

SOIL FERTILITY INTERACTION RESPONSES OF
A DARK RED LATOSOL (TYPIC EUTRUSTOX)
FROM JAIBA, MINAS GERAIS, BRAZIL

By

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CHAPTER I

INTRODUCTION

In Minas Gerais State, located in the southeast portion of Brazil, a great effort is being made in order to broaden the agricultural production of this state. A good deal of human effort and financial resources are presently being used to develop a suitable technology, so that new land areas can be brought into a more productive type of farming.

An example of this concentrated effort is in the Jaiba Agroindustrial District, located at the northern part of the state, comprising more than 3,000 square kilometers of land, where a large portion is well suited for irrigation.

Most of the land of this area is composed of latosols (Oxisols), and most of the present farming is of a subsistence type, and for cotton, castor bean, corn and beef cattle production.

As a result of the low fertility status of the soils, unfavorable pattern of rainfall distribution, and inefficient technology used for cropping, crop yields at present have been in general much lower than would be desirable.

The fertility problems of these oxisols are those inherited from prolonged weathering, i.e., low cation exchange capacity, high amounts of aluminum and iron oxides, low

organic matter content and high phosphorus fixing capacity. Phosphate is likely to be the first deficiency, then calcium and magnesium, and after some time of cultivation, potassium and sulphur. Nitrogen will always be required for prolonged intensive cultivation (14).

At the Jaiba Agroindustrial District, the landscape is formed by smooth rolling terrain, some places almost level, and localized dolines (9). Mechanization is highly encouraged, except in those areas where a great number of moundings pose some difficulties.

Generally, the soils are excessively drained with a narrow range of soil-water storage. According to Wolf (62), oxisols, coupled with restricted crop rooting and less than ideal rainfall patterns, can result in yields which will greatly depend upon the rainfall distribution. Also according to this author, some clayey oxisols, because of a substantial unsaturated flow of water, have characteristics of sandy soils, with large amounts of ionic transport and redistribution with time. In this case, when soil water is held at low tensions, soil structure is more important than soil texture in governing water availability to a growing crop.

According to the Koeppen Climatic Classification System (13), Jaiba is identified by the type Aw, defined as Savanna Tropical Climate. The annual mean rainfall precipitation is about 876.7 mm, with an average annual temperature of 24.4 Centigrade. During the coldest month the average

temperature is higher than 18° C, and precipitation during the driest month is lower than 60 mm (13).

The rainy season occurs between late October and early April with a drought spell, known locally as "veranico," of variable length in January or February. The prolonged dry season, late April to early October, gave origin to a deciduous forest, in which the trees are bare during approximately six months of the year. Alvim and Araujo (3) suggested that forest vegetation surrounded by savanna areas, named "Cerrado" in Brazil, such as the "Mata da Jaiba," appeared because of the better fertility status of these soils, mainly due to its limestone origin.

In considering that the incoming radiation and evapotranspiration are very high during this drought spell, that these soils are excessively drained and that some crops can wilt in a very short period of time, application of a high level of inputs can many times be very risky. However, it is not a surprise that irrigation is increasing rapidly in the area.

The objective of this study was to determine the fertility status of a dark red latosol (Latossol Vermelho Escuro Ortho) collected at the Jaiba Agroindustrial District. This oxisol occupies 15,495 ha of the project as a whole, and is the kind of soil that is cropped most intensively at present.

Greenhouse and laboratory techniques were employed and, hopefully, the data presented will be valuable to field researchers as well as farmers of this area.

CHAPTER II

LITERATURE REVIEW

Although a large number of fertility experiments have already been carried out in Brazilian oxisols, little is known about the fertility status of soils in northern Minas Gerais State.

During the agricultural year of 1972-73, the Cotton Project of PIPAEMG (47) installed five experiments in this region, trying to determine an economical level for fertilizer application in this culture. After statistical analysis was completed on the yield data collected, two locations showed no response to fertilizer application, and the remaining three locations showed response to phosphorus applications. In no place, response to either nitrogen or potassium was found. Moreover, no interaction effects were detected in all five locations.

Purcino (49) ~~found~~ in 1973-74, using higher levels than PIPAEMG in 1972-73, in six experiments found response to phosphorus in five locations, nitrogen response in one location, and no response to potassium. Also in this set of experiments, no response was found to boron, manganese, zinc, and molybdenum.

The same author in 1975-76 (48), in two observation sites, was able to show that when irrigation was used, deep incorporation of 120 kg/ha of P_2O_5 as rock phosphate caused yield increases by as much as fourfold. Under these conditions there was no advantage for the use of banded superphosphate. Contrariwise, the rock phosphate caused no increases in yield when irrigation was not used, and the effects of banded superphosphate were not consistent.

In 1972-73, PIPAEMG (47), utilizing several techniques for nitrogen application to cotton crops in two sites of northern Minas Gerais, found no response to the techniques or to the levels of nitrogen application used.

Analyzing corn yield data collected in two locations of Minas Gerais, Teixeira et al. (58) concluded that nitrogen applications caused yields to increase. These experiments were conducted in soils type "Cerrado Vermelho" and in Latossolo Roxo (Eutruxox). In both locations nitrogen applications were considered more important than the effect of plant population ranges studied.

Novais e Defelipo (41), using a soil considered locally to be fertile (Patos de Minas, MG, Brazil), conducted an experiment to determine the effects of NPK application on Irish potato crop yields. They concluded that there was a great response to nitrogen applications. The response to potassium fertilization was small, and phosphorus application decreased production.

The same authors (42), in another trial using a red-yellow latosol under Cerrado vegetation, in a first-year crop, found that upland rice greatly responded to phosphorus application. The response to potassium applications was very small, and nitrogen fertilizations caused yields to decrease.

Teixeira et al. (59), studying the phosphorus, copper, and cobalt status of pasture land in Morrinhos, Góias, concluded that these three elements were deficient in those soils and were responsible for some clinic symptoms observed in the cattle herds of that region.

Pereira et al. (45), studying the efficiency of phosphorus, copper, and cobalt in grasslands of Teófilo Otoni, Minas Gerais, concluded that the cattle of that region needed phosphorus and cobalt supplementation with forage diets. The use of copper supplementation did not appear to be necessary, unless other factors were influencing its metabolism.

Novais et al. (40), working with corn in a soil from Patos de Minas, Minas Gerais, found that the number of ears per plant and the mean weight of ears increased with nitrogen applications. They also found that different corn hybrids had different nutritional requirements and that increased plant population caused yields to decrease.

Paula Lima et al. (44), studying the effects of applications of phosphorus and potassium in two dark red latosols and a red yellow cambic podzol in Minas Gerais State, found that phosphorus was the most important nutrient to increase

soybean yields in the dark red latosol. Unlikely, in the cambic podzol, soybean varieties were more responsive to potassium applications.

Using the Neubauer method with oat seedlings, Alvarez et al. (1) studied the effects of liming on the behavior of phosphorus and sulphur in an eutrophic purple latosol (Capinópolis - Minas Gerais) and in a middle-textured red yellow latosol (Pirapora - Minas Gerais). They concluded that overall, liming did not affect the production of dry matter, but more generally, modified the optimum equilibrium phosphorus-sulphur. The application of both phosphorus and sulphur increased the production of dry matter.

Bahia Filho et al. (4), working with six latosols from Minas Gerais, concluded that the level of phosphorus application for maximum oat dry matter yield was directly proportional to the buffer capacity of a given latosol. The maximum dry yield was obtained with application of 0.79 to 0.98 of the maximum capacity for phosphorus absorption.

Guimarães et al. (24), working with two latosols and a cambic podzol from Minas Gerais, concluded that there was a soybean response to nitrogen applications in three locations. The check treatments showed nitrogen deficiency symptoms, and they suggested that some factor related to symbiotic nitrogen fixation by the plant roots was disturbed.

Ferrari et al. (16), studying the soybean response to application of phosphorus, potassium, and liming in 14 latosols in Minas Gerais State, concluded that there was a

yield increase caused by phosphorus application in all 14 locations. The interaction phosphorus x liming caused yields to increase in ten locations, and potassium fertilizations were beneficial in seven locations.

Pereira et al. (46), working with a native grass (Melinis minutiflora) in a dark red latosol from Goias State, concluded that nitrogen and phosphorus increased production of green forage.

Serpa et al. (53), working with a soil from IPEACS, Rio de Janeiro State, using a switch-back experimental design, concluded that during the drought period of the year, nitrogen applications improved the forage quality with a corresponding increase in the daily milk production.

Tosi et al. (60), working with eight soils from São Paulo State, most of them latosols, using two kinds of perennial legumes, found that phosphorus increased yields in all eight locations. In six locations the responses were quadratic when using levels up to 150 kg/ha of P_2O_5 .

Gomide et al. (23), working in a dystrophic red latosol, under Cerrado vegetation from Ituitaba, Minas Gerais State, found in an experiment comparing five different kinds of grasses that all grasses contained low figures for calcium, magnesium, phosphorus, and zinc after chemical evaluation in the laboratory.

Malavolta et al. (28), working with three soils under Cerrado vegetation from São Paulo State, employing the

method of isotopic dilution, found that all three soils had different initial amounts of available phosphorus.

Nakagawa et al. (39), using a sandy dark red latosol from Bariri, São Paulo State to study the effects of N, P, K, and liming upon peanut production, found that only liming caused yields to increase, although no increase in Ca-leaf contents were detected. In this study, potassium increased the phosphorus, calcium, and nitrogen content of the leaves without any increase in yields.

Silva et al. (54), in a study evaluating the cocoa production capacity of four latosols from Bahia State, concluded that all soils were highly responsive to fertilization with NPK and liming. Yield increases up to 972 percent were obtained in a Valencia latosol.

Resende (52), studying the mineral nutrition of "Barbatimão," a Cerrado native legume used for tanin production, found that in a dark red latosol, nitrogen was the element most important for seedling growth. Phosphorus and potassium were beneficial to a lesser degree. He also noted that liming had no effect on the growth of this legume plant.

McClung et al. (34) in greenhouse experiments, found many soils of the central plateau of Brazil to have a poor S supply. The most acute deficiency was found on a soil from an upland savanna, but surface soil from virgin forests also responded to sulphur application. They also concluded that responses to sulphur in this region will not be common

unless nitrogen and phosphorus levels are improved. If these elements are plentifully supplied and cropping is intensive, sulphur deficiencies may occur in many soils.

Gomide et al. (22), working on a sandy loam soil from Viçosa, Minas Gerais State, using six kinds of grasses locally important as cattle feed, determined that the forages could be deficient in potassium and phosphorus for cattle nutrition and borderline for zinc. Nitrogen fertilization had no effect on the uptake of phosphorus, calcium, magnesium, potassium, copper, iron, and zinc.

Martini and Suarez (30), utilizing tomato plants as an indicative crop, studied the potassium response of seven latosols and andosols from Costa Rica. They determined that when plant growth was considered, applications of this element were more important in latosols than in the andosols, and that potassium fertilization of the B horizon was a very important point for good plant growth. The relation $(Ca + Mg)/K$ when narrow, caused poor plant growth.

McClung et al. (31) found evidence of severe phosphorus deficiency in grasses and legumes grown in pot culture, using six Campo Cerrado soils from São Paulo and Goiás States. The minus phosphorus treatment in most cases produced only five to ten percent as much growth as the complete treatment. Dry matter production by Pangola grass was lower in all four soils from Goiás when the elements iron, zinc, copper, boron, sulphur, and molybdenum were omitted from the fertilizer mixture. Similar results were obtained for alfalfa in one soil

from São Paulo. The data did not indicate which of these elements were involved in this response. Less growth of grass occurred when nitrogen was omitted, but in no case, either with grasses or legumes, did the omission of potassium have a measurable effect on dry matter production. Omission of lime resulted in reduced growth of alfalfa and soybeans, and in one soil, of Pangola grass.

Mikkelsen et al. (35), using a dark red latosol, a red yellow latosol, and a deep regosol from virgin areas of São Paulo State, found that yields of cotton, corn, and soybeans increased sharply with application of dolomitic limestone. The limestone corrected excessive soil acidity, supplied calcium and magnesium as plant nutrients, and enhanced the uptake of phosphorus, nitrogen, and sulphur. Used together with limestone, responses were obtained with potassium, phosphorus, nitrogen, sulphur, and the micronutrients zinc, boron, and molybdenum. The specific requirement for each nutrient was dependent on the crop being grown and the level of lime application.

McClung et al. (32), based on results from 22 field experiments carried out in soils generally classified as "Terra Roxa Misturada" (dark red latosols) in the State of São Paulo, found that outstanding yield responses were obtained from applications of lime with increments ranging from 50% to as high as 300% at some locations. Lime tended to reduce the response to phosphorus, and only two significant yield increases due to phosphorus applications were indicated in a

series of eight individual experiments. Potassium responses were found in four cotton experiments out of eight in the 1959-60 trials. Yield increases due to potassium application, when they appeared, were generally large, varying from 50% to 200%. In terms of frequency of response, sulphur was a limiting factor second only to lime. Nitrogen deficiencies occurred in relatively few experiments in which this element was applied. They also concluded that micronutrient deficiencies deserved further research with more sensitive crops such as corn and legumes.

Lopes (27), working with 518 soil samples collected under Cerrado vegetation in Brazil (49.2% of the samples were from Cerrado, 28.6% from Campo Gerrado, 10.4% from Cerradão and 3.1% from forest vegetation) concluded that the soils generally had highly acidic soil reaction, with values below critical suggested levels for calcium, magnesium, potassium, phosphorus, zinc, and copper. He also concluded that aluminum saturation in these soils would be toxic for most crops, and that cation exchange capacity was very low. Manganese and iron levels were judged satisfactory according to levels used in other countries. Overall, the soils were considered medium to well supplied with organic matter.

Ramos (50), using wheat in greenhouse experiments, studied the influence of nitrogen and phosphorus fertilization on the fertility status of five soils from Campos Gerais in the State of Parana. The soils were derived from Ponta Grossa shale and Purnas sandstone, and in their native state

had low levels of phosphorus, calcium, and magnesium. He found response to phosphorus application, as well as a significant nitrogen x phosphorus interaction. There was a significant response to nitrogen on cultivated soils, even in the absence of phosphorus fertilization. Nitrogen response on the native soils was nil, unless phosphorus was applied. On the other hand, in the absence of nitrogen, only the native soils reacted significantly to phosphorus applications. The residual effect of phosphorus was minimum, indicating that these soils have considerable capacity to fix this nutrient. He also concluded that the fertility status of these soils may be modified after several years of cultivation, depending on the level of management.

Freitas et al. (20), in a two-year lime and fertilizer study conducted at five locations representing the Cerrado areas of the Federal District of Brazil, determined soil response to nitrogen, phosphorus, potassium, sulphur, zinc, boron, and molybdenum, using corn and soybeans as test crops. The application of lime and fertilizer resulted in obtaining high production levels of both test crops. The two-year average annual increases for lime application was 821 kg/ha of corn and 415 kg/ha of soybeans. Complete fertilization resulted in an annual increase of 4950 kg/ha of corn and 1,810 kg/ha of soybeans. They suggested also that the costs of the very high rates of phosphorus and zinc applied during the initial application be prorated over several years, similar to the cost of liming.

