

Besides being an important source of carbohydrate and the chief source of saprogenic precursors of cortisone (Martin and Ortiz 1963), yams provide much needed minerals in the diet. Table 2 shows that the tubers of *D. alata* were much richer in protein and mineral nutrients than the other yam species; the protein content of its peeled tuber (8.76%) was about 60% more than that of *D. cayenensis*; 18% more than that of *D. rotundata* (var. aro), and 8% greater than that of *D. rotundata* (var. efuru). Busson (1965) reported that the protein in the tuber of *D. alata* contained even higher amounts of essential amino acids than that of *D. cayenensis*. This is of significant interest to Nigerians who have a preference for using *D. alata* for making a much relished porridge called "Ikokore."

It is to be expected that continuous cultivation of yams in the same soil would rapidly deplete the soil of its nitrogen and potash reserves (Table 2). The danger might not be as imminent in soils derived from metamorphic parent material rich in K reserve, e.g. in the savanna zone of western Nigeria, as in soils of sedimentary origin, e.g. rainforest zone of southern Nigeria, which are known to be very low in potash (Smyth and Montgomery 1962).

Therefore, yam production in the rainforest zone of southern Nigeria requires a judicious application of N and K for high yields.

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Effect of Potassium and Sulfur on Growth, Yield, and Composition of Cassava

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Three field experiments were conducted in Colombia to investigate the differential effects of KCl and K₂SO₄ on cassava root yields. At Pance, where soil SO₄^{=-S} content was 9.0 ppm, there were no differences in yields between KCl and K₂SO₄ plots, but at Carimagua and Tranquero where soil SO₄^{=-S} content was 4.0-4.5 ppm, K₂SO₄ produced

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significantly higher root yields than KCl. A KCl + S 'source' produced yields equal to those produced by K_2SO_4 at equivalent rates of potassium.

Cassava root yields increased with potassium fertilization. Potassium applied at a rate of 120 kg K_2O /ha appeared to be adequate. Maximum root yields obtained were 40 and 20 t/ha at Pance and Tranquero, respectively. There was a high positive correlation between cassava root yields and total plant fresh weight produced per hectare.

Cassava has been reported to respond well to potassium fertilization by several investigators; however, yield depressions have also been reported at potassium rates higher than 200 kg K_2O /ha applied in the form of KCl (CIAT 1974, Kumar et al. 1971, Samuels 1970). Similar yield depressions at high potassium rates have been reported for yams (Ferguson and Haynes 1970) and for sweet potato (Duncan et al. 1958). The yield depressions have remained unexplained, but it has been suggested that the chloride ion has some deleterious effects on starch accumulation (Oke 1968).

The principal objectives of this study were: (1) to investigate the differential effects of two potassium sources, potassium chloride and potassium sulfate, on cassava root yields; and (2) to evaluate the main effects of sulfur on cassava root yields obtained from highly weathered soils.

Materials and Methods

Three experiments were conducted in Colombia at Pance, Carimagua, and Tranquero. Pance is located 14 km south of Cali in the Cauca Valley of Colombia at an altitude of about 1000 m. The soil, which is derived from volcanic ash, is heavy and poorly drained. Carimagua is located in the Eastern Plains of Colombia, South of the Meta River. The area has a gently sloping topography with an average elevation of 150–200 m. The mean annual rainfall of the area is 1800 mm and the mean annual temperature is 26–27 °C. Tranquero is located 10 km North of Carimagua. The soil at Carimagua has been classified as a clayey,

kaolinitic isohyperthermic typic haplustox (Naderman 1973). The soil at Tranquero was very similar to that found at Carimagua. Chemical data on the soils at the three sites are presented in Table 1.

The treatments imposed on the three experiments were two sources and four rates of potassium fertilizer. Potassium chloride (KCl) and potassium sulfate (K_2SO_4) were the potassium sources used and potassium was applied at rates of 0, 60, 120, and 240 kg K_2O /ha at Pance and Tranquero and 60, 90, 120, and 240 kg K_2O /ha at Carimagua. A KCl + S 'source' was included at Tranquero to investigate the effects of the sulfur contained in K_2SO_4 . Elemental sulfur was applied in amounts equivalent to the sulfur content of each rate of potassium applied as K_2SO_4 .

