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Growth and Calcium Uptake of Maize (Zea mays) at Different Calcium Level in Three Ghanaian Soils

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ABSTRACT

A planthouse pot-experiment was conducted to study the effect of calcium fertilization on growth and Ca uptake of maize in three Ghanainan soils (Kumasi, Akroso and Ofin, occurring on a common catena) and to estimate critical Ca levels in maize plant tissue and soils. Calcium as calcium sulphate was applied at different rates, 0.0, 27.5, 55.0, 82.5, 110.0, 137.5 and 165.0mg Ca kg^{-1} soil, to each of the three soils. The soils were then allowed to incubate at room temperature for thirty days after which soil exchangeable Ca was determined and maize planted. Plants were harvested 42 days after planting and whole plant tops analyzed for Ca content. Plant height, and shoot and root dry matter (DM) yields were also measured. Calcium application and soil type had significant effects on shoot and root DM and on tissue-Ca content. The largest shoot DM yields and plant height were obtained on Akroso soil, followed by Kumasi and Ofin soils in that order. The largest shoot and root DM on all soils were achieved at the application rate of 82.5-110.0 mg Ca kg^{-1} soil. The tissue-Ca content of maize plants at this optimum range of Ca application rate was 1.3-1.5% for Kumasi, 1.0-1.4% for Akroso, and 0.9-1.3% for Ofin soils. Soil exchangeable Ca that supported the largest shoot and root DM yields was 54 mEq Ca kg^{-1} soil for Kumasi, 42 for Akroso and 35 for Ofin. For the Kumasi-Akroso-Ofin soil association, a plant tissue-Ca content of 1.3-1.5% and exchangeable Ca value of 54 mEq Ca kg^{-1} soil could be used as general working values for diagnosing Ca sufficiency in maize.

Keywords: calcium requirement, Ca use effc.iency, exchangeable Ca, Ghana soils, maize, tissue-Ca, tropical soils.

INTRODUCTION

Maize ranks third after wheat and rice in the world production of cereal crops [3]. Occupying over 12% of the total cultivated arable land and about 44% of the cereal area of Ghana, it is the single most important cereal in Ghana. As a food crop item, it ranks second only to cassava in the production of calories in the diet of Ghanaians [1]. Maize is well-known as a crop which is very responsive to fertilizers [2], and it was the most intensively studied crop in the FAO Fertilizer Programme in Ghana [6]. According to Donkoh and Renterghem [6], research on fertilizer use by maize in Ghana started in 1948; most of these studies (especially those by the FAO's Freedom from Hunger Campaign - Fertilizer Programme) were and are still devoted to the three major nutrients, N, P and K.

Plant uptake of secondary nutrients (Ca, Mg and S) is quite appreciable, but in Ghana and most other developing countries application of these has not received the attention it deserves [7]. There are a number of reasons for the lack of awareness of the role of the secondary nutrients. Among these is that the traditional low analysis fertilizers (single superphosphate and sulphate of ammonia), which were of major importance until quite recently, contain Ca and S and other impurities. With the low crop yield levels generally attained in the country, the amount of these elements appeared to be adequate. The level of Ca and Mg availability to the plant is associated with soil acidity. The correction of soil acidity through liming would therefore also overcome this source of deficiency. In recent times, the low-yielding crop varieties are giving way to higher-yielding ones which have higher nutritional needs. To meet such needs, and in the interest of greater economy, the use of high analysis fertilizers such as triple superphosphate (TSP) and urea is being encouraged in place of such low analysis ones as single superphosphate (SSP) and sulphate of ammonia. These high analysis fertilizers are relatively purer and contain little of other elements either as impurities or associated ions. With the use of high-yielding crop varieties and increasing cropping intensity, the need to apply the secondary nutrients may become greater in Ghana, as well as many other developing countries, to sustain crop productivity.

