	32	47	38	40	41	37

Average yields are means of three replicate culture with 30 days of growth
$\bar{\bar{x}}$ means of composite yields with (+) and without (-) the designated element.
LSD related to the Composite mean LSD .01 = 9.4531 and LSD .05 = 7.0194
* significant at .05 ** significant at .01

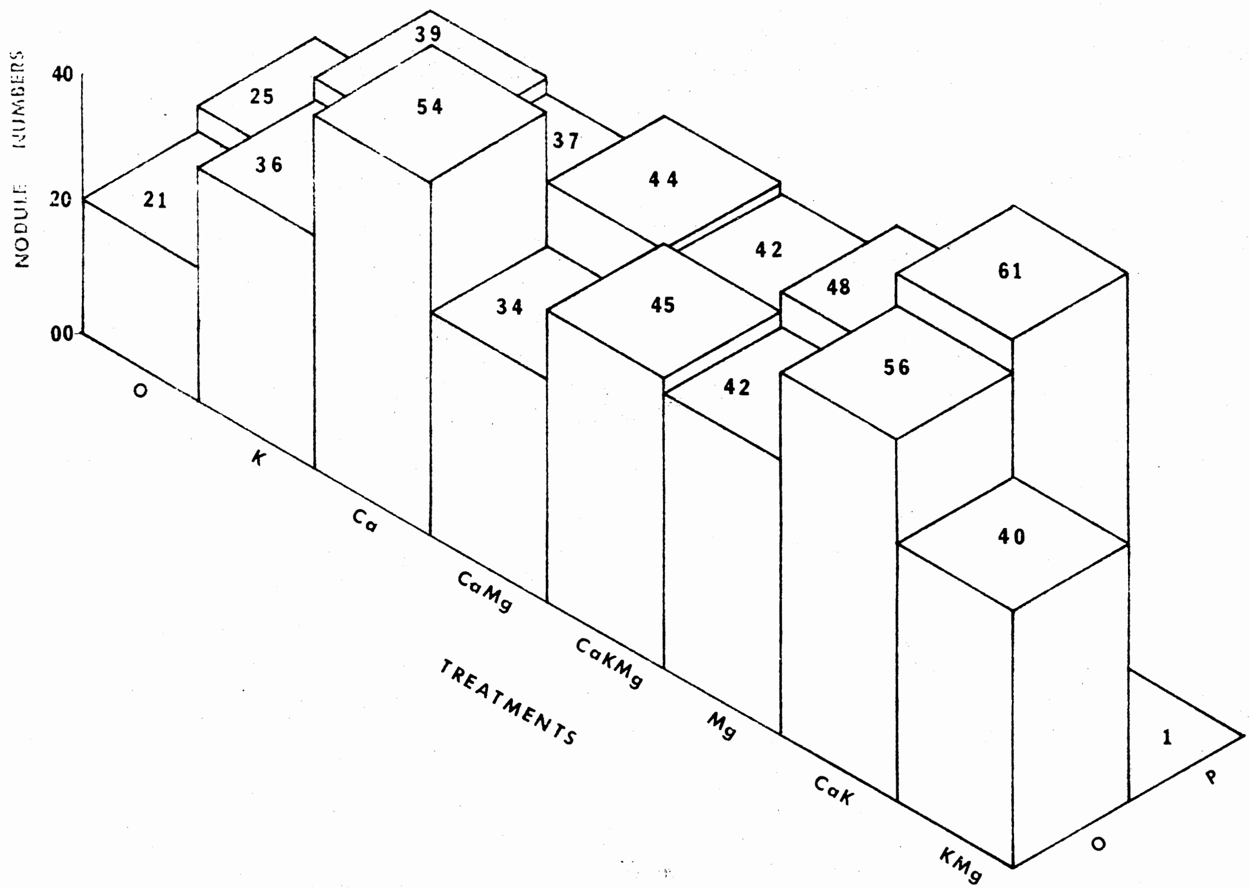

Figure 8. Residual Effects of Various Soil Fertility Treatments on Nodule Number of Soybean, in a Dark Red Latosol, from Jaiba, MG, Brazil. Experiment 3.

for CaK and CaMg 56 and 34 nodules were obtained, respectively. The composite mean nodule number was also positively affected by the presence of Ca 47 nodules, without Ca numbered only 32 nodules.

When K was applied alone the response was 36 nodules which was higher than the control. The application of K with Ca resulted in 56 nodules, K combined with P produced 39 nodules while KMg was 40 nodules, the composite mean nodule number when K was omitted was 38 while the addition of K raised the nodule number to 40.

The effect of applying Mg was positive in all treatments with the exception when combined with K and P. For single addition Mg numbered 42 nodules with the control 21 nodules. When Mg was combined with Ca, K and P yields were 34, 50 and 48 nodules respectively. The composite mean nodule number were depressed by the Mg presence, 37 nodules, while the Mg absence resulted in 41 nodules.

The Analysis of Variance, Table XXIX, in the Appendix, indicated that Ca, KMg, KPMg sources had highly significant responses and CaPMg, CaKP and CaKMg were significant. It can be surmised that Ca and K improved the nodule number while P and Mg depressed nodule formation. When P and Mg were combined with K an unbalanced fertility situation was significant in depressing nodule number.

Nodule Weight

Nodule weight under influence of residual effect of the treatments applied previously to the first experiment will now be observed and the Figure 9 and Table XIV show the data obtained.

The highest nodule weight was obtained from the cultures when Ca and Mg were applied together with a yield of .0128 g of dry nodule wt,

TABLE XIV

ORTHOGONAL EFFECTS OF VARIOUS SOIL FERTILITY TREATMENTS ON NODULE WEIGHT OF SOYBEANS, FORREST VARIETY, IN A DARK RED LATOSOL, FROM JAIBA, MINAS GERAIS, BRAZIL. EXPERIMENT 3

Treat. Symbol	Nodule Dry wt. (g)	Treat. Symbol	Nodule Dry wt. (g)	Treat. Symbol	Nodule Dry wt. (g)	Treat. Symbol	Nodule Dry wt. (g)
0	0.0041	K	0.0061	Mg	0.0048	KMg	0.0063
P	0.0038	KP	0.0096	MgP	0.0070	KMgP	0.0001
Ca	0.0052	CaK	0.0083	CaMg	0.128	CaKMg	0.0102
CaP	0.0070	CaKP	0.0066	CaMgP	0.0100	CaKMgP	0.0088
-P	+P	-Ca	+Ca	-K	+K	-Mg	+Mg
$\bar{\bar{x}}$ 0.0072	0.0066	0.0052	0.0086	0.0068	0.0070	0.0063	0.0075

Average yields are means of three replicate culture with 30 days of growth
$\bar{\bar{x}}$ means of Composite yields with (+) and without (-) the designated element.
LSD related to the Composite mean LSD .01 = 0.0021 and LSD .05 = 0.0016
* significant at .05   ** significant at .01

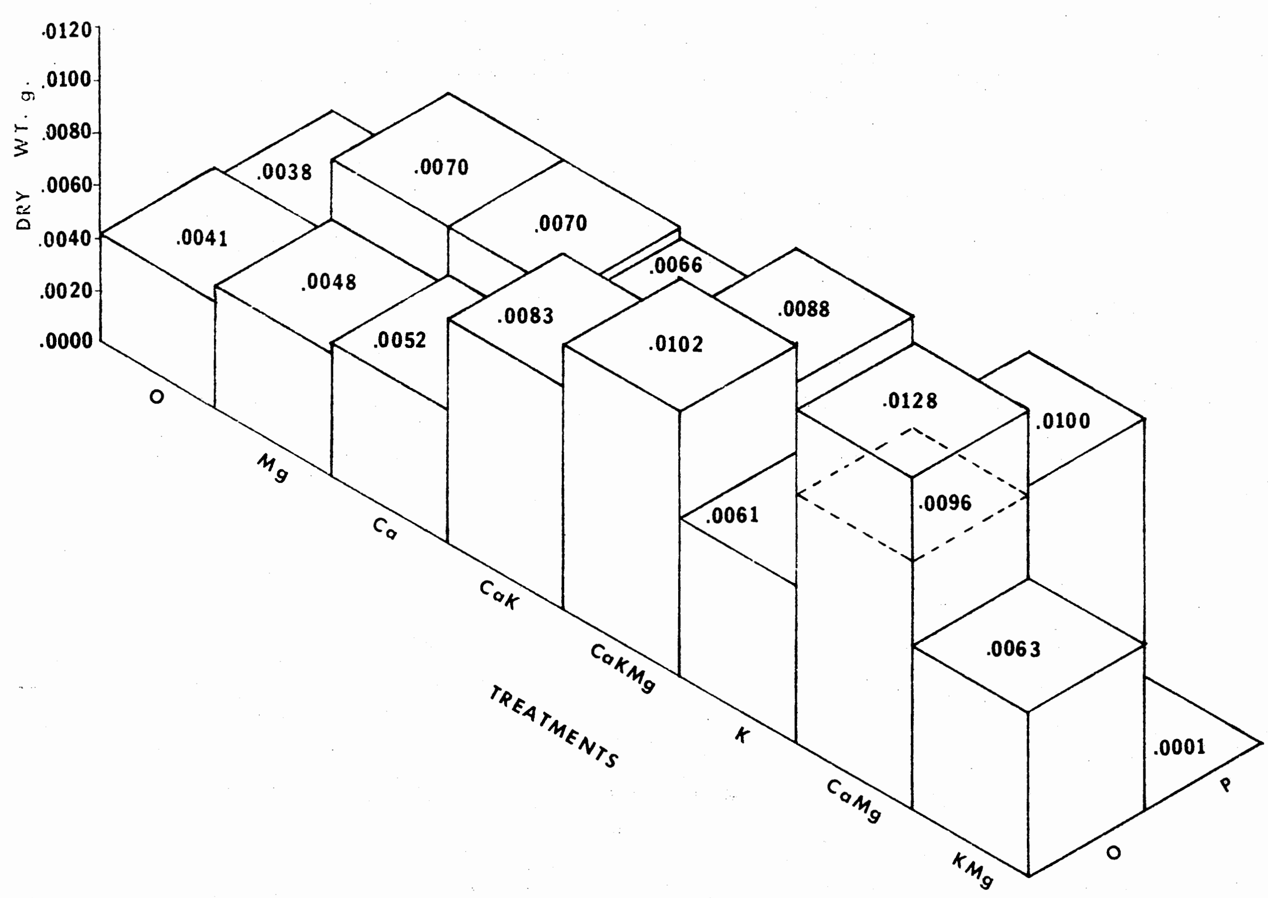

Figure 9. Residual Effects of Various Soil Fertility Treatments on Nodule Weight of Soybean, in a Dark Red Latosol, from Jaiba, MG, Brazil. Experiment 3.

followed by CaKMg .0102 g and CaPMg .0100 g. The lowest yield resulted from the application of K, P and Mg together with a yield of .0001 g of dry nodule wt.

The addition of P alone depressed yield resulting in .0038 g with the control yield .0041 g. P combined with the principal cation bases Ca, Mg and K resulted in the following yields .0070 g, .0070 g and .0096 g respectively. The composite mean yield was depressed when P was present, .0066 g, without P resulted in .0072 g dry nodule weight.

Ca influenced positively the dry nodule wt in this experiment yielding when applied alone .0052 g against .0041 g for the control. All Ca treatments yielded higher than the control and the effect of applying Ca combined with K, P and Mg was as follows: CaK .0083 g, CaP .0070 g and CaMg .0128 g. The composite mean nodule wt increased with the presence of Ca yielding .0086 g, without Ca yielded .0052 g dry nodule wt.

The effect of applying K to the soil increased dry nodule wt yield from .0041 g for the control to .0061 g. The combination of K with Ca resulted in .0083 g yield, KP yielded .0096 g while KMg was .0063 g dry nodule wt. The composite mean yield when K was present .0070 g was higher than that obtained without K .0068 g dry nodule wt.