A basal application of 100 kg N (as urea) per hectare was made at all sites. Phosphorus was applied at a rate of 75 kg P_2O_5 at Pance and 100 kg P_2O_5 /ha at Carimagua and Tranquero. Lime, which had a Ca/Mg ratio of 10/1.0 was applied at a rate of 0.5 t/ha at Carimagua and Tranquero. Zinc was applied at a rate of 5.0 kg/ha as $ZnSO_4$. Potassium, nitrogen, and sulfur (at Tranquero) were split applied in double bands, half at planting and half 2 months later at Pance and Carimagua. The second application was made 1 month after planting at Tranquero to take advantage of the last rains. Half the phosphorus was applied during the liming operation and the rest was applied at planting. All the zinc was applied at planting.

A split-plot design with potassium sources as main plots and potassium rates as split plots was used at Pance and Carimagua. Potassium

Table 1. Characteristics of the soils at Pance, Carimagua, and Tranquero (0–15 cm).

	(1:1 H_2O)	O.M. (%)	P (Bray II) (ppm)	SO_4^{2-} -S (ppm)	Al ⁺⁺⁺ (meq/ 100 g)	Ca (meq/ 100 g)	Mg (meq/ 100 g)	K (meq/ 100 g)
Pance	5.6	5.0	2.4	9.0	—	9.7	5.70	0.11
Carimagua	4.8	5.0	0.9	4.0	3.7	0.3	0.30	0.13
Tranquero	4.9	2.5	1.8	4.5	1.6	0.1	0.05	0.05

Table 2. Effect of potassium sources and rates of application on total plant fresh weight, root yield, and harvest index of cassava 40 weeks after planting at Pance, Carimagua, and Tranquero.

K source	K rate (K ₂ O kg/ha)	Pance		Carimagua ^a		Tranquero	
		Total plant fresh wt (t/ha)	Root yield (t/ha)	Total plant fresh wt (t/ha)	Root yield (t/ha)	Total plant fresh wt (t/ha)	Root yield (t/ha)
KCl	0	42.0	29.0	—	—	17.2	9.5
	60	47.6	31.0	8.5	4.5	19.4	11.4
	90	—	—	9.0	5.0	—	—
	120	54.8	40.0	8.5	4.8	24.4	15.7
	240	65.8	44.3	8.5	4.5	23.7	13.9
K ₂ SO ₄	0	46.6	31.3	—	—	—	—
	60	49.6	35.5	14.5	9.0	23.2	13.8
	90	—	—	15.0	9.0	—	—
	120	61.3	42.3	15.0	9.5	25.8	15.8
	240	62.5	43.4	18.0	11.5	30.3	19.0
KCl + S	60	—	—	—	—	24.8	16.1
	120	—	—	—	—	22.8	15.2
	240	—	—	—	—	29.3	18.4

^aThere was a serious outbreak of cassava bacterial blight 2 months after planting.

rates were main plots and potassium sources split plots at Tranquero. There were three replications at Pance and Tranquero and four replications at Carimagua.

Mature stems of the cultivar Llanera were obtained from the CIAT farm at Palmira. These were cut into 20–25 cm lengths and planted in a vertical position on ridges. Spacing was 1.0 × 1.0 m giving a density of 10 000 plants/ha. The experiments at Pance and Carimagua were planted on 3 April and 4 May 1974, respectively, at the beginning of the rainy season. The Tranquero experiment was planted on 1 October 1974, toward the end of the rains. Harvesting was carried out 40 weeks after planting at Pance and Carimagua and 38 weeks after planting at Tranquero. Ten central plants constituted the harvest sample at Pance and Carimagua. At Tranquero, 12 central plants were harvested.