Souza Britto et al. (56), using a 3 x 3 x 3 factorial design, studied the influence of various combinations of nitrogen, phosphorus, and potassium on corn growth on a red yellow latosol, developed under Cerrado vegetation. They determined that the highest yield was obtained using 120 kg/ha of nitrogen, 60 kg/ha of phosphorus, and 60 kg/ha of potassium.

Carvalho et al. (7) carried out a greenhouse experiment to investigate nutrient deficiencies which restricted the development of six tropical legumes on a dark red latosol from a Cerrado area. They found that phosphorus increased both dry matter production and nodulation, and that dry matter production was not affected by the omission of potassium, sulphur, and micronutrients. Symbiotic nitrogen fixation and dry matter decreased with absence of liming. Nitrogen application increased nitrogen fixation and dry matter production.

Tanaka et al. (57) determined that the production of tomato plants cultivated on a sandy loam red yellow latosol from Matão, São Paulo State was increased 925% with chemical fertilizers, with the greatest response resulting from application of phosphorus, which increased production from 2.6 to 8.5 kilos per plant. Nitrogen increased plant production by 3.9 kilos and potassium by 1.5 kilos. Liming caused a minor production increase.

França et al. (17), using a red latosol, Cerrado phase, and five tropical legumes, determined that the soil was

highly phosphorus deficient and that omission of both potassium and sulphur did not cause any negative effect on dry matter yields or nitrogen fixation. They also determined that liming was a very important practice for high yields and nitrogen fixation. Nitrogen application decreased nodule weight, but increased total nitrogen content in the plants.

Kalckmann (26), discussing several fertilizer trials carried out in three Brazilian states, concluded that the use of fertilizer is a very important technique to increase food production in Brazil. He suggested that phosphorus may be considered the key element in fertilization, followed by nitrogen and potassium. He also affirmed that food output in Brazil could be increased from 20% to 100% by the widespread use of fertilizers.

Eira et al. (11), working with corn on a dark red podzol collected under Cerrado vegetation, found great response to lime, phosphorus, and nitrogen applications. Neither micronutrients nor potassium responses were found to be significant.

Freitas et al. (21), working with sweet corn in two soils collected under Cerrado vegetation and a soil formerly cultivated with coffee for thirty years, found response to liming and application of different levels of fertilizers. They found an overall need for phosphorus and zinc, with the Cerrado soils showing a need for higher levels of fertilizer applications for higher yield production. Nitrogen response was detected in all three locations, and potassium response

was observed only in one of the Cerrado soils. They also suggested that an adequate level of potassium, as well as sulphur and magnesium, is required for high production. Soybeans planted in the following season benefited from the residual effect of the fertilizers applied for the first experiment. Residual effect of phosphorus was considered to be very high.

Jones et al. (25) studied the behavior of four tropical legumes to fertilizer applications on a red yellow latosol collected under Cerrado vegetation. They found that all four legume species showed a significant response to phosphorus applications as well as to liming. There was not response to fertilization with potassium, and they suggested that tropical legumes are able to get potassium more easily from this soil than crops such as cotton, corn, and soybeans.

Miller et al. (36), working on a red yellow latosol at the "Estação Experimental do Instituto de Pesquisas e Experimentação Agropecuarias do Centro Oeste" at Uberaba, Minas Gerais, using dry beans, found a great response to phosphorus and nitrogen applications. They also noted that plots that did not receive phosphorus had 30% less plants during harvesting, and that this nutrient shortened the maturity time.

Fontes et al. (18), studying the dry bean response to fertilizer applications in six locations at the Zona da Mata region in Minas Gerais State, found response to phosphorus application in all six locations. There was response to liming in only one location, and nitrogen and potassium were

not effective in increasing dry bean yields. Where they found liming response, they also noted a marked effect for residual of phosphorus during a second planting. The residual effect of liming in this site lasted longer than that for phosphorus.

Alvim and Araujo (3), studying the vegetation distribution under the area known as "Cerrado" in Brazil, concluded that this distribution within the phytogeographic region was apparently controlled by the soil more than any other ecological factors. The Cerrado plants are apparently tolerant of soils low in calcium content and with low pH, where typical forest trees and good forage plants cannot grow. Liming was considered the most recommendable treatment for improving the soils. Under the Cerrado area surveyed by these two authors, forests were found only in soils with pH above 5 and relatively rich in calcium.

Cheong and McConaghy (8), working with three Mauritius soils (representing latosolic reddish prairie, low humic latosol and humic ferruginous latosols groups), using labeled phosphorus and Sorghum vulgare cv. "Sweet Sudan" as an indicator plant, determined that the soluble phosphate applied had been converted mainly to iron-bound and aluminum-bound forms, and only acid soils showed any appreciable alteration of the guano phosphate (towards iron-bound forms) during the experimental period.

Olsen (43), working in Uganda, under conditions similar to the Cerrado area in Brazil, studied the effect of large

applications of nitrogen on the productivity of four tropical grasses. He found that the grasses exhibited a strong response to nitrogen up to 448 kg/ha with slight additional response to the 896 kg/ha level. Above 896 kg/ha of nitrogen there was an actual decline in dry matter production. He also pointed out that dry matter production of the grasses increased almost threefold with high rates of nitrogen.

Dutra et al. (10) carried out five experiments using varieties of soybeans and dry beans in dark red latosols in two locations of Goias State, Brazil. In both locations they found a significant quadratic response to phosphorus applications and no response to nitrogen application levels. In Goiania they noted that application of potassium tended to depress yields. They concluded that this was an unexpected situation, because the initial available potassium was below the critical level suggested for Brazilian soils. They also found varieties of both crops to respond in a different way to fertilizer applications.

McClung and Quinn (32) reported that a sandy loam soil, type classed as Bauru inferior, with pH between 4.8 and 5.2, greatly responded to additions of sulphur. They worked in an established pasture of Batatais grass (Paspalum notatum) which had been heavily fertilized with nitrogen for about 18 months. They also found response to applications of phosphorus and pointed out that combination of sulphur and phosphorus resulted in up to sixfold increases in dry matter

production. Sodium and calcium sulfate applications resulted in prompt correction of chlorosis and improvement in growth. Recovery was somewhat delayed under treatment with elemental sulphur, but after about two months, these plots performed as well as those treated with sulfates.

Freitas et al. (19), working with humic latosols from Goiás and São Paulo State, indicated that these soils were very deficient in several plant nutrients and to be quite responsive to added lime and inorganic fertilizers. They planted corn, soybeans, and cotton as indicative crops.

In Goiás, the most striking response in the early stages of development appeared to be phosphorus, but completely non-fertilized corn plots did not show the purple-red discoloration of phosphorus deficiency. They suggested that phosphorus was not the first limiting factor at this location, even though growth was extremely poor when this element was not supplied. In this case, calcium was supposed to be the first limiting factor. In the soybean experiment they observed a very definite response to nitrogen in spite of excellent nodulation. Soybeans also responded to phosphorus, zinc, lime, and, in the absence of lime, to molybdenum. Besides the phosphorus response, they also reported corn response to nitrogen, potassium, and zinc.

In São Paulo, the early responses of cotton appeared to be to lime, to sulphur, and to both. The soybean experiment was surprisingly good from the start. Failure of the crops to respond to phosphorus was considered surprising in view

of the considerable evidence of generally poor phosphorus status on the Campos Cerrados. They emphasized that differences in the nature of the responses in São Paulo and Goiás illustrate the fact that the nutrient status of Campo Cerrado areas is complex and variable from place to place. It is worthy to note that the soil from Goiás failed to show a positive response to sulphur in the field experiment, although a greenhouse experiment test had indicated that the very same soil responded to addition of this nutrient.

Viegas and Freire (61), studying the data collected from corn experiments conducted in "Terra Roxa Misturada" in Campinas, São Paulo State for several years, determined a very high influence of applications of phosphorus, potassium, and NPK on some plant and ear characteristics. The effects of the nutrients were manifested by increased number of plants which attained maturity, their size, and the proportion of those bearing ears, as well as the weight of the ears and their shelling percentages. When corn grain was considered, the mean effect of phosphorus increased yields by 113%; the mean effect of potassium boosted yields by up to 106%, and the addition of NPK caused a 242% increase in production.

Viegas et al. (62) studied the behavior of three corn varieties under different levels of fertilization and row spacing in five different types of soils in São Paulo State. They concluded that the average response to fertilization did not differ for the types of soils. The quadratic trend

for NPK fertilization was significant, indicating a maximum yield when 50-150-50 kg/ha was applied. The types of soils covered by their trials were: Massape, Terra Roxa, Arenito Bauru, Glacial and Terciario.

Miranda et al. (37) reported results of experiments in which effects of manure, limestone, and an NPK fertilizer were tested under continuous corn on a "Terra Roxa Misturada" soil, with the initial pH of 5.6. They found a null average effect for lime, but its interaction with NPK was significant and positive. The yield increases due to manure application were very good and more or less constant during the experimental period. The interaction NPK x manure was significant and negative. The NPK effect was significant and tended to increase considerably as the years passed.

Costa Verdade et al. (9) reported that in São Paulo State, from 209 fertilizer trials carried out in several types of soils, using cotton as an indicative crop, 32 experiments showed response to nitrogen application, and only 9 responded to potassium fertilization. There was a marked effect for phosphorus applications, and only in very few experiments the response to this nutrient was not statistically significant. When studying the soil content of phosphorus soluble in H_2SO_4 0.05 N, it was possible to differentiate the two types of reactions: one for sandy soils and the other for the clayey soils. Oxalic acid + potassium oxalate 1N was not an adequate soil extractor to predict soil requirements for phosphorus fertilization.

Alvarez et al. (2) in Ribeirão Preto, São Paulo State, working in a "Terra Roxa" soil, studied the effect of NPK application on sugar cane growth. Using a 3 x 3 x 3 factorial design, they determined that potassium was the element that gave the highest yield increases. Nitrogen also increased the yields linearly, but its effect was less noticeable than that of potassium. The response to phosphorus application was not statistically significant. The soil in this experiment had been previously cropped for several years.

Breda Filno et al. (5) carried out six trials in different regions of São Paulo State to study the effect of nitrogen, phosphorus, and potassium on the yield of sweet potatoes (Ipomoea batatas) grown in poor Cerrado soils. Two of these experiments were localized in areas cropped for some years and previously fertilized, and the other sites were cropped for the first time. Potassium increased significantly the yields in all experiments, and the phosphorus effect was low in the soils previously cropped and fertilized. However, in the other four locations, phosphorus greatly improved production. Nitrogen increased the yield in only one location with depressive effect in some other places.

Myiasaka et al. (38) studied the effect of lime, green manure, and mineral fertilizers on the yield of dry beans (Phaseolus vulgaris L.) on a poor soil with Cerrado vegetation in Campinas, São Paulo. The response to green manure

was positive, but small in the presence of NPK, and negative in the absence of mineral fertilizers. Lime and phosphorus were the principal yield-increasing factors. In the average of two years, the effect of phosphorus corresponded to 123%. In the first year superphosphate was superior to Olinda rock-phosphate; in the second, however, it was inferior. Liming enhanced the effect of superphosphate but depressed that of Olinda rockphosphate. While the average annual yield of the check treatment was only 174 kg/ha, some treatments yielded production close to those normally obtained in fertile soils.

Mascarenhas et al. (29) tested the response of soybeans to increasing level applications of lime, phosphorus, and potassium for two years on a red latosol with Cerrado vegetation recently cleared. Despite the low pH, lime was ineffective. However, there was a great response to phosphorus addition. Although this soil tested extremely low for potassium, the effect of K application was not appreciable.

Brensing and Lynd (6) reported that in eastern Oklahoma, highly significant and profitable increases in wheat yields were obtained with proper rates and combination of nitrogen, phosphorus, and potassium fertilization on upland permeable claypan prairie soils. Results showed the need for proper balance of these plant nutrients. Response to various fertilization combinations varied with the soil type and previous soil management. However, the first limiting plant nutrient for wheat yields at all field experiment locations was phosphorus, and highest yields were obtained only when

adequate phosphorus was applied. Wheat yields increased with nitrogen fertilization when N treatments were combined with adequate phosphorus and potassium. The magnitude of response to nitrogen addition was influenced greatly by previous soil treatments. Yields were not increased on well-managed Dennis silt loam to various N and P_2O_5 combinations unless combined with application of 40 lbs. of K_2O per acre. Results from this and previous studies had shown no significant difference in yields from different times of applying nitrogen fertilizer to wheat crops. Nitrogen fertilizer applied on Parsons silt loam to the wheat stubble just prior to plowing was as effective as the same N rates applied at planting. Residual effects from nitrogen, phosphorus, and potassium fertilization applied to crops that failed on claypan prairie soils gave significant increases in wheat yields.

The 1973 annual report on tropical soils from the Soil Science Department of North Carolina State University (55) pointed out that there was considerable doubt that non-legume crops grown in oxisols require large quantities of nitrogen for maximum yields. In corn experiments carried out in the Brasilia Experiment Station on a Typic Haplustrox (dark red latosol), they found that nitrogen was less critical than phosphorus, magnesium, or zinc for plant growth. On the other hand, they reported that in soils from Minas Gerais State, the level of nitrogen requirement for maximum corn yields was considerably beyond 160 kg/ha. In this group of experiments, corn responses to nitrogen applications

increased with increasing pH. Still in Minas Gerais, they found that the response to applied phosphate was likewise affected by soil pH. Corn yields in soil with pH 5 were higher than in soils with pH 6. Response to phosphorus applications were only slightly affected by available soil phosphorus. They also found a negligible response for potassium additions to the soil for corn growth.

In 1973 a complete review of soils research in Tropical Latin America was published by the North Carolina Agricultural Experiment Station (51). In this review Batholomew (page 74) wrote that "nitrogen is the element most likely to limit crop growth in tropical regions." On page 105, Sanchez pointed out that "the need for substantial nitrogen on beans implies that symbiotic nitrogen fixation by Rhizobia has not been effective in the region" and that "more emphasis on the use of legume as a nitrogen source for pasture is badly needed." Citing Rodrigues (page 90), this author stated that "the average application rate for Tropical America was 14 kg N/ha, which indicates that the proportion of crops receiving nitrogen applications is still low." Kamprath (page 138) concluded that "the highly weathered soils, oxisols and ultisols of the tropics along with andosols, are generally very deficient in phosphorus" and therefore "without the application of phosphorus, sustained crop production at high yield is not possible." "Many of these soils fix large quantities of added phosphorus." Cox (page 162) suggested that "the potassium status of soils and

plants in Latin America varies considerably." "Responses to K are very much related to the sensitivity of the crop being grown" (page 167). According to Kamprath (page 180) "mineralization of organic sulphur may initially supply some sulphur, particularly when the soils are high in organic matter," but "the highly weathered savanna soils in South America are likely to be sulphur deficient particularly where they have undergone repeated burning."

