Characteristics and management problems of Vertisols in the Nigerian savannah

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Abstract

The Vertisols in Nigeria occur mainly in the Savannah region. Extensive occurrences are restricted mainly to the northeastern part of the country bounded by latitudes 8°30' and 12°30'N and longitudes 10° and 14°E.

The soils are developed mainly on calcareous materials which include lagoonal clays, olivine basalt, ancient alluvium and shales, all of Quaternary or Cretaceous origin. The Ngala Vertisols are usually underlain by a sandbed within 100-200 cm depth. All the soils, except the Ngala series, exhibit gilgai microrelief features. Calcium carbonate and Fe-Mn nodules or concretions are also common features in all the soils.

Clay contents range from 42 to 75%, and soil pH from 6.3 to 8.0. The soils are non-saline, but are mildly to strongly sodic, especially the subsoils. They are high in basic cationic nutrients, but are very low in organic matter, N. P and Cu.

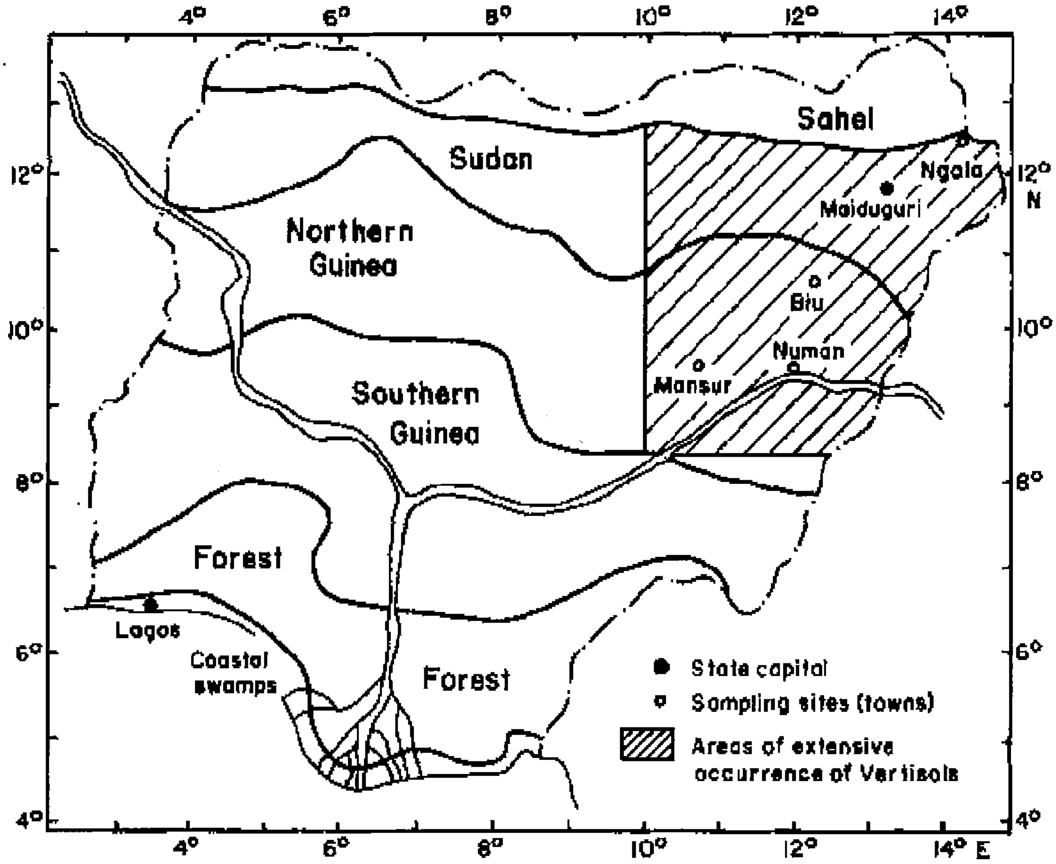
Management problems discussed include cultivation problems due to extreme stickiness of the soils when wet and their intractability when dry, and the lack of appropriate tillage implements. Other problems are those related to seasonal flooding, nutrient deficiencies, sodicity in irrigated fields and soil erosion. The potential productivity of the soils is probably quite high, but a number of management problems must be solved before this potential can be fully exploited. Some integration of livestock and crops would seem workable.

