

sulfur bearing potassium sources, the N/S ratios of these plant parts were narrowed considerably. This could mean that there was an increase in the proportion of sulfur bearing amino acids in cassava leaf blade and root protein since most plant sulfur has been reported to be in the protein form (Stewart and Porter 1969). There is need for a more comprehensive investigation on the effects of sulfur fertilization on the nutritional quality of cassava leaf and root protein.

CIAT. *Cassava production systems*. In Annual Report, Centro Internacional de Agricultura Tropical, Cali, Colombia, 1974.

Duncan, A. A. et al. *Effects of potassium chloride and potassium sulfate on yield and quality of sweet potato*. Proc. Amer. Hort. Soc. 71, 1958, 391-398.

Ferguson, T. U., and Haynes, P. H. *The response of yams (Dioscorea spp.) to nitrogen, phosphorus, potassium and organic fertilizer*. Proc. Int. Symp. Trop. Root Crops (Hawaii), 1, 1970, 93-96.

Freitas, L. M. M. de, F. Pimental Gomes, and Lott, W. L. *Effects of sulfur fertilizer on coffee*. IRI Research Institute, Inc., Bull. No. 41, 1972, 24 p.

Itallie, Th. B. van. *Cation equilibria in plants in relation to the soil*. Soil Sci. 65, 1948, 393-416.

Kumar, B. M., Mandal, R. C., and Magoon, M. L. *Influence of potash on cassava*. Ind. J. Agron. 16, 1971, 82-84.

Lott, W. L., McClung, A. C., and Metcalf, J. C. *Sulfur deficiency in coffee*. International Bank for Economic Co-operation, Research Institute Bull. No. 22, 1960, 24 p.

McClung, A. C., Freitas, L. M. M. de, and Lott, W. L. *Analyses of several Brazilian soils in relation to plant responses to sulfur*. Soil Science Society of America Proc. 23(3), 1959, 221-224.

Naderman, G. C. *Yellowing of rice (Oryza sativa L.) as related to root development and mineral nutrition in soils of the Eastern Plains of Colombia*. Ph.D. thesis, Cornell University, Ithaca, N.Y., 1973.

Oke, O. L. *Cassava as a food in Nigeria*. World Rev. Nutr. Diet. 9, 1968, 227-248.

Samuels, G. *The influence of fertilizer levels and sources on cassava production on a lares clay in Puerto Rico*. Proc. Carib. Food Crop Soc. 7, 1970, 33-36.

Stewart, B. A., and Porter, L. K. *Nitrogen-sulfur relationships in wheat (Triticum aestivum L.), corn (Zea mays) and beans (Phaseolus vulgaris)*. Agron. J. 61, 1969, 267-271.

Tabatabai, M. A., and Bremner, J. M. *A simple turbidimetric method of determining sulfur in plant materials*. Agron. J. 62, 1970, 805-806.

## The Interaction of Lime with Minor Elements and Phosphorus in Cassava Production

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Cassava appears to be a promising food crop for the acid and infertile soils of the Llanos Orientales of Colombia due to its tolerance to soil acidity. Large numbers of varieties have been screened for acid soil tolerance in plots receiving various amounts of lime. Most varieties responded positively to only minor applications of lime while showing a marked negative response to high liming rates. In a lime  $\times$  minor element trial it was shown that liming significantly reduced the uptake of Zn, Mn, Cu, and B and that high liming rates reduced yields by inducing the deficiency of Zn and possibly Mn and B. Cassava appears to have a very high requirement for Zn.

In an experiment studying the effect of lime on P-uptake, cassava responded to P mainly at low liming rates, whereas at high liming rates the response to P was reduced. Thus, liming may improve the availability of soil P and reduce the fixation of applied P. At low liming rates cassava responded markedly to applications as high as 200 kg P<sub>2</sub>O<sub>5</sub>/ha as TSP; the basal application was consistently superior to a split application, while the method of application did not affect yields significantly.