The 1976 Annual Technical Report from the "Centro de Pesquisas Agropecuarias do Cerrado" (12) gives a very comprehensive inlook at the Cerrado area problems in Brazil. Some of these problems are presented below:

The principal soil occurrences of this area in Brazil are the dark red latosol and the red-yellow latosol. They are both deep, well-drained, permeable, with low natural fertility, cation exchange capacity, water-storage capacity, and soil reaction. The dark red latosol has high aluminum saturation throughout the whole soil profile, while the aluminum saturation on the red-yellow latosol is high only at the surface layer (page 20).

Due to deep incorporation of liming and decreased aluminum saturation, crops have shown great yield increases, especially because of an improved large root system. This larger root system makes it possible for plants to withstand longer drought spells during the crop season (page 38). Deeper incorporation of liming at 30 cm is significantly better than incorporation at 15 cm (page 40).

The soils under Cerrado vegetation are extremely poor in phosphorus and require large amounts of this nutrient for good crop yields. The high fixation of phosphates in these soils is considered a major difficulty in expanded agriculture in this region (page 53). Maximum soybean production was achieved with application of 1,200 kg/ha of P_2O_5 , while application of 300 kg/ha yielded 80% of the maximum production capacity (page 53). Because of the high cost of the nutrient phosphorus in Brazil, it is not economical for applications of less than 250 kg/ha of P_2O_5 for crop production in the Cerrado area (page 55). Sources of phosphorus nutrient and methods of application are also important points in the economics of this fertilizer nutrient (pages 56-65).

Experimentation has shown that corn production without any application of nitrogen has been 60% of the maximum yield achieved using 140 kg/ha of this nutrient. Two possible explanations for this is the fact that these soils have a good supply of organic matter which is mineralized after liming. Nitrogen fixation by Spirillum sp has also been detected in symbiosis with some non-legume crops (page 66).

Natural levels of potassium are considered medium and low for calcium, magnesium, and zinc (page 65).

Screening crops and varieties that better produce under the adverse conditions of this part of Brazil has also been under intensive investigation.

CHAPTER III

MATERIALS AND METHODS

The soil used in this study was a dark red latosol (Typic Eutruxox) collected at the Jaiba Agroindustrial District, northern Minas Gerais, Brazil. Only surface soil (0-20 cm) was used. The natural vegetation covering this soil was a tropical deciduous forest at an altitude of 470 meters. This area had been recently cleared for the first-year cultivation. As a legal requirement, this collected material was steam sterilized by the USA Quarantine Service at Miami, Florida. The chemical and particle size analysis of this soil appear in Table I.

TABLE I
SOIL ANALYSIS FROM OSU SOIL AND WATER LABORATORY

pH	BI	P #A	K #A	Ca ppm	Mg ppm	Fe ppm	Zn ppm	Mn ppm	% OM
6.1	6.8	15	285	2,760	300	680	1	208	3.32
CEC meq/100 g		% Sand		% Silt		% Clay		Texture	
25.4		24.5		19.5		56.0		Clay	

All experiments hereafter described were conducted in a greenhouse facility at the Oklahoma State University campus in Stillwater, Oklahoma. Five plants per pot culture of corn Hybrid NK 9514 were used as a crop indicator for all experiments. According to the need, the treatments were daily watered using distilled water either from the top or the bottom of the pots. Data referring to the top dry weight and root dry weight were collected in all experiments for statistical analysis. All experiments were conducted in a randomized block design.

Daily minimum and maximum temperatures were registered during the experimental period (Appendix Table XXXVI).

First Set of Experiments

Using pots containing 100 grams of soil and 400 grams of coarse quartz sand, two experiments were conducted in an incomplete factorial design with three replications. Treatment combinations for this set of experiments appear in Table II.

First Experiment of the First Set

The sources and nutrient levels for the first experiment of the first set are shown in Table III.

Second Experiment of the First Set

The three replicate pots per treatment of the first experiment were thoroughly mixed together then repotted, and

TABLE II
TREATMENT COMBINATIONS FOR THE FIRST SET OF EXPERIMENTS

Treatment	Symbol	Treatment	Symbol
1	0	10	N2P1
2	N1	11	N2K
3	P1	12	N2P1K
4	K1	13	P2
5	N1P1	14	N1P2
6	N1K1	15	N2P2
7	P1K1	16	P2K
8	N1P1K	17	N1P2K
9	N2	18	N2P2K

TABLE III
SOURCES AND NUTRIENT LEVELS FOR SET 1, EXPERIMENT 1

Nutrient	Source	Levels (ppm)
Nitrogen	NH_4NO_3	0, 100, 200
Phosphorus	$\text{CaH}_4(\text{PO}_4)_2 \cdot \text{H}_2\text{O}$	0, 50, 100
Potassium	K_2SO_4	0, 200

the same experiment was repeated using double levels for each nutrient. In this experiment each treatment received a teaspoon of Eufaula sand soil known to have high, natural, active soil microbial activity.

Second Set of Experiments

The main objective of this second set of experiments was a more detailed study of the effect of the potassium levels as well as the response of this soil to different sources of potassium and sulphur, if any.

The soil from the first set of experiments was thoroughly mixed, and new treatments were established. Five experiments were then carried out using the treatment combinations shown in Table IV.

The sources and nutrient levels used in this second set of experiments appear in Table V.

First Experiment of the Second Set

The pot size was the same as in the first set of experiments, using the soil as already described. Three replicate pots per treatment were used.

Second Experiment of the Second Set

The soil from the three replicate pots per treatment of the first experiment was mixed together and repotted. Four hundred ppm of nitrogen were added to all treatments.

TABLE IV

TREATMENT COMBINATIONS FOR SECOND SET OF EXPERIMENTS

Treatment	Symbol*	Treatment	Symbol
1	O	10	3 KS
2	N	11	3 KS + N
3	P	12	3 KS + NP
4	1 KS	13	2 KCl
5	1 KS + N	14	2 KCl + N
6	1 KS + NP	15	2 KCl + NP
7	2 KS	16	2 NaS
8	2 KS + N	17	2 NaS + N
9	2 KS + NP	18	2 NaS + NP

*Numerals preceding symbols refer to the level of KS (K_2SO_4), KCl, and NaS (Na_2SO_4). Nitrogen and phosphorus levels were kept constant. The amount of sulphate in 2 KS is the same as in 2 NaS, and the amounts of K are the same in 2 KS and 2 KCl.

TABLE V
SOURCES AND NUTRIENT LEVELS FOR THE
SECOND SET OF EXPERIMENTS

Nutrient	Sources	Levels (ppm)
Nitrogen	NH_4NO_3	400
Phosphorus	$\text{CaH}_4(\text{PO}_4)_2 \cdot \text{H}_2\text{O}$	200
Potassium	K_2SO_4 and KCl	400, 800, 1,200
Sulphur	K_2SO_4 and Na_2SO_4	800

The third, fourth, and fifth experiments of this set were prepared in the same manner as described for the second experiment. In each of them, the pots received 400 ppm of nitrogen as NH_4NO_3 .

Third Set of Experiments

Using 50 grams of fresh new soil and 450 grams of pure coarse quartz sand, a new series of experiments was set up. The main objective of this last group of experiments was to study the response of this latosol to application of single sources of nitrogen, phosphorus, potassium, and sulphur. The treatment combinations for this set of experiments appear in Table VI.

The sources and nutrient levels for this set of experiments are shown in Table VII.

For the first experiment of this new group of trials, using the set of treatments already described, five corn plants were grown per pot. In the second experiment, the soil from the first trial was mixed between replications and repotted, and no nutrient was added to the residual of previous treatments.

TABLE VI
TREATMENT COMBINATIONS FOR THE THIRD SET OF EXPERIMENTS

Treatment	Symbol
1	0
2	N
3	P
4	P + CaS
5	KCl
6	KS
7	NaS
8	S Flower

TABLE VII
SOURCES AND NUTRIENT LEVELS FOR THE THIRD SET OF EXPERIMENTS

Nutrient	Sources	Levels (ppm)
Nitrogen	NH_4NO_3	400
Phosphorus	$\text{CaH}_4(\text{PO}_4)_2 \cdot \text{H}_2\text{O}$	200
	$\text{CaH}_4(\text{PO}_4)_2 \cdot \text{H}_2\text{O} + \text{CaSO}_4$	
Potassium	KCl, K_2SO_4	800
Sulphur	S Flower, Na_2SO_4	800
	$\text{CaH}_4(\text{PO}_4)_2 \cdot \text{H}_2\text{O} + \text{CaSO}_4$	

CHAPTER IV

RESULTS AND DISCUSSION

Experimental results are summarized in Tables VIII to XVI and Figures 1 to 9. Detailed tables containing the statistical procedures used for analyzing the data collected are presented in the Appendix, Tables XVII to XXXV.

Because of the erratic results obtained with the root dry weight data, only the above-ground or top dry weight determinations will be presented and discussed. The erratic results of the root dry weights are attributed to the difficulty of recovering the entire root system of corn plants and separating the actual root tissue from the soil particles when cultured in small pots, such as the ones used in this group of greenhouse experiments.

First Set of Experiments

Two 3 x 3 x 2 NPK factorial experiments were conducted in the first set of experiments (Figures 1 and 2, Tables VIII, IX). In the first experiment (Figure 1, Table VIII), when low levels of nutrients were applied, the mean highest yields (2.25 g) were obtained using 200, 50, and 200 ppm of nitrogen, phosphorus, and potassium, respectively (treatment N2P1K). Application of phosphorus without the addition of

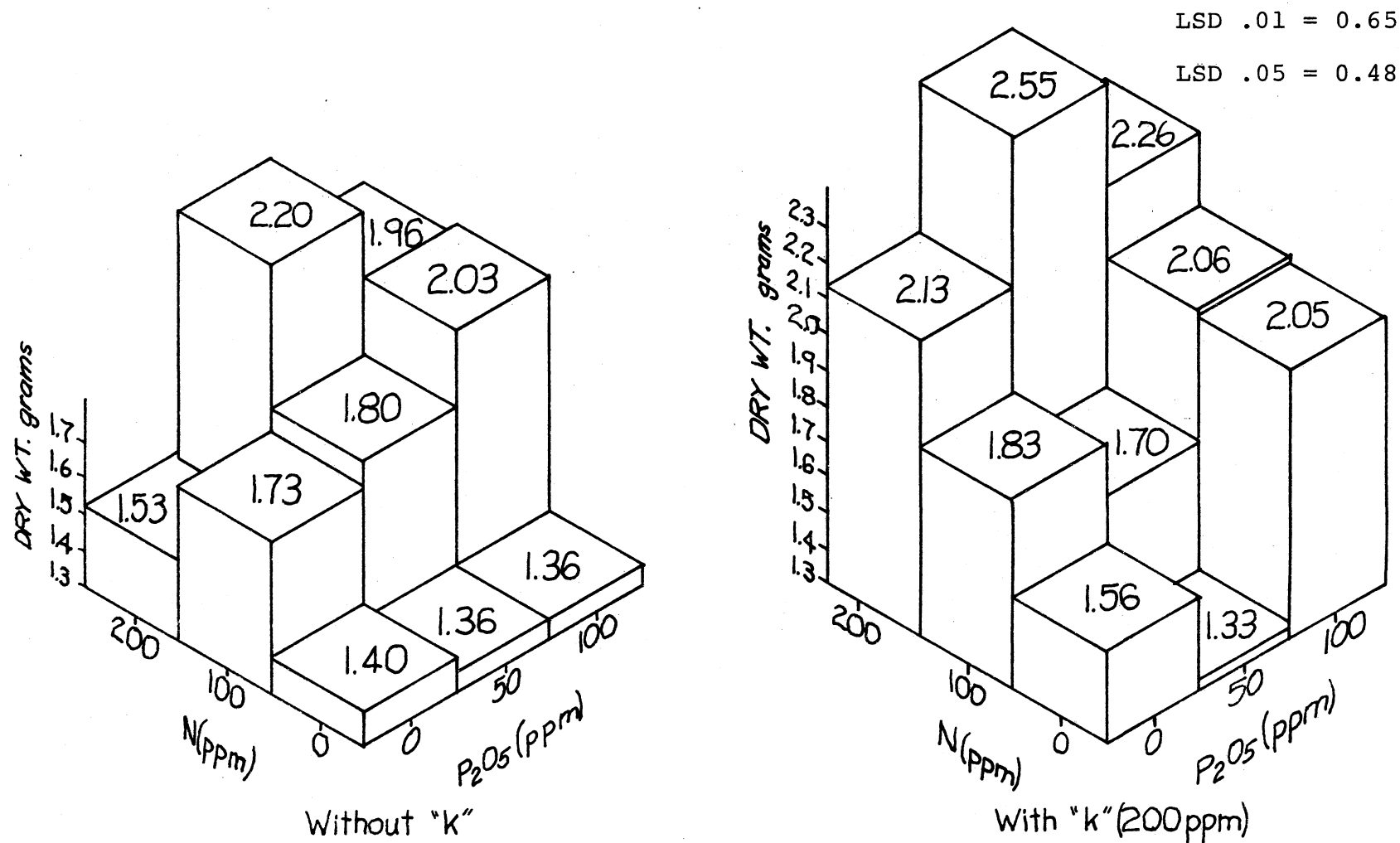


Figure 1. Effect of Various Soil Fertility Treatments on Growth of Corn Plants, Dark Red Latosol, Jaiba, Minas Gerais, Brazil. Set 1, Experiment 1.

