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Extractable Silicon and Iron Status of Some Southwestern Nigerian Soils

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Abstract

Citric acid extractable silicon (CAES) and iron (CAEI) in selected Southwestern Nigerian soils which differ in drainage and parent material were investigated. The CAES and CAEI of the soils increase with increasingly poor drainage. The CAES in the well drained soils of the sedimentary environment is lower than those from the metamorphic area. The amount of CAEI present and its distribution appears abundant for most crops. The CAES of the whole profile in the study area could be predicted from that of the surface horizon. The common soil units in the study area, *Ferric Luvisols, Eutric Gleysols and Vertic Cambisols* had averages of 169, 210 and 373 ppm CAES respectively.

Introduction

Silicon and iron are the second and fourth most abundant elements respectively in the earth's crust. Silicon occurs in soils as free silica to complex silicates, and iron (Fe) is unique in its ability to form numerous stable compounds, and its occurrence as the native metal in meteorites and earth's interior.

In soil genesis study, silica solubility reflects the stage of weathering, clay mineralogy and reactivity of the oxidic surface in tropical soils (Beckwith and Reeve, 1963; Iler, 1955). High activity clays are usually associated with high extractable silica. Several workers (Fox and Silva, 1967; Nair and Aiyer, 1968; and Plucknet, 1972) have indicated that the determination of soluble silica could serve as a qualitative test for the clay activity. Silica solubility in soil profiles is related to soil moisture regime and the labile silica is normally abundant in hydromorphic soils (D'Hoore and Coulter, 1972; Moss, 1957; and Ojo-Atere *et al.,* 1973). The total free iron content of soils serves as qualitative weathering index, showing gradual increase as weathering advances. The concentration of Fe^{2+} often reaches several ppm in flooded soils. Silicon is probably not essential for most plants. However, general vigour of many *gramineae* species, particularly sugarcane and rice, is decreased, if grown in soils low in available silica (Okuda, 1965; Rodrigo, 1964, and Sanchez, 1976). The citrate extractable-Si gives information about the capacity of soil to supply silicon to plants (Beckwith and Reeve, 1963). Amounts of soluble Si in water or 1% citric acid were positively correlated with response of wheat to P-fertilizer. Also, citric acid extractable-Si (CAES) gives higher correlation with Si-content of rice plants than with other extractants like water, 0.02N-HCl, 0.5N-$NaHCO_3$ (Plucknet, 1972).

Though some work has been done on the sorption, solubility and extent of free silica on some of the soils of southern Nigeria (Ashaye, 1972; Gallez et al. 1977 and Gallez *et al.,* 1975), data on the labile pool of silicon in different soil series of southewestern Nigeria are lacking. The intent of this study was to assess the magnitude of labile pool of silicon (CAES) and iron (CAEI) in soils varying in drainage and parent material, and establish the relationship between extractable silicon and other soil properties.

Materials and Method

The study area (3° and 5°E; 6° and 9°N) has mean annual rainfall of about 1,000 mm in the norther part and 2,000 mm in the south. The rainfall distribution is bimodal with peaks in June and September. The dry season extends from November to March. The average minimum and maximum air temperature are 20°C and 32°C respectively. Parent materials in the northern part of the area were derived mainly from Precambrian basement complex rocks, occurring in a complex pattern. The common rocks are granites, syenites, gneisses, schists, quartzites and amphibolites. The upland soils (Alfisols) usually consist of a veneer of pedisediments over saprolites. The lower slope soils, formed from alluvium and colluvium belong to Inceptisols or Entisols. Soils of the southern area are derived from sedimentary materials of Tertiary to Pleistocene age and belong to the Alfisols or Ultisols. The vegetation in the northern part is wooded savanna while lowland rain forest dominates the south and southeastern areas (Fig. 1).