The influence of applying Mg to the soil was beneficial s nce the yield was increased from .0041 g for the control to .0048 g. When Mg was applied combined with Ca, K and P the following yields were obtained: CaMg .0128 g, KMg .0063 g and PMg .0070 g dry nodule wt. The composite mean nodule wt with Mg yielded .0075 g, without Mg the yield was .0063 g dry nodule weight.

The A. O. V., Table XXX, in the Appendix, indicated that Ca, CaMg and KMg were highly significant at .01 level. CaKPMg source was significant at .05 level and it can be noted that P when combined with all other three bases together had a positive effect on nodule weight, which was not noted when P was applied alone or combined with one or the other two bases.

Nitrogenase Activity

Nitrogenase activity in the nodules of soybean was determined as micromoles C_2H_4 per g fresh nodule weight per hour and the results are shown in Figure 10 and Table XV.

The highest value was obtained with CaP 271.6 and the lowest was with KPMg .1.

P effect increased the nitrogenase activity from 128.5 for the control up to 149.3. When comparing the P effect combined with the principal cation bases Ca, Mg and K it was noted that CaP resulted in 271.6, KP in 166.3 and PMg 154.4. The composite mean nitrogenase activity with P shows a lower value 165.0 than that obtained without P 169.0.

The addition of Ca resulted in nitrogenase activity 157.1 with the control 128.5. Ca effect when combined with P, K and Mg was also positive resulting values 271.6, 139.9 and 188.8 respectively. The composite mean nitrogenase activity was higher with Ca presence 188.6, without Ca composite mean was 145.4.

The effect of adding K to the soil resulted in increasing nitrogenase activity from 128.5 for the control to 149.3. The combination of K with Ca, P and Mg resulted in CaK 139.9, KP 166.3 and KMg 155.3. The composite mean nitrogenase activity without K resulted in a nitro-

TABLE XV

ORTHOGONAL EFFECTS OF VARIOUS SOIL FERTILITY TREATMENTS ON NITROGENASE ACTIVITY OF SOYBEANS, FORREST VARIETY, IN A DARK RED LATOSOL, FROM JAIBA, MINAS GERAIS, BRAZIL. EXPERIMENT 3

Treat. Symbol	Act. μmoles/g hr^{-1}	Treat. Symbol	Act. μmoles/g hr^{-1}	Treat. Symbol	Act. μmoles/g hr^{-1}	Treat. Symbol	Act. μmoles/g hr^{-1}
O	128.5	K	210.7	Mg	198.7	KMg	155.3
P	149.3	KP	166.3	MgP	154.4	KMgP	0.1
Ca	157.1	CaK	139.9	CaMg	188.8	CaKMg	172.9
CaP	271.6	CaKP	237.0	CaMgP	203.0	CaKMgP	138.5
-P	+P	-Ca	+Ca	-K	+K	-Mg	+Mg
$\bar{\bar{x}}$ 169.0	165.0	145.4	188.6	181.4	152.6	182.5	151.5

Average yields are means of three replicate culture with 30 days of growth
$\bar{\bar{x}}$ means of composite yields with (+) and without (-) the designated element.
LSD related to the Composite mean LSD .01 = 37.8146 and LSD .05 = 28.0790
* significant at .05 ** significant at .01

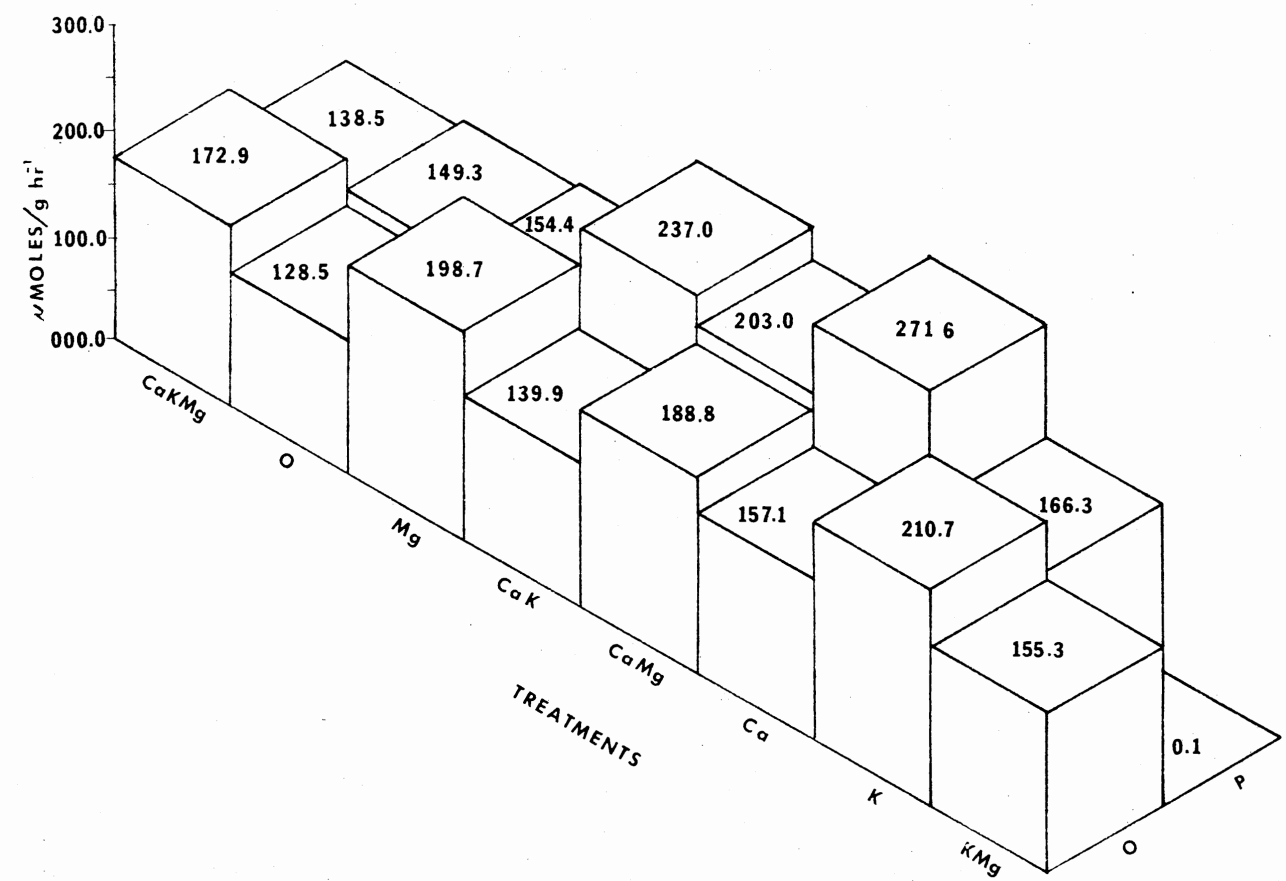

Figure 10. Residual Effects of Various Soil Fertility Treatments on Nitrogenase Activity of Soybean, in a Dark Red Latosol, from Jaiba, MG, Brazil. Experiment 3.

genase activity of 181.4, the addition of K depressed the value to 152.6.

Treating soil with Mg increased nitrogenase activity up to 198.7 with the control measurement of 128.5. When Mg was added combined with Ca, K and P resulted in 188.8 for CaMg, 154.4 for KMg and 155.5 for PMg. The composite mean nitrogenase activity with Mg addition was 151.5, without Mg was 182.5.

Analysis of Variance, Table XXXI, in the appendix indicated that Ca, CaP, KMg and PMg sources were highly significant, and K, Mg and CaKMg were significant.

Fourth Experiment

The fourth experiment was replanted following the third experiment without additional treatment. Shoot and root growth as dry weight are presented in this experiment.

Shoot Growth

Data for shoot growth is shown in Figure 11 and Table XVI.

The largest yield of shoot growth was obtained with CaPMg treatment, 4.13 g of dry matter, with smallest obtained for KPMg yielding 1.00 g of dry matter.

The effects of P application, alone or combined with the principal cation bases Ca, K and Mg, yielded P 2.57 g, CaP 3.28 g, KP 3.47 g and PMg 3.77 g with the control 2.92 g, only the application of P alone depressed yield. The composite mean yield was also depressed when P was present, 3.25 g, as compared without P with 3.35 g of dry matter.

The effect when Ca was applied alone was positive with the yield increased from 2.92 g for the control to 3.53 g. The effect of com-

TABLE XVI

ORTHOGONAL EFFECTS OF VARIOUS SOIL FERTILITY TREATMENTS ON SHOOT GROWTH OF SOYBEANS, FORREST VARIETY, IN A DARK RED LATOSOL, FROM FAIBA, MINAS GERAIS, BRAZIL. EXPERIMENT 4

Treat. Symbol	Av. Yield Dry wt. (g)	Treat. Symbol	Av. Yield Dry wt. (g)	Treat. Symbol	Av. Yield Dry wt. (g)	Treat. Symbol	Av. Yield Dry wt. (g)
O	2.92	K	2.23	Mg	3.25	KMg	3.17
P	2.57	KP	3.47	MgP	3.77	KMgP	1.00
Ca	3.53	CaK	3.81	CaMg	3.95	CaKMg	3.97
CaP	3.28	CaKP	4.03	CaMgP	4.13	CaKMgP	3.75
-P	+P	-Ca	+Ca	-K	+K	-Mg	+Mg
$\bar{\bar{x}}$ 3.35	3.25	2.80	3.81	3.43	3.18	3.23	3.37

Average yields are means of three replicate culture with 32 days of growth
$\bar{\bar{x}}$ means of composite yields with (+) and without (-) the designated element
LSD related to the Composite mean LSD .01 - 0.3823 and LSD .05 = 0.2838
* significant at .05 ** significant at .01

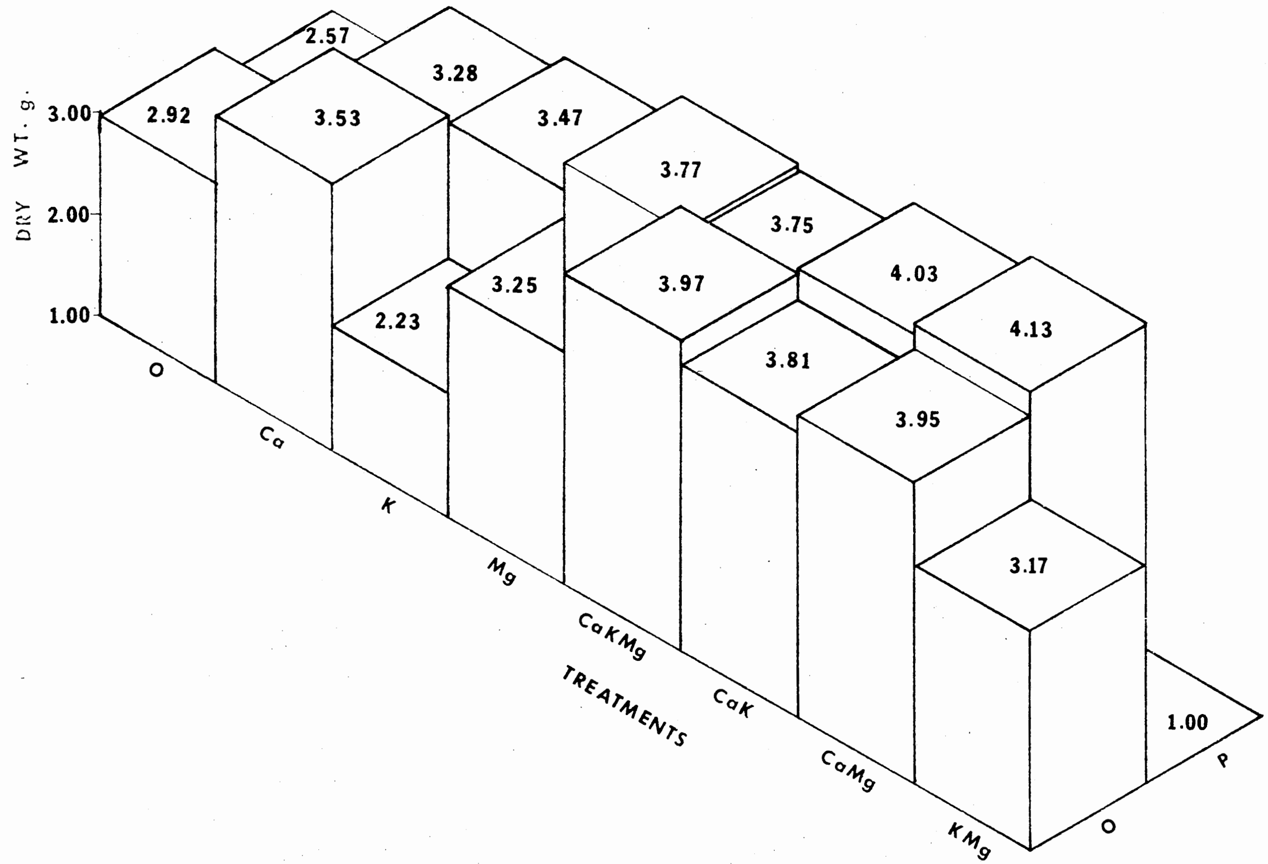

Figure 11. Residual Effects of Various Soil Fertility Treatments on Shoot Growth of Soybean, in a Dark Red Latosol, from Jaiba MG, Brazil. Experiment 4.

bining Ca with K, P and Mg also increased growth yield 3.81 g, 3.28 g and 3.95 g of dry matter respectively. The composite mean yield increased by 1.01 g when Ca was present without Ca 2.80 g, with Ca 3.81 g of dry matter.