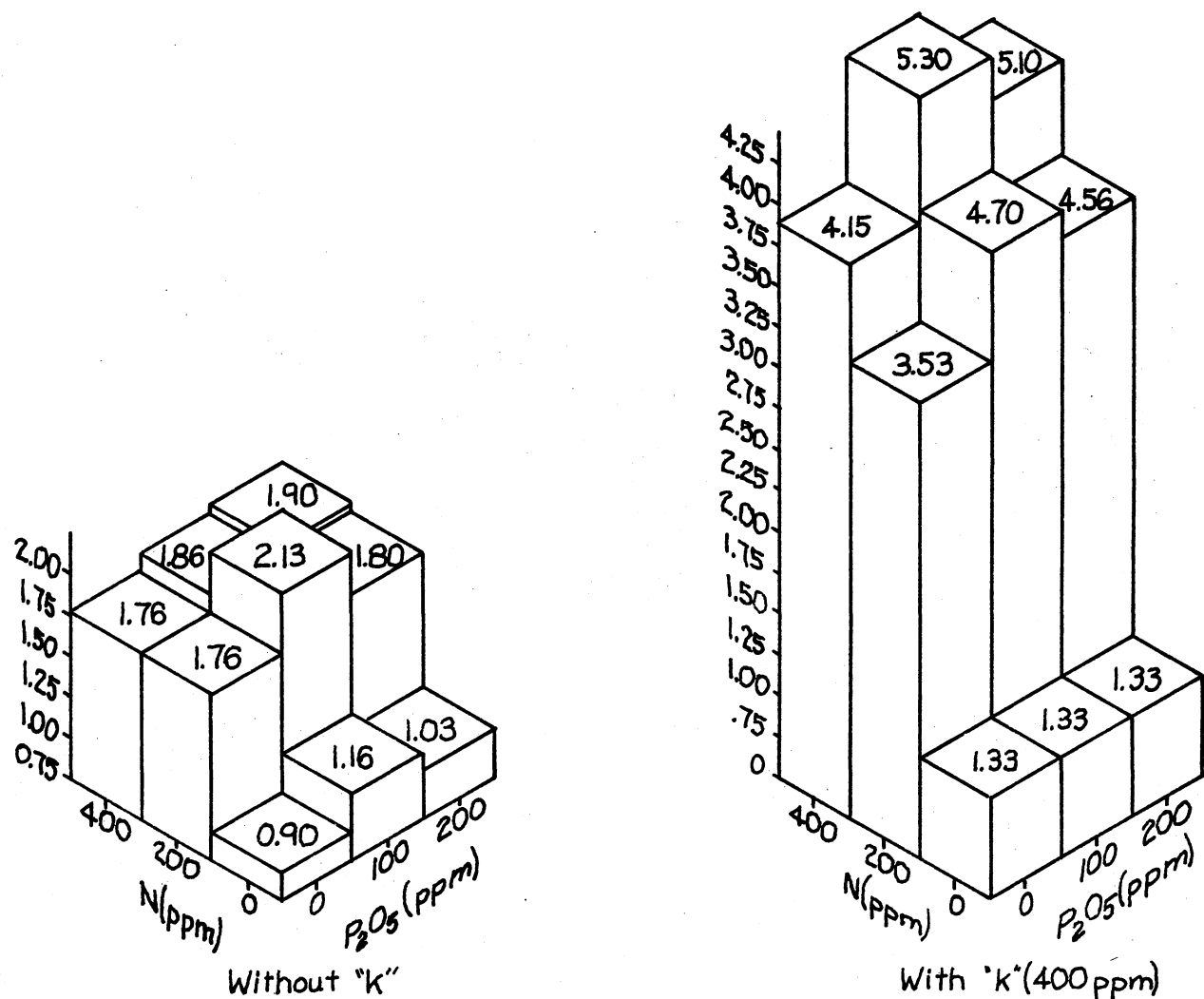


Figure 2. Effect of Various Soil Fertility Treatments on Growth of Corn Plants, Dark Red Latosol, Jaiba, Minas Gerais, Brazil. Set 1, Experiment 2.

TABLE VIII

ORTHOGONAL EFFECTS OF VARIOUS SOIL FERTILITY TREATMENTS ON
GROWTH OF CORN PLANTS, DARK RED LATOSOL, JAIBA, MINAS
GERAIS, BRAZIL (SET 1, EXPERIMENT 1)

Treatment Symbol	Av. Yield Dry Wt. (g)	Treatment Symbol	Av. Yield Dry Wt. (g)
0	1.40	K	1.56
N1	1.73	N1K	1.83
P1	1.36	P1K	1.33
N1P1	1.80	N1P1K	1.70
N2	1.53	N2K	2.13
N2P1	2.20	N2P1K	2.55
P2	1.26	P2K	2.03
N1P2	2.03	N1P2K	2.06
N2P2	1.96	N2P2K	2.26

Without K					With K				
	NO	N1	N2	\bar{P}		NO	N1	N2	\bar{P}
PO	1.40	1.73	1.53	1.55	PO	1.56	1.83	2.13	1.84
P1	1.36	1.80	2.20	1.79	P1	1.33	1.70	2.55	1.86
P2	1.36	2.03	1.96	1.78	P2	2.05	2.06	2.26	2.12
\bar{N}	1.37	1.85	1.90	1.71	\bar{N}	1.65	1.86	2.31	1.95

Average yields are means of three replicate cultures with 5 plants of NK Hybrid 9514 corn per culture with 22 days growth.

Treatment $F = 4.46^{**}$ $R^2 = 0.69$ C. V. = 16.03 LSD 0.01 = 0.65 LSD 0.05 = 0.48.

Response significance: nitrogen levels, linear**, phosphorus levels, linear*, potassium level*, interactions N_1P_1 , N_2P_1 , N_1P_2 , N_2P_2 slightly less than significant (OSL = 5.3%).

TABLE IX

ORTHOGONAL EFFECTS OF VARIOUS SOIL FERTILITY TREATMENTS ON
GROWTH OF CORN PLANTS, DARK RED LATOSOL, JAIBA, MINAS
GERAIS, BRAZIL (SET 1, EXPERIMENT 2)

Treatment Symbol	Av. Yield Dry Wt. (g)		Treatment Symbol	Av. Yield Dry Wt. (g)	
0	0.90		K	1.33	
N1	1.76		N1K	3.53	
P1	1.16		P1K	1.33	
N1P1	2.13		N1P1K	4.70	
N2	1.76		N2K	4.15	
N2P1	1.86		N2P1K	5.30	
P2	1.03		P2K	1.33	
N1P2	1.80		N1P2K	4.56	
N2P2	1.90		N2P2K	5.10	

Without K					With K				
	NO	N1	N2	\bar{P}		NO	N1	N2	\bar{P}
PO	0.90	1.76	1.76	1.47	PO	1.33	3.53	4.15	3.00
P1	1.16	2.13	1.86	1.72	P1	1.33	4.70	5.30	3.78
P2	1.03	1.80	1.90	1.58	P2	1.33	4.56	5.10	3.66
\bar{N}	1.03	1.90	1.84	1.59	\bar{N}	1.33	4.27	4.85	3.48

Average yields are means of 3 replicate cultures with 5 plants
of NK Hybrid 9514 corn per culture with 25 days growth.
Treatment F = 55.92** $R^2 = 0.96$ C. V. = 14.09% LSD 0.01 =
0.79 LSD 0.05 = 0.59.

Response significance: nitrogen levels, quadratic**, phos-
phorus levels, quadratic**, potassium level**, interactions
 N_1K^{**} , N_qK^{**} , P_1K^* .

nitrogen and potassium (treatments P1 and P2) (1.36 g) and application of 100 ppm of phosphorus in the presence of 200 ppm of potassium without any application of nitrogen (treatment P2K) (1.33 g) yielded lower weights of dry matter than the check treatment (1.40 g). Statistical computation on these data (Appendix, Table XVII) indicated linear response to additions of both nitrogen and phosphorus, as well as a significant response to potassium for higher yields. Also in this analysis, when the four degrees of freedom for the N x P interaction were split, the effects (linear = l, quadratic = q) N_1P_q , N_qP_1 , appeared to be significant. The effect N_qK was slightly less than significant (OSL = 5.3%).

For the group of treatments "without K," at the 100 ppm level of nitrogen, applications of phosphorus caused yields to increase (1.73 g, 1.80 g, and 2.03 g, respectively). At the level of 200 ppm of nitrogen, the yield sharply increased with application of 50 ppm of phosphorus (2.20 g), and slightly dropped when 100 ppm were applied (1.96 g).

When 200 ppm of potassium were applied (group of treatments "with K") at any level of phosphorus, nitrogen applications caused yield increases. In this group of treatments, it is worth to note that at the 0 and 100-ppm levels of nitrogen, application of 50 ppm of phosphorus had a decreasing effect on yields (1.33 g and 1.70 g, respectively), when comparing with the 0 and 100-ppm levels of phosphorus, within the same levels of nitrogen. Contrariwise, at the 200-ppm level of nitrogen, application of 50 ppm of phosphorus

caused a highly significant increase in top dry matter (2.55 g).

For the second experiment (Figure 2, Table IX), when doubled levels of nutrients were applied over the residual effects of the previous experiment, the highest yield (5.30 g) was obtained with the application of 400, 100, and 400 ppm of nitrogen, phosphorus, and potassium, respectively (treatment N2P1K). In this second experiment, no treatment combination had a lower yield than the check treatment (0.90 g).

Statistical computation of these data (Appendix, Table XVIII) indicated quadratic response to additions of both nitrogen and phosphorus, as well as a highly significant response to potassium. The interactions N_1K , N_qK were highly significant, and the effect P_1K was significant.

For both groups of treatments, "without K" and "with K," application of phosphorus levels caused no yield improvement, unless some nitrogen was provided. When 400 ppm of potassium was applied (group of treatments "with K") the yield increments caused by both nitrogen and phosphorus were larger than the increments caused by these nutrients under the "without K" group of treatments, except for the case noted above.

Finally, in this set of experiments, besides the demonstration of the importance of nitrogen, phosphorus, and potassium for improved corn production in this Brazilian dark red latosol, the data collected also suggested that

there exists in this soil a favorable NPK balance for higher yields. In these two experiments this balance seemed to be induced by the N2P1K ratio used since this treatment in both trials gave the highest yields.

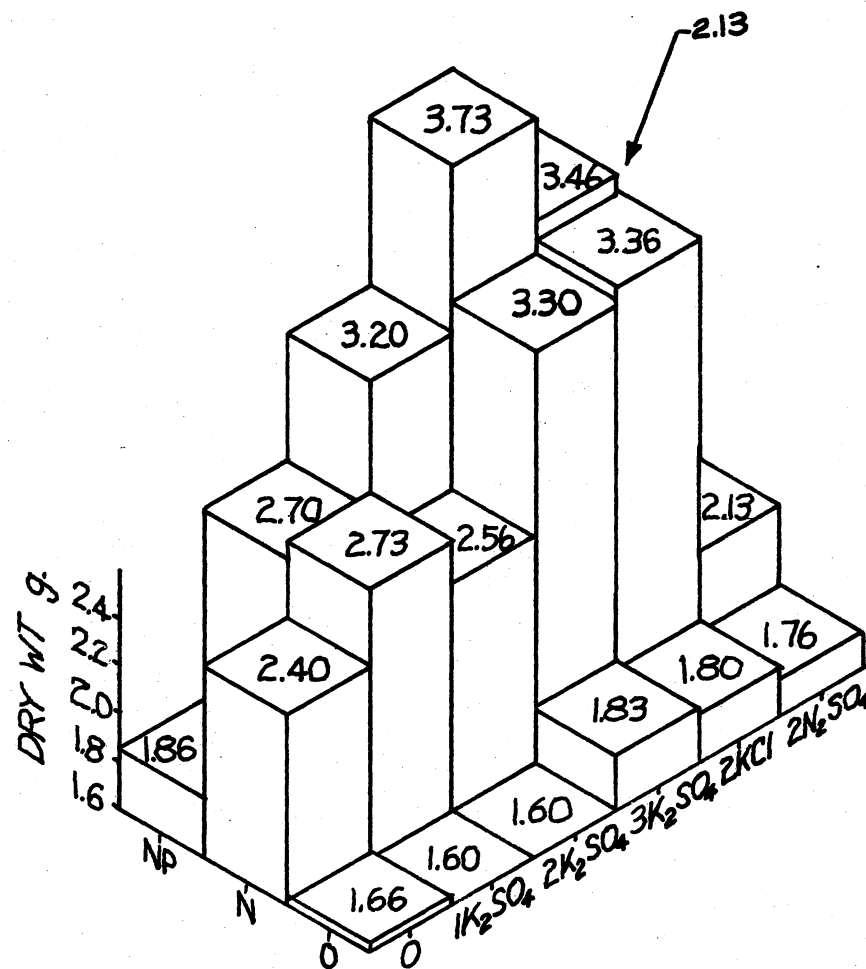
Second Set of Experiments

Due to the marked response to applications in the first set of experiments, a new group of treatments was set up to study the response of this latosol to increasing levels of potassium. Because the previous trials had utilized only K_2SO_4 as a carrier for K, treatments including KCl as K carrier were included at this time. To determine a possible plant nutrient response to sulphur as sulphate without K, a treatment using Na_2SO_4 was also included.

This set of experiments included five trials. Because of the high corn requirement for nitrogen and the possible loss by leaching of this nutrient, ammonium nitrate was applied to all pots in every trial, but in experiments 2 through 5 only the residual of the previous treatment for phosphorus, potassium, and sulphur were available for corn growth.

Results of this second set of trials are summarized in Figures 3 to 7 and Tables X to XIV. Part of the statistical computation appears in Appendix Tables XIX to XXXIII.

In the first experiment of this set (Figure 3, Table X), there were not responses to applications of potassium and sulphur, unless nitrogen or nitrogen and phosphorus were



LSD .01 = 0.61

LSD .05 = 0.46

Figure 3. Effect of Various Soil Fertility Treatments with Different Sulfate Sources on Growth of Corn Plants, Dark Red Latosol, Jaiba Minas Gerais, Brazil. Set 2, Experiment 1.

TABLE X

ORTHOGONAL EFFECTS OF VARIOUS SOIL FERTILITY TREATMENTS WITH
DIFFERENT POTASSIUM AND SULPHUR SOURCES ON GROWTH OF CORN
PLANTS, DARK RED LATOSOL, JAIBA, MINAS GERAIS
BRAZIL (SET 2, EXPERIMENT 1)

Treatment Symbol	Av. Yield Dry Wt. (g)	Treatment Symbol	Av. Yield Dry Wt. (g)
O	1.66	3 KS	1.83
N	2.40	3 KS + N	3.30
NP	1.86	3 KS + NP	3.73
1 KS	1.60	2 KCl	1.80
1 KS + N	2.73	2 KCl + N	3.36
1 KS + NP	2.70	2 KCl + NP	3.46
2 KS	1.60	2 NaS	1.76
2 KS + N	2.56	2 NaS + N	2.13
2 KS + NP	3.20	2 NaS + NP	2.13

	O	1 KS	2 KS	3 KS	2 KCl	2 NaS	\bar{X}
O	1.66	1.60	1.60	1.83	1.80	1.76	1.71
N	2.40	2.73	2.56	3.30	3.36	2.13	2.74
NP	1.86	2.70	3.20	3.73	3.46	2.13	2.84
\bar{X}	1.97	2.34	2.45	2.95	2.87	2.01	2.43

Average yields are means of three replicate cultures with 5

NK Hybrid 9514 corn per culture with 30 days growth.

KS refers to K_2SO_4 , and NaS to Na_2SO_4 .