Introduction

The Vertisols in Nigeria occur over an area of about 4 million ha, between latitudes 8°30' and 12°30'N and longitudes 10° and 14° E within the savannah ecological zone of the country (Klinkenberg and Higgins, 1968). The bulk of Nigerian Vertisols occur in the Sudan and Northern Guinea Savannah zones in the northeast of the country (Figure 1) in subhumid and semi-arid environments. The mean annual rainfall in the area ranges from 500 to 1000 mm, most of it falling between May and September. The mean annual potential evapotranspiration ranges from 1600 to 2000 mm, while mean annual air temperatures vary from 24 to 28°C (Kowal and Knabe, 1972).

Unfortunately, except for a few very restricted studies of the soils (Tomlinson, 1965; Klinkenberg and Higgins, 1968; Siewierski et al, 1982; Esu, 1983), little is known about their properties and peculiar problems of their management. Large Vertisol areas are still uncultivated, although some are fairly intensively grazed.

Figure 1. Major vegetation zones of Nigeria.



This paper examines the properties of Nigerian savannah Vertisols, and highlights some associated management problems of these soils.

Materials and methods

Study area

Representative pedons were sampled from Ngala, Biu, Numan and Mansur (Figure 1). The Ngala Vertisols are derived from Quaternary lagoonal clay deposits of the Chad Basin formation and are found on the nearly level "Firki" clay plains (Tuley, 1972). The Firki clay plains are often interspersed by a number of sand islands, while the vertic clay deposits are often underlain by a sandbed at variable depths of 100-200 cm. The Biu Vertisols are found on the flat to gently sloping Biu plains, and are derived from Tertiary to recent calcareous olivine basalt (Esu, 1983). They have also been described as lithomorphic Vertisols by Klinkenberg and Higgins (1968). The Numan Vertisols are derived from Quaternary alluvium underlain by Bima sandstone and are found on nearly level plains. The Mansur Vertisols are located on gently sloping terrain (2-4%) and are derived from Tertiary clays and shales of the Kerri-Kerri formation (Bowden, 1972).

Field studies

Vertisols in northeastern Nigeria which were previously mapped by remote sensing were surveyed. At Ngala, Biu, Mansur and Numan, where extensive occurrences were delineated, a number of auger borings and one or two representative pedons were studied to give a broad overview of the main soil characteristics. Bulk soil samples were collected from seven representative pedons for laboratory analysis.

As part of the field study, a number of large-scale farm projects located on Vertisols were visited, including the wheat fields of the South Chad Irrigation Project in the Ngala area, the sugarcane plantations of the Savannah Sugar Company in Numan and a number of private cotton, sorghum, and maize farms. During the visits extension staff and farmers discussed current management problems and how such problems were being solved.

Laboratory studies

Soil samples were air-dried, ground and passed through a 2-mm sieve. Physico-chemical properties were determined according to standard laboratory procedures.

Results and discussion

Morphological properties

The most striking feature of the soils is the occurrence of numerous wide, oblique and vertical cracks which divide the surface into "microslabs" when the surface is dry. When water is poured on them, the "slabs" expand visibly and the small cracks seal. In addition to the cracks, gilgai microrelief features are in the form of either microknolls and basins or low mounds and shallow depressions. These features are strongly expressed in the Biu, Numan and Mansur Vertisols.

In general, the surface soil structure is very unstable. Structural units slake instantaneously when moistened, so that the granulated surface layer easily turns into mud, and the soil becomes very sticky. This phenomenon is most common in the Mansur and Numan Vertisols but also occurs in the Biu and Ngala Vertisols. The substrata of the Biu, Numan and Mansur Vertisols are often massive due to high amounts of moisture retained in the soil even during the peak of the dry season. However, the Ngala Vertisols, perhaps because of the underlying sand layer which helps to drain the substratum, often maintain continuous strong, coarse and prismatic structural units.

In general, the soils are calcareous, the $CaCO_3$ being present in the form of nodules or concretions. Manganiferrous concretions and Mn nodules are common in the Ngala, Biu and Numan Vertisols, but are abundant in the Mansur Vertisols.

