Characterization of selected Kenyan acid soils

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Abstract

Declining soil fertility is a major cause of food insecurity in sub-Saharan Africa. In order to describe Kenyan acids soils, 11 sites were selected, described and sampled. Laboratory analyses conducted included: soil pH, total carbon and nitrogen, loss on ignition, extractable phosphorus, exchangeable bases and Al, cation and anion exchange capacities, and ammonium oxalate and dithionate citrate bicarbonate extractable iron. With a few exceptions, the results indicate the following general trends: low soil pH, low P, low effective cation exchange capacity, and relatively high aluminum saturation. Low plant nutrient reserves, particularly phosphorus, and likely aluminum toxicity seem to be the major limitations for sustainable agricultural use and management of these soils.

Key Words

Soil acidity, exchangeable bases, aluminum saturation, available phosphorus.

Introduction

Low crop production in acid soils is usually due to several factors affecting different physiological and biochemical processes, both in the soil and plant (Foy, 1984). Typically, the main constraints in the kaolinite-rich soils common in humid tropical and subtropical climate regions include weak buffering capacity; low P bioavailability due to high P fixation capacity; toxicities of Al, Fe, Mn (occasionally H); deficiencies of Ca, Mg, K, Zn, S, and Mo; and low cation exchange capacity (CEC) (Clark *et al.* 1988). These deficiencies or toxicities often act together to limit plant growth (Clark 1982). This study was undertaken as a part of a larger project whose main objective is to improve the productivity of maize and sorghum grown on acid soils in central Brazil and East Africa. An understanding of the soil chemical context of the root-soil environment, as well as the broader agro-ecological context into which enhanced germplasm is likely to be introduced, is essential. The objective of this study was to obtain baseline information on the soil chemical properties of representative soils in different maize growing regions of Kenya, the target area for eventual introduction of germplasm with enhanced Al-tolerance and P-use efficiency.

Methods

The exploratory soil map of Kenya (Sombroek *et al.* 1982) was used to identify acid soils in major maize growing areas. Samples were collected from 8 pedons west of the Rift Valley (Kuniet, KN01; Chepkoilel, KN02; Vihiga, KN03; Ikholomani , KN04; Bumala, KN05; Siaya, KN06; Kisii, KN07; and Kericho, KN08), and 3 pedons east of the Rift Valley (Kangema, KN09; Kerugoya, KN10; and Embu, KN11) (Figure 1).

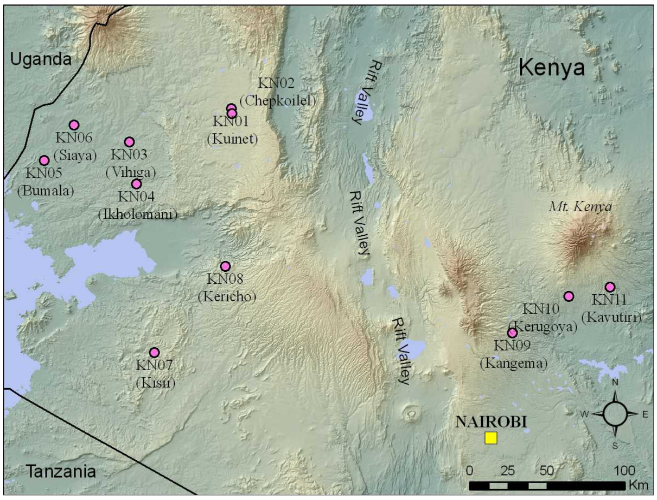

Figure 1. A map of western Kenya showing the sampling locations.

Soil pH was measured using a 1:1 soil: water/solution ratio (Thomas 1996), total carbon (C) and nitrogen (N) was determined using an automatic analyzer (Leco CHN – 2000, LECO Corporation, 3000 Lakeview Avenue, St. Joseph, MI), and phosphorus (P) was determined according to the Bray-1 procedure. Exchangeable bases, Al, and CEC were determined by the unbuffered 1 M NH_4Cl method (Sumner and Miller 1996). Oxalate-extractable P (P_{ox}), Al (Al_{ox}) and Fe (Fe_{ox}) were determined by the acid ammonium oxalate procedure. The modified Dithionate-Citrate-Bicarbonate (DCB) procedure described by Loppert and Inskeep (1996) was used to extract Al_d and Fe_d. The major modification of this procedure involved shaking the samples overnight instead of heating