In the semideciduous forest zone of Ghana, the Kumasi, Akroso and Ofin soil series (formed on a common catena) constitute major maize-growing soils. These soils, being coarse-textured and in a high rainfall area, are intensively leached and are, therefore, likely to be deficient in Ca and Mg. Knowledge of the Ca and Mg needs of maize in these soils would be useful in increasing the productivity of the crop in the semideciduous forest zone of Ghana and other situations of similar ecology. This paper describes the effect of the application of Ca on the growth and Ca uptake of mazie in the three soils, Kumasi, Akroso and Ofin; and the estimation of the critical Ca levels in maize plant tissue and soils. Similar studies would be extended to Mg in future.

MATERIALS AND METHODS

A pot experiment was conducted in the planthouse of the Department of Crop Science of the University of Science and Technology, Kumasi, Ghana, (located at latitude 06° 43' N and longitude 01° 36' W). The planthouse operated under natural daylight of 12 h duration. The mean temperature and mean humidity of the planthouse for the day/night, respectively, were 30/22°C and 60/95% RH.

The experiment consisted of 21 treatments: three soil types, each with seven rates of applied Ca which were 0.0, 27.5, 55.0, 82.5, 110.0, 137.5 and 165.0 mg Ca ka^{-1} soil as calcium sulphate ($CaSO_4.2H_2O$). The treatments were each replicated four times and arranged in a completely randomized design.

The soils were sampled from the surface (0 - 18cm) of the Kumasi, Akroso and Ofin soil series of Ghana. These soils are members of a catena formed over a biotite granite parent material, under a semideciduous forest vegetation, and in a zone with a mean annual rainfall of 1375 - 1625mm. The Kumasi series occurs at the summit or upper slope, Akroso at midslope, and Ofin at the bottom of the topography. Other characteristics of the soils are listed in Tab 1.

Plastic pots (2 l capacity) were each filled with 2kg of soil that had been treated with calcium sulphate at the requisite Ca rate and allowed to incubate for 30 days. Exchangeable Ca was determined in the incubated soils by extracting 10g soil with 100ml of 1.0 N ammonium acetate solution at pH 7.0 for one hour. The soils in plastic pots were watered to about 20% by weight (400 ml of water pot^{-1}) and four seeds of maize cultivar, La Posta (recommended to Ghanaian farmers by the Crops Research Institute of Ghana), were sown to a pot. Five days after emergence and nine days after planting (DAP), plants were thinned to one pot^{-1}. The plants were given 50 ml of Ca-free Hoagland solution (full strength) pot^{-1} $week^{-1}$, and watered when necessary (by weighing pots with contents). (The Hoagland solution was prepared to contain the following salts and their amount per liter: KNO_3, 7.6 g; KH_2PO_4, 1.6 g; $MgSO_4.7H_2O$, 3.1 g; Fe(III)NaEDTA, 0.81 g; H_3BO_3, 15.5 mg; $MnCl_2.4H_2O$, 9.0 mg; $ZnSO_4.7H_2O$, 5.8 mg; $CuSO_4.5H_2O$, 0.80 mg; $H_2MoO_4.H_2O$, 0.20 mg).

Plant height was measured from the soil surface to the base of the youngest leaf at harvest time. Plants were harvested 42 DAP when, for each pot, the above-ground plant materials and roots were taken and sectioned with scissors into 1cm lengths, keeping underground part and the tops separate.

Table 1 Some physical and chemical properties of soils (surface soil, 0-18cm) used in the study

Soil (Texture)	Classification[a] (Soil Taxonomy)	pH[b]	Clay	Sand	C	N	P^c ($mg\ kg^{-1}$)	Exchangeable cations and CEC[d] ($mEq\ kg^{-1}$)					
			($g\ kg^{-1}$)					Ca	Mg	K	Na	H+Al	CEC
Kumasi (Sandy loam)	Paleustult	5.1	150	750	9.0	0.91	2.25	24	10	1.6	1.2	58	95
Akroso (Sandy loam)	Haplustult	5.3	100	800	9.3	0.84	2.50	15	8	3.9	1.4	62	90
Ofin (Loamy sand)	Aquic Ustifluvent	5.9	70	870	3.8	0.42	5.00	8	8	1.4	1.0	65	83

[a]Information on soil classification supplied through Mr. R.D. Asiamah by courtesy of Soil Research institute of Ghana; [b]pH measured in soil/water, 1.25; [c]available phosphorus by Brah P1 extractant; CEC (cation exchange capacity) as sum of exchangeable cations.