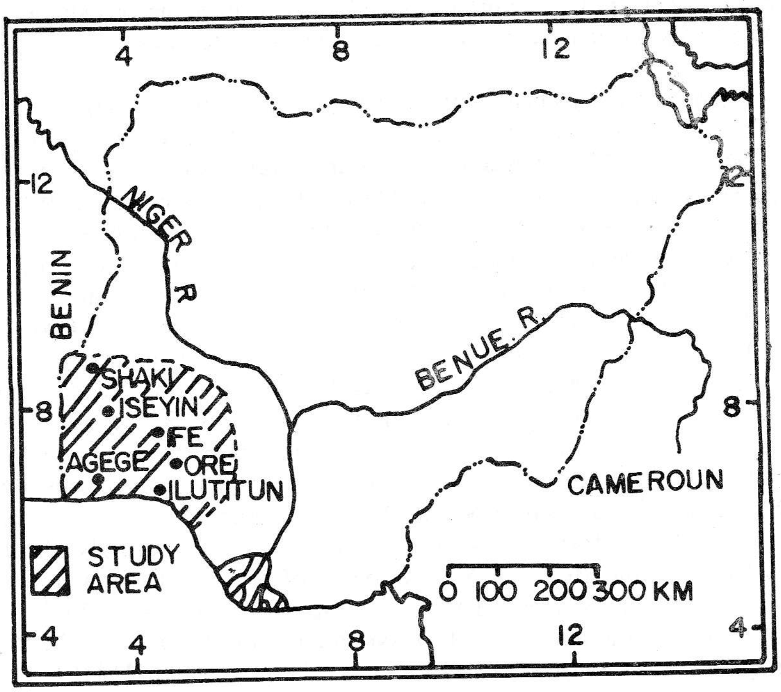

Fig.1: Map of Nigeria showing the study area

Table 1: CITRIC ACID EXTRACTABLE Si AND Fe IN SOME SOUTHWESTERN NIGERIAN SOILS.

	FAO Classification	Si		Fe	
		0-15 cm	Whole Profile	0-15 cm	Whole Profile
	Well drained				
Egbeda (cp 168)	Ferric Luvisol	76	131	44	244
Egbeda (cp 189)	Ferric Luvisol	220	231	882	607
Olorunda (cp 257)	Ferric Luvisol	131	208	522	396
Balogun (cp 35)	Ferric Luvisol	99	109	326	215
Iregun (cp 249)	Ferric Luvisol	108	228	392	472
Itagunmodi	Ferric Luvisol	121	158	784	639
Iwo (Profile 2)	Ferric Luvisol	190	211	558	355
Ibadan (Profile 4)	Ferric Luvisol	60	200	385	421
Ibadan (TO 16)	Ferric Luvisol	69	138	392	354
Kishi (TO 13)	Ferric Luvisol	49	77	294	252
Amodu (TO 10)	Eutric Nitosols	75	140	196	458
Owena	Eutric Nitosol	154	158	490	376
Oba	Ferric Cambisol	123	204	392	458
Asejire (cp 132)	Albic Arenosol	134	295	393	384
Apomu (TO 06)	Albic Arenosol	43	17	196	217
Alagba (ST 16/220)	Dystric Nitosol	150	105	633	263
Kulfo (CT 12/24)	Dystric Nitosol	39	85	294	289
Molo	Orthic Ferralsol	146	115	555	374
	Imperfectly drained				
Origo (Profile 1)	Vertic Cambisol	238	468	999	1104
Origo (Profile 4)	Vertic Cambisol	69	398	392	1462
Lagun (Profile 2)	Vertic Cambisol	276	420	908	952
Majeroku (Profile 3)	Vertic Cambisol	49	206	882	512
	Poorly drained				
Adio (cp 234)	Eutric Gleysol	125	311	588	722
Jago (Profile 6)	Eutric Gleysol	143	132	1406	812
Jago (cp 179)	Eutric Gleysol	236	426	882	1987
Jago (cp 183)	Eutric Gleysol	197	304	784	1097
Oshun (cp 288 R)	Eutric Gleysol	479	500	3920	3406
Matako (PBN 13146)	Eutric Gleysol	82	55	288	206
Idasan (TR 11/20)	Dystric Gleysol	167	151	751	218
Wawa (t 014)	Gleyic Luvisol	39	86	980	429
	Very Poorly drained				
Ofiki (T 007)	Eutric Fluvisol	423	136	7065	1607
Ikire	Eutric Gleysol	89	167	980	328