K effect was depressive on the composite mean yield and when in single application. With single application of K the yield was 2.23 g compared to 2.92 g for the control. The composite mean yield was depressed from 3.43 g, when K was omitted, to 3.18 g with K application. However, K in association with Ca, P and Mg increased dry matter production, CaK 3.81 g, KP 3.47 g and KMg 3.17 g of dry matter.

Applying Mg to the soil, alone or combined with Ca, K and P, increased yield. With the control 2.92 g, Mg addition resulted in 3.25 g, CaMg 3.95 g, KMg 3.17 g and PMg 3.77 g dry matter. The composite mean yield was 3.37 g when Mg was present and the Mg omission depressed yield, with 3.23 g dry matter.

The analysis of variance, Table XXXII, in the Appendix, indicated that Ca, CaK, KMg and CaKPMg sources had a highly significant effect. KPMg, although highly significant, depressed yield and thus indicated an unbalanced plant nutrient situation resulting in depressive growth. PMg and CaPMg had a positive significant effect on improving yields.

Root Growth

The data for root growth is in Figure 12 and Table XVII. The highest yield 2.00 g dry matter was obtained when the soil was treated with the CaMg combination followed by CaK combination that resulted in 1.82 g yield. The lowest yield as the KPMg treatment resulting .30 g yield.

TABLE XVII

ORTHOGONAL EFFECTS OF VARIOUS SOIL FERTILITY TREATMENTS ON ROOT GROWTH OF SOYBEANS, FORREST VARIETY, IN A DARK RED LATOSOL, FROM JAIBA, MINAS GERAIS, BRAZIL. EXPERIMENT 4

Treat. Symbol	Av. Yield Dry wt. (g)	Treat. Symbol	Av. Yield Dry wt. (g)	Treat. Symbol	Av. Yield Dry wt. (g)	Treat Symbol	Av. Yield Dry wt. (g)
O	0.92	K	1.00	Mg	1.17	KMg	1.42
P	1.05	KP	1.35	MgP	1.57	KMgP	0.30
Ca	1.32	CaK	1.82	CaMg	2.00	CaKMg	1.38
CaP	1.10	CaKP	1.15	CaMgP	1.27	CaKMgP	1.20
-P	+P	-Ca	+Ca	-K	+K	-Mg	+Mg
$\bar{\bar{x}}$ 1.32	1.12	1.10	1.40	1.30	1.20	1.21	1.29

$\underline{\underline{A}}$verage yields are means of three replicate culture with 32 days of growth
$\bar{\bar{x}}$ means of composite yields with (+) and without (-) the designated element.
LSD related to the Composite mean LSD .01 = 0.3176 and LSD .05 = 0.2359
* significant at .05 ** significant at .01

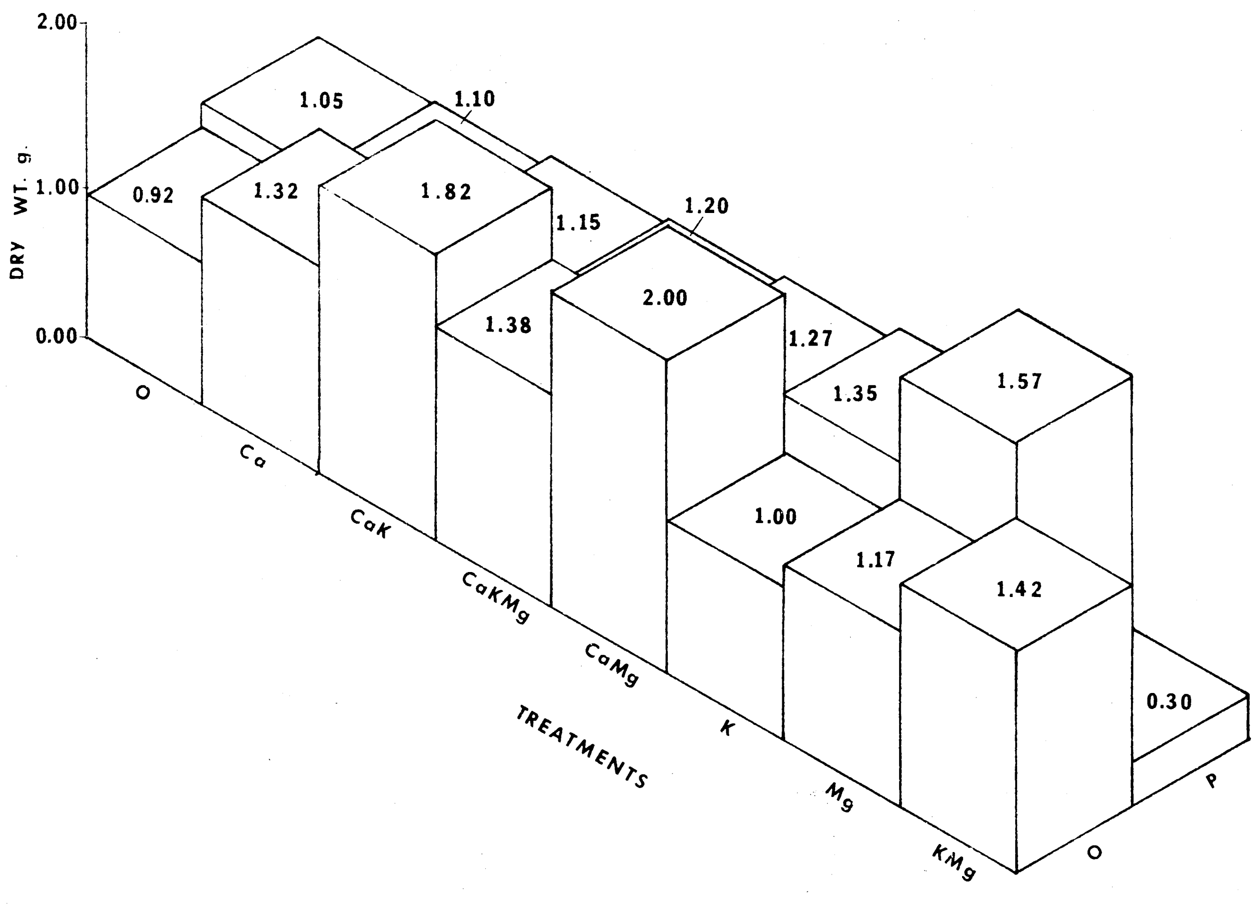

Figure 12. Residual Effects of Various Soil Fertility Treatments on Root Growth of Soybean, in a Dark Red Latosol, from Jaiba, MG, Brazil, Experiment 4.

The effect of applying P alone or combined with the principal base cations Ca, Mg and K resulted in increased yields. Thus for the control the yield was .92 g, with P 1.05 g, CaP 1.10 g, KP 1.35 g and PMg 1.57 g. The composite mean yield was depressed with P addition yielding 1.12 g, while P absence resulted in 1.32 g yield.

Ca applied to the soil either alone or combined with K, P and Mg increased yield, since the control yielded .92 g and Ca 1.32 g, CaK 1.82 g, CaP 1.10 g and CaMg 2.00 g dry matter. The composite mean yield was positively affected by Ca presence yielding 1.40 g without Ca 1.10 g.

The addition of K to the soil increased slightly the yield from .92 g for the control up to 1.00 g dry matter. K combined with Ca, P and Mg also increased yields 1.82 g, 1.35 g and 1.42 g respectively. The composite mean yield was depressed when K was present 1.20 g, without K the composite mean yield was 1.30 g.

Applying Mg to the soil alone or combined increased yield. The control was .92 g with Mg 1.17 g, CaMg 2.00 g, KMg 1.42 and PMg 1.57 g of dry matter. The composite mean yield was increased with Mg yielding 1.29 g, without Mg was 1.21 g.

The Analysis of Variance, Table XXXIII, in the Appendix, indicated that a highly significant effect resulted with the application of KMg and CaKPMg and that significant positive effect resulted from Ca and P sources.

Fifth Experiment

This was the final experiment of this series and followed the fourth experiment without additional soil treatment. Shoot and root growth, nodule number, nodule weight and nitrogenase activity was determined in this experiment.

Shoot Growth

The data for shoot growth is shown in Figure 13 and Table XVIII. The highest yield was obtained with KPMg treatment yielding 2.66 g dry matter compared to 1.63 g for the control. The lowest yield was from the CaP treatment with 1.37 g. Apparently in this experiment the single application of Ca, K, P and Mg depressed the yield.

P applied alone depressed the yield resulting in 1.58 g dry matter. P combined with Ca resulted in the lowest yield 1.37 g. Positive effect of combining P with the principal bases Ca, K and Mg was noted only for KP combination 1.82 g, PMg combination depressed the yield 1.52 g with the control yield 1.63 g. The composite mean yield increased with P addition 1.87 g, the absence of P resulted in the decrease of the composite mean yield 1.61 g dry matter.

As previously mentioned the single addition of Ca depressed the yield 1.57 g. This same depressive effect resulted with combining Ca and P 1.37 g the lowest yield. When Ca was combined with K and Mg the yield was slightly improved 1.65 g for both combination with the control with 1.65 g and KP combination 1.82 g. The composite mean yield with K increased yield from 1.58 g without K to 1.89 g.

The effect of applying Mg depressed yield when applied alone or combined with P 1.53 g and 1.52 g respectively. The yield was slightly improved when Mg was combined with Ca and K resulting in 1.65 g yield for both with the control yielding 1.63g. The composite mean yield was increased with Mg yielding 1.77 g, without Mg yield was 1.70 g.