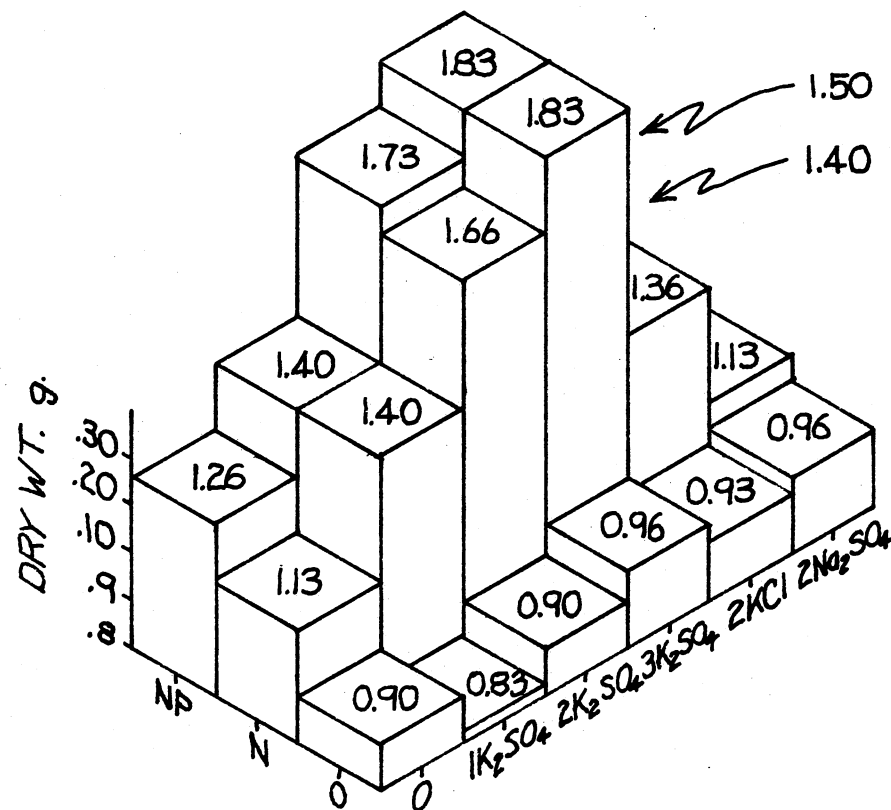
Treatment F = 20.23** C. V. = 11.38% LSD 0.01 = 0.61

LSD 0.05 = 0.46.

applied. When these nutrients were provided, there was a highly significant linear trend for K_2SO_4 levels. In all situations studied (group of treatments O, N, and NP), the comparable level of potassium as KCl yielded better production than when K_2SO_4 was used. Under these conditions the KCl treatments yielded production comparable to the 3 K_2SO_4 treatments. There was not a significant response to application of Na_2SO_4 alone (1.76 g), but when applied in the presence of either N or NP, yields were significantly better (2.13 g) than the check treatment (1.66 g).

The second experiment (Figure 4, Table XI) of this set was the first experiment studying the residual effects of phosphorus, potassium, and sulphur. Only nitrogen was applied to all pots. And here, as in the first experiment of this set, there were no responses to the residual effect of potassium without the previous N or NP treatments. This was also apparent with Na_2SO_4 residual effects except with the NP combination. However, KCl yielded lower residual responses than comparable K_2SO_4 treatments indicating an influence of the SO_4 component only when combined with K. The overall residual effects of KCl and Na_2SO_4 levels and the interaction $K_1 \times NP$ was found to be close to the 1% probability significance level.

In the third experiment of this set (Figure 5, Table XII), treatment F value was not statistically significant. However, when the degrees of freedom were split, it was found that the linear trend for the residual effects of



LSD .01 = 0.40

LSD .05 = 0.30

Figure 4. Residual Effect of Previous Soil Fertility Treatments on Growth of Corn Plants, Dark Red Latosol, Jaiba, Minas Gerais, Brazil. Set 2, Experiment 2.

TABLE XI

ORTHOGONAL RESIDUAL EFFECTS OF PREVIOUS SOIL FERTILITY
TREATMENTS ON GROWTH OF CORN PLANTS, DARK RED
LATOSOL, JAIBA, MINAS GERAIS, BRAZIL
(SET 2, EXPERIMENT 2)

Treatment Symbol	Av. Yield Dry Wt. (g)	Treatment Symbol	Av. Yield Dry Wt. (g)
O	0.90	3 KS	0.97
N	1.13	3 KS + N	1.83
NP	1.26	3 KS + NP	1.83
1 KS	0.83	2 KCl	0.93
1 KS + N	1.40	2 KCl + N	1.37
1 KS + NP	1.40	2 KCl + NP	1.50
2 KS	0.90	2 NaS	0.97
2 KS + N	1.67	2 NaS + N	1.13
2 KS + NP	1.73	2 NaS + NP	1.40

	O	1 KS	2 KS	3 KS	2 KCl	2 NaS	\bar{X}
O	0.90	0.83	0.90	0.96	0.93	0.96	0.91
N	1.13	1.40	1.66	1.83	1.36	1.13	1.42
NP	1.26	1.40	1.73	1.83	1.50	1.40	1.52
\bar{X}	1.09	1.21	1.43	1.54	1.26	1.16	1.28

Average yields are means of three replicate cultures with 5

NK Hybrid 9514 corn per culture with 20 days growth.

KS refers to K_2SO_4 , and NaS to Na_2SO_4 .

Treatment F = 10.19** C. V. = 14.13% LSD 0.01 = 0.40

LSD 0.05 = 0.30.

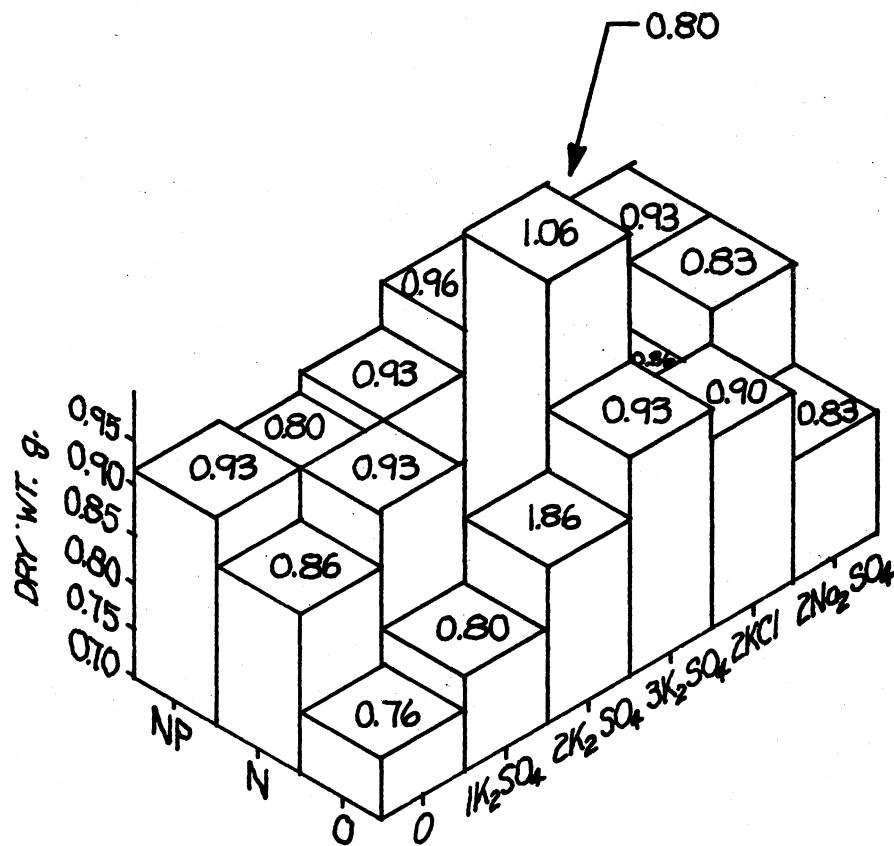


Figure 5. Residual Effect of Previous Soil Fertility Treatment on Growth of Corn Plants, Dark Red Latosol, Jaiba, Minas Gerais, Brazil. Set 2, Experiment 3.

TABLE XII

ORTHOGONAL RESIDUAL EFFECTS OF PREVIOUS SOIL FERTILITY
TREATMENTS ON GROWTH OF CORN PLANTS, DARK RED
LATOSOL, JAIBA, MINAS, GERAIS, BRAZIL
(SET 2, EXPERIMENT 3)

Treatment Symbol	Av. Yield Dry Wt. (g)	Treatment Symbol	Av. Yield Dry Wt. (g)
O	0.79	3 KS	0.90
N	0.89	3 KS + N	1.07
NP	0.92	3 KS + NP	0.97
1 KS	0.80	2 KCl	0.90
1 KS + N	0.94	2 KCl + N	0.89
1 KS + NP	0.91	2 KCl + NP	0.80
2 KS	0.85	2 NaS	0.83
2 KS + N	0.81	2 NaS + N	0.93
2 KS + NP	0.92	2 NaS + NP	0.94

	O	1 KS	2 KS	3 KS	2 KCl	2 NaS	\bar{X}
O	0.76	0.80	0.86	0.93	0.90	0.83	0.85
N	0.86	0.93	0.80	1.06	0.86	0.93	0.91
NP	0.93	0.90	0.93	0.96	0.80	0.93	0.91
\bar{X}	0.85	0.88	0.86	0.98	0.85	0.90	0.89

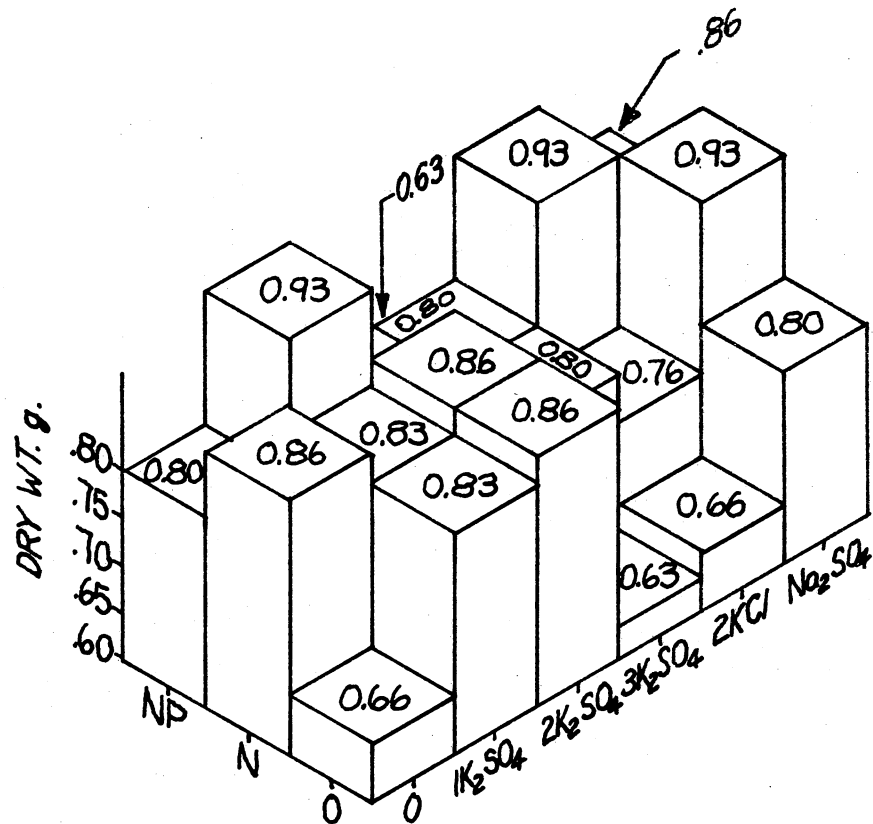
Average yields are means of three replicate cultures with 5
NK Hybrid 9514 corn per culture with 18 days growth.
KS refers to K_2SO_4 , and NaS to Na_2SO_4 .
Treatment F = n.s. C. V. = 14.36%.

K_2SO_4 levels was significant. There were no significant effects for the residuals of both KCl and Na_2SO_4 under the three conditions studied (O, N, and NP residual effects), and in this trial, the residual effects of KCl yielded comparable responses to the same level of residual K_2SO_4 .

The fourth experiment (Figure 6, Table XIII) showed an overall highly significant effect for Na_2SO_4 residual. However, the Na_2SO_4 residual under the NP residual combination (0.86 g) yielded a lower production than the N residual condition (0.93 g). Unlikely, there was not an overall significant effect for KCl residuals. Nevertheless, the residuals of KCl and NP altogether produced one of the highest yields of this trial. It was also found that a significant quadratic trend was apparent for K_2SO_4 residuals and for the interaction K_q with residuals of N or NP treatments.

The fifth and last experiment in this set (Figure 7, Table XIV) showed an overall highly significant residual effect for both KCl and Na_2SO_4 . However, the N and NP residual effects were not significant. Nevertheless, the interactions of N and NP residual with KCl residual were significant. There was also a highly significant linear trend for residual effects of K_2SO_4 and with this treatment the effect of residuals of N and NP were statistically significant.

Finally, in this set of experiments it is noteworthy that from trial 1 to 4, the maximum, average, and check pot yields decreased from trial to trial, as well as the number of days that each experiment lasted from germination to



LSD .01 = 0.17

LSD .05 = 0.13

Figure 6. Residual Effect of Previous Soil Fertility Treatments on Growth of Corn Plants, Dark Red Latosol, Jaiba, Minas Gerais, Brazil. Set 2, Experiment 4.

TABLE XIII

ORTHOGONAL RESIDUAL EFFECTS OF PREVIOUS SOIL FERTILITY
TREATMENTS ON GROWTH OF CORN PLANTS, DARK RED
LATOSOL, JAIBA, MINAS GERAIS, BRAZIL
(SET 2, EXPERIMENT 4)

Treatment Symbol	Av. Yield Dry Wt. (g)	Treatment Symbol	Av. Yield Dry Wt. (g)
O	0.67	3 KS	0.63
N	0.87	3 KS + N	0.80
NP	0.80	3 KS + NP	0.80
1 KS	0.83	2 KCl	0.67
1 KS + N	0.83	2 KCl + N	0.77
1 KS + NP	0.93	2 KCl + NP	0.95
2 KS	0.87	2 NaS	0.80
2 KS + N	0.87	2 NaS + N	0.93
2 KS + NP	0.63	2 NaS + NP	0.87

	O	1 KS	2 KS	3 KS	2 KCl	2 NaS	\bar{X}
O	0.66	0.83	0.86	0.63	0.66	0.80	0.74
N	0.86	0.83	0.86	0.80	0.76	0.93	0.84
NP	0.80	0.93	0.63	0.80	0.93	0.86	0.83
\bar{X}	0.77	0.85	0.78	0.74	0.78	0.86	0.80

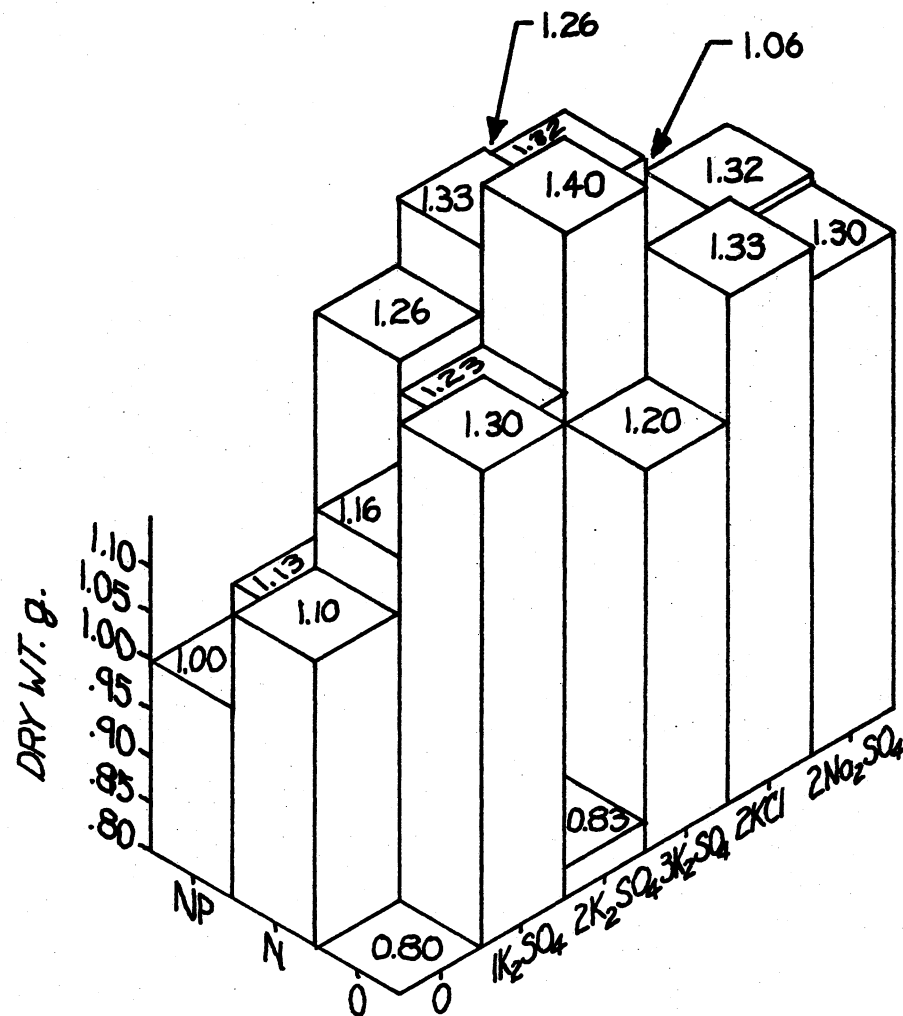
Average yields are means of three replicate cultures with 5

NK hybrid 9514 corn per culture with 16 days growth.