The plant materials for each pot were oven-dried at 70°C for 72 h and weighed. The above-ground material was ground and ashed at 450°C overnight. The ash was taken up in 2 M HCl and filtered through No. 42 Whatman filter paper. Total Ca in the filtrate and the Ca in the ammonium acetate extracts of soils were measured by the Versenate (EDTA) titration method [9]. Statistical analyses of data were done, using the Duncan Multiple Range Test for means separation.

RESULTS AND DISCUSSION

In all the three soils, maize growth, measured in terms of shoot dry matter (DM) yield, increased with increasing Ca application up to an optimum rate of 82.5 - 110.0 mg Ca kg^{-1} soil (Table 2); at this rate the highest shoot DM yields of maize plants (42 days old) were obtained, and were 4.3g $plant^{-1}$ for Akroso, 4.1 for Kumasi, and 3.9 for Ofin. The plant heights at this optimum Ca application rate were 56, 54 and 51cm for Akroso, Kumasi and Ofin, respectively. The significant responses ($P = 0.05$) in maize growth (shoot DM) to Ca application, with respect to the control, indicated that the available native Ca levels in the soils (24, 15 and 8 mEq Ca kg^{-1} soil for Kumasi, Akroso and Ofin, respectively) (Table 1) were too low to support good growth of maize.

There were significant differences ($P = 0.05$) among soil types in shoot DM and plant height [LSD ($P = 0.05$): achieved at the optimum Ca application rate (Tab 2).Plant height and shoot DM values were greatest for Akroso, followed by Kumasi and Ofin soils in that order.Similar trend in the response of soybean to Ca application in these soils was also found by Ankomah and Osei-Kofi (unpublished data). This indicates that in this respect Akroso soils are potentially more productive than Kumasi soils which in turn are potentially more productive than Ofin soils.

Soil exchangeable Ca increased with increasing Ca application (Tab 2). According to Doll and Lucas [5], exchangeable Ca in the soil can range from 12 to over 250 mEq kg^{-1} with no apparent evidence of any deficiency or excess in plants. In this study, however, critical soil exchangeable Ca levels were determined. The amounts of soil exchangeable Ca at the optimum Ca application rate of 82.5 - 110.0 mg Ca kg^{-1} soil (ie., at which the largest shoot DM yields were achieved) were considered to be the external critical Ca requirements, and was 54 mEq kg^{-1} for Kumasi, 42 for Akroso, and 35 for Ofin soils. The highest value of 54 mEq Ca kg^{-1} soil attained in this study falls within the range considered as very high for soils with low CEC [4] and could be used as a general working value for diagnosing Ca sufficiency in maize for the Kumasi-Akroso-Ofin soil association. These critical exchangeable Ca values could also be a guide in the magnesium (Mg) fertilization of these soils in ensuring proper soil Ca/Mg ratios. According to Doll and Lucas [5], a review of the literature shows that the Ca/Mg ratio should not be less than unity (on equivalent basis) for good production of field crops.