TABLE XVIII

ORTHOGONAL EFFECTS OF VARIOUS SOIL FERTILITY TREATMENTS ON SHOOT GROWTH OF SOYBEANS, FORREST VARIETY, IN A DARK RED LATOSOL, FROM JAIBA, MINAS GERAIS, BRAZIL. EXPERIMENT 5

Treat. Symbol	Av. Yield Dry wt. (g)	Treat. Symbol	Av. Yield Dry wt. (g)	Treat. Symbol	Av. Yield Dry wt. (g)	Treat. Symbol	Av. Yield Dry wt. (g)
0	1.63	K	1.52	Mg	1.53	KMg	1.65
P	1.58	KP	1.82	MgP	1.52	KMgP	2.66
Ca	1.57	CaK	1.65	CaMg	1.65	CaKMg	1.68
CaP	1.37	CaKP	2.45	CaMgP	1.82	CaKMgP	1.70
-P	+P	-Ca	+Ca	-K	+K	-Mg	+Mg
$\bar{\bar{x}}$ 1.61	1.87	1.73	1.74	1.58	1.89	1.70	1.77

Average yields are means of three replicate culture with 36 days of growth
$\bar{\bar{x}}$ means of composite yields with (+) and without (-) the designated element
LSD related to the Composite mean LSD .01 = 0.2200 and LSD .05 = 0.1633
* significant at .05 ** significant at .01

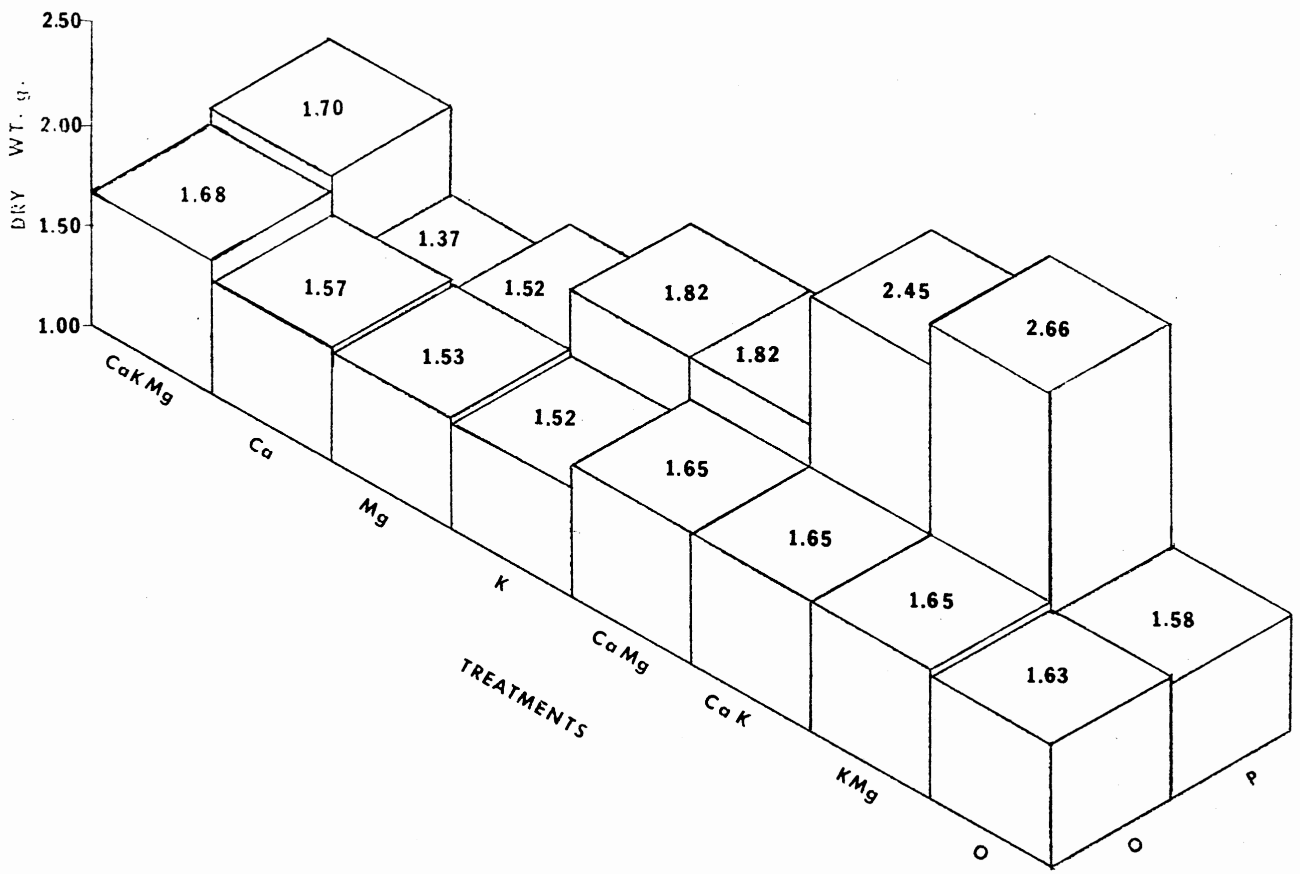

Figure 13. Residual Effects of Various Soil Fertility Treatments on Shoot Growth of Soybean, in a Dark Red Latosol, from Jaiba, MG, Brazil. Experiment 5.

The Analysis of Variance, Table XXXIV, in the Appendix, indicated that the K, P. KP, CaKMg and CaKPMg treatments were highly significant.

Root Growth

Results from the root growth determinations of the fifth experiment is shown in Figure 14 and Table XIX.

The highest yield, as with shoot growth, was obtained with the KPMg treatment yielding .78 g, with the lowest yield obtained with the control .32 g dry matter.

P influence when applied alone or combined with the principal cation bases Ca, K and Mg yielded as follows: P .52 g, CaP .35 g, KP .50 g and PMg .38 g. The composite mean yield increased with P addition .51 g, without P resulted in .42 g yield.

Ca alone increased yield to .40 g. Ca combined with K, P and Mg also increased yields; CaK .52g, CaP .35 g and CaMg .35 g. The composite mean yield with Ca .44 g decreased from .48 g without Ca.

K effect was positive resulting in a yield of .38 g with the control yield .32 g. The treatments where K was combined with Ca, P and Mg also increased yields, CaK .52 g, KP .50 g and KMg .52 g. The composite mean yield with K addition yielded .51 g, without K resulted in .41 g yield.

Mg when applied alone increased yield from .32 g for the control to .47 g. The Mg combinations with Ca, K and P also increased yields; CaMg .35 g, KMg and PMg both were .52 g. The composite mean yield was increased slightly by Mg .47 g, without Mg .45 g.

The Analysis of Variance, Table XXXV, in the Appendix, indicated that root growth was affected highly significantly by K and CaKMg sources.

TABLE XIX

ORTHOGONAL EFFECTS OF VARIOUS SOIL FERTILITY TREATMENTS ON ROOT GROWTH OF SOYBEANS, FORREST VARIETY, IN A DARK RED LATOSOL, FROM JAIBA, MINAS GERAIS, BRAZIL. EXPERIMENT 5

Treat. Symbol	Av. Yield Dry wt. (g)	Treat. Symbol	Av. Yield Dry wt. (g)	Treat. Symbol	Av. Yield Dry wt. (g)	Treat. Symbol	Av. Yield Dry wt. (g)
O	0.32	K	0.38	Mg	0.47	KMg	0.52
P	0.52	KP	0.50	MgP	0.38	KMgP	0.78
Ca	0.40	CaK	0.52	CaMg	0.35	CaKMg	0.38
CaP	0.35	CaKP	0.63	CaMgP	0.52	CaKMgP	0.38
-P	+P	-Ca	+Ca	-K	+K	-Mg	+Mg
$\bar{\bar{x}}$ 0.42	0.51	0.48	0.44	0.41	0.51	0.45	0.47

Average yields are means of three replicate culture with 36 days of growth
$\bar{\bar{x}}$ means of composite yields with (+) and without (-) the designated element.
LSD related to the Composite mean LSD .01 = 0.1117 and LSD .05 = 0.0830
* significant at .05 ** significant at .01

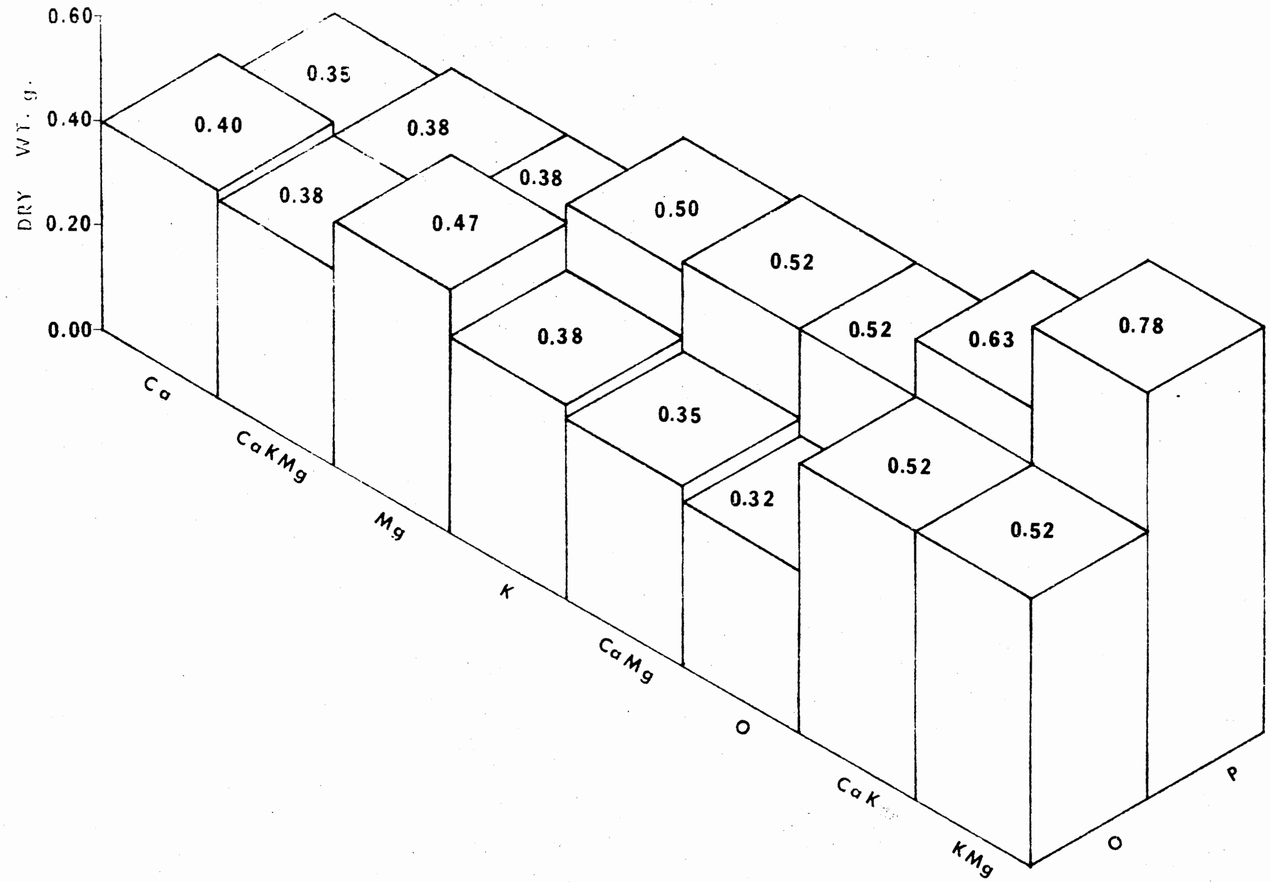

Figure 14. Residual Effects of Various Soil Fertility Treatments on Root Growth of Soybean, in a Dark Red Latosol, from Jaiba, MG, Brazil. Experiment 5.

P, CaMg and CaKPMg effects were statistically significant.

Nodule Number

Results of nodule number counts per plant by soil treatment are presented in Figure 15 and Table XX.

The highest nodule number was obtained with CaKMg treatment, 37 nodules, the lowest nodule number was obtained when the soil was treated with single application of P, 20 nodules.

The single application of P depressed yields from 22 nodules for the control to 20 nodules. The combination of the principal cation bases Ca, Mg and K with P resulted in 22, 30 and 32 nodules respectively, combination with Ca resulted in the same yield as the control, however, PMg and KP combinations increased nodule development. The composite mean nodule number was increased with P 29 nodules, without P 27.6 nodules.

The effect of Ca treatment only resulted in the same as the control 22 nodules, as was also true for the CaP treatment. However, CaK, 25 nodules and CaMg, 32 nodules, resulted in increased nodule numbers compared to the control. Composite mean nodule number was increased with Ca 29 compared to without Ca 27.6 nodules.

Applying K alone to the soil reduced nodule number, 21 nodules, but K combined with Ca, P and Mg increased nodule numbers to 25, 32 and 34 nodules respectively. Composite mean nodule number was increased from 25 nodules without K to 31 with K.