KS refers to K_2SO_4 , and NaS to Na_2SO_4 .

Treatment F = 4.71** C. V. = 9.75% LSD 0.01 = 0.17

LSD 0.05 = 0.13.



LSD .01 = 0.33

LSD .05 = 0.25

Figure 7. Residual Effect of Previous Soil Fertility Treatments on Growth of Corn Plants, Dark Red Latosol, Jaiba, Minas Gerais, Brazil. Set 2, Experiment 5.

TABLE XIV

ORTHOGONAL RESIDUAL EFFECTS OF PREVIOUS SOIL FERTILITY
TREATMENTS ON GROWTH OF CORN PLANTS, DARK RED
LATOSOL, JAIBA, MINAS GERAIS, BRAZIL
(SET 2, EXPERIMENT 5)

Treatment Symbol	Av. Yield Dry Wt. (g)	Treatment Symbol	Av. Yield Dry Wt. (g)
O	0.80	3 KS	1.20
N	1.10	3 KS + N	1.40
NP	1.00	3 KS + NP	1.33
1 KS	1.30	2 KCl	1.33
1 KS + N	1.16	2 KCl + N	1.06
1 KS + NP	1.13	2 KCl + NP	1.26
2 KS	0.83	2 NaS	1.30
2 KS + N	1.23	2 NaS + N	1.33
2 KS + NP	1.26	2 NaS + NP	1.33

	O	1 KS	2 KS	3 KS	2 KCl	2 NaS	\bar{X}
O	0.80	1.30	0.83	1.20	1.33	1.30	1.13
N	1.10	1.16	1.23	1.40	1.06	1.33	1.21
NP	1.00	1.13	1.26	1.33	1.26	1.33	1.22
\bar{X}	0.97	1.20	1.11	1.31	1.22	1.33	1.19

Average yields are means of 3 replicate cultures with 5 NK
Hybrid 9514 corn per culture with 27 days growth.

KS refers to K_2SO_4 , and NaS to Na_2SO_4 .

Treatment F = 3.93** C. V. = 12.67% LSD 0.01 = 0.33

LSD 0.05 = 0.25.

harvesting. The only exception to this was experiment 5. In this experiment, harvesting was performed when all plants showed very marked chlorotic symptoms. Experiments 1 to 4 were harvested when 50% of the plants were depicting deficiency symptoms.

The data from these experiments indicated that this soil had adequate available sulphur for corn vegetative growth when the first trial was initiated. Later on, the residual effect of K_2SO_4 was considerably better than that of KCl. Na_2SO_4 alone did not markedly influence yields in the first two experiments.

The last three experiments showed that the initial sulphur was rapidly depleted, and in these trials, the application of Na_2SO_4 induced increased corn growth.

The high requirement for potassium applications was shown by the linear trend of K_2SO_4 in four experiments. In only one instance, experiment 4, the quadratic trend for K_2SO_4 was significant.

It was also apparent that the behavior of K_2SO_4 , KCl, and Na_2SO_4 are dependent upon the actual level of nitrogen and phosphorus, single or in combination, in this soil.

Third Set of Experiments

The objective of this third set of experiments was to determine the response of this Brazilian dark red latosol to addition of single sources of nitrogen, phosphorus, potassium, and sulphur. Soil not previously cropped was diluted

with coarse washed quartz sand (50 g of soil and 450 g of sand). Data for this set of trials are shown in Figures 8 and 9 and Tables XV and XVI. The statistical work for both trials can be found in the Appendix, Tables XXXIV and XXXV.

In the first experiment of this set (Figure 8, Table XV) there was a significant response to applications of both NH_4NO_3 (1.16 g) and KCl (1.16 g) when compared with all other treatments. The check treatment and K_2SO_4 had the same yields (0.93 g), and the application of $\text{CaH}_4(\text{PO}_4)_2 \cdot \text{H}_2\text{O}$ (0.76 g), $\text{CaH}_4(\text{PO}_4)_2 \cdot \text{H}_2\text{O}$ plus CaSO_4 (0.86 g), NaSO_4 (0.86 g), and sulphur "flower" (0.83 g) yielded lower production than the check treatment (0.93 g), although the values were not statistically significant.

In the second experiment (Figure 9, Table XVI), no additional nutrient source was applied, and only the residual nutrients from the previous trial were available for plant growth. The residual effects of both KCl (1.73 g) and K_2SO_4 (1.70 g) were significantly better than the residual from the check treatment (1.53 g). Although the residuals of $\text{CaH}_4(\text{PO}_4)_2 \cdot \text{H}_2\text{O}$ (1.66 g) and Na_2SO_4 (1.60 g) yielded better production than the residual from the check treatment, the differences were not considered significant. The check pots and residual of the $\text{CaH}_4(\text{PO}_4)_2 \cdot \text{H}_2\text{O}$ plus CaSO_4 treatment had the same yield (1.53 g). However, the residual for NH_4NO_3 (1.33 g) yielded a significantly lower production than the residual for the check treatment (1.53 g).

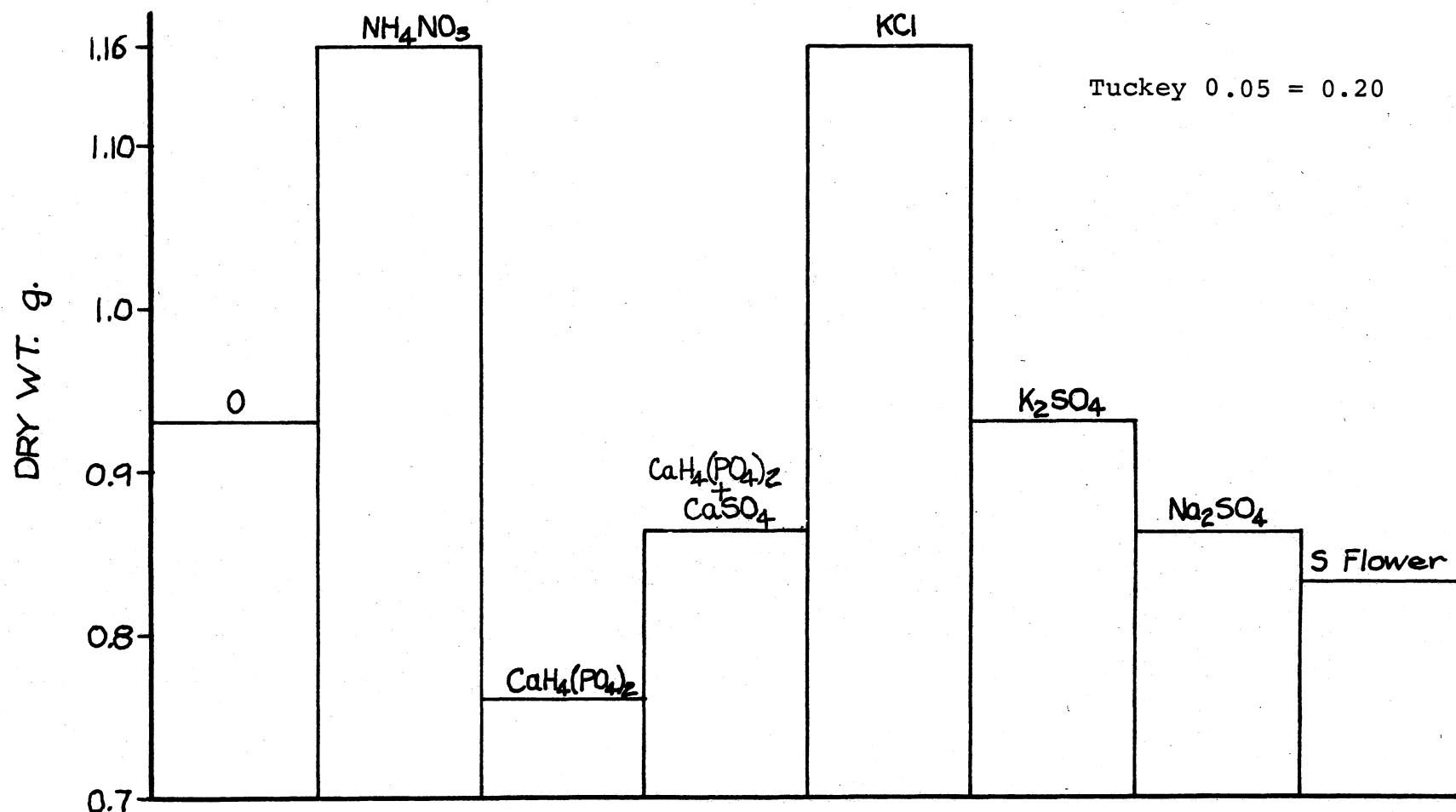


Figure 8. Effect of Various Fertility Treatments with Different Phosphorus, Sulphur, and Potassium Sources of Growth of Corn Plants, Dark Red Latosol, Jaiba, Minas Gerais, Brazil. Set 3, Experiment 1.

TABLE XV

EFFECTS OF VARIOUS SOIL FERTILITY TREATMENTS WITH DIFFERENT
PHOSPHORUS, SULPHUR, AND POTASSIUM SOURCES ON GROWTH OF
CORN PLANTS, DARK RED LATOSOL, JAIBA, MINAS GERAIS,
BRAZIL (SET 3, EXPERIMENT 1)

Treatment Symbol	Av. Yield Dry Wt. (g)
O	0.93 b
N	1.16 a
P	0.76 b
P + CaS	0.86 b
KCl	1.16 a
KS	0.93 b
NaS	0.86 b
S Flower	0.83 b

Average yields are means of three replicate cultures with 5 plants of NK Hybrid 9514 corn per culture with 16 days growth.

Figures followed by the same letter are not statistically different at 5% probability level.

Treatment F = 4.89** C. V. = 12.37% Tuckey 0.05 = 0.20.

N refers to NH_4NO_3 , P to $\text{CaH}_4(\text{PO}_4)_2 \cdot \text{H}_2\text{O}$, KS to K_2SO_4 , NaS to Na_2SO_4 , CaS to CaSO_4 .

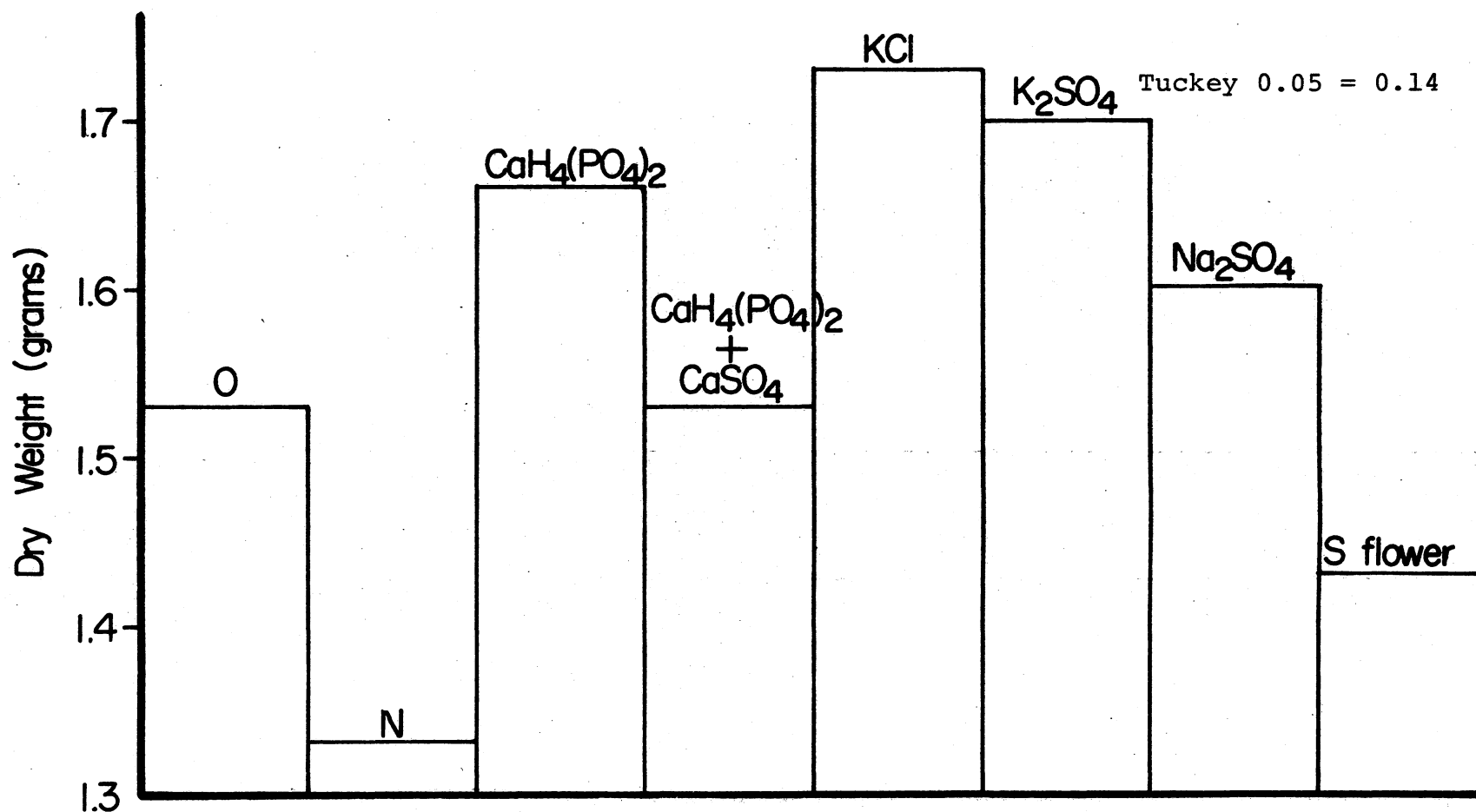


Figure 9. Residual Effect of Previous Soil Fertility Treatments with Different Phosphorus, Sulphur, and Potassium Sources on Growth of Corn Plants, Dark Red Latosol, Jaiba, Minas Gerais, Brazil. Set 3, Experiment 2.

