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P status and sorption capacities of some native rangeland soils in northern Nigeria

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ABSTRACT

A study was conducted to determine the phosphorus (P) status of some soils carrying native pastures in northern Nigeria. Sorption capacities and forms of P in these soils were also studied. Consequently, soils developed from basement complex were obtained from nine locations in the zone for the study. Total P and available P contents of these soils were low. Available P ranged from 4.18 to 9.65 mg kg^{-1} while total P ranged from 133 to 235 mg kg^{-1} with a mean of 187.8 mg kg^{-1}. Organic P accounted for about 7.65 to 21.8% of the total P. The relative abundance of the P forms was in the order; Residual P> Organic P> Fe-P>Ca-P > AI-P. There was a clear dominance of the inactive over the active forms, which partly explains the low available P in the soils. The sorption of added P varied with the soils, and was generally high. The P sorption capacity was positively related to the clay content ($r= 0.71$, $P< 0.05$) and Fe_2O_3 content ($r= 0.70$, $P= 0.05$). The low contents of total and available P in these soils is an indication that plants growing on these soils are not likely to obtain an adequate supply of P for good growth and development without P fertilizer application.

Key words: Basement complex, native rangelands, P fractions, P sorption capacities.

INTRODUCTION

Northern Nigeria falls within the savanna area which is characterized mainly by grasses and scattered shrubs and trees. Rainfall ranges from about 250mm in the arid to 1500mm per annum in the sub-humid zone. The distribution of soils indicates that over 50% is covered by ferruginous tropical soils (Mohammed-Saleem 1986). Using orders names of the U.S. Soil Taxonomy, ultisols and alfisols occur in the Sub-humid zone (SHZ), whereas the semi-arid zone (SAZ) consists mainly of entisols (Enwezor *et al.* 1989).

Forage grasses and legumes grow on a variety of soils in northern Nigeria. A good knowledge of the general nature of these soils, particularly their fertility status, enables prediction of the kind of soil amendment or fertilizers likely to be required. Phosphorus is one of the essential elements required by plants and animals for proper growth and development, yet after N, P is the most limiting nutrient in tropical soils (Anon. 1990). Phosphorus has been shown to be deficient in some locations in the zone (Mohammed-Saleem 1986; Mohammed-Saleem *et al.* 1986; Mohammed-Saleem and Otsyina 1987). However, how wide-spread the deficiency of P in these soils is not well known.

The relative abundance of different P forms and the capacity of a soil to fix P are useful parameters for assessing the availability of P in a soil (Udo *et al.* 1984). The soils of northern Nigeria are mainly the ferrugionous type which are derived from pre-to upper-cambrian basement complexes, most of which have been classified as Entisols, Ultisols and Alfisols (Enwezor *et al.* 1989).

Besement complex soils are principally composed of metamorphic and igneous materials. Over most of the areas underlain by basement complex, there is a discontinuous mattle of weathered genesis and granite but this is generally thin with a high clay content which does not serve as an efficient aquifer (Kowal and Knabe 1972).

In soils of the humid tropics, P deficiency has been found to be widespread (Olson and engelstad 1972). The low availability of P in tropical soils is attributed to the nature of the chemical forms of soil P and the high contents of oxides of Fe and Al which are associated with high P fixation (Udo 1981). For instance, phosphorus fixation is recognized as the major obstacle to agricultural development of volcanic ash soils in Hawaii, where upwards of 1,350 kg of phosphorus per hectare may be needed to satisfy the P fixation capacity (Younge and Plucknett 1966), although P availability to plants grown on tropical soils varies with the morphological properties of the soil, previous management, and the local climatic conditions (Olsen and Engelstad 1972).

The purpose of the study was to evaluate the P status of some soils derived from basement complex by studying the sorption capacity as well as the distribution of various P forms in selected soils of northern Nigeria.

The results from this study are expected to provide background or baseline information for managing soils of similar origin or physico-chemical properties in other parts of the tropics.

MATERIALS AND METHODS

Nine locations namely: Kurmin Biri, Kagoro, Lafia, Lere, Kontagora, Shika (Sub-humid zone - SHZ); Kano, Fika and Maiduguri (Semi-arid zone-SAZ) that spread over the major soil areas as indicated by Enwezor *et al.* (1989) were sampled. Thirty samples per hactare per location and soil were taken at 0-20 cm (surface) and 20-60 cm (sub-surface) depths. These samples were air-dried and sieved through a 2 mm mesh sieve. Some of the composite samples were ground to pass through 0.5 mm mesh for organic carbon determination. Soil analysis was done in triplicate.