The Eastern Plains (Llanos Orientales) of Colombia are presently underutilized for agri-

cultural production because of extreme soil acidity and infertility. Soils with similar characteristics are found in large areas of the Venezuelan Llanos and the Campo Cerrado of Brazil. Presently they are utilized mainly for

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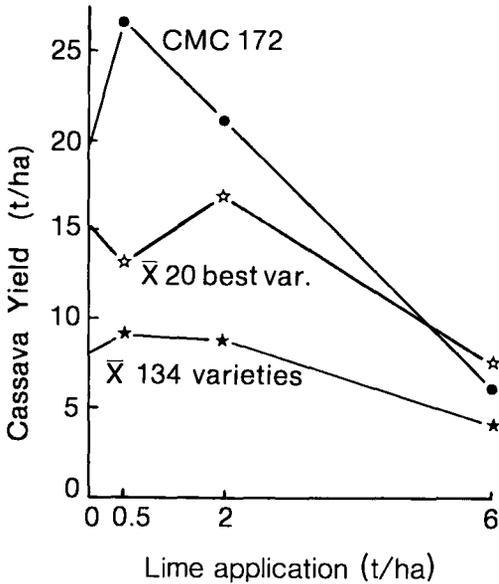


Fig. 1. Effect of liming on the average yield of 134 cassava varieties, the 20 best varieties, and the highest yielding variety CMC 172.

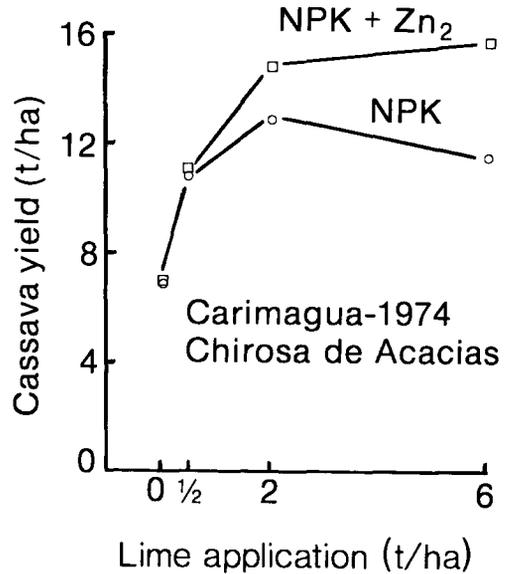


Fig. 2. The response of cassava to lime with and without the application of 20 kg/ha of Zn.

extensive beef production, while small plots of food crops are grown in cut and burned forests that intersect the predominant savannah vegetation. Cassava and plantain are the most commonly grown crops.

During several years of investigation at Carimagua, a research station in the centre of the Llanos, it was found that cassava and cowpea are among the most acid-soil tolerant crops, while corn, sorghum, beans, and several rice varieties are extremely susceptible to soil acidity. The acid-soil tolerance is very important considering the high cost of transportation of lime in an area where roads are nearly nonexistent.

### Materials and Methods

The soils where the experiments were conducted are classified as oxisols (Guerrero 1971), have good internal drainage, and the texture is a clay loam. The soil is extremely acid (pH 4.5), low in P, K, Ca, and Mg, while exchangeable Al occupies about 85% of the effective cation exchange capacity.

#### Experiment I: The Response of 134 Cassava Varieties to Application of Lime

To evaluate the acid-soil tolerance of cas-

sava, a large number of varieties were grown in double rows of 6.25 m length across four plots having lime treatments of 0, 0.5, 2, and 6 t/ha. The lime was applied as a mixture of calcitic limestone and MgO with a milliequivalent Ca:Mg ratio of 10:1. The plots were fertilized with 140 kg N, 100 kg P<sub>2</sub>O<sub>5</sub>, and 200 kg K<sub>2</sub>O/ha as urea, triple superphosphate (TSP), and KCl, respectively. The trial was harvested after 9 months due to disease problems of cassava bacterial blight (CBB) and superelongation.