The colour of the A-horizon is dominantly hue 10YR for the Ngala and Numan Vertisols, and 5Y and 2.5Y for the Biu and Mansur Vertisols, with moist values ranging between 3 and 5. Chromas rarely exceed 1.5 except in the Mansur Vertisols, which are on slopes. According to the criteria of *Soil Taxonomy (*Soil Survey Staff, 1975), the Ngala, Biu and Numan Vertisols may be classified as Pellusterts, while the Mansur Vertisols are classified as Chromusterts. These are equivalent to Pellic and Chromic Vertisols, respectively, in the FAO/Unesco system (FAO/Unesco, 1974).

Particle size distribution

The dominent textural class of these Vertisols is clay (Table 1). In general, the Ngala and Numan Vertisols, which appear to be better drained than the other Vertisols, contain the highest amounts of clay, while the Biu and Mansur Vertisols have lower clay contents.

Sand content in the Ngala Vertisols increases with depth to the underlying sand layer, while the silt content decreases rapidly from the surface to the substrat. The Biu Vertisols, perhaps because of their basaltic origin, have a rather low sand content (14-16%), while the silt content is almost as high as the clay content.

Table 1. Particle size distribution and selected chemical properties of representative pedons.

Depth (cm)	Particle size distr.. pH			1:2.5 water	EC (dS m^{-1})	Organic C (%)	Total N (%)	Available-P (Bray I) (ppm)
	Sand (%)	Silt (%)	Clay (%)					

Ngala Vertisols on lagoonal clays								
Pedon 1 Typic Pellustert (USDA)/Pellic Vertisol (FAO)								
0-50	18	31	51	6.8	0.42	0.42	0.20	trace
50-85	15	27	58	7.9	0.74	0.32	0.06	trace
85-105	20	14	68	7.9	1.52	0.20	0.06	trace
160-180	97	3	nil	8.6	0.66	-	-	-
Pedon 2 Typic Pellustert (USDA)/Pellic Vertisol (FAO)								
0- 60	7	21	72	6 3	0.38	0.28	0.14	trace
60-113	17	11	72	7 3	1.12	0.30	0.14	trace
113-178	22	6	72	7.4	0.96	0.20	0.08	trace
178-218	25	8	67	7 4	2 20	-	-	-
218-225	92	4	4	8 0	0.52	-	-	-
Biu Vertisols on olivine basalt								
Pedon 3 Entic Pellustert (USDA)/Pellic Vertisol (FAO)								
0-60	14	42	44	6.3	1.20	0.40	0.17	0.7
60-115	14	42	44	7.8	1.60	0.40	0.08	1.4
115-160	14	38	48	8.0	3.20	0.40	0.14	1.4
Pedon 4 Entic Pellustert (USDA)/Pellic Vertisol (FAO)								
0-20	14	42	44	7.0	1.10	0.93	-	0.7
20-87	15	41	44	7.8	2.80	0.70	-	trace
87-120	16	36	48	7.8	1.90	0.71	-	trace
Numan Vertisols on ancient alluvium								
Pedon 5 Typic Pellustert (USDA)/Pellic Vertisol (FAO)								
0-25	8	22	70	7.4	0.16	0.72	0.18	trace
25-135	7	18	75	7.8	0.11	0.48	0.13	trace
135-180	11	16	73	7.8	0.34	0.42	0.13	0.35
Mansur Vertisols on clay and shales								
Pedon 6 Entic Chromustert (USDA)/Chromic Vertisol (FAO)								
0-25	28	20	52	6.9	0.06	0.89	0.05	11.10
25-43	26	22	52	7.2	0.05	0.87	0.11	8.34
43-100	32	22	46	7.6	0.07	1.59	0.05	8.34
Pedon 7 Entic Chromustert (USDA)/Chromic Vertisol (FAO)								
0-31	34	24	42	6.6	0.08	1.41	0.06	0.34
31-69	34	16	50	6.9	0.06	0.73	0.04	1.38
69-117	36	18	46	7.2	0.52	0.73	0.03	1.81

The Mansur Vertisols contains the highest sand fraction, while the Numan Vertisols have the lowest sand and silt contents.

Chemical properties

Soil reaction

Soil pH in all the soils ranged between 6.3 and 7.4 for the surface soils and 6.9 to 8.0 for the subsoils (Table 1). In general, the pH increases with depth, perhaps corresponding to increased $CaCO_3$ and exchangeable Na contents (Table 2).