Particle size analysis was carried out by the hydrometer method (Bouyoucos 1962), organic carbon by the method of Allison (1965) and pH was determined using a soil: water ratio of 1:2. Available P was extracted by Bray P1 solution (Jackson 1969). Phosphorus in the extracts was determined colorimetrically (Murphy and Riley 1962). The free Fe and Al ioxides of soils (0-20 cm) were extracted with Na dithionite-citrate bicarbonate solutions (Mehra and Jackson 1960).

Total P was determined by $HC10_4HF$ digestion method (Jackson 1964) and organic P by the ignition method (Saunders and Wiliams 1955). Inorganic P fractions (Ca-P, AI-P and Fe-P) were determined according to the procedure of Chang and Jackson (1957). The residual P was taken as the difference between Total P on one hand and inorganic and organic P on the other hand, as follows (Udo 1981).

Residual P= Total P - (Organic P + Inorganic P).

P sorption studies were carried out using surface soil (0-20 cm) from the nine locations. This was done by equilibrating 3 g soil sample in 30 ml of 0.01 M $CaCl_2$ containing various amounts of $Ca(H_2PO_4)_2$ to represent 0, 10, 20, 30 and 40 mg kg^{-1} of P for six days at 25^0C (Fox and Kaprath 1970; Fox 1974). The suspensions were shaken for 30 minutes twice daily. A few drops of toluene were added to suppress microbial activity. After equilibration, the P in the equilibrium solution was determined by the method of Murphy and Riley (1962). The reduction in solution P concentration after equilibration was taken as the P sorbed by the soils. The analyses were done in triplicate and the means recorded. The relationships among some soil parameters were carried out using simple linear regression (Finney 1965).

RESULTS AND DISCUSSION

Some pertinent physical and chemical properties of the soils are presented in Table 1.

The soils were either moderately acidic (pH 5-6) or slightly acidic (pH 6-6.5) at the surface. The majority of the surface soils fell within the 6.0-6.5 pH range. Particle size analysis showed that the texture of soils varied from sand to sandy clay loam, with clay content between 6 to 20% at the surface and sand content between 60.8 to 88.8%. The high sand content is a characteristic of soils of northern Nigeria (Mohammed-Saleem 1986; Kowal and Knabe 1972).

The soils had low organic C contents which were lower in the sub-surface soils than in the surface soils. Organic C content varied from 0.17 in Kano (SAZ) to 1.63% in Lere (SHZ) at the surface.

The amorphous oxide contents were low in all the soils. The Fe_2O_3 contents of the soils ranged from 0.27 to 1.25% while the AI_2O_3 contents of the soils ranged from 0.05 to 2.84% (Table 1).

Total P

The amounts and distribution of the various forms of P in the surface soils are given in Table 2. Total P contents ranged from 133 to 235 mg kg^{-1}. The total P has been shown to be much lower throughout northern Nigeria than in the South; with values varying from 40 to 600 mg kg^{-1} with a mean of 100 mg kg^{-1} (Anon. 1964). The total P values of the soils are therefore comparable with the range reported for alfisols of the Savanna of northern Nigeria.

Organic P

The soil organic P contents ranged from 18 mg kg^{-1} in the SAZ to 40.7 mg kg^{-1} in the SHZ (Table 2). The organic P contents accounted for a substantial percentage of the total P. For Savanna soils of northern Nigeria, values that range from 20 to 40% have been reported with most figures varying between 20 and 25% (Olaitan and Lombin 1985). The organic P values in the present study varied between 7.65 and 21.8% of the total P with only two locations, Kurmin Biri and Lere, constituting above 20%. The organic P levels were lower in areas located in the SAZ (Fika, Maiduguri and Kano) than the SHZ areas (Table 1).

In tropical soils, a substantial fraction of P supply is known to come from the mineralization of organic P (Olson and Engestad 1972). The readiness of the

Table 1. Some physical and chemical properties of the soils used in the study.