The soil profiles sampled and the drainage class are indicated in Table 1. Samples from different genetic horizons were air dried, sieved through 2-mm sieve and analysed. Soil pH was determined (soil: water ratio 1:1) by a glass electrode; and the particle size distribution was by hydrometer method. Organic carbon was determined by dichromate digestion (modified Walkley and Black) as cited by Bremner and Jenkinson (1960). Cation exchange capacity (CEC) and exchangeable bases were determined by ammonium acetate method. Citric acid extractable silicon (CAES) and iron (CAEI) were determined by shaking 1 g of soil with 50-ml 1% citric acid for 4-hours on reciprocating shaker, and then allowed to stand overnight. It was further shaken for 1-hour the following day and centrifuged for 15-minutes at 2,000 rpm. The clear supernatant was filtered through Whatman No. 42 paper into a polyethylene bottle. The silicon concentration was determined by the colorimetric molybdenum blue method (Kilmer, 1965), and iron by the &, &^{1} dipyridyl (Heaney and Davison, 1977) method.

The value obtained as the sum of products of the extractable *silicon (ppm)* of a horizon and the corresponding horizon depth (cm), of every horizon in a profile, as a ratio of the profile depth (cm), gives the silicon content of the whole profile. Similar technique was used to calculate the silicon content of the surface 15-cm soil depth when the surface genetic horizon is less than 15 cm deep. Citric acid extractable iron in whole soil profile and surface 15 cm soil depth were similarly calculated.

Results and Discussion

Labile Pool of Silicon and Iron:

The CAES in 32-representative southwestern Nigerian soil profiles studied varied from 17 to 500 ppm, with an average of 205 ppm (Table 1). The drainage is the first criterion used in the identification of soil series in southwestern Nigeria (Smyth and Montgomery, 1962; Moss, 1957), and CAES in the different drainage categories differed significantly. Soils with increasing drainage problems generally had increasing amounts of CAES (Fig. 2). For instance, well drained, poorly and imperfectly drained soils had averages of 150, 245 and 373 ppm CAES respectively. The well drained soil profiles had an average of 374 ppm CAEI, whereas poorly, very poorly and imperfectly drained soils had averages of 1109, 957 and 1007 ppm CAEI, respectively. The amount of iron present and its distribution appear abundant for most crops.

The CAES of the surface soils (0-15 cm) varied from 39 to 479 ppm, whereas in some 50 East African soils, it was 130 to 2,800 ppm (Birch, 1953). It was reported that wheat crop in those soils had no response to P-application when CAES exceeded 1,800 ppm (Birch, 1953). Duplessis and Du T Burgen (1966) indicated that P-uptake in wheat was increased with silica application. Increase in vigour and yield of rice was reported (Okuda, 1965; Rodrigo, 1964; Sanchez, 1976 and Huang *et al.,* 1980) due to silicate applications which enhanced more erect habits, great tolerance of insect and disease attack, lower uptake of Fe and Mn when present in toxic amounts and a rise in the oxidizing power of rice roots. The low surface soil CAES in some soils studied could become a limiting factor in continuous rice production.

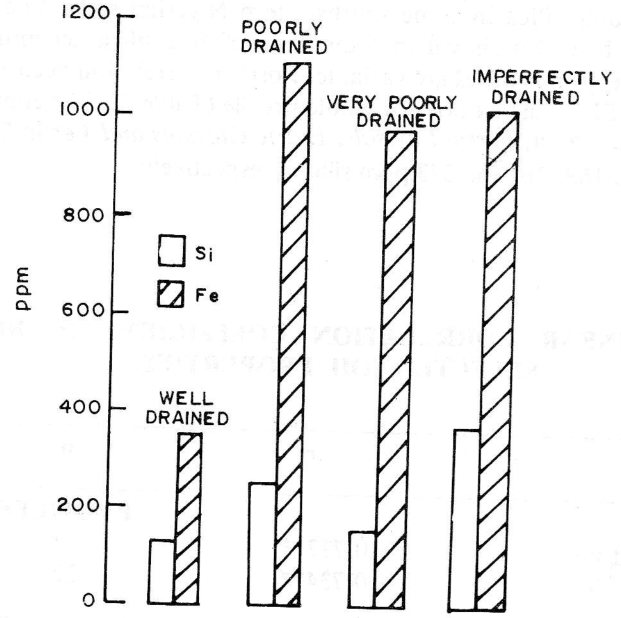

FIG. 2: CITRIC ACID SOLUBLE SI AND FE DISTRIBUTION IN SOIL PROFILE OF DIFFERENT DRAINAGE CONDITIONS.