The soils are not saline. The electrical conductivity of the saturation extract averages less than 1.0 ds m-1 in the surface soils and less than 3.0 dS m-1 for the subsoils (Table 1). Sodicity is also not yet a major problem since the ESP is within the favourable limits of less than 15%, except for the Ngala Vertisols where ESP values range from 7.3 to 52.2% from the surface to the subsoil (Table 2). However, given the slow permeability of the soils and the high rate of evapotranspiration during the dry periods of the year, the soils are likely to become sodic under irrigation, especially because the ESP values generally increase with soil depth.

Organic carbon, total N and available P

Despite the generally dark colour of the soils, the organic carbon hardly exceeds 1.0%. The distribution of organic matter is uniform throughout the profile, although subsoil organic C contents in some of the Mansur Vertisols are higher than surface soil values (Table 1). This is probably because of considerable pedoturbation within the profile as the soils expand, contract, crack and self-mulch. Zein et al (1969) have calculated that in a Sudan Vertisol, 0.33% of the surface soil was mixed into the subsoil over a 2-year period.

Table 2. Selected chemical characteristics of representative pedons.

Depth (cm)	Exchangeable cations (meq/100 g soil)				CEC (pH 8.2)	ESP (%)	Extractable		
	Ca	Mg	K	Na			Fe (ppm)	Zn (ppm)	Cu (ppm)
Ngala Vertisols on lagoonal clays									
Pedon 1 Typic Pellustert (USDA)/Pellic Vertisol (FAO)									
0-50	21.2	7.1	1.2	3.8	28.3	13.4	9.0	2.32	trace
50-85	20.1	6.9	1.6	6.7	37.9	17.7	0.8	1.04	trace
85-105	21.5	8.7	1.8	8.5	39.6	21.5	6.0	1.06	trace
105-160	16.8	8.1	1.7	10.0	38.5	26.0	-	-	-
160-180	2.2	0.7	0.2	1.2	2.3	52.2	-	-	-
Pedon 2 Typic Pellustert (USDA)/Pellic Vertisol (FAO)									
0-60	27.0	8.9	0.7	3.5	48.2	7.3	5.0	4.48	trace
60-113	26.7	8.4	0.4	4.4	43.0	10.2	4.0	2.32	trace
113-178	22.8	7.5	0.3	4.2	38.6	10.9	3.4	2.64	trace
178-218	21.3	6.9	0.2	4.1	38.8	10.6	-		
218-225 3.0	0 8	0.1	1.1	4.0	27.5	-	-	-	
Biu Vertisols on olivine basalt									
Pedon 3 Entic Pellustert (USDA)/Pellic Vertisol (FAO)									
0-60	12.5	7.20	0.54	0.43	23.6	1.8	2.2	2.24	trace
60-115	13.28	7.71	3.08	0.98	25.6	3.8	8.0	1.060	trace
115-160	15.63	9.56	3.85	2.28	31.4	7.3	1.6	1.12	trace
Pedon 4 Entic Pellustert (USDA)/Pellic Vertisol (FAO)									
0-20	15.22	4.69	0.60	0.78	27.1	3.7	-	-	-
20-87	18.46	5.10	0.60	2.83	32.4	10.5	-	-	-
87-120	13.97	5.51	0.80	5.22	29.1	20.5	-	-	-
Numan Vertisols on ancient alluvium									
Pedon 5 Typic Pellustert (USDA)/Pellic Vertisol (FAO)									
0-25	21.75	9.87	1.54	0.78	34.94	2.2	0.6	0.60	trace
25-135	22.00	10.20	1.28	1.57	36.05	4.4	0.6	0.72	trace
135-180	19.50	11.84	2.84	4.34	39.52	11.0	0.6	0.88	trace
Mansur Vertisols on clay and shales									
Pedon 6 Entic Chromustert (USDA)/Chromic Vertisol (FAO)									
0-25	17.50	8.08	0.36	1.35	36.6	3.7	-	1.36	trace
25-43	11.67	8.88	0.25	0.85	42.0	2.0	-	2.64	trace
43-100	16.67	8.88	0.83	0.29	42.0	1.3	-	1.52	trace
Pedon 7 Entic Chromustert (USDA)/Chromic Vertisol (FAO)									
0-31	10. 75	7.50	0.49	0.28	32.0	0.9	-	1.12	trace
31-69	10.75	8.33	0.27	0.86	28.8	3.0	-	1.12	trace
69-117	12.13	7.50	0.31	2.17	30.8	7.0	-	0.80	trace

Contents of N and P. like the organic matter content, are very low and probably limit the production of most crops. Total N ranges from 0.06 to 0.20% in all the soils, while available P was either present only in trace amounts or in most cases completely absent in the entire profile. Only Pedon 6 of the Mansur Vertisols contained appreciable amounts of available P (Table 1).