Data collected included plant height, total plant fresh weight, root yield, and harvest index. At Tranquero, root number per plant, root size, and percentage marketable root yield were also determined. A marketable root weighed approximately 250 g. Leaf samples were taken for N and K analysis. Samples from Tranquero were also analyzed for sulfur. The fifth opened leaf from the top was the sample leaf. Root samples were taken at Tranquero, at harvest,

for N, K, S, and Cl analysis. The roots were washed, towel dried, and cut into small portions to facilitate drying. The leaf and root samples were dried in a forced air oven at 70 °C for 15 h and ground in a small Wiley mill to pass a 40 mesh screen. Prior to grinding, the leaves were separated into blades and petioles. Nitrogen was determined by micro-Kjeldahl, potassium by flame photometry, and leaf blade sulfur by the turbidimetric method of Tabatabai and Bremner (1970). Root sulfur and chloride contents were determined by the Analytical Service Laboratory, Department of Agronomy, Cornell University.

Results

Growth

Plant growth was vigorous at Pance and there were no significant differences in height between plants in plots receiving potassium as K₂SO₄ and those receiving potassium as KCl. At both Carimagua and Tranquero, plants in plots fertilized with potassium as K₂SO₄ were significantly taller than those receiving potassium from KCl. Plant height increased with potassium rates.

Total plant fresh weight produced per hectare was greatly increased by potassium fertilization (Table 2). At both Carimagua and

Table 3. Influence of potassium sources and rates of application on potassium and nitrogen contents of various plant parts and size of roots.

K source	K rate (K ₂ O kg/ha)	K content (meq/100 g)				N content of roots (%)	Size of roots (g)
		Leaf blades		Petioles	Roots		
		Pance ^a	Tranquero ^b	(Tranquero) ^b	(Tranquero) ^c		
KCl	0	12.8	25.6	10.2	7.7	0.71	226
	60	18.7	37.0	41.0	12.8	0.62	317
	120	18.7	42.2	56.3	15.9	0.64	341
	240	20.5	42.2	66.6	18.0	0.54	290
K ₂ SO ₄	0	14.0	—	—	—	—	—
	60	15.4	37.1	33.3	14.6	0.51	300
	120	17.4	41.0	55.0	18.4	0.43	310
	240	25.6	42.2	64.0	20.5	0.47	375
KCl + S	60	—	37.1	30.7	12.8	0.44	343
	120	—	41.0	56.3	17.0	0.54	300
	240	—	42.2	56.3	17.0	0.46	328

^aSampled 24 weeks after planting.^bSampled 32 weeks after planting.^cSampled 38 weeks after planting.

Tranquero, plant fresh weight was significantly higher in plots receiving potassium as potassium sulfate than that obtained in plots receiving potassium as potassium chloride. Plant fresh weight production increased with increasing rates of potassium when K₂SO₄ was the potassium source but decreased at the highest rate of potassium when KCl was the potassium source at Carimagua and Tranquero but not at Pance. The KCl + S 'source' produced amounts of fresh plant material equal to those produced by the K₂SO₄ source at equivalent potassium rates.

Root Yield

Potassium fertilization increased cassava root yields significantly over those of control plots at both Pance and Tranquero (Table 2). At Carimagua there were no control plots and rates of potassium higher than 60 kg K₂O/ha did not produce significantly higher root yields than the 60 kg/ha rate (Table 2). The K₂SO₄ source produced significantly higher root yields than the KCl source at both Carimagua and Tranquero but not at Pance. The KCl + S 'source' produced yields that were equal to those obtained from plots receiving potassium as K₂SO₄. This indicated that the main reason for the superiority of K₂SO₄ over KCl as a source of potassium for cassava at Carimagua and Tranquero was its sulfur content.

There was a depression in cassava root yields at the highest rate of potassium applied as KCl at Tranquero, but this did not occur when K₂SO₄ or KCl + S were the sources of potassium. Cassava root yields at Pance and Tranquero were positively correlated with total plant fresh weight produced per hectare.