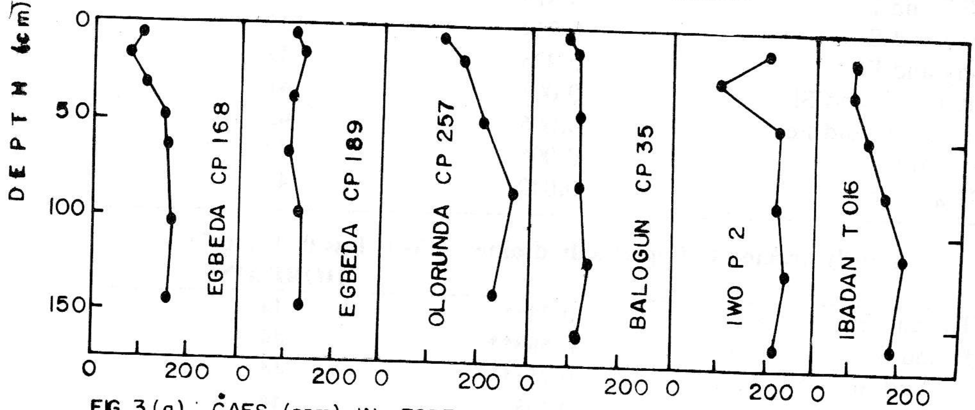

FIG. 3 (a) : CAES (ppm) IN FOREST WELL DRAINED SEDENTARY SOILS ON BASEMENT COMPLEX ROCKS

In general, there is an increase in CAES subsoils (Fig. 3a, b, c, d, e and f). Slight differences were observed in CAES distribution between horizons within a profile and between comparable horizons of different profiles of the same soil series. Herbillion *et al.* (1977) also reported a similar trend in water or dilute HCl soluble silica in some southwestern Nigerian soils. The work of Ashaye (1969) had also shown that the zone of free silica accumulation in sedimentary area soil profiles are variable. Positive correlation occurs between CAES and CAEI in surface soils or whole profile (Table 2). The common soil units in the study area, *Ferric Luvisols, Eutric Gleysols and Vertic Cambisols* had averages of 169, 210 and 373 ppm silicon respectively.

Table 2: LINEAR CORRELATION COEFFICIENT (r) BETWEEN SELECTED SOIL PROPERTIES.

Pair	r	n
All soils		**PROFILES**
Surface Si and Fe	0.777**	32
Profile Si and Fe	0.734**	32
Well drained Soils (Class 4)		**HORIZONS**
CEC and Si	0.821**	35
CEC and Fe	0.419*	35
Clay and Si	0.234	35
Clay and Fe	0.228	35
Organic C and Si	0.003	41
Organic C and Fe	0.006	42
pH and Si	0.006	42
pH and Fe	0.040	42
Poorly drained to imperfectly drained soils (Class 0, 1 and 2)		**HORIZONS**
CEC and Si	0.785**	44
pH and Si	0.583**	44
Clay and Si	0.455**	44
Organic C and Si	0.138	44
CEC and Fe	0.106	44
Clay and Fe	0.030	44
pH and Fe	0.002	44

*, ** significant at the 5 and 1% levels respectively.

Extractable silicon and some soil properties:

Well drained soils: The surface horizons from 18 well drained soil profiles had an average of 110 ppm CAES and were lower than that of the whole profiles. The low CAES in the surface soils could have been due to low clay content in the surface horizon which are primarily sandy loam or loamy sand. There is a significant positive correlation between the CAES of the surface horizon and whole profile (Table 2). The linear relation between CAES in surface soils (CAESS) and whole profile (CAESP) can be expressed thus:

$$CAESP = 0.758\,(CAESP) + 72.4.$$

Such a relationship could be used in the study area to predict the CAES of a profile from a single determination of that of the surface hoziron.