Soil	Depth (cm)	pH (1:2 H_2O)	Organic C, %	Sand, %	Silt, %	Clay, %	DCB Fe_2O_3	Extractable Al_2O_3	Available P mgkg^{-1}
Kurmin Biri	0-20	5.8	0.67	60.8	19.2	20.0	0.74	0.12	4.5
	20-60	5.7	0.33	52.8	21.2	26.0	ND	ND	1.42
Fika	0-20	5.6	0.41	88.8	5.2	6.0	0.44	0.25	5.30
	20-60	6.7	0.31	74.8	15.2	10.0	ND	ND	2.96
Kontagore	0-20	6.5	0.91	62.8	31.2	6.0	0.34	0.16	5.35
	20-60	6.1	0.12	52.8	35.2	12.0	ND	ND	0.51
Maiduguri	0-20	6.1	0.35	76.8	15.2	8.0	0.30	0.36	4.18
	20-60	6.2	0.14	84.3	6.0	9.7	ND	ND	2.57
Kano	0-20	6.3	0.17	88.3	5.2	6.0	0.27	0.05	9.65
	20-60	6.1	0.14	82.8	11.2	6.0	ND	ND	2.57
Shika	0-20	6.3	0.60	78.8	13.2	8.0	0.94	2.84	8.00
	20-60	6.0	0.45	84.8	9.2	6.0	ND	ND	1.35
Kagoro	0-20	5.8	0.27	68.8	21.2	10.0	1.25	0.12	8.17
	20-60	5.6	0.16	16.3	22.0	11.2	ND	ND	0.32
Lere	0-20	6.4	1.63	62.8	27.2	10.0	0.55	0.26	8.00
	20-60	5.7	0.67	56.3	28.0	15.7	ND	ND	0.84
Lafia	0-20	6.3	1.15	68.8	25.2	8.0	0.68	0.24	7.88
	20-60	6.1	0.14	86.8	7.2	6.0	ND	ND	1.61

ND =Not determined
DCB =Dithionite citrate bicarbonate
* values are means of three replicates

Table 2. Forms and distribution of phosphorus in the surface soils of northern Nigeria.

	Forms of P (mg kg^{-1})					
Soil	Organic	Ca	Al	Fe	Residual	Total
Kurmin Biri	27.9	2.5	0.2	27.1	95.3	133
Fika	21.5	8.3	0.4	4.6	157.2	192
Kontagora	20.3	2.5	0.2	4.4	155.6	183
Maiduguri	17.8	9.2	0.4	5.6	145.9	179
Kano	18.0	7.0	0.2	3.4	206.1	235
Shika	18.9	1.7	0.4	5.2	156.3	180
Kagoro	32.1	4.2	0.2	7.1	164.4	208
Lere	36.4	3.7	0.2	10.7	116.0	167
Lafia	40.7	4.9	0.3	15.0	149.1	210

* values are means of three replicates

organic P to mineralize and extent of the availability of the mineralized P are dependent on the organic C: organic P ratio. Low C:P values generally indicate fast mineralization and high availability of mineralized P (Sare and Udo 1988). The low C:P values in these soils suggest fast mineralization of organic P which is expected to contribute to the pool of available P.

Inorganic P forms

The total inorganic P comprises active and inactive forms. The former consists of Al-P, Fe-P and Ca-P while the latter of occluded, reductant soluble and residual P (Chang andJackson 1957). The relative abundance of the various inorganic forms was similar in all the soils. On the whole, the inactive residual P formed about 79% of the total P while organic P formed about 14.2%. This means that most of the soil P were in the unavailable form which the plants cannot use. The active forms which were found to be low are generally accepted as the main source of available inorganic P for plants (Thomas and Peaslee 1973).

The relative abundance of the three discrete active forms (Ca-P, Al-P and Fe-P) showed Al-P to be the least while Fe-P was highest. The relative proportion of the various P forms was in the order of Residual P> Organic P> Fe-P>Ca-P>Al-P.

The low content of Ca-P relative to the other forms but Al-P indicates a rather high degree of weathering of the soils. Pedro (1976) noted that inorganic fraction tends to increase with the degree of weathering.

Available P

Values of available P extracted by the Bray-1 method are shown in Table 1. The available P content ranged from 4.18 to 9.65 mg kg^{-1}. Available P is influenced by such factors as pH, free oxides of Fe and Al, and parent material among several others (Enwezor *et al.* 1989). A significant positive correlation (r=0.63, P<0.05) was found between available P and pH while a significant negative correlation was observed with clay content (r= 0.47; P<0.05) (Table 3). Neither Fe_2O_3 nor Al_2O_3 had a significant relationship with available P. However, Fe_2O_3 had a significant role in fixing P in the soil (r=0.70; P<0.05). All the soils had available P less than the critical level of 15 mg kg^{-1} (Adepetu *et al.* 1979) established for Negerian soils for good plant growth.

P sorption capacity

The results of P sorption studies are given in Table 4. Percentage phosphorus adsorbed from the addition of various quantities of P to the soils ranged from 21.67 in Lafia to 98.13% in Kagoro (Table 4). The adsorption capacities of the soils were significantly correlated with clay content (r=0.71; P<0.05) and Fe_2O_3 (r=0.70; P<0.05). There was no significant correlation with dithionite citrate bicarbonate (DCB)

Table 3. Linear correlation coefficients (r) among clay content, available P, Fe_2O_3, Al_2O_3 and pH of soils of northern Nigeria.