#### Experiment II: The Interaction of Lime and Minor Elements

To study the effect of lime on minor element availability, the same four lime treatments as described under experiment I were combined with the following minor element treatments in subplots: 10 and 20 kg Zn/ha as zinc sulfate, 10 kg Cu/ha as copper sulfate, 10 kg Mn/ha as manganese sulfate, 2 kg B/ha as R-64, and 200 g Mo/ha as ammonium molybdate. A constant fertilization consisted of 100 kg N, 100 kg P<sub>2</sub>O<sub>5</sub>, and 200 kg K<sub>2</sub>O/ha applied as urea, TSP, and KCl + K<sub>2</sub>SO<sub>4</sub> (1:1), respectively. Chirosa was used as the test variety and harvested at 10 months.

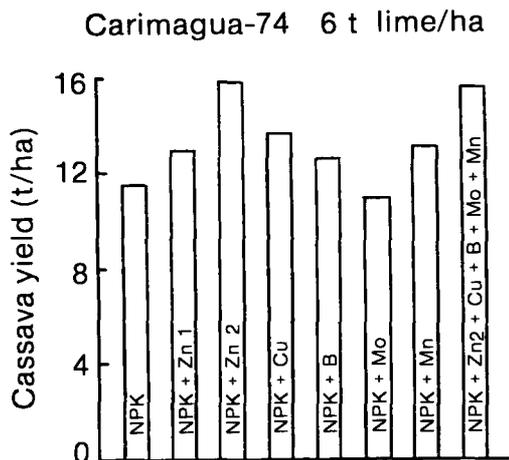


Fig. 3. The response of cassava to the application of minor elements at a liming rate of 6 t/ha.

### Experiment III: The Interaction of Lime and Phosphorus

To study the effect of liming on the response of cassava to P-application, five levels of lime (0, 0.4, 4, 8, 16 t/ha) were combined with three levels of P (0, 50, 100 kg  $P_2O_5$ /ha as TSP) in the subplots. The plots were fertilized with N and K as described in experiment I and harvested after 10 months. Chiroso was used as the test variety.

### Experiment IV: The Effect of Various Levels, Methods, and Time of Application of Phosphorus

Using a split-split plot design, four P levels of 50, 100, 150, and 200 kg  $P_2O_5$ /ha in the main plots were combined with two times of application (100% at seeding and 50% at seeding and 50% at 3 months) in the subplots; three methods of application (broadcast, band, and circle applied TSP) were used in the sub-subplots. Zero-P checks constituted additional treatments. All plots received 0.5 t of lime/ha and 100 kg N and 200 kg  $K_2O$ /ha as urea and KCl +  $K_2SO_4$ , respectively. Llanera was used as the test variety. The trial was harvested after 10 months.

## Results and Discussion

### Experiment I

The application of 0.5 t lime/ha did not have much effect on pH or exchangeable Al

content but was meant mainly to supply Ca and Mg for crop growth. With the application of 6 t lime/ha the pH increased to 5.3 and the Al decreased to 0.8 meq/100 g, a level at which most crops do not suffer from Al toxicity.

Fig. 1 shows the average response to liming of 134 varieties, the best 20 varieties, and the highest yielding variety, CMC 172. Some varieties showed a positive response to 2 t lime/ha, but the majority showed a positive response only to 0.5 t lime/ha with a marked negative response to higher lime applications. At high lime application rates many varieties were stunted and had chlorotic and deformed growing points.

Analyses of the uppermost fully expanded leaves of four varieties showed that liming increased the Ca and Mg contents while decreasing the K, Mn, and Zn contents. Zinc levels were in the deficiency range (< 50 ppm) at all liming rates, but were low enough to result in deficiency symptoms (< 20 ppm) only at the highest liming rate. Thus the problem appeared to be a lime-induced Zn-deficiency.