Mg increased nodule production either alone or combined. For Mg alone the result was 28 nodules, when combined with Ca 32 nodules, KMg, 34 nodules and PMg 30 nodules. The composite mean nodule number was

TABLE XX

ORTHOGONAL EFFECTS OF VARIOUS SOIL FERTILITY TREATMENT ON NODULE NUMBER OF SOYBEANS, FORREST VARIETY, IN A DARK RED LATOSOL, FROM JAIBA, MINAS GERAIS, BRAZIL. EXPERIMENT 5

Treat. Symbol	Nodule Number	Treat. Symbol	Nodule Number	Treat. Symbol	Nodule Number	Treat. Symbol	Nodule Number
O	22	K	21	Mg	28	KMg	34
P	20	KP	32	MgP	30	KMgP	34
Ca	22	CaK	25	CaMg	32	CaKMg	37
CaP	22	CaKP	35	CaMgP	27	CaKMgP	32
-P	+P	-Ca	+Ca	-K	+K	-Mg	+Mg
$\bar{\bar{x}}$ 27.6	29	27.6	29	25	31	25	32

Average yields are means of three replicate culture with 36 days of growth
$\bar{\bar{x}}$ means of composite yields with (+) and without (-) the designated element.
LSD related to the Composite mean LSD .01 = 5.3275 and LSD .05 = 3.9559
* significant at .05 ** significant at .01

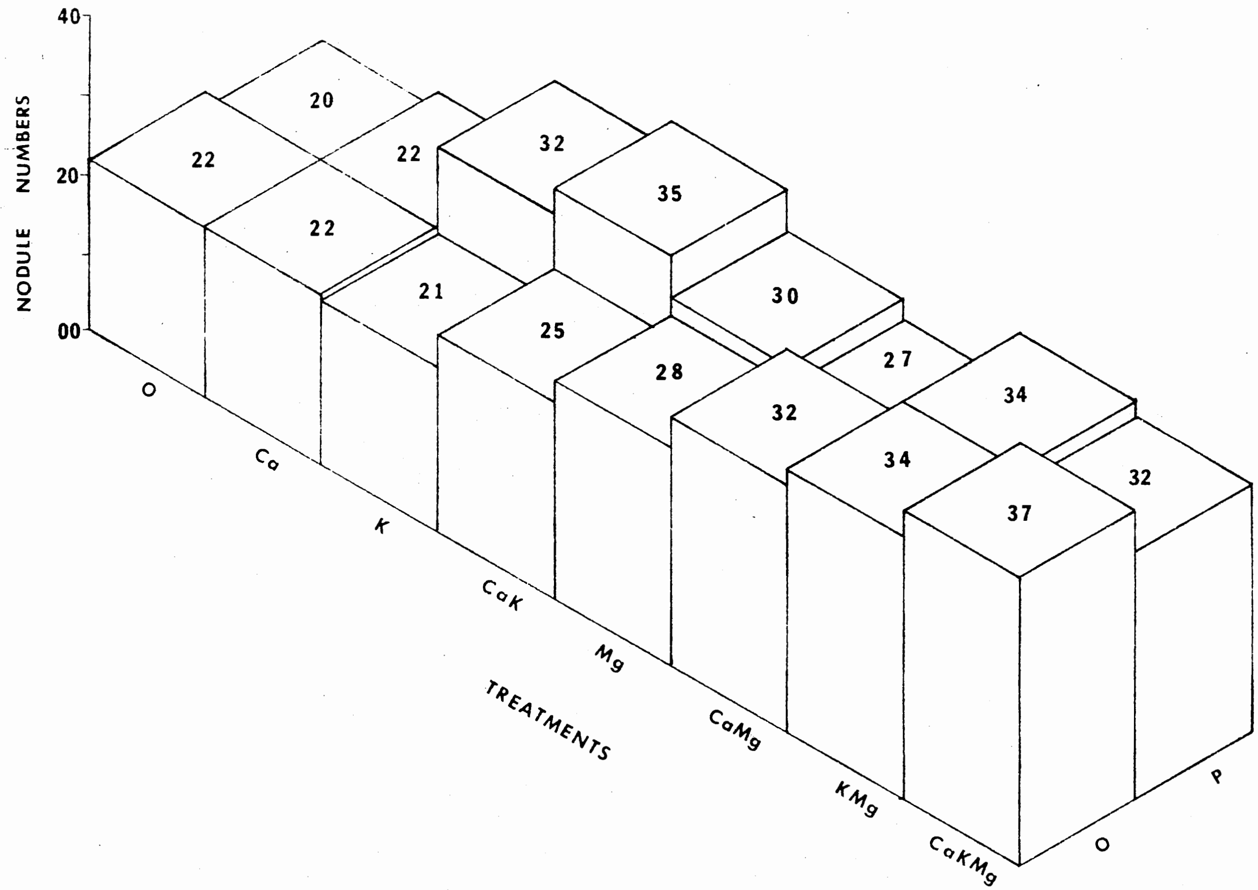

Figure 15. Residual Effects of Various Soil Fertility Treatments on Nodule Number of Soybean, in a Dark Red Latosol, from Jaiba, MG, Brazil. Experiment 5.

increased with Mg addition from 25 without Mg to 32 nodules.

The analysis presented in the A. O. V., Table XXXVI, in the Appendix, indicates that K when applied alone had a highly significant effect that was negative. Mg resulted in a positive effect that was highly significant.

Nodule Weight

The results for fresh nodule weight in this experiment are presented in Figure 16 and Table XXI.

The largest nodule weight was obtained by treating the soil with KPMg .3707 g and the lowest yield was obtained with Ca applied alone .1428 g.

Treating the soil with P slightly increased nodule weight from .1692 for the control up to .1770 g. Comparing the effects of combining P with the principal cation bases Ca, Mg and K the results obtained were .1500 g, .2050 g and .2283 g respectively. Composite mean yield was increased from .1756 g without P up to .2468 g with P addition.

Ca as a single treatment depressed yield with control yield .1692 g and Ca treatment .1428 g. All Ca combination with K, P and Mg depressed yields: CaK .1570 g, CaP .1500 g and CaMg .1599 g. The composite mean yield was slightly decreased with Ca addition .2076 g, without Ca .2148 g.

Applying K to the soil as a single treatment increased yield .1913 and increase in yield also occurred when K was combined with P and Mg, .2283 g and .2050 g respectively. However, K combined with Ca depressed yield resulting in .1570 g yield. The composite mean yield was increased with K presence .2438 g, without K .1786 g.

TABLE XXI

ORTHOGONAL EFFECTS OF VARIOUS SOIL FERTILITY TREATMENT ON NODULE WEIGHT OF SOYBEANS, FORREST VARIETY, IN A DARK RED LATOSOL, FROM JAIBA, MINAS GERAIS, BRAZIL. EXPERIMENT 5

Treat. Symbol	Nodule Fsh wt. (g)	Treat. Symbol	Nodule Fsh wt. (g)	Treat. Symbol	Nodule Fsh wt. (g)	Treat. Symbol	Nodule Fsh wt. (g)
O	0.1692	K	0.1913	Mg	0.1812	KMg	0.1957
P	0.1770	KP	0.2283	MgP	0.2050	KMgP	0.3707
Ca	0.1428	CaK	0.1570	CaMg	0.1599	CaKMg	0.2078
CaP	0.1500	CaKP	0.3105	CaMgP	0.2438	CaKMgP	0.2892
-P	+P	-Ca	+Ca	-K	+K	-Mg	+Mg
$\bar{\bar{x}}$ 0.1756	0.2468	0.2148	0.2076	0.1786	0.2438	0.1908	0.2317

Average yields are means of three replicate culture with 36 days of growth
$\bar{\bar{x}}$ means of composite yields with (+) and without (-) the designated element.
LSD related to the Composite mean LSD .01 = 0.0450 and LSD .05 = 0.0334
* significant at .05 ** significant at .01

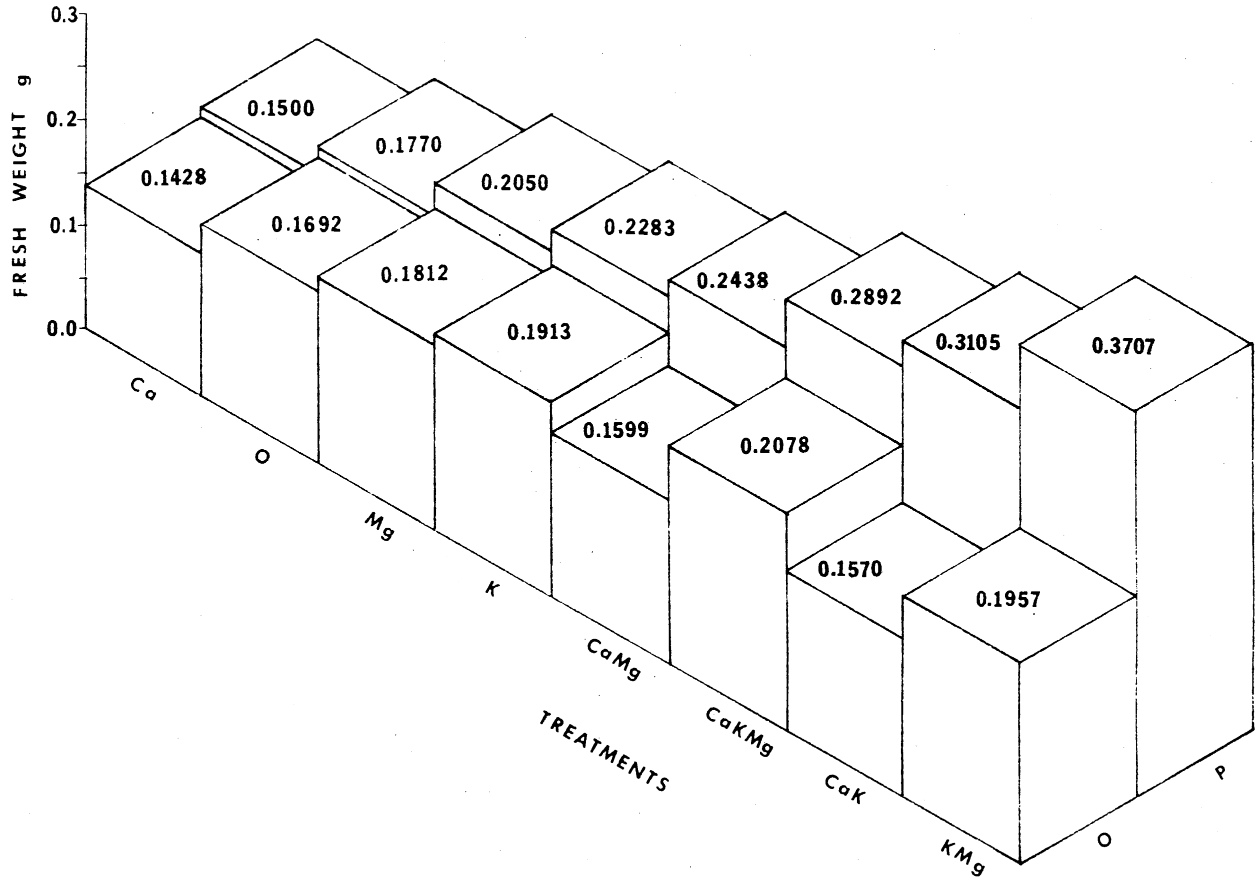

Figure 16. Residual Effects of Various Soil Fertility Treatments on Nodule Weight of Soybean, in a Dark Red Latosol, from Jaiba, MG, Brazil. Experiment 5.

The effect of treating the soil with Mg increased the yield .1812 g when compared with the control .1692 g. Mg combined with Ca decreased nodule weight .1599 g. However, when Mg was combined with both K and P yield of nodule weight were .1957 and .2050 g respectively. The composite mean yield without Mg was .1908 g, with Mg with composite mean yield was increased .2319 g.

The Analysis of Variance, Table XXXVII, in the Appendix, indicates that K, P, CaK were highly significant sources with Mg, KP and CaKPMg significant.