TABLE XVI

RESIDUAL EFFECTS OF PREVIOUS SOIL FERTILITY TREATMENTS
WITH DIFFERENT PHOSPHORUS, SULPHUR, AND POTASSIUM
SOURCES ON GROWTH OF CORN PLANTS, DARK RED
LATOSOL, JAIBA, MINAS GERAIS,
BRAZIL (SET 3, EXPERIMENT 2)

Treatment Symbol	Av. Yield Dry Wt. (g)
O	1.53 b
N	1.33 d
P	1.66 ab
P + CaS	1.53 bc
KCl	1.73 a
KS	1.70 a
NaS	1.60 ab
S Flower	1.43 cd

Average yields are means of three replicate cultures with 5 plants of NK 9514 Hybrid corn per culture with 29 days. Figures followed by the same letter are not statistically different at 5% probability level.

Treatment F = 7.93** C. V. = 5.57%. Tuckey 0.05 = 0.14.

N refers to NH_4NO_3 , P to $\text{CaH}_4(\text{PO}_4)_2 \cdot \text{H}_2\text{O}$, KS to K_2SO_4 , NaS to Na_2SO_4 , and CaS to CaSO_4 .

In both experiments the effect of only elemental sulphur yielded less than the check treatment; that may have been an effect of the acidifying properties of this nutrient source.

In the first experiment the presence of gypsum enhanced the effect of phosphorus and, contrariwise, the presence of this compound depressed the residual effect of phosphorus. However, in both cases the differences were not statistically significant.

Potassium chloride (1.16 g) was significantly better than K_2SO_4 (0.93 g) in the first trial. The residual effects of these treatments, however, were not statistically different.

In every case, K_2SO_4 was apparently a better sulphate source than either Na_2SO_4 , elemental sulphur, or $CaH_4(PO_4)_2 \cdot H_2O$ plus $CaSO_4$.

As reviewed in the literature, the response of tropical soils to improved fertility is quite variable (19). Many authors have found response to several fertilizer nutrient applications, while others did not report the same findings (55).

Field experimentation in Brazil has demonstrated that for most soils, phosphorus is the first limiting factor (12), while fewer trials have shown a very marked response to potassium fertilization. Nitrogen seems to be almost always required for higher yields (51), especially when phosphorus and potassium levels are adequate. Many authors have reported nitrogen application responses even to legume crops

(24). On the other hand, lack of nitrogen response, where it occurs, appears to be due to the liming effect upon organic matter mineralization or to symbiotic fixation of nitrogen by Spirillum sp. with non-legume crops such as corn and wheat (12).

Sulphur deficiency is reported to a much lesser degree, and probably this occurs because generally farmers in Brazil, when applying NPK fertilizer, make use of a sulphur carrier, mainly superphosphate (19).

It is also noteworthy that the need for fertilization varies from crop to crop and even between varieties of the same crop, as found in many investigations (10).

According to the findings in this study, there appears to exist in this dark red latosol from Jaiba an optimum NPKS balance necessary for high levels of crop production. There is a marked effect for nitrogen and potassium applications as well as for phosphorus, when the level of these two nutrients are in favorable ratio. Indigenous soil sulphur availability appears to be sufficient only for an initial cropping, and addition of this nutrient seems to be required for continuous cultivation.

Single nutrient application, although with statistically significant results for NH_4NO_3 and KCl and for residuals of both KCl and K_2SO_4 , did not cause yield increases as large as when NPKS were properly combined.

Although it is acknowledged that greenhouse experimental results often cannot be duplicated under field conditions,

results reported from these studies are close indicators to field responses of this soil, especially with irrigation, as the pot cultures during these experiments were maintained near field capacity.

CHAPTER V

SUMMARY AND CONCLUSIONS

Nine greenhouse experiments were conducted with a dark red latosol (typic Eutrostox) collected at the Jaiba Agro-industrial District in Minas Gerais State, Brazil, with the objective of studying the complex fertility responses of this soil. Growth response to differential plant nutrient levels and combinations applied to the 0-20 cm depth soil epipedon was determined by measuring dry weight of the "above ground" or plant top growth for corn hybrid NK 9514 (Zea mays L.) utilizing five plants per pot culture with three replicate cultures per treatment.

In the first set of experiments, composed of two trials, a 3 x 3 x 2 NPK factorial design was utilized. NH_4NO_3 was the nitrogen source with 0, 100, and 200 ppm levels. $\text{CaH}_4(\text{PO}_4)_2 \cdot \text{H}_2\text{O}$ was the source of phosphorus with 0, 50, and 100 ppm levels, and as potassium source, K_2SO_4 , at 0 and 200 ppm levels, was added to the soil.

In this experiment, the highest yield was achieved by the treatment N2P1K. Statistical computation of these data indicated linear response to additions of both nitrogen and phosphorus, as well as a significant response to potassium.

The interactions N_1P_q and N_qP_1 were significant, and the effect N_qK had an observed significant level of 5.3%.

Doubled nutrient levels were used in the second trial of this set of experiments, and likewise, as in the first experiment, the N_2P_1K treatment showed the highest yield. The statistical analysis of these data revealed a quadratic effect for levels of both nitrogen and phosphorus and a highly significant effect for potassium application.

Thoroughly mixing the soil from the first set of experiments, a new group of treatments was established, and five new trials were carried out. The objective of this second set of experiments was to study the response of this soil to increasing levels and sources of potassium and to determine a possible plant nutrient response to sulphur as sulphate without K. In this set of experiments three levels of K_2SO_4 , one of KCl, one of Na_2SO_4 were used along with the check treatment, under three different regimes, i.e., application of no other nutrient, application of nitrogen, and finally, application of nitrogen and phosphorus combination.

These nutrient treatments were applied to the soil only for the first trial. In experiments 2 to 5, only the residual effect of previous treatments was available for corn plant growth, except for applications of 400 ppm of nitrogen to all pots.

The first experiment of this set showed that there was no response to applications of potassium and sulphur unless nitrogen or nitrogen and phosphorus were applied. When this

condition was satisfied, the statistical analysis showed a linear trend for K_2SO_4 levels. Under the same level of application, KCl yielded significantly more dry matter than K_2SO_4 .

The second experiment in this set depicted the same trend for K_2SO_4 levels as in the first experiment, but this time the comparable level of K_2SO_4 yielded significantly better than KCl.

In the third experiment the overall treatment F value was not significant. However, when the degrees of freedom were split, the linear trend for K_2SO_4 was found to be significant. There were not significant effects for residuals of both KCl and Na_2SO_4 , and the residual of K_2SO_4 yielded comparable production to the same level of KCl.

The fourth experiment showed a highly significant effect for Na_2SO_4 , while there was no effect for KCl residuals. The analysis of degrees of freedom for K_2SO_4 showed a quadratic trend for levels of this fertilizer nutrient.

Finally, in the last experiment of this set, there was a highly significant effect for residuals of both KCl and Na_2SO_4 as well as a linear trend for K_2SO_4 residual levels.

A last group of experiments with two trials was carried out with fresh new soil. The main purpose of this series of experiments was to study the response of this soil to additions of single sources of nitrogen, phosphorus, potassium, and sulphur. A randomized, block design with three replications was used with eight treatments: check, NH_4NO_3 ,

$\text{CaH}_4(\text{PO}_4)_2 \cdot \text{H}_2\text{O}$, $\text{CaH}_4(\text{PO}_4)_2 \cdot \text{H}_2\text{O}$ plus CaSO_4 , KCl , K_2SO_4 , Na_2SO_4 and elemental sulphur. Nutrients were applied only in the first experiment and for the second one, only the residual of previous treatment was available for plant growth. There was a significant effect for application of both NH_4NO_3 and KCl and for residuals of KCl and K_2SO_4 . There were no significant benefits from applications or residuals of $\text{CaH}_4(\text{PO}_4)_2 \cdot \text{H}_2\text{O}$; $\text{CaH}_4(\text{PO}_4)_2 \cdot \text{H}_2\text{O}$ plus CaSO_4 ; Na_2SO_4 , and elemental sulphur.

Overall, the findings of this study can be summarized as follows:

1. There was an optimum fertility balance for corn plant growth in this dark red latosol. This balance seemed to be induced by the N2P1K ratio used in the first set of experiments.
2. The response to levels of one nutrient was dependent upon the level of other nutrients.
3. Quadratic responses to N, P, and K were achieved only with addition of high levels of these nutrients.
4. Initially, this soil was well supplied with available sulphur and the effect of KCl was superior to K_2SO_4 .
5. K_2SO_4 was a better source of sulphate than Na_2SO_4 due to the potassium requirement of this soil for high yields. Nevertheless, application of Na_2SO_4 caused significant yield increases after intensive cropping.
6. Although elemental sulphur was not tested under

intensive cropping, this sulphur carrier did not have a beneficial effect upon yield.

7. Although the application of NH_4NO_3 and KCl gave significant yield increases, application of a single source of nutrient was not adequate for high yield increases.

8. Although highly responsive to phosphorus application under proper conditions, this element did not appear to be the first limiting factor in this soil. Single application of $\text{CaH}_4(\text{PO}_4)_2 \cdot \text{H}_2\text{O}$ depressed yield, and its residual effect was only somewhat better than the check treatment. However, none of the differences was statistically significant.

9. CaSO_4 had no significant effect upon the response to $\text{CaH}_4(\text{PO}_4)_2 \cdot \text{H}_2\text{O}$ application or its residual effect.

10. The non-significant overall F value for the experiment 3 of the second set indicates that, with the third cropping, the applied plant nutrient had been depleted. Figure 5 shows that the influence of treatments resulted in less differences in growth as compared to the check yields. The coefficient of variance for this trial was 14.36%.

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APPENDIXES

TABLE XVII
ANALYSIS OF VARIANCE FOR VARIABLE SHOOT WT. (SET 1, EXPERIMENT 1)

		C. V.	Shoot Wt. Mean		
		16.03454%	1.82963		
Source	DF	Sum of Squares	Mean Square	F Value	Prob. > F
Regression	19	6.58629630	0.34664717	4.02762	0.0003
Error	34	2.92629630	0.08606754	R-Square	Std. Dev.
Corrected Total	53	2.51259259		0.69237658	0.29337269

Source	DF	Sequential SS	F Value	Prob. > F
Rep	2	0.04703704	0.27	0.7660
N1	1	3.18027778	36.95	0.0001
N2	1	0.02675926	0.31	0.5809
P1	1	0.61361111	7.12	0.0115
P2	1	0.00009259	0.00	0.9740
K	1	0.75851852	8.81	0.0055
NP11	1	0.00375000	0.04	0.8359
NP12	1	0.86680556	10.07	0.0032
NP21	1	0.00013889	0.00	0.9682
NP22	1	0.16115741	1.87	0.1802
NK1	1	0.04694444	0.54	0.4653
NK2	1	0.34453704	4.00	0.0535
PK1	1	0.00694444	0.08	0.7781
PK2	1	0.17120370	1.98	0.1675
NPK11	1	0.26041667	3.02	0.0910
NPK12	1	0.07347222	0.85	0.3620
NPK21	1	0.01680556	0.19	0.6614
NPK22	1	0.00782407	0.09	0.7649

1 = linear trend, and 2 = quadratic trend.

TABLE XVIII
ANALYSIS OF VARIANCE FOR VARIABLE SHOOT WT. (SET 1, EXPERIMENT 2)

			C. V.	Shoot Wt. Mean	
			14.09199%	2.53889	
Source	DF	Sum of Squares	Mean Square	F Value	Prob. > F
Regression	19	122.37611111	6.44084795	50.31656	0.0001
Error	34	4.35222222	0.12800654	R-Square	Std. Dev.
Corrected Total	53	126.72833333		0.96565707	0.35778001

Source	DF	Sequential SS	F Value	Prob. > F
Rep	2	0.68777778	2.68	0.0809
N1	1	42.25000000	330.06	0.0001
N2	1	8.00333333	62.62	0.0001
P1	1	1.28444444	10.03	0.0032
P2	1	1.20333333	9.40	0.0042
K	1	48.35574074	377.75	0.0001
NP11	1	0.32666667	2.55	0.1194
NP12	1	0.12500000	0.97	0.3300
NP21	1	0.10888889	0.85	0.3629
NP22	1	0.20166667	1.57	0.2180
NK1	1	16.53777778	129.19	0.0001
NK2	1	1.51703704	11.85	0.0016
PK1	1	0.69444444	5.42	0.0259
PK2	1	0.17925926	1.40	0.2449
NPK11	1	0.32666667	2.55	0.1194
NPK12	1	0.34722222	2.71	0.1088
NPK21	1	0.22222222	1.73	0.1965
NPK22	1	0.00462963	0.03	0.8503

1 = linear trend, and 2 = quadratic trend.

TABLE XIX
ANALYSIS OF VARIANCE FOR VARIABLE SHOOT WT. Na_2SO_4
(SET 2, EXPERIMENT 1)

		Mean 1.99444444	C. V. 9.00027544%		
Source	DF	Sum of Squares	Mean Square	F Value	Prob > F
Rep	2	0.03111111	0.015555556		
NP	2	0.90777778	0.453888889	14.08	0.0016
NS	1	0.00500000	0.005000000	0.15	0.7025
NP*NS	2	0.22333333	0.111666667	3.46	0.0710
Residual	10	0.32222222	0.032222222		
Corrected Total	17	1.48944444	0.087614379		

NP refers to N and P combinations, and NS to Na_2SO_4 .

TABLE XX
ANALYSIS OF VARIANCE FOR VARIABLE SHOOT WT. Na_2SO_4
(SET 2, EXPERIMENT 2)

		Mean 1.13333333	C. V. 15.8660046%		
Source	DF	Sum of Squares	Mean Square	F Value	Prob. > F
Rep	2	0.063333333	0.031666667		
NP	2	0.480000000	0.240000000	7.42	0.0107
NS	1	0.020000000	0.020000000	0.61	0.5449
NP*NS	2	0.013333333	0.006666667	0.20	0.8181
Residual	10	0.323333333	0.032333333		
Corrected Total	17	0.900000000	0.052941176		

NP refers to N and P combinations, and NS to Na_2SO_4 .

TABLE XXI
ANALYSIS OF VARIANCE FOR VARIABLE SHOOT WT. Na₂SO₄
(SET 2, EXPERIMENT 3)

		Mean	0.877777778	C. V.	14.3602560%
Source	DF	Sum of Squares	Mean Square	F Value	Prob. > F
Rep	2	0.001111111	0.000555556		
NP	2	0.057777778	0.028888889	1.81	0.2114
NS	1	0.008888889	0.008888889	0.55	0.5226
NP*NS	2	0.004444444	0.002222222	0.13	0.8709
Residual	10	0.158888889	0.015888889		
Corrected Total	17	0.231111111	0.0135947712		

NP refers to N and P combinations, and NS to Na₂SO₄.