### Experiment II

Fig. 2 shows the response of the Chiroso variety to liming in the absence and presence of soil-applied Zn. Although yields are rather low due to a CBB attack later in the growing season, it is clear that this variety responded positively to liming up to 2 t/ha in the absence of Zn and up to 6 t/ha in the presence of Zn. The high Zn treatment was the only minor element treatment resulting in a positive response beyond 2 t/ha of lime. This confirms the observation that the yield reduction at high lime levels was due to induced Zn-deficiency. Leaf analyses at 2 months of age again showed that Zn, Mn, Cu, and B levels declined with liming. Zn levels in the absence of soil-applied Zn were relatively high in this variety, but reached deficiency levels at the 6 t lime treatment. No deficiency symptoms were observed. In the presence of 20 kg Zn/ha, Zn content also declined markedly with liming but did not reach the deficiency range even with the highest lime treatment. The yield response due to minor element treatments at the highest lime level indicated that the application of each minor element except Mo increased yields, but only the increase due to the high Zn-treatment was statistically significant (Fig. 3).

A recently established trial of the response of 45 cultivars to liming in the presence of 20

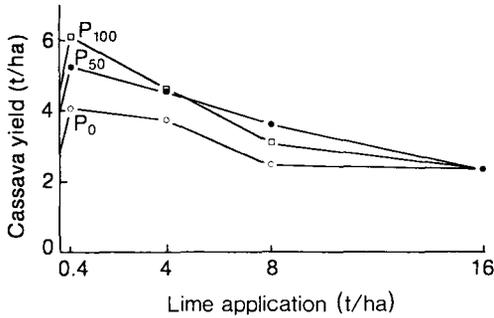


Fig. 4. The response of cassava to the application of lime and phosphorus (numbers on the curves indicate P application rates in kg  $P_2O_5$ /ha).

kg/ha soil-applied Zn showed that the average plant height was positively affected by liming rates up to 6 t/ha. Not one variety showed Zn deficiency symptoms at this lime level. Thus cassava appears to respond positively to liming, like other crops tested, but appears highly susceptible to deficiency of Zn and possibly other minor elements. Still the crop grows well with no or little lime applied in comparison with corn and beans (CIAT 1972).

### Experiment III

Fig. 4 shows the response of the variety Chiroso to lime and phosphorus application. Although yields are low due to disease problems and an early harvest, it is clear that the crop responded positively to only the low lime treatment of 0.4 t/ha with a negative response to higher liming rates. This again is due to lime-induced Zn deficiency.

At the low liming rates there was a clear response to the application of P, while at higher liming rates there was less response to P; at the 16 t/ha lime level there was no P response at all. Liming probably did improve the availability of P, but its effect was confused because of Zn deficiency, which may have been aggravated by the application of P.

### Experiment IV

Fig. 5 shows the response of the Llanera variety to different levels and times of application of P as TSP. There was a marked positive response to levels as high as 200 kg  $P_2O_5$ /ha, but the major response occurred in the first increment with the application of 50 kg  $P_2O_5$ /ha. The basal application of all the P at

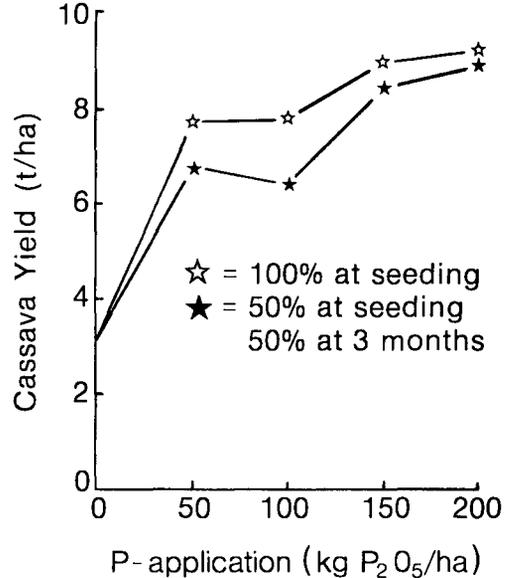


Fig. 5. The response of cassava to five levels and two times of application of P (average of three methods of application).

the time of seeding was consistently superior to the split application at seeding and at 3 months. There were no significant differences among methods of application, i.e. broadcast, band, or circle applied TSP. This is not true, however, for all P-sources. A recent trial, not yet harvested, indicates that the broadcast application of basic slag is highly superior to its band application.