Nitrogenase Activity

Data obtained for nitrogenase activity as micromoles C_2H_4 per gram fresh nodule/per hour in the fifth experiment are shown in Figure 17 and Table XXII.

The highest nitrogenase activity was obtained when the soil was treated with CaPMg resulting in 186.3 μmoles. The lowest was obtained when Ca was applied causing 80.3 μmoles.

Applying P alone to the soil increased nitrogenase activity 131.6 μmoles compared to 124.9 μmoles for the P combination with Ca, K and Mg with CaP 123.9, KP 112.3 and PMg 138.4 μmoles. The composite mean nitrogenase activity with P was higher than that without P 138.1 and 105.9 μmoles respectively.

Ca applied alone depressed nitrogenase activity considerably resulting in 80.3 μmoles. When Ca was combined with P, K and Mg was less than the control 124.9 μmoles. CaP was 139.9, CaK 122.3 and CaMg 95.4 μmoles. The composite mean nitrogenase activity measure with Ca 122.4 μmoles was slightly higher than that without Ca 121.6 μmoles.

TABLE XXII

ORTHOGONAL EFFECTS OF VARIOUS SOIL FERTILITY TREATMENTS ON NITROGENASE ACTIVITY OF SOYBEANS, FORREST VARIETY, IN A DARK RED LATOSOL, FROM JAIBA, MINAS GERAIS, BRAZIL. EXPERIMENT 5

Treat. Symbol	Act. μmoles/g hr^{-1}	Treat. Symbol	Act. μmoles/g hr^{-1}	Treat. Symbol	Act. μmoles/g hr^{-1}	Treat. Symbol	Act. μmoles/g hr^{-1}
O	124.9	K	105.7	Mg	101.4	KMg	118.4
P	131.6	KP	112.3	MgP	138.4	KMgP	140.2
Ca	80.3	CaK	122.3	CaMg	95.4	CaKMg	98.8
CaP	123.9	CaKP	122.7	CaMgP	186.3	CaKMgP	149.2
-P	+P	-Ca	+Ca	-K	+K	-Mg	+Mg
$\bar{\bar{x}}$ 105.9	138.1	121.6	122.4	122.8	121.2	115.5	128.5

Average yields are means of three replicate culture with 36 days of growth
$\bar{\bar{x}}$ means of composite yields with (+) and without (-) the designated element.
LSD related to the Composite mean LSD .01 = 23.1303 and LSD .05 = 17.1753
* significant at .05 ** significant at .01

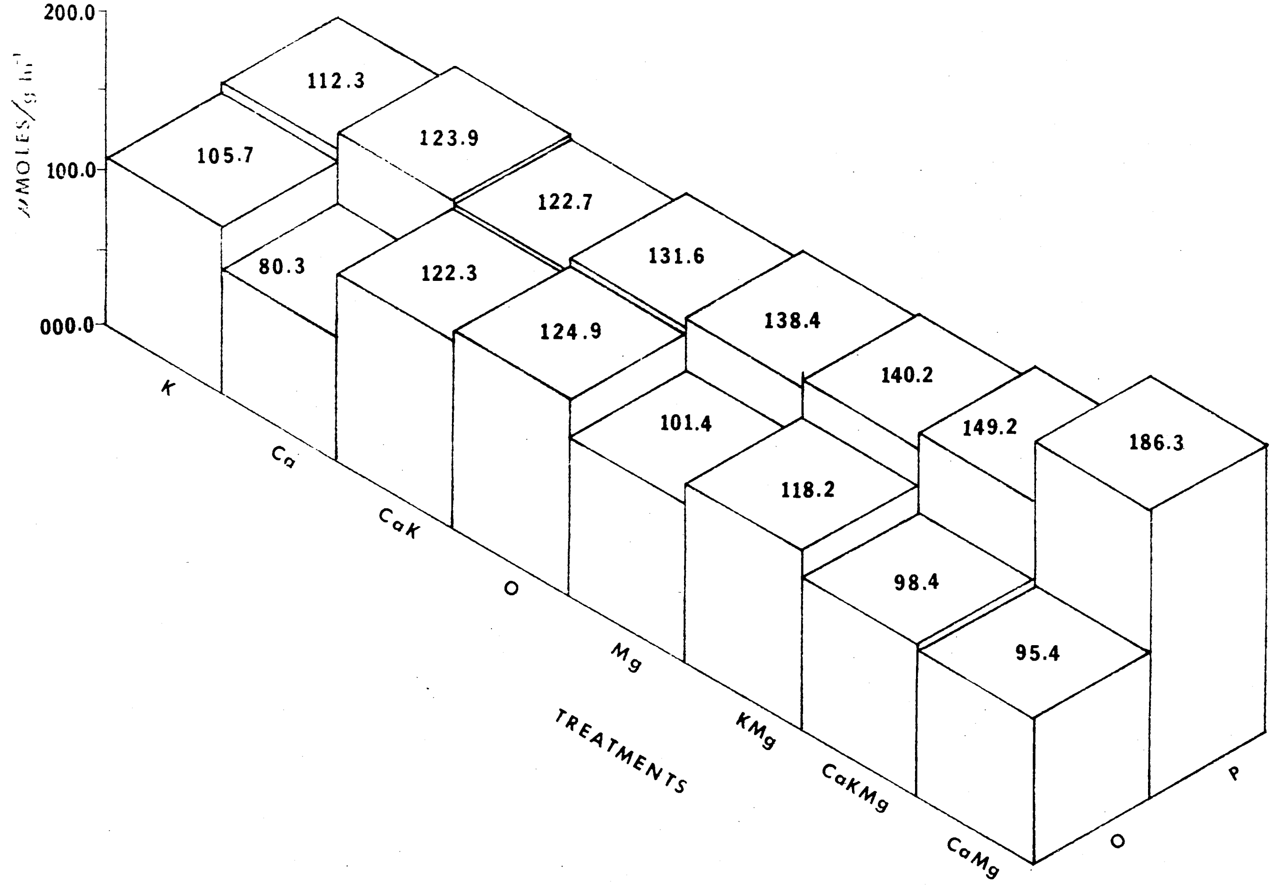

Figure 17. Residual Effects of Various Soil Fertility Treatments on Nitrogenase Activity of Soybean, in a Dark Red Latosol, from Jaiba, MG, Brazil. Experiment 5.

When the soil received K applied alone or combined depressed yields. K treatment was 105.7, CaK, KP and KMg were as follows: CaK 122.3, KP 112.3 and KMg 118.4 μmoles. The composite mean nitrogenase activity without K 122.8 μmoles was slightly higher that that with K 121.3 μmoles.

The effect of applying Mg alone was depressive for nitrogenase activity with 101.4 μmoles compared to the control 124.9 μmoles. When Mg was combined with Ca, K and P results apparently were depressed: CaMg 95.4 and KMg 118.4 μmoles. PMg combination increased nitrogenase activity 138.4 μmoles. The composite mean nitrogenase activity was higher when Mg was present 128.5 μmoles, without Mg 115.5 μmoles.

The Analysis of Variance, Table XXXVIII, in the Appendix, indicated that only P had a highly significant effect on nitrogenase activity with PMg having a significant effect.

The literature available concerning results of previous experiments indicate highly variable responses to soil fertility treatments regarding improved soybean production with Brazilian soils even when the soil types are under similar cropping regimes (22).

The effects of calcium (49) principally supplied for liming the soil has been stressed not only because it enhanced the uptake of native sulfur, nitrogen and phosphorus, but also can apparently increase the nitrogen-content, weight of soybeans (40) and nodulation (62). Ca (58) apparently was essential for good nodulation.

Nodulation (10) and weight seemed to be affected by Ca x P interactions and P alone appeared to have a dominant role on optimum nodulation.

Levels (38) of some important element in tropical soil are below the critical proposed levels and will depress significantly the yields.

Magnesium was found (56) to be essential and more important than calcium as a nutrient for Rhizobium. It was confirmed that Mg can increase the nodule number.

It is important to stress that there is great variation related to fertilization needs, varying either between the varieties of same crops or for different crops (22, 14).

Water deficiency should be considered as a governing plant stress factor, when the crop is planted in the field (69). In the greenhouse this variable should be well controlled.

Results of this study presents preliminary indication of the expected responses for this soil in the field for improved soybean production.

CHAPTER V

SUMMARY AND CONCLUSIONS

This study was with a Brazilian dark red latosol (Typic Eustrustox) soil from the Jaiba Agroindustrial District in Minas Gerais State. Five consecutive pot culture greenhouse experiments were completed with the intent of studying the effects of principal base cations Ca^{++}, Mg^{++}, and K^{+}, alone or in combination, with and without P on the behavior of soybean growth, nodulation and some indicator enzyme characteristics of nodules related to nitrogenase activities with this soil.

Forrest soybean variety, 5 plants per pot culture were used with three replicate cultures per treatment with complete factorial for all possible combinations of P, Ca, Mg and K each at single levels. These were applied to the first experiment and the following four consecutive experiments were with the residual effects.

Shoot growth in the first experiment was affected positively by sources Ca, P and the interaction CaP, negative influence was caused by treating with KMg. In the second experiment Ca and CaK sources influenced improved shoot growth. In the third positive effect on shoot growth resulted from Ca, CaMg, KP, KPMg, CaKMg and CaKPMg. Ca, KMg, PMg, CaPMg and CaKPMg had a positive effect for increased shoot growth in the fourth experiment, KPMg had a negative depressing effect on shoot growth. Shoot growth in the fifth experiment was positively influenced by KP, CaKMg and CaKPMg sources, while K and P resulted in a negative depressing influence.

Root growth was positively affected in the first experiment only by the interaction of Ca, K and Mg source. In the second experiment only the negative effect of K was apparent. Ca, CaP, KMg, CaPMg, CaKMg and CaKPMg influenced positively root growth in the third experiment with an apparent negative influence of KPMg source. The fourth experiment indicated a positive influence on root growth with Ca, P, KMg and CaKPMg. Residual from the K, P, CaMg, CaKMg and CaKPMg sources resulted in positive effect in this final experiment.

Nodule number in the third experiment was beneficially influenced by Ca, KMg, CaPMg, CaKP, CaKMg and CaKPMg. KPMg had a negative effect on nodulation. In fifth experiment beneficial effect was attained only by the Mg source, K had a slight depressive effect.

Nodule weight was influenced positively with Ca, CaMg, KMg and CaKPMg in the third experiment. In the fifth experiment an improvement on nodule weight resulted with K, P, Mg, KP and CaKPMg source. CaK resulted in a negative depressive effect on nodule weight.

Nitrogenase activity improved with Ca, K, Mg, CaP, KP, KMg, PMg and CaKPMg sources in the third experiment. Nitrogenase activity in the final experiment was influenced positively by P and PMg sources.

The overall findings and conclusions are summarized as follows:

1. Calcium apparently was an important element influencing shoot and root growth, nodulation, nodule number and nitrogenase activity either alone or in combination in these studies through the fourth experiment. In the fifth experiment apparently Ca without the other plant nutrient additions was not effective, but when combined with the other elements the residual effects were positive.

2. Phosphorus alone apparently was not influential but when combined with Ca, K and Mg an increase for shoot growth, nodule number and nitrogenase activity was attained.

3. Magnesium was particularly influential for increased growth only when combined with calcium.

4. Influence of potassium was dependent upon combinations with Ca and Mg, initially with Ca in the later studies with Mg as the Ca levels were depleted.

5. Highest shoot growth yields were obtained with the CaPMg and root growth with CaMg source.

6. Largest numbers of nodules were attained with the CaKP source.

7. Highest nodule weight was obtained with the KPMg source. Nodule number and nitrogenase activity with this source were lowest and it was indicated that the large nodule weight had low small nitrogenase activity.

8. Highest nitrogenase activity resulted with the CaP source. Apparently the CaP source resulted in less quantity of nodules with smaller weights, but apparently the highest activity for fixing nitrogen.

9. These results indicated complex plant nutrient interactions that influence growth, nodulation and nitrogenase activity for Forrest variety soybean with this soil, a Typic Eutrustox from Jaiba, Minas Gerais, Brazil.