In all the three soils, Ca uptake and tissue-Ca concentration in tops of plants increased with increasing Ca application up to the optimum 110.0 mg Ca kg^{-1} soil (Table 3). The tissue-Ca

Table 2 Shoot and root dry matter yields (g $plant^{-1}$) of maize plants at 42 days after planting (DAP), and soil exchangeable calcium[a] (mEq kg^{-1} soil) as influenced by application of calcium to Kumasi, Akroso and Ofin soils

Ca applied	Kumasi			Akroso			Ofin		
(mg Ca kg^{-1} soil)	Shoot DM	Root DM	Ex Ca	Shoot DM	Root DM	Ex Ca	Shoot DM	Root DM	Ex Ca
0.0	3.3	1.6	24	3.1	1.8	15	3.2	1.7	8
27.5	3.4	1.7	35	3.4	1.9	25	3.2	1.7	17
55.0	3.6	1.7	42	3.7	2.2	32	3.4	1.8	24
82.5	3.9	1.8	48	4.3	2.3	36	3.8	1.9	31
110.0	4.1	1.7	54	4.2	2.4	42	3.9	1.9	35
137.5	3.8	1.6	60	4.1	2.2	50	3.5	1.7	42
165.0	3.8	1.6	65	4.2	2.1	56	3.5	1.7	52

LSD ($P = 0.05$): Shoot dry matter, 0.17; Root dry matter, 0.14 soil exchangeable Ca was determined after 30 days of incubation of soils by extracting with 1.0-N ammonium acetate solution at pH 7.0.

Table 3 Calcium uptake (mg Ca plant $^{-1}$), tissue-Ca concentration (%), and Ca use efficiency (CUE)[a] of maize at 42 DAP as influenced by calcium application to Kumasi, Akroso and Ofin soils

Ca applied	Kumasi			Akroso			Ofin		
(me Ca kg^{-1} soil)	Ca uptake	Tissue Ca	CUE	Ca uptake	Tissue Ca	CUE	Ca uptake	Tissue Ca	CUE
0.0	25.1	0.76	0.132	20.7	0.68	0.147	19.2	0.60	0.167
27.5	29.9	0.88	0.114	29.5	0.88	0.114	21.8	0.68	0.147
55.0	33.8	0.94	0.107	40.0	1.08	0.093	29.9	0.88	0.114
82.5	49.9	1.28	0.078	44.2	1.04	0.096	35.0	0.92	0.109
110.0	61.6	1.52	0.066	59.8	1.44	0.069	50.8	1.32	0.076
137.5	54.0	1.44	0.069	52.5	1.28	0.078	33.6	0.96	0.104
165.0	54.0	1.44	0.069	44.8	1.08	0.093	35.9	1.04	0.069

LSD ($P = 0.05$): Ca uptake, 0.2; Tissue-Ca concentration, 0.11; CUE, 0.011

[a] CUE was estimated as dry matter yield of tops (g) produced per unit amount (mg) of Ca in tops of plants.

concentration at this optimum Ca application rate (above which there was no increase in shoot DM yields) were 1.52% in Kumasi, 1.44% in Akroso, and 1.32% in Ofin. These values agree with the tissue-Ca sufficiency range of 0.9 - 1.6% determined for whole maize plants 30-45 days after emergence by Lockman [8]. For the Kumasi-Akroso-Ofin soil association, a tissue-Ca concentration of 1.3 - 1.5% in 42 days-old whole maize plant tops could be considered as the internal critical Ca requirement, and could be used as general working values for diagnosing Ca sufficiency in maize.

Calcium use efficiency was estimated as dry matter yield of tops (g) produced per unit amount (mg) of Ca in tops of plants. At the natural Ca fertility levels the Ca use efficiencies (CUE) were significantly different among the three soils ($P = 0.05$) and was 0.132, 0.147 and 0.167 g DM mg^{-1} Ca for Kumasi, Akroso and Ofin respecitvely (Table 3). Calcium utilization efficiencies decreased with increasing Ca application and Ca uptake. CUE values were similar ($P = 0.05$) for all the three soils (0.066 - 0.076 g DM mg^{-1} Ca) at the optimum Ca application of 110.0 mg Ca kg^{-1} soil. Thus, in these soils a CUE value below 0.066 g DM mg^{-1} Ca for maize would represent a luxury consumption of Ca.

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