Harvest Index

At Carimagua, plants receiving potassium as K₂SO₄ had higher harvest indices than those receiving potassium as KCl. Harvest index remained relatively stable at all rates of potassium applied as K₂SO₄ at Carimagua, but decreased at high rates of potassium when KCl was the potassium source. This difference could be attributed to the fact that CBB was initially more severe in KCl plots because of the less vigorous growth of the plants. Harvest index was not significantly affected by potassium sources or rates of application at Pance and Tranquero.

Root Number

Potassium fertilization did not have a significant effect on the number of storage roots per plant and there were no differences among potassium sources on the number of storage roots produced per plant.

Root Size

The size of cassava roots was increased by

Table 4. Influence of potassium sources and rates of application on sulfur and chloride contents and nitrogen/sulfur ratio of selected plant parts sampled at Tranquero.

K source	K rate (K ₂ O kg/ha)	Sulfur content (%)			Chloride content of roots (%)	N/S ratio		
		Leaf blade		Roots		Leaf blade		Roots
		12 wks ^a	24 wks	(38 wks)	(38 wks)	12 wks	24 wks	(38 wks)
KCl	0	0.27	0.34	0.06	0.05	17.7	15.1	12.0
	60	0.30	0.54	0.06	0.07	15.9	15.2	10.0
	120	0.27	0.30	0.05	0.09	18.9	16.9	12.8
	240	0.29	0.29	0.06	0.11	16.7	17.2	9.0
K ₂ SO ₄	60	0.37	0.37	0.06	0.05	12.8	13.7	8.5
	120	0.37	0.33	0.06	0.06	13.6	15.2	7.2
	240	0.37	0.33	0.06	0.06	13.6	14.8	7.8
KCl + S	60	0.31	0.38	0.05	0.06	16.1	13.3	8.8
	120	0.29	0.32	0.06	0.07	17.8	16.2	9.0
	240	0.30	0.35	0.05	0.09	17.0	15.1	9.2

^aNumber of weeks indicates time of sampling after planting.

potassium fertilization. Potassium rates higher than the 60 kg K₂O/ha rate did not produce larger roots than those produced by plants receiving potassium at the rate of 60 kg K₂O/ha. Only the K₂SO₄ source produced consistent increases in root size with increasing rates of potassium fertilizer.

Percentage Marketable Root Yield

Potassium fertilization increased percentage marketable root yield from 70 to over 80%, but the difference was not significant. There was no significant difference among potassium sources in percentage marketable root yield although it was consistently higher in plots receiving potassium as K₂SO₄ compared to KCl plots.

Potassium

Leaf blade and petiole potassium contents are presented in Table 3, along with potassium contents of cassava root samples from Tranquero. There was a generally good relationship between soil applied potassium and the potassium contents of the plant parts sampled. Petioles seemed to be more sensitive than either leaf blades or roots in detecting changes in the potassium status of cassava plants in relation to soil applied potassium fertilizer. The potassium contents of leaf blade samples from Pance were lower than those of leaf blades from Carimagua and Tranquero. This was partly a dilution effect owing to the greater amount

of plant material produced at Pance. The higher base status of the soil at Pance also probably resulted in a much greater uptake of calcium and magnesium by plants grown at Pance compared to those grown at Carimagua or Tranquero, thus reducing the concentration of potassium in plant cells (Itallie 1948).

Nitrogen

Potassium fertilization did not have a significant effect on the nitrogen content of the plant parts sampled (Table 3), except for root samples from Tranquero, which showed a marked reduction in nitrogen content as a result of potassium fertilization.

Sulfur

During the dry season, 8–20 weeks after planting at Tranquero, cassava plants in control plots and plots fertilized with potassium as KCl showed symptoms of sulfur deficiency. Leaves in these plots were small and had a yellowish-green coloration. Plants in plots fertilized with potassium as K₂SO₄ and KCl + S produced large green leaves.