Results

The surface soil properties are presented in Table 1. The surface soils east of the Rift Valley were 0.75 pH_{H2O} units more acidic. Total C varied significantly with site, ranging from 17.3 to 57.4 g/kg while N ranged from 1.5 to 3.8 g/kg. The relatively lower C content in the western, medium-altitude areas may be a result of the greater rate of soil organic matter decomposition, probably due to the warmer temperatures, and the inverse may be true for the higher altitudes. In addition, the influence of the type of vegetative cover could be the reason for the relatively greater C and N content in pedons KN07 and KN08. Pedon KN07 was previously under fallow (woodlot with grass under-story) and pedon KN08 was under pasture grass, probably resulting in accumulation of surface litter and below ground root debris.

Table 1. Some chemical properties of selected Kenyan soils.

Sample ID	Depth	pH			ΔpH	N	C	Extractable P (mg/kg)	
	(cm)	H_2O	KCl	$CaCl_2$		(---g/kg---)		Bray-1	Oxalate
KN01A	0-15	4.3	3.5	4.0	0.8	1.7	22.2	5	310.0
KN02A	0-20	5.0	3.9	4.3	1.1	1.6	20.0	8	330.6
KN03A	0-25	5.3	3.9	3.9	1.4	1.5	19.9	3	394.1
KN04A	0-11	6.2	4.9	4.9	1.3	1.9	25.4	3	310.4
KN05A	0-20	5.6	4.2	4.5	1.4	1.9	31.6	3	315.4
KN06A	0-20	5.1	3.8	4.2	1.3	1.6	17.3	3	187.0
KN07A	0-20	6.0	4.9	5.2	1.1	2.8	26.9	5	479.6
KN08A	0-12	5.5	4.3	4.9	1.2	2.7	39.5	9	403.8
KN09A	0-15	4.6	3.7	3.7	0.9	3.8	57.4	6	500.7
KN10A	0-20	4.6	3.6	3.9	1.0	3.2	31.3	46	4249.3
KN11A	0-25	4.7	3.8	3.9	0.9	3.5	42.5	16	511.3

The exchange properties of the surface soils are presented in Table 2. Exchangeable bases were lower in eastern than in western Kenya soils. Pedons KN02, KN07, and KN08 had greater exchangeable K than the rest.

Table 2. Exchangeable cations and ion exchange capacity selected Kenyan acid soils.

Sample ID	Depth	K	Mg	Ca	Na	Al	Al Saturation	CEC	ECEC	AEC
	(cm)	($cmol_c$/kg)					(%)	($cmol_c$/kg)		
KN01	0-15	0.5	0.6	2.4	0.7	2.3	39.6	5.8	9.5	0.6
KN02	0-20	1.1	1.4	3.7	0.5	0.8	11.6	7.0	10.5	3.3
KN03	0-25	0.2	0.8	3.3	0.5	1.6	27.4	5.8	8.8	1.9
KN04	0-24	0.5	1.6	4.5	0.3	1.1	14.6	7.6	13.7	1.1
KN05	0-11	0.4	1.7	3.2	0.3	2.0	26.5	7.2	11.6	1.5
KN06	0-18	0.3	1.1	2.6	0.4	0.4	8.3	4.4	9.3	0.8
KN07	0-11	1.6	3.1	3.6	0.5	0.4	4.3	8.6	22.0	1.1
KN08	0-20	0.7	1.9	6.3	0.3	2.1	19.0	11.0	18.1	2.2
KN09	0-20	0.3	0.6	1.3	0.3	4.5	58.5	7.7	9.9	1.9
KN10	0-20	0.4	1.0	1.6	0.3	2.9	47.6	6.2	10.7	1.1
KN11	0-12	0.4	0.2	1.4	0.3	3.3	60.7	5.3	8.5	2.0