## Conclusions

In acid soils like those of the Llanos Orientales of Colombia many cassava varieties respond to modest liming rates while suffering from minor element (especially Zn) deficiencies at high rates. A positive response to high liming rates could only be obtained in combination with relatively high applications of Zn.

High liming rates appear to reduce the response of cassava to soil applied-P. However, at low liming rates, cassava responded very markedly to levels as high as 200 kg  $P_2O_5$ /ha. Basal application of TSP was superior to its split application, whereas the method of application did not significantly affect yield.

Chacon, O. *Efectos de la cal agricola y el molibdeno sobre el rendimiento de la soya y del mani*. Oriente Agro. 1(1), 1968, 16-22.

CIAT. *Annual Report*. Centro Internacional de Agricultura Tropical (CIAT), Cali, Colombia, 1972, 164.

Guerrero, R. *Soils of the Colombian Llanos Orientales — Composition and classification of selected soil profiles*. Ph.D. thesis, North Carolina State University, Raleigh, North Carolina, 1971.

## Phosphorus Requirement of Three Sweet Potato Cultivars

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Sweet potato cultivars Tib 3, Tib 4, and Tis 2534 were grown in a Shante soil series at seven levels of phosphorus concentrations in a soil solution ranging from 0.01 to 1.6 ppm P.

Differential response and external P requirement were apparent between the cultivars. At 0.01 ppm P, over 70% of the maximum yield was obtained with the three cultivars. Yields of 95% occurred at 0.05, 0.10, and 0.15 ppm P, respectively, for the cultivars Tib 3, Tib 4, and Tis 2534.

Tissue phosphorus concentrations of 0.22% in the blade and 0.08% in the petiole of the index leaf at 9 weeks after planting appeared to be sufficient for 95% yield for the three cultivars.

The phosphorus response of sweet potato has generally been reported as small or insignificant; however, in some instances, large responses of 50% and above have been observed. Soil data are usually not included in these reports, so meaningful generalization is difficult.

Fox et al. (1974) attempted to determine more generally applicable parameters, basing their experiments on soil solution criteria, rather than on rates of fertilizer applied. They observed that sweet potato yielded 75 and 95% of the maximum yield with 0.003 ppm P and 0.1 ppm P in the soil solution concentration, respectively.

The work presented here uses the soil solution criteria to determine the phosphorus requirement of three sweet potato cultivars in a pot experiment.

### Materials and Methods

The experiment was conducted as a randomized complete block design with three replications. Three sweet potato cultivars Tib 3

(early maturing, relatively low yielding), Tib 4 (intermediate maturing), Tis 2534 (late maturing, high yielding), and 7 external phosphorus concentrations were studied in the experiment.

Twenty kilograms of a Shante soil series (Quartzsipsamment, USDA) was used per pot. The soil has the following properties: loamy sand texture; pH 5.8; Org. C 1.2%; CEC 3.04 meq/100 g; Bray P 3.3 ppm. Phosphorus (finely ground single superphosphate) was applied at planting at rates of 0, 3, 6, 8, 12, 15, and 28 ppm P. These rates were based on the phosphorus absorption isotherm of the soil to provide equilibrium soil solution concentrations of 0.01, 0.025, 0.05, 0.1, 0.2, 0.4, and 1.6 ppm P. Each pot also received before planting 100 ppm N, 10 ppm S, 150 ppm K, and 2 ppm Zn as  $\text{NH}_4\text{NO}_3$ ,  $(\text{NH}_4)_2\text{SO}_4$ , KCl, and  $\text{Na}_2\text{EDTA}$ . A further 25 ppm N as  $\text{NH}_4\text{NO}_3$ , 50 ppm K as  $\text{K}_2\text{SO}_4$ , and 10 ppm Mg as  $\text{MgSO}_4$  were added 10-12 weeks after planting (WAP).

Six plants were planted per pot and watered with deionized water. At 4 WAP plants were staked. One plant was harvested from each pot at 3, 5, 7, and 11 WAP. For each treatment, plants of the three replications were combined, separated in leaf blades, petioles, and stems,

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