The sulfur content of leaf blade samples taken 12 weeks after planting increased when K₂SO₄ and KCl + S were the sources of potassium, but changed little when KCl was the potassium source (Table 4). At 24 weeks, leaf blade samples from plots receiving potassium as KCl showed a slight decrease in sulfur content compared to samples from con-

trol plots. Samples from plots receiving potassium as K_2SO_4 and $KCl + S$ had sulfur contents that were higher than those of samples from KCl plots. There was no change in root sulfur content as a result of fertilization with sulfur bearing potassium sources.

There was a general tendency for N/S ratios of leaf blades and roots to decrease with potassium fertilization when K_2SO_4 and $KCl + S$ were the sources of potassium. The N/S ratios widened when KCl was the potassium source.

Chloride

Root samples taken from Tranquero showed a continuous increase in chloride concentration with increasing rates of potassium applied as KCl (Table 4). Root samples from plots receiving potassium as K_2SO_4 had relatively stable chloride concentrations at all rates of potassium. Root samples from plots receiving potassium as $KCl + S$ showed increasing chloride contents with increasing potassium rates but to a lesser extent than those from KCl plots.

Discussion

The general superiority of potassium sulfate over potassium chloride as a source of potassium for cassava at both Carimagua and Tranquero was due mainly to the sulfur content of potassium sulfate. The extractable sulfur contents of the soils at both sites were low. At Pance where available sulfur was adequate, there were no differences in growth or yields between plants in plots receiving potassium as potassium chloride and those receiving potassium as potassium sulfate.

In the Campo Cerado of Brazil, where soils have similar characteristics as those encountered at Carimagua and Tranquero, young coffee plants were reported to show sulfur deficiency symptoms during the dry season (Frietas et al. 1972, Lott et al. 1960). These soils had extractable sulfur contents that were generally lower than 3.0 ppm. This is in agreement with the sulfur deficiency symptoms observed at Tranquero during the dry season. The growth and yield differences obtained in this study as a result of sulfur fertilization are in conformity with those obtained by McClung et al. (1959) who used soil from the Campo Cerado in a pot experiment with Pearl Millet as the test crop. They obtained growth responses to sulfur fertilization generally on

soils with available sulfur contents of less than 6.0 ppm. When soil SO_4-S was greater than 8.0 ppm no growth responses were obtained. The results from the present study also confirm those obtained in a pot experiment with cassava grown on soil from Carimagua (CIAT 1974).

It does appear that induced or aggravated sulfur deficiency caused by an excessive uptake of chloride is one possible explanation for the yield depressions reported in the literature when high rates of potassium, as KCl , are applied to cassava on soils that are low in sulfur. A toxic effect of the chloride ion per se does not appear to be the cause of these yield depressions nor does it seem to have serious ill effects on carbohydrate accumulation. In the present study, cassava root yields obtained from plots receiving potassium as $KCl + S$ were equal to those obtained from plots receiving potassium as K_2SO_4 despite the higher chloride content of roots from $KCl + S$ plots (Table 4).

The great difference between cassava root yields obtained at Pance and those obtained at Tranquero was principally a result of the different ecological conditions encountered at the two sites. At Pance, besides the higher soil fertility status, the climatic conditions were more favourable for plant growth. Rainfall distribution was better than at Tranquero where the plants endured a severe dry season of 3 months. At an altitude of 1000 metres, temperature conditions were more moderate than the 26–27 °C mean annual temperature of the Tranquero area. This would enable more carbohydrates to be accumulated in roots (higher harvest index) at Pance than at Tranquero where respiration would be higher. Thus, although the same cultivar was used at both sites and fertilizer treatments were similar, the greater amount of plant material produced at Pance coupled with a higher harvest index resulted in much higher root yields being produced at Pance than at Tranquero.

The fifth opened leaf from the top appeared to be a reliable sample leaf for detecting changes in the potassium status of cassava plants. The petioles were much more sensitive than leaf blades, and roots were the least sensitive of the plant parts sampled. The suitability of leaf analysis as a basis for making fertilizer recommendations for cassava will be treated in another paper.

Although the sulfur contents of leaf blades and roots were not changed greatly by applying

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.

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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 P₂O₅/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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