Adverse cation ratios: notably low Mg:K ratio (> 1:2) may lead to Mg deficiency; Ca:Mg ratios < 1:3 may lead to Ca deficiency, and at ≥ 5:1, Mg deficiency and possible P inhibition may occur (Landon 1984). Based on this criteria, soils in this study are likely to have Ca deficiency and/or possible P inhibition due to Ca:Mg imbalance (ratios < 3:1); exceptions are pedons KN01, KN03 and KN08. Also, Mg deficiency is likely to occur in pedons KN01, KN02 and KN11. The exchangeable Na levels in these soils are generally greater than expected for such highly weathered soils. It is not clear whether the extracted Na was readily exchangeable or originated from dissolution of weatherable minerals in the inorganic matrix. Exchangeable

Al ranged from 0.4 to 4.5 cmol$_c$ /kg, while aluminum saturation percentages (ASP) ranged from 4.3 to 60.7 %. Exchangeable Al levels greater than 2 cmol$_c$ /kg is generally considered excessive for many crops (Landon 1984). The ASP is a measure of the proportion of the exchange sites occupied by Al at the pH of the soil. Typically, the yield of Al-sensitive crops may not be affected much in soils with ASP values lower than 30% (Landon 1984). The ASP values of eastern Kenya soils were greater than 30%. The implications of these results to food crop production in Kenya are that: (1) sorghum, a common staple crop in the western region and (2) maize, common beans, and sweet potato which are grown in most arable parts of the country, are likely to be affected by the Al levels observed in some of these soils.

The majority of the soils had low CEC/ECEC values. The AEC values found in this experiment ranged from 0.6 to 3.3 cmol$_c$/kg, and are significantly greater than those commonly reported for variable charge soils (Hyun *et al.* 2003; Qafoku and Sumner 2001;). Hyun *et al.* (2003) reported lower AEC values (between 0.03 and 0.92 cmol$_c$ /kg) for four Brazilian Oxisols, three volcanic ash soils from South Korea, one weathered soil from Costa Rica, and one from Indiana (USA).

The amounts of DCB extractable Fe (Fe_d) and Al (Al_d) were greater than the corresponding values for oxalate extractable portions of Fe (Fe_{ox}) and Al (Al_{ox}) (Table 3). The values of Al_{ox} were greater than those of Fe_{ox}. The Al_{ox}/Al_d ratios were always greater than the corresponding Fe_{ox}/Fe_d ratios.

Table 3. Ammonium oxalate and DCB extractable Fe and Al in selected Kenyan acid soils.

Sample ID	Al_{ox}	Fe_{ox}	Al_d	Fe_d	$\frac{Al_{ox}}{Al_d}$	$\frac{Fe_{ox}}{Fe_d}$
	(…………..……g/kg…………..…)					
KN01A	4.81	3.36	10.4	93.9	0.464	0.036
KN02A	4.70	3.13	12.7	64.9	0.370	0.050
KN03A	5.83	3.51	15.6	67.5	0.374	0.052
KN04A	9.67	2.49	13.6	83.1	0.712	0.030
KN05A	7.30	2.10	22.0	105.4	0.331	0.020
KN06A	4.41	1.73	13.8	56.9	0.319	0.030
KN07A	5.12	4.85	6.3	68.6	0.810	0.070
KN08A	7.49	3.88	14.5	89.7	0.518	0.042
KN09A	7.23	5.05	18.2	110.1	0.397	0.044
KN10A	14.43	8.78	15.4	103.6	0.938	0.086
KN11A	7.35	10.22	15.5	80.8	0.473	0.127

This suggests that Al is largely present in these soils either in poorly crystalline inorganic forms or possibly as Al-organic matter complexes. Iron on the other hand, dominated the DCB extractable fractions. The Fe_{ox}/Fe_d ratios are used to assess the degree of crystallinity of Fe oxides in a soil. Low Fe_{ox}/Fe_d ratios indicate a high degree of crystallinity of Fe oxides.

Conclusion

These results suggest that most of the Kenyan acid soils studied have low levels of essential plant nutrients, particularly exchangeable bases and P, and high levels of exchangeable Al. Soils east of the Rift Valley are significantly more acidic and their exchange sites have greater Al saturation than those west of the Rift Valley. The implications of this are twofold: (1) In order achieve increased and sustained crop yields, soil management practices that will increase nutrient availability and enhance uptake are required; and (2) Al-tolerant crop varieties are likely to do well in the Kenyan soils with high Al saturation, particularly those east of the rift Valley.

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