In the well drained soil horizons, CEC is positively correlated ($r = 0.821^{**}$) with CAES. Though kaolinite is the dominant clay mineral in the soil from upper and middle slope positions, increasing amount of high activity clays like hydrous mica, vermiculite, montmorillonite and 2:1 to 2:2 intergrades, particularly in the lower slope positions (Gallez *et al.*, 1975; Iler, 1955; Marion *et al.*, 1976; Moormann *et al.*, 1975, and Nair and Aiyer, 1968), could contribute to higher CEC and CAES. In these well drained soils, no significant correlation occurs between CAES and clay, organic carbon or pH. The work of Sadiq *et al.*, (1980) shows lack of correlation between extractable silica and physical or chemical properties of soils.

Alagba, Mole and Kulfo series from sedimentary area had lower CAES of 101 ppm than the well drained soils from the metamorphic area with an average of 167 ppm. An earlier work by Herbillon et al. (1977) at I.I.T.A. also indicated that less than two ppm NaCl extractable silica were present in the sedimentary soils compared to 2.3 to 4.3 ppm in the metamorphic area. Low CAES were also reported in the sedimentary area by Ashaye (1969). Ogunwale and Ashaye (1975) observed that the parent materials in the sedimentary area of southewestern Nigeria had undergone at least one cycle of weathering, and that the soils have low activity clays, dominated by kaolinite (Gallez et al., 1975). The work of Ashaye (1969) indicated that free silica in some soils from the sedimentary area followed the zone of sequands and argillans, but no particular trend was observed in the CAES of the sedimentary soils examined.

Very poorly to imperfectly drained soils:

Soils under poor drainage categories have high CAES (Fig. 3 e, f, g), and are in agreement with the views of Nair and Aiyer (1968) and D'Hoore and Coulter (1972). Among the four drainage categories investigated soils had the presence of montmorillonite in these soils (Ashaye, 1972) could have contributed to the high CAES (Beckwith and Reeve, 1963b).

The surface horizon of Ofiki series belonging to very poorly drained category had a very high CAES of 423 ppm. Among the poorly drained soils, the sandy Matako profile had the lowest CAES of 55 ppm and clayey Osun series had the highest content of 500 ppm. Significant correlation occurs between CAES and CEC, pH or clay content (Table 2) in the very poorly to imperfectly drained soils.

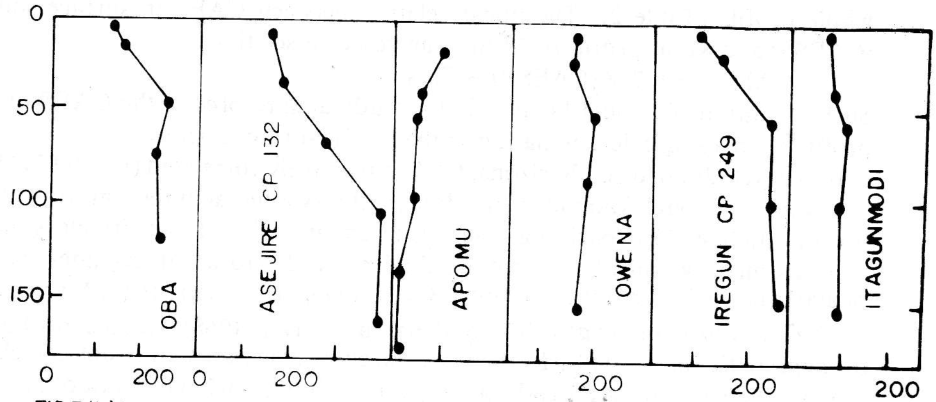

FIG.3(b): CAES (ppm) IN FOREST WELL DRAINED HILL WASH SOILS ON BASEMENT COMPLEX ROCKS.