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APPENDIXES

TABLE XXIII

ANALYSIS OF VARIANCE PROCEDURE DEPENDENT VARIABLE:: SHOOT WT. EXPERIMENT 1

Shoot Wt. Mean
1.84833333

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
Model	17	5.66709583	0.33335858	2.15	0.0329
Error	30	4.66177083	0.15539236		Std Dev
Corrected Total	47	10.32886667			0.39419838

Source	DF	Anova SS	F Value	PR > F
Rep	2	0.16042917	0.52	0.6020
Ca	1	1.05020833	6.76	0.0143 *
K	1	0.01613333	0.10	0.7495
Ca*K	1	0.12607500	0.81	0.3749
P	1	0.82687500	5.32	0.0282 *
Ca*P	1	0.78030000	5.02	0.0326 *
K*P	1	0.00100833	0.01	0.9363
Ca*K*P	1	0.00003333	0.00	0.9884
Mg	1	0.25813333	1.66	0.2073
Ca*Mg	1	0.57640833	3.71	0.0636
K*Mg	1	0.72030000	4.64	0.0395 *
Ca*K*Mg	1	0.44467500	2.86	0.1011
P*Mg	1	0.51667500	3.32	0.0782
Ca*P*Mg	1	0.12813333	0.82	0.3711
K*P*Mg	1	0.03740833	0.24	0.6272
Ca*K*P*Mg	1	0.02430000	0.16	0.6953

* significant at .05 level

TABLE XXIV

ANALYSIS OF VARIANCE PROCEDURE DEPENDENT VARIABLE: ROOT WT. EXPERIMENT 1

Root Wt. Mean
1.3462500

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
Model	17	2.35377500	0.13845735	1.06	0.4326
Error	30	3 92635000	0.13087833		Std Dev
Corrected Total	47	6.28012500			0.36177111

Source	DF	Anova SS	F Value	PR > F
Rep	2	0.55185000	2.11	0.1391
Ca	1	0.14083333	1.08	0.3079
K	1	0.14300833	1.09	0.3042
Ca*K	1	0.00270000	0.02	0.8868
P	1	0.00700833	0.05	0.8186
Ca*P	1	0.00403333	0.03	0.8618
K*P	1	0.00440833	0.03	0.8556
Ca*K*P	1	0.01613333	0.12	0.7290
Mg	1	0.01840833	0.14	0.7103
Ca*Mg	1	0.03630000	0.28	0.6023
K*Mg	1	0.05200833	0.40	0.5332
Ca*K*Mg	1	1.03253333	7.89	0.0087 **
P*Mg	1	0.00100833	0.01	0.9306
Ca*P*Mg	1	0.00003333	0.00	0.9874
K*P*Mg	1	0.10267500	0.78	0.3828
Ca*K*P*Mg	1	0.24083333	1.84	0.1851

** significant at .01 level

TABLE XXV

ANALYSIS OF VARIANCE PROCEDURE DEPENDENT VARIABLE: SHOOT WT. EXPERIMENT 2

Shoot Wt. Mean
0.81041667

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
Model	17	0.79656250	0.04685662	3.24	0.0024
Error	30	0.43322917	0.01444097		Std Dev
Corrected Total	47	1.22979167			0.12017060

Source	DF	Anova SS	F Value	PR > F
Rep	2	0.00510417	0.18	0.8389
Ca	1	0.28520833	19.75	0.0001 **
K	1	0.01333333	0.92	0.3443
Ca*K	1	0.21333333	14.77	0.0006 **
P	1	0.01020833	0.71	0.4071
Ca*P	1	0.01020833	0.71	0.4071
K*P	1	0.04083333	2.83	0.1030
Ca*K*P	1	0.01333333	0.92	0.3443
Mg	1	0.04687500	3.25	0.0817
Ca*Mg	1	0.03520833	2.44	0.1289
K*Mg	1	0.05333333	3.69	0.0643
Ca*K*Mg	1	0.01333333	0.92	0.3443
P*Mg	1	0.02520833	1.75	0.1964
Ca*P*Mg	1	0.00020833	0.01	0.9052
K*P*Mg	1	0.03000000	2.08	0.1598
Ca*K*P*Mg	1	0.00083333	0.06	0.8118

** singificant at .01 level

TABLE XXVI

ANALYSIS OF VARIANCE PROCEDURE DEPENDENT VARIABLE: ROOT WT. EXPERIMENT 2

Root Wt. Mean
1.09479167

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
Model	17	3.87171875	0.22774816	0.93	0.5520
Error	30	7.35947917	0.24531597		Std Dev
Corrected Total	47	11.23119792			0.49529382

Source	DF	Anova SS	F Value	PR > F
Rep	2	0.23885417	0.49	0.6193
Ca	1	0.03796875	0.15	0.6968
K	1	1.35005208	5.50	0.0258 *
Ca*K	1	0.12505298	0.51	0.4808
P	1	0.37630208	1.53	0.2251
Ca*P	1	0.01171875	0.05	0.8285
K*P	1	0.23380208	0.95	0.3367
Ca*K*P	1	0.01505208	0.06	0.8060
Mg	1	0.14630208	0.60	0.4460
Ca*Mg	1	0.00630208	0.03	0.8737
K*Mg	1	0.89380208	3.64	0.0659
Ca*K*Mg	1	0.00130208	0.01	0.9424
P*Mg	1	0.12505208	0.51	0.4808
Ca*P*Mg	1	0.07130208	0.29	0.5938
K*P*Mg	1	0.01880208	0.08	0.7838
Ca*K*P*Mg	1	0.22005208	0.90	0.3512

* significant at .05 level

TABLE XXVII

ANALYSIS OF VARIANCE PROCEDURE DEPENDENT VARIABLE: SHOOT WT. EXPERIMENT 3

Shoot Wt. Mean
1.50625000

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
Model	17	7.05927083	0.41525123	6.31	0.0001
Error	30	1.97385417	0.06579514		Std Dev
Corrected Total	47	9.03312500			0.25650563

Source	DF	Anova SS	F Value	PR > F
Rep	2	0.37781250	2.87	0.0723
Ca	1	2.56687500	39.01	0.0001 **
K	1	0.00750000	0.11	0.7380
Ca*K	1	0.14083333	2.14	0.1539
P	1	0.12000000	1.82	0.1870
Ca*P	1	0.10083333	1.53	0.2253
K*P	1	0.42187500	6.41	0.0168 *
Ca*K*P	1	0.17520833	2.66	0.1132
Mg	1	0.22687500	3.45	0.0732
Ca*Mg	1	0.31687500	4.82	0.0361 *
K*Mg	1	0.60750000	9.23	0.0049 **
Ca*K*Mg	1	0.40333333	6.13	0.0192 *
P*Mg	1	0.14083333	2.14	0.1539
Ca*P*Mg	1	0.04083333	0.62	0.4370
K*P*Mg	1	0.58520833	8.89	0.0056 **
Ca*K*P*Mg	1	0.82687500	12.57	0.0013 **

* significant at .05 level
** significant at .01 level

TABLE XXVIII

ANALYSIS OF VARIANCE PROCEDURE DEPENDENT VARIABLE: ROOT WT. EXPERIMENT 3

Root Wt. Mean
0.38750000

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
Model	17	0.78489583	0.04617034	7.59	0.0001
Error	30	0.18260417	0.00608681		Std Dev
Corrected Total	47	0.96750000			0.07801798

Source	DF	Anova SS	F Value	PR > F
Rep	2	0.02906250	2.39	0.1091
Ca	1	0.27000000	44.36	0.0001 **
K	1	0.00520833	0.86	0.3623
Ca*K	1	0.01020833	1.68	0.2052
P	1	0.00000000	0.00	1.0000
Ca*P	1	0.03000000	4.93	0.0341 *
K*P	1	0.01687500	2.77	0.1063
Ca*K*P	1	0.00020833	0.03	0.8545
Mg	1	0.00750000	1.23	0.2758
Ca*Mg	1	0.02083333	3.42	0.0742
K*Mg	1	0.07529833	12.36	0.0014 **
Ca*K*Mg	1	0.07520833	12.36	0.0014 **
P*Mg	1	0.02083333	3.42	0.0742
Ca*P*Mg	1	0.05333333	8.76	0.0060 **
K*P*Mg	1	0.11020833	18.11	0.0002 **
Ca*K*P*Mg	1	0.06020833	9.89	0.0037 **

* significant at .05 level
** significant at .01 level

TABLE XXIX

ANALYSIS OF VARIANCE PROCEDURE DEPENDENT VARIABLE: NODULE NUMBER. EXPERIMENT 3

Nod. Mean
39.12500000

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
Model	17	10085.29166667	593.25245098	4.18	0.0003
Error	30	4253.95833333	141.79861111		Std Dev
Corrected Total	47	14339.25000000			11.90792220

Source	DF	Anova SS	F Value	PR > F
Rep	2	513.37500000	1.81	0.1810
Ca	1	2760.33333333	19.47	0.0001 **
K	1	52.08333333	0.37	0.5490
Ca*K	1	560.33333333	3.95	0.0560
P	1	184.08333333	1.30	0.2636
Ca*P	1	85.33333333	0.60	0.4440
K*P	1	270.75000000	1.91	0.1772
Ca*K*P	1	538.00000000	4.15	0.0506
Mg	1	200.08333333	1.41	0.2442
Ca*Mg	1	533.33333333	3.76	0.0619
K*Mg	1	1702.08333333	12.02	0.0016 **
Ca*K*Mg	1	705.33333333	4.97	0.0334 *
P*Mg	1	90.75000000	0.64	0.4300
Ca*P*Mg	1	645.33333333	4.55	0.0412 *
K*P*Mg	1	1180.08333333	8.32	0.0072 **
Ca*K*P*Mg	1	12.00000000	0.08	0.7731

* significant at .05 level
** significant at .01 level

TABLE XXX

ANALYSIS OF VARIANCE PROCEDURE DEPENDENT VARIABLE: NODULE WEIGHT. EXPERIMENT 3

Nod. Wt. Mean
0.00692500

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
Model	17	0.00045477	0.00002675	3.53	0.0012
Error	30	0.00022712	0.00000757		Std Dev
Corrected Total	47	0.00068189			0.00275148

Source	DF	Anova SS	F Value	PR > F
Rep	2	0.00003431	2.27	0.1212
Ca	1	0.00013940	18.41	0.0002 **
K	1	0.00000037	0.05	0.8271
Ca*K	1	0.00000243	0.32	0.5752
P	1	0.00000469	0.62	0.4375
Ca*P	1	0.00000192	0.25	0.6182
K*P	1	0.00000901	1.19	0.2339
Ca*K*P	1	0.00000114	0.15	0.7006
Mg	1	0.00001587	2.10	0.1580
Ca*Mg	1	0.00007550	9.97	0.0036 **
K*Mg	1	0.00007154	9.45	0.0045 **
Ca*K*Mg	1	0.00000833	1.10	0.3025
P*Mg	1	0.00002437	3.22	0.0829
Ca*P*Mg	1	0.00000161	0.21	0.6477
K*P*Mg	1	0.00001008	1.33	0.2576
Ca*K*P*Mg	1	0.00005419	7.16	0.0120 *

* significant at .05 level
** significant at .01 level

TABLE XXXI

ANALYSIS OF VARIANCE PROCEDURE DEPENDENT VARIABLE: NITROGENASE ACTIVITY. EXPERIMENT 3

Act. Mean
166.95416667

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
Model	17	161118.35916667	9477.55053922	4.18	0.0003
Error	30	68070.22000000	2269.00733333		Std Dev
Corrected Total	47	229188.57916667			47.63409843