Exchangeable bases and cation exchange capacity *(CEC)*

Data related to exchangeable bases (Table 2) show that the soils have very high base status with Ca, followed by Mg, dominating the exchange complex. Levels of exchangeable K are in general adequate to support the production requirements of crops such as wheat, maize, rice, sorghum, and millet.

The CEC (pH 8.2) is high for all the soils and ranges from 23.6 to 48.2 meq/100 g of soil. As with the values for organic C, there appears to be no consistent change in sorptive capacity of the soils with depth. Since the organic matter content of the soils is low, it is probable that clay minerals are the major contributors to cation exchange capacity.

Micronutrients

There has been little investigation of micronutrient availability in the Vertisols of the Nigerian savannah. Iron, Zn and Cu status were investigated in this study (Table 2). Of these three, Zn is the most important micronutrient in the area for arable crop production; average Zn content varied from 0.60 to 4.48 ppm, which is slightly higher than the critical level of 1.0 ppm suggested for most crops. Copper is the most important from the livestock point of view, because of the very low amounts in these soils. Indeed, Cu appears to be the most deficient micronutrient in all the soils. Only marginal to low levels of Fe are present in the soils.

Problems of soil management

The Vertisols in Nigeria offer a considerable potential for agricultural development, particularly under irrigation, provided their management problems can be overcome. Large areas remain uncultivated because of the serious problems associated with the soil management. Major efforts to use these Vertisols have involved government-sponsored projects, such as the production of wheat and rice on 2000 ha in the South Chad Irrigation Project on the Ngala Vertisols, and the production of sugarcane on the Numan Vertisols by the Savannah Sugar Company. Other major users are local farmers and a few large-scale entrepreneurs who cultivate cotton, sorghum, maize, cowpea and millet. The vast areas which are presently not cultivated are used mainly as dry-season grazing with no control of stock density and pasture species.

Tillage is a major management problem. The high clay content makes these soils very hard and almost intractable when dry, and consequently they cannot easily be cultivated with a hoe or an ox-drawn plough. Cultivation with specially designed tractor-drawn rotovators is the common practice in the South Chad Irrigation Project and the Savanna Sugar Company plantations, but this gives some compaction problems in the root zone.

Since the Vertisols are generally in flat terrain with poor drainage, they are seasonally waterlogged, especially in years with high rainfall. Consequently, only crops that tolerate waterlogged conditions are grown on the soils. The use of ridges to grow crops that are sensitive to waterlogged conditions could be a useful management strategy. The construction of open ditches/drains to the depth of the underlying sandy layer would considerably ameliorate the problems of waterlogging. These Vertisols of the Nigerian savannah, especially the Mansur Vertisols on gentle slopes, are susceptible to soil erosion. This can be largely attributed to the low infiltration rates, slow permeability and the dominant 2:1 layered silicate expanding clays. Research on the control of soil erosion should be another area of management interest.

The Vertisols in Nigeria are generally well supplied with the basic cationic nutrients (Ca, Mg and K), but are clearly deficient in N. P and some micronutrients, notably Cu. Soil S was not determined in the present study, but widespread S deficiency in northern Nigerian Savannah soils has been reported by Bromfield (1972).

Copper deficiency is likely to pose the most serious micronutrient problem, especially for livestock production. About 45% of Nigerian livestock are found in the area covered by the Vertisols, and for many years this area has been used by nomadic cattle herders. So far, seasonal movement of herds in search of 'green pastures', has protected the vegetation of the savannah Vertisols from overgrazing.

The use of such fertilizers as sulphate of ammonia might be preferred on these soils. Phosphate and some micronutrient fertilization will also obviously be inevitable. Few fertilizer experiments have been done to determine the nutrient requirements of crops on these soils. There is also a need to study the feasibility of integrating forage legumes into food crop systems under smallholder conditions.

Acknowledgement

The report covers part of a current study being funded by the Ahmadu Bello University Board of Research.

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