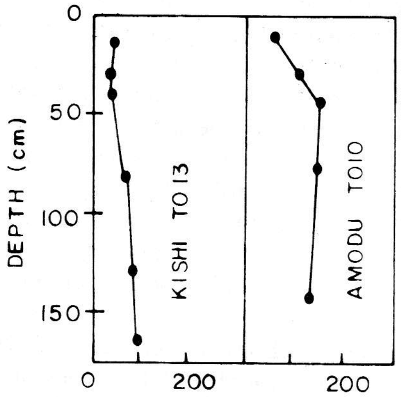

FIG. 3(c) CAES (ppm) IN SAVANNA WELL DRAINED SOILS ON BASEMENT COMPLEX

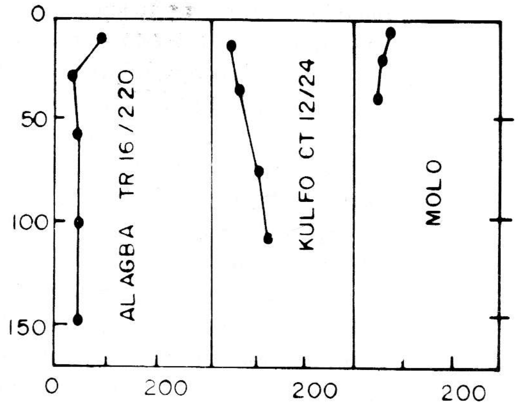

FIG. 3(d) CAES (ppm) IN WELL DRAINED SEDIMENTARY ENVIRONMENT

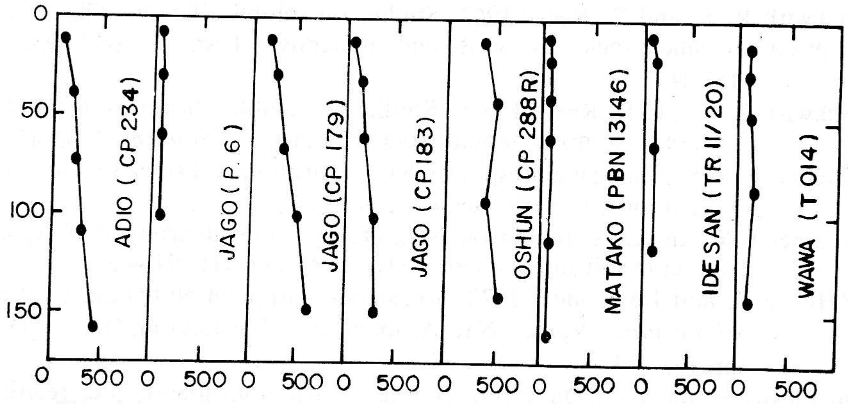

FIG. 3(e) : CAES (ppm) IN POORLY DRAINED SOILS.

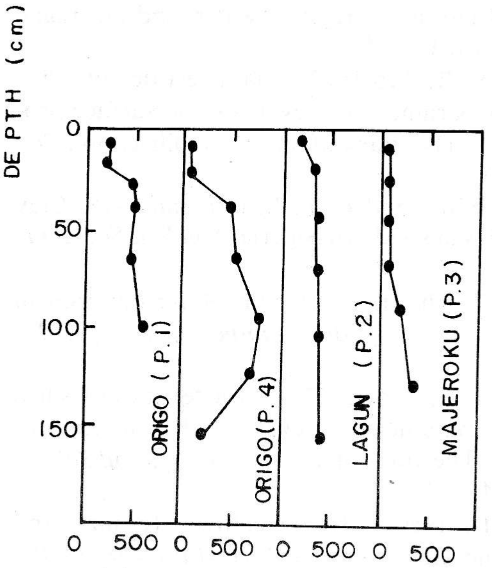

FIG. 3(f) : CAES (ppm) IN IMPERFECTLY POORLY DRAINED SOILS.

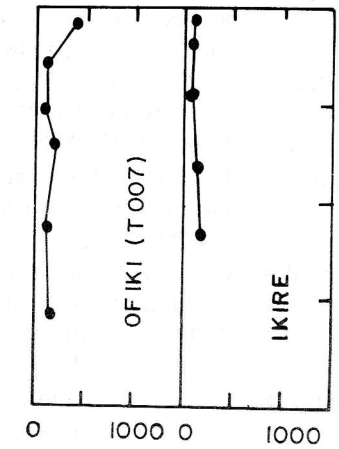

FIG. 3(g) : CAES (ppm) IN VERY POORLY DRAINED SOILS.

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