Source	DF	Anova SS	F Value	PR > F
Rep	2	4403.48666667	0.97	0.3905
Ca	1	22507.34083334	9.92	0.0037 **
K	1	9895.76333334	4.36	0.0454 *
Ca*K	1	225.33333333	0.10	0.7548
P	1	175.56750000	14.13	0.7828
Ca*P	1	32064.34083333	4.89	0.0007 **
K*P	1	11089.92000000	1.02	0.0348 *
Ca*K*P	1	2307.41333334	5.07	0.3213
Mg	1	11507.21333334	0.15	0.0318 *
Ca*Mg	1	347.76333333	8.81	0.6982
K*Mg	1	19983.84083333	5.99	0.0058 **
Ca*K*Mg	1	13594.60083334	13.81	0.0204 *
P*Mg	1	31334.52000000	0.25	0.0008 **
Ca*P*Mg	1	565.81333334	0.48	0.6212
K*P*Mg	1	1081.10083334	0.02	0.4953
Ca*K*P*Mg	1	34.34083333		0.9029

* significant at .05 level
** significant at .01 level

TABLE XXXII

ANALYSIS OF VARIANCE PROCEDURE DEPENDENT VARIABLE: SHOOT WT. EXPERIMENT 4

Shoot Wt. Mean
3.30208333

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
Model	17	30.55239583	1.79719975	7.75	0.0001
Error	30	6.95739583	0.23191319		Std Dev
Corrected Total	47	37.50979167			0.48157366

Source	DF	Anova SS	F Value	PR > F
Rep	2	0.54760417	1.18	0.3210
Ca	1	12.30187500	53.05	0.0001 **
K	1	0.72520833	3.13	0.0872
Ca*K	1	2.04197500	8.80	0.0059 **
P	1	0.13020833	0.56	0.4595
Ca*P	1	0.09187500	0.40	0.5338
K*P	1	0.20020833	0.86	0.3602
Ca*K*P	1	0.25520833	1.10	0.3025
Mg	1	0.24083333	1.04	0.3163
Ca*Mg	1	0.24083333	1.04	0.3163
K*Mg	1	3.74083333	16.13	0.0004 **
Ca*K*Mg	1	0.52083333	2.35	0.1444
P*Mg	1	1.20833333	5.19	0.0300 *
Ca*P*Mg	1	1.20833333	5.19	0.0300 *
K*P*Mg	1	4.94083333	21.30	0.0001 **
Ca*K*P*Mg	1	2.16750000	9.35	0.0047 **

* significant at .05 level
** significant at .01 level

TABLE XXXIII

ANALYSIS OF VARIANCE PROCEDURE DEPENDENT VARIABLE: ROOT WT. EXPERIMENT 4

Root Wt. Mean
1.25000000

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
Model	17	7.06548667	0.41561275	2.60	0.0109
Error	30	4.80458333	0.16015278		Std Dev
Corrected Total	47	11.87000000			0.40019093

Source	DF	Anova SS	F Value	PR > F
Rep	2	0.45875000	1.43	0.2546
Ca	1	1.14083333	7.12	0.0122 *
K	1	0.11020833	0.69	0.4133
Ca*K	1	0.04687500	0.29	0.5925
P	1	0.77520833	4.84	0.0356 *
Ca*P	1	0.46020833	2.87	0.1004
K*P	1	0.27000000	1.69	0.2040
Ca*K*P	1	0.36750000	2.29	0.1403
Mg	1	0.06750000	0.43	0.5211
Ca*Mg	1	0.02083333	0.13	0.7209
K*Mg	1	1.30030833	8.12	0.0078 **
Ca*K*Mg	1	0.00520833	0.03	0.8581
P*Mg	1	0.28520833	1.78	0.1921
Ca*P*Mg	1	0.25520833	1.59	0.2105
K*P*Mg	1	0.10083333	0.63	0.4337
Ca*K*P*Mg	1	1.40083333	8.75	0.0060 **

* significant at .05 level
** significant at .01 level

TABLE XXXIV

ANALYSIS OF VARIANCE PROCEDURE DEPENDENT VARIABLE: SHOOT WEIGHT. EXPERIMENT 5

Shoot Wt. Mean
1.73750000

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
Model	17	5.55822917	0.32695466	4.26	0.0003
Error	30	2.30427083	0.07680903		Std Dev
Corrected Total	47	7.86250000			0.27714442

Source	DF	Anova SS	F Value	PR > F
Rep	2	9.30406259	1.98	0.1558
Ca	1	0.00020833	0.00	0.9588
K	1	1.14083333	14.85	0.0006 **
Ca*K	1	0.01687500	0.22	0.6427
P	1	0.77520833	10.09	0.0034 **
Ca*P	1	0.04083333	0.53	0.4716
K*P	1	0.93520833	12.18	0.0015 **
Ca*K*P	1	0.05333333	0.69	0.4113
Mg	1	0.07529833	0.98	0.3303
Ca*Mg	1	0.18750000	2.44	0.1287
K*Mg	1	0.00187500	0.02	0.8769
Ca*K*Mg	1	1.08000000	14.06	0.0008 **
P*Mg	1	0.02083333	0.27	0.6063
Ca*P*Mg	1	0.25520833	3.32	0.0783
K*P*Mg	1	0.04083333	0.53	0.4716
Ca*K*P*Mg	1	0.63020833	8.20	0.0076 **

** significant at .01 level

TABLE XXXV

ANALYSIS OF VARIANCE PROCEDURE DEPENDENT VARIABLE: ROOT WEIGHT. EXPERIMENT 5

Root Wt. Mean
0.46250000

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
Model	17	1.20750000	0.07102941	3.58	0.0011
Error	30	0.59500000	0.01983333		Std Dev
Corrected Total	47	1.80250000			14.08308678

Source	DF	Anova SS	F Value	PR > F
Rep	2	0.54500000	13.74	0.0001
Ca	1	0.02083333	1.05	0.3136
K	1	0.12000000	6.05	0.0199 *
Ca*K	1	0.00750000	0.38	0.5432
P	1	0.10083333	5.08	0.0316 *
Ca*P	1	0.01333333	0.67	0.4187
K*P	1	0.01333333	0.67	0.4187
Ca*K*P	1	0.01333333	0.57	0.4187
Mg	1	0.00520833	0.26	0.6121
Ca*Mg	1	0.09187500	4.63	0.0395 *
K*Mg	1	0.00187500	0.09	0.7606
Ca*K*Mg	1	0.15187500	7.66	0.0096 **
P*Mg	1	0.00020833	0.01	0.9190
Ca*P*Mg	1	0.01020833	0.51	0.4787
K*P*Mg	1	0.00187500	0.09	0.7606
Ca*K*P*Mg	1	0.11020833	5.56	0.0251 *

* significant at .05 level
** significant at .01 level

TABLE XXXVI

ANALYSIS OF VARIANCE PROCEDURE DEPENDENT VARIABLE: NODULE NUMBER. EXPERIMENT 5

Nod. Mean
28.37500000

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
Model	17	1520.12500000	89.41911765	1.99	0.0489
Error	30	1351.12500000	45.03750000		Std Dev
Corrected Total	47	2871.25000000			6.71099844

Source	DF	Anova SS	F Value	PR > F
Rep	2	30.87500000	0.34	0.7125
Ca	1	30.08333333	0.67	0.4202
I	1	432.00000000	9.59	0.0042 **
Ca*K	1	5.33333333	0.12	0.7332
P	1	33.33333333	0.74	0.3964
Ca*P	1	27.00000000	0.60	0.4448
K*P	1	90.75000000	2.01	0.1661
Ca*K*P	1	0.75000000	0.02	0.8982
Mg	1	560.33333333	12.44	0.0014 **
Ca*Mg	1	12.00000000	0.27	0.6095
K*Mg	1	10.08333333	0.22	0.6395
Ca*K*Mg	1	4.08333333	0.09	0.7654
P*Mg	1	140.08333333	3.11	0.0880
Ca*P*Mg	1	30.08333333	0.67	0.4202
K*P*Mg	1	108.00000000	2.40	0.1320
Ca*K*P*Mg	1	5.33333333	0.12	0.7332

** significant at .01 level

TABLE XXXVII

ANALYSIS OF VARIANCE PROCEDURE DEPENDENT VARIABLE: NODULE WEIGHT. EXPERIMENT 5

Nod. Wt. Mean
0.21120625

Source	DF	Sum of Squares	Me n Square	F Value	PR > F
Model	17	0.19821459	0.01165968	3.62	0.0010
Error	30	0.09657053	0.00321902		Std Dev
Corrected Total	47	0.29478513			0.05673639

Source	DF	Anova SS	F Value	PR > F
Rep	2	0.01445459	2.25	0.1234
Ca	1	0.00061849	0.19	0.6643
K	1	0.05101900	15.85	0.0004 **
Ca*K	1	0.00003942	0.01	0.9126
P	1	0.06084040	18.90	0.0001 **
Ca8P	1	0.00128030	0.40	0.5330
K*P	1	0.01971136	6.12	0.0192 *
Ca*K*P	1	0.00025163	0.08	0.7817
Mg	1	0.02007781	6.24	0.0182 *
Ca*Mg	1	0.00040426	0.13	0.7255
K*Mg	1	0.00012129	0.04	0.8474
Ca*K*Mg	1	0.00662465	2.06	0.1618
P*Mg	1	0.00471042	1.46	0.2359
Ca*P*Mg	1	0.00418694	1.30	0.2631
K*P*Mg	1	0.00013434	0.04	0.8394
Ca*K*P*Mg	1	0.01373972	4.27	0.0476 *

* significant at .05 level
** significant at .01 level

TABLE XXXVIII

ANALYSIS OF VARIANCE PROCEDURE DEPENDENT VARIABLE: NITROGENASE ACTIVITY. EXPERIMENT 5

Act. Mean
121.96666667

Source	DF	Sum of Squares	Mean Square	F Value	PR > F
Model	17	33860.64833334	1991.80284314	2.35	0.0200
Error	30	25468.31833333	848.94394444		Std Dev
Corrected Total	47	59328.96666667			29.13664264

Source	DF	Anova SS	F Value	PR > F
Rep	2	5763.20166667	3.39	0.0469
Ca	1	6.75000000	0.01	0.9295
K	1	31.36333333	0.04	0.8489
Ca*K	1	136.01333333	0.16	0.6918
P	1	12454.96333333	14.67	0.0006 **
Ca*P	1	2385.72000000	2.81	0.1041
K*P	1	1830.27000000	2.16	0.1524
Ca*K*P	1	880.65333333	1.04	0.3166
Mg	1	2035.80750000	2.40	0.1320
Ca*Mg	1	609.18750000	0.72	0.4036
K*Mg	1	57.64083333	0.07	0.7962
Ca*K*Mg	1	3250.52083333	3.83	0.0597
P*Mg	1	3834.18750000	4.52	0.0419 *
Ca*P*Mg	1	497.94083333	0.59	0.4497
K*P*Mg	1	27.90750000	0.03	0.8573
Ca*K*P*Mg	1	58.52083333	0.07	0.7947

* significant at .05 level
** significant at .01 level

VITA 2

José Fernando Moraes Gomes

Candidate for the Degree of

Master of Science

Thesis: SOYBEAN (Glycine max (L.) Merril) RESPONSE TO SOIL FERTILITY TREATMENTS, WITH A DARK RED LATOSOL (TYPIC EUTRUSTOX) FROM JAIBA, MINAS GERAIS, BRAZIL

Major Field: Agronomy

Biographical:

Personal Data: Born in Olimpia, São Paulo State, Brazil, September 23, 1944, son of João Gomes Filho and Conceição Aparecida Moraes Gomes.

Education: Completed high school in 1966 at Colégio Universitário da Universidade Rural, Itaguaí, Rio de Janeiro, Brazil. In June, 1971 received an Engenheiro Agronomo diploma from Universidade de Brasília, Brasília, Brazil, and in May, 1978 completed the requirements for the Master's degree in Agronomy at Oklahoma State University, Stillwater, Oklahoma.

Professional Experience: Taught Physical and Biological Science at middle and high school levels from 1968 to 1974. As Engenheiro Agronomo worked as Local Supervisor at the Federal District Credit Association and Rural Assistance from May to December, 1972. Engenheiro Agronomo of the Ministry of Agriculture as per approval through special context, worked at the National Department of Rural Engineering in the Agriculture Aviation Division, from 1973 up to now, and since January, 1976, was granted a leave to pursue a Master's degree at Oklahoma State University.

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