TABLE XXII
ANALYSIS OF VARIANCE FOR VARIABLE SHOOT WT. Na₂SO₄
(SET 2, EXPERIMENT 4)

	Mean	0.822222222	C. V.	6.53696574%		
Source	DF	Sum of Squares	Mean Square			
Rep	2	0.017777778	0.008888889	F Value		Prob. > F
NP	2	0.084444444	0.042222222	14.61		0.0014
NS	1	0.035555556	0.035555556	12.30		0.0058
NP*NS	2	0.004444444	0.002222222	0.76		0.5077
Residual	10	0.028888889	0.002888889			
Corrected Total	17	0.171111111	0.0100653595			

NP refers to N and P combinations, and NS to Na₂SO₄.

TABLE XXIII
ANALYSIS OF VARIANCE FOR VARIABLE SHOOT WT. Na_2SO_4
(SET 2, EXPERIMENT 5)

		Mean	1.144444444	C. V.	12.1145443%	
Source	DF	Sum of Squares	Mean Square			
Rep	2	0.041111111	0.020555556	F Value		Prob. > F
NP	2	0.087777778	0.043888889	2.28		0.1516
NS	1	0.568888889	0.568888889	29.59		0.0005
NP*NS	2	0.054444444	0.027222222	1.41		0.2873
Residual	10	0.192222222	0.019222222			
Corrected Total	17	0.944444444	0.055555556			

NP refers to N and P combinations, and NS to Na_2SO_4 .

TABLE XXIV
ANALYSIS OF VARIANCE FOR VARIABLE SHOOT WT. K_2SO_4
(SET 2, EXPERIMENT 1)

		C. V.	Shoot Wt. Mean		
		11.5519	2.43333333		
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	13	18.62166667	1.43243590	18.13	0.0001
Error	22	1.73833333	0.07901515	R-Square	Std. Dev.
Corrected Total	35	20.36000000		0.914620	0.28109634
Source	DF	Type I SS	F Value	Pr > F	
Rep	2	1.02166667	6.47	0.0062	
NP	2	10.44500000	66.09	0.0001	
K1	1	4.17088889	52.79	0.0001	
K2	1	0.04000000	0.51	0.4843	
K3	1	0.18688889	2.37	0.1383	
K1*NP	2	2.41077778	15.26	0.0001	
K2*NP	2	0.21500000	1.36	0.2773	
K3*NP	2	0.13144444	0.83	0.4485	

1 = linear trend; 2 = quadratic trend; 3 = cubic trend.
K = K_2SO_4 ; NP = N and P combinations.

TABLE XXV

ANALYSIS OF VARIANCE FOR VARIABLE SHOOT WT. K_2SO_4
(SET 2, EXPERIMENT 2)

		C. V.	Shoot Wt. Mean		
		14.1593	1.32222222		
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	13	4.83111111	0.37162393	10.60	0.0001
Error	22	0.77111111	0.03505051	R-Square	Std. Dev.
Corrected Total	35	5.60222222		0.862356	0.18721780
Source	DF	Type I SS	F Value	Pr > F	
Rep	2	0.08222222	1.17	0.3281	
NP	2	3.22388889	45.99	0.0001	
K1	1	1.08888889	31.07	0.0001	
K2	1	0.00000000	0.00	1.0000	
K3	1	0.02222222	0.63	0.4344	
K1*NP	2	0.38211111	5.45	0.0119	
K2*NP	2	0.02166667	0.31	0.7373	
K3*NP	2	0.01011111	0.14	0.8665	

1 = linear trend; 2 = quadratic trend; 3 = cubic trend.
K refers to K_2SO_4 ; NP = N and P combinations.

TABLE XXVI
ANALYSIS OF VARIANCE FOR VARIABLE SHOOT WT. K_2SO_4
(SET 2, EXPERIMENT 3)

		C. V.	Shoot Wt. Mean		
		10.3880	0.89722222		
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	13	0.23861111	0.01835470	2.11	0.0589
Error	22	0.19111111	0.00868687	R-Square	Std. Dev.
Corrected Total	35	0.42972222		0.555268	0.09320337
Source	DF	Type I SS	F Value	Pr > F	
Rep	2	0.00888889	0.51	0.6065	
NP	2	0.05722222	3.29	0.0561	
K1	1	0.06805556	7.83	0.0105	
K2	1	0.02250000	2.59	0.1218	
K3	1	0.01250000	1.44	0.2431	
K1*NP	2	0.01544444	0.89	0.4253	
K2*NP	2	0.01166667	0.67	0.5211	
K3*NP	2	0.04233333	2.44	0.1107	

1 = linear trend; 2 = quadratic trend; 3 = cubic trend.
K = K_2SO_4 ; NP = N and P combinations.

TABLE XXVII
ANALYSIS OF VARIANCE FOR VARIABLE SHOOT WT. K_2SO_4
(SET 2, EXPERIMENT 4)

		C. V.	Shoot Wt. Mean		
		10.7159	0.79444444		
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	13	0.31944444	0.02457265	3.39	0.0057
Error	22	0.15944444	0.00724747	R-Square	Std. Dev.
Corrected Total	35	0.47888889		0.667053	0.08513210
Source	DF	Type I SS	F Value	Pr > F	
Rep	2	0.00055556	0.04	0.9625	
NP	2	0.05055556	3.49	0.0483	
K1	1	0.01422222	1.96	0.1752	
K2	1	0.04000000	5.52	0.0282	
K3	1	0.01800000	2.48	0.1293	
K1*NP	2	0.00411111	0.28	0.7558	
K2*NP	2	0.08166667	5.63	0.0106	
K3*NP	2	0.11033333	7.61	0.0031	

1 = linear trend; 2 = quadratic trend; 3 = cubic trend.
K = K_2SO_4 ; NP = N and P combinations.

TABLE XXVIII

ANALYSIS OF VARIANCE FOR VARIABLE SHOOT WT. K_2SO_4
(SET 2, EXPERIMENT 5)

		C. V.	Shoot Wt. Mean		
		14.0443	1.14722222		
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	13	1.17861111	0.09066239	3.49	0.0048
Error	22	0.57111111	0.0259560	R-Square	Std. Dev.
Corrected Total	35	1.74972222		0.673599	0.16111982
Source	DF	Type I SS	F Value	Pr > F	
Rep	2	0.00888889	0.17	0.8438	
NP	2	0.24388889	4.70	0.0200	
K1	1	0.40138889	15.46	0.0007	
K2	1	0.00250000	0.10	0.7592	
K3	1	0.16805556	6.47	0.0185	
K1*NP	2	0.01211111	0.23	0.7939	
K2*NP	2	0.02166667	0.42	0.6639	
K3*NP	2	0.32011111	6.17	0.0075	

1 = linear trend; 2 = quadratic trend; 3 = cubic trend.
K = K_2SO_4 ; NP = N and P combinations.

TABLE XXIX
ANALYSIS OF VARIANCE FOR VARIABLE SHOOT WT. KCl
(SET 2, EXPERIMENT 1)

	Mean	1.000000000	C. V.	13.7840488%		
Source	DF	Sum of Squares	Mean Square	F Value	Prob. > F	
Rep	2	0.023333333	0.011666667			
NP	2	0.130000000	0.065000000	3.42	0.0729	
KC	1	0.222222222	0.222222222	11.69	0.0066	
NP*KC	2	0.034444444	0.017222222	0.90	0.5626	
Residual	10	0.190000000	0.019000000			
Corrected Total	17	0.600000000	0.035294118			

NP refers to N and P combinations, and KC to KCl.

TABLE XXX

ANALYSIS OF VARIANCE FOR VARIABLE SHOOT WT. KCl
(SET 2, EXPERIMENT 2)

		Mean 1.18333333	C. V. 15.4288044%		
Source	DF	Sum of Squares	Mean Square	F Value	Prob. > F
Rep	2	0.09333333	0.046666667		
NP	2	0.69333333	0.346666667	10.40	0.0040
KC	1	0.12500000	0.125000000	3.75	0.0791
NP*KC	2	0.04000000	0.020000000	0.60	0.5713
Residual	10	0.33333333	0.033333333		
Corrected Total	17	1.28500000	0.075588235		

NP refers to N and P combinations, and KC to KCl.

TABLE XXXI
ANALYSIS OF VARIANCE FOR VARIABLE SHOOT WT. KCl
(SET 2, EXPERIMENT 3)

		Mean	0.855555556	C. V.	13.7748074%		
Source	DF	Sum of Squares	Mean Square	F Value	Prob. > F		
Rep	2	0.007777778	0.003888889				
NP	2	0.004444444	0.002222222	0.16	0.8543		
KC	1	0.000000000	0.000000000	1.92	0.1962		
NP*KC	2	0.053333333	0.026666667	0.00	1.0000		
Residual	10	0.138888889	0.013888889				
Corrected Total	17	0.204444444	0.0120271438				

NP refers to N and P combinations, and KC to KCl.

TABLE XXXII

ANALYSIS OF VARIANCE FOR VARIABLE SHOOT WT. KC1
(SET 2, EXPERIMENT 4)

		Mean	0.783333333	C. V.	6.99220286%		
Source	DF	Sum of Squares	Mean Square	F Value	Prob. > F		
Rep	2	0.003333333	0.001666667				
NP	2	0.130000000	0.065000000	21.66	0.0004		
KC	1	0.000555556	0.000555556	0.18	0.6781		
NP*KC	2	0.041111111	0.020555556	6.85	0.0134		
Residual	10	0.030000000	0.003000000				
Corrected Total	17	0.205000000	0.0120588235				

NP refers to N and P combinations, and KC to KC1.

TABLE XXXIII
ANALYSIS OF VARIANCE FOR VARIABLE SHOOT WT. KCl
(SET 2, EXPERIMENT 5)

		Mean	1.09444444	C. V.	15.2588529%
Source	DF	Sum of Squares	Mean Square	F Value	Prob. > F
Rep	2	0.001111111	0.000555556		
NP	2	0.014444444	0.007222222	0.25	0.7791
KC	1	0.293888889	0.293888889	10.53	0.0087
NP*KC	2	0.241111111	0.120555556	4.32	0.0437
Residual	10	0.278888889	0.027888889		
Corrected Total	17	0.829444444	0.048790859		

NP refers to N and P combinations, and KC to KCl.

TABLE XXXIV

ANALYSIS OF VARIANCE FOR VARIABLE SHOOT WT. SINGLE NUTRIENT SOURCES
(SET 3, EXPERIMENT 1)

	Mean	0.941666667	C. V.	12.37%		
Source	DF	Sum of Squares	Mean Square			
Rep	2	0.003333333	0.001666667	F Value		Prob. > F
Trt	7	0.465000000	0.0664285714	4.89		0.0059
Rep*Trt	14	0.190000000	0.0135714286			
Error	14	0.190000000	0.0135714286	LSD .01		0.283154547
Corrected Total	23	0.658333333	0.02862318	LSD .05		0.204009116

TABLE XXXV
ANALYSIS OF VARIANCE FOR VARIABLE SHOOT WT. SINGLE NUTRIENT SOURCES
(SET 3, EXPERIMENT 2)

Mean 1.56666667					
Source	DF	Sum of Squares	Mean Square	C. V. = 5.37%	
Rep	2	0.040833333	0.0204166667	F Value	Prob. > F
Trt	7	0.393333333	0.0561904762	7.93	0.0008
Rep*Trt	14	0.099166667	0.0070833333		
Error	14	0.099166667	0.0070833333	LSD .01	0.204564095
Corrected Total	23	0.533333333	0.0231884058	LSD .05	0.147385716

TABLE XXXVI

DAILY TEMPERATURES DURING THE EXPERIMENTAL PERIODS (°C)

Days	1976																1977							
	Sept.		Oct.		Nov.		Dec.		Jan.		Feb.		Mar.		Apr.		May							
	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
1					31.1	23.3			24.4	22.2	30.0	21.1	26.7	21.1	35.6	21.3	32.2	21.1						
2					33.3	24.4			25.6	22.2	28.9	22.2	23.3	20.0	36.1	20.0	36.7	22.2						
3					28.9	22.2					31.1	22.2	27.8	21.1	36.7	18.3	38.9	22.2						
4	42.2	24.4			31.1	23.3	31.1	23.3			32.2	22.2	26.7	16.7	34.4	15.6	36.7	21.1						
5	46.6	24.4			35.6	24.4	32.2	21.1			32.2	21.1	30.0	18.9	31.1	14.4	37.8	23.3						
6	40.0	22.2			36.7	23.3	25.0	17.8			33.3	21.1	31.1	18.9	36.7	18.9	36.7	21.1						
7	38.8	22.2					28.9	16.7			30.0	20.0	36.7	21.1	40.0	21.1	38.9	31.1						
8	40.0	22.2					27.8	20.0			33.3	22.2	36.7	22.2	41.1	21.1	40.0	22.2						
9	31.1	16.7					27.8	25.4			33.3	28.9	33.3	21.1	36.7	17.8	38.9	21.1						
10	32.2	22.2					27.8	18.9					27.8	21.1	35.6	21.1	35.6	21.1						
11	38.8	21.1					27.8	21.1					26.7	21.1	32.2	21.1	35.6	21.1						
12	37.7	22.2					27.8	22.2							33.3	21.1	38.9	22.2						
13	35.5	22.2	35.5	22.2			32.2	23.3									38.9	22.2						
14	40.0	22.2	35.5	21.1			34.4	22.2									38.9	22.2						
15	41.1	23.3	37.7	22.2			32.2	21.1									40.0	22.2						
16	43.3	23.3	34.4	22.2			32.2	22.3									40.0	20.0						
17	37.7	22.2	24.4	16.6			37.8	24.4																
18	37.7	22.2	24.4	16.7			34.4	23.3									32.2	21.1						
19	40.0	21.1	25.6	16.7			31.7	22.2									35.5	20.0						
20	41.1	22.2	28.9	18.9			26.1	22.2									32.2	17.7						
21	40.0	22.2	36.7	22.2			26.7	20.0	28.9	21.1							26.7	15.6						
22	37.7	21.1	36.7	22.2			31.1	21.1	30.0	22.2	33.3	24.4					23.3	20.0						
23	38.8	22.2	36.7	22.2			32.2	22.2	24.4	22.2	24.4	23.3					33.3	21.1						
24	37.7	22.2	31.1	22.2			33.3	22.2	30.0	22.2	32.2	23.3					32.2	25.6						
25	35.5	21.1	25.6	23.3			31.1	21.1	32.2	22.2	25.6	16.7					35.6	25.6						
26			28.9	22.2			34.4	22.2	32.2	23.3	24.4	16.7					37.8	20.0						
27			27.8	23.3			33.3	20.0	34.4	22.2	30.0	22.2					38.9	20.0						
28			31.1	22.2			27.8	21.1	32.2	14.4	31.1	22.2	37.2	22.2			40.0	22.2						
29			25.6	22.2			30.0	21.1	27.8	18.9			37.8	17.8			38.9	22.2						
30			23.3	22.2			23.3	25.5	27.8	20.0			37.8	18.9			32.2	22.2						
31			32.2	22.2			25.6	15.5	30.0	18.9			28.9	18.9										

VITA²

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