	Al_2O_3	Available P	Clay	pH (H_2O) (1:2)	Sorption capacity
Fe_2O_3	0.310	-0.266	0.332*	-0.018	0.695*
Al_2O_3		-0.165	-0.189	-0292	-0.189
Available P			-0.470*	0.630*	-0.016
Clay				-3.334*	0.707*
PH(H_2O) (1:2)					-0.156

*Significant at 5% level

Table 4. Phosphorus sorption capacities of soils at nine locations in northern Nigeria.

Added	Recovered mg kg^{-1}	Sorbed	Sorbed %
Kurmin Biri			
10	0.73	9.27	92.70
20	0.56	19.44	97.20
30	2.10	27.50	91.66
40	4.48	35.52	88.80
Kontagora			
10	4.34	5.66	56.60
20	13.16	6.84	34.20
30	22.96	7.04	23.47
40	36.96	8.04	25.15
Maiduguri			
10	3.64	6.36	63.60
20	9.94	10.06	50.30
30	19.60	10.04	33.47
40	27.72	12.28	30.70
Lere			
10	1.40	8.60	86.00
20	5.32	14.68	73.40
30	10.36	19.64	65.47
40	17.78	22.22	55.55
Fika			
10	2.80	7.20	72.00
20	8.68	11.32	56.60
30	17.50	12.50	41.67
40	27.44	12.56	31.44
Kano			
10	3.64	6.36	63.60
20	11.20	8.80	44.00
30	19.74	10.26	34.20
40	29.12	10.88	27.20
Lafia			
10	4.20	5.80	58.00
20	11.34	8.66	43.30
30	20.72	9.28	30.93
40	31.36	9.64	21.67
Kagoro			
10	0.56	9.44	94.40
20	0.56	19.44	97.20
30	0.56	29.44	98.13
40	0.90	39.10	97.75
Shika			
10	2.52	7.48	74.80
20	9.24	10.76	53.80
30	17.92	12.08	40.27
40	25.63	14.38	35.95

extractable Al_2O_3.

The sorption capacites of the soils were noted to be generally high. The implication of this phenomenon is that it reduces the availability of P to the plants growing on them. It was also noted that adsorption capacities of the soils decreased as more P was added to them (Table 4). These results are in agreement with Adepetu (1981) and Ayodele *et al.* (1983) who noted that the fixation of P in soils in Nigeria is a major obstacle to availability of P to plants. Small applications of P are mostly ineffective until the P fixation capacity has been satisfied, and the amount of P required to satisfy the fixation capacity often must be high (Campbel and Keay 1970). This perhaps explains the results obtained in this study.

Fixation of applied increments of P is far more serious in certain tropical soils than in soils in temperate regions and is related to the clay mineralogy on the amorphous nature of the colloidal hydrate oxides of Fe and Al. Fox *et al.* (1968) working on Hawaiian soils ranked fixation capacities of the soils in the order; amorphous hydrate oxides>gibbsite>geothite>Kaolinite> montmorillonite. The soils used for the present study are mainly kaolinitic types, and have been found to have high sorption capacities.

The low fraction of active P and the high fixation capacity of the soils to adsorb P suggests low availability of P to the growing forages in these soils, which have been reflected in the low biomass and mineral P content of forages in the zone (Omoregie 1995).

The implication of high P fixation lies in the fact that there is need to satisfy or "quench" the soil's phosphorus fixing capacity by heavy P dressings before effective crop response occurs. This also has some economic implications. The average small farmers producing the food crops of the tropics are not likely to bear the cost of phosphorus fertilizer required to satisfy a soil of high fixing capacity. Thus, liming the soil to a higher pH level has been used to enhance P availability to crops in such places as Campo Cerrado soils of Brazil, the eastern plains of Colombia and Ultisols of southeastern United States (Olson and Engelstad 1972).

Rate of phosphorus loss from soils of the tropics is determined primarily by cropping intensity and erosion, leaching being slight except on very sandy soils (Enwezoe *et al.* 1989). Northern Nigeria experiences a rainfall range of 250-1500mm (arid to sub-humid zone) per annum. Consequently, loss of P through erosion and leaching is expected to be minimal. However, intensive cropping is practiced in the zone, because of scarcity of arable land. Hence, loss of P is mostly through crop removal. Gains of P in the soils depend entirely on the amount of P added in manure or commercial fertilizer. Addition of P fertilizer to these and similar soils become inevitable if high yields of crops are to be achieved.

CONCLUSION

The study showed that the soils derived from basement complexes are low in phosphorus and have high capacity to fix this nutrient. The relative abundance of the various P forms indicated that the inactive P and organic forms constituted the major portion of total P, whereas the active P (Fe-P, Ca-P and Al-P) forms were relatively low.

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