International Journal of Development and Sustainability
ISSN: 2168-8662 – www.isdsnet.com/ijds
Volume 3 Number 2 (2014): Pages 268-275
ISDS Article ID: IJDS13072401

Distribution of organic and available forms of phosphorous and micronutrients in the soils of a toposequence in Mokwa, Niger State, Nigeria

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Abstract

Soil samples were collected from an identified toposequence in Mokwa, Niger State of Nigeria, a southern Guinea savannah agro-ecological zone. The sampling sites were the topmost, middle and lowest parts of the slope. The samples were prepared and analyzed for their general characteristics, micronutrients (Copper, Cu; Zinc, Zn; Iron, Fe and Manganese, Mn) and organic and available Phosphorous (P) using standard laboratory methods. The micronutrients were found to be low in values (Cu: 0.03-0.1; Zn: 0.04-0.44; Mn: 0.14-0.51 and Fe: 0.10-0.45 cmol/kg soil respectively). There was no recognizable trend of distribution of these nutrients through the profiles, except for zinc which decreased down the depths in Pedon C. The soils are moderately high in exchangeable cations (Ca: 5.4-16.8; Mg: 2.4-6.8; Na: 1.33-2.17 cmol/kg soil, respectively), have neutral pH (6.9-7.3) and are inherently low in available and organic P (0.1-3.2 and 0.8-6.9 mg/kg respectively) and organic matter (0.62-3.52 mg/kg soil). The nutrient management practices in these soils must include the application of organic manures to boost nutrient availability to crop plants.

Keywords: Micronutrients; phosphorous forms; toposequence; distribution

Cite this article as: Aduloju, M.O. and Abdulmumini, A.A. (2013), "Distribution of organic and available forms of phosphorous and micronutrients in the soils of a toposequence in Mokwa, Niger State, Nigeria", *International Journal of Development and Sustainability*, Vol. 3 No. 2, pp. 268-275.

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1. Introduction

Micronutrients are important essential plant nutrient elements, though needed by plants in small or minute quantities. Without these elements, plants may not be able to complete their life cycles. Iron (Fe) has been recognized as an essential nutrient element a long time ago. Though it is abundant in rocks and soils, it is also one of the most commonly deficient micronutrients (Brady and Weil, 1999). This is due to the fact that many compounds of Iron, comprising the Ferric (Fe^{3+}) and Ferrous (Fe^{2+}) ions are extremely insoluble. The solubility of these ions is much lower at high pH than at low pH values. Both species of iron hydroxide [$Fe(OH)_2$ and $Fe(OH)_3$] can also be precipitated at high pH values. Other iron compounds also become less soluble at higher pH values. Precipitation of previously available Fe may result from over-liming a soil. This Fe deficiency is called lime-induced chlorosis. Iron deficiencies can also result if the soil minerals do not release enough Fe^{2+} to replace that being oxidized year by year to Fe^{3+}. Excess manganese (Mn) and copper (Cu) can also lead to Fe deficiency. These minerals serve as oxidizing agents and convert Fe^{2+} to the more insoluble Fe^{3+} iron. Acid soils which would otherwise have been able to supply Fe to crops would then appear to be deficient in that nutrient element.

Phosphorous is a critical element in nature. Its management is second only to the management of nitrogen in importance for the production of healthy crops and profitable yields. The natural supply of P in most soils is small and the availability of that which is present is low. Information about the forms of P and the amount of these micronutrients in the soils of specific locations in Nigeria is necessary for soil P management for abundant and sustainable crop production.

Limited work has been reported on the forms of P in Nigerian soils. There are reports on the distribution and forms of P in a forest soil profile in Ibadan, south-west Nigeria (Bates and Baker, 1960); and some selected forest and savannah soils in some other areas in Nigeria (Udo and Ogunwale, 1977). Nigerian soils are highly weathered and inherently low in phosphorus (Udo, 1976). Phosphate management problems in weathered tropical soils are mostly associated with the abundance of free Fe and Al oxides and low organic matter. It has been reported that most nutrient elements, including micronutrients, are positively correlated with the soil organic matter in Nigerian soils (Agboola and Corey, 1976).

The savannah soils of Nigeria are inherently low in nutrients (Lombin, 1983a, 1983b). There have been reported cases of Zn deficiency in some soils of the Nigerian southern Guinea savannah (Aduloju, 2000; Ogunwale, 2003) and general micronutrient deficiency in savannah soils (Lombin, 1983a; 1983b; Aduloju, 2004). Most farmers in Nigeria apply various grades of N-P-K and Urea fertilizer to their crops when and if it is available and affordable, but micronutrient fertilizer is almost never used, except for research purposes. This has resulted in micronutrient deficiencies, especially of zinc, in some areas in the southern Guinea savannah region of Nigeria (Aduloju, 2000; 2004). This work aims at providing information about the general characteristics, the organic and available forms of P and some important micronutrients (Cu, Zn, Fe, Mn) in the soils of the study area to help in guiding the nutrient management practices, especially the P nutrition of crops, for optimum productivity of, and to guide against nutrient toxicity/imbalance in these soils.

2. Materials and methods

2.1. Experimental site

The study area is located in Mokwa, Niger State of Nigeria (Latitude 5^{0}4' North and Longitude 9^{0}19' East) in the Guinea savanna agro-ecological zone of Nigeria. The area is characterized by small trees, shrubs and tall grasses and noted for grain production. The annual rainy season is between June and October and a dry season between November and May. The annual rainfall is about 1000-1500 mm. The major occupation of the inhabitants of this zone is arable crop farming.

2.2. Soil sampling

A toposequence was identified for the study and the site was observed to be free from mining activities. Profiles were dug at the top, middle and bottom parts of the slope and samples were collected from each recognized horizon. There were 4 horizons in Profile A: 0-14 cm; 14-30 cm; 30-39 cm and 39-93 cm. There were also 4 horizons in Profile B: 0-10 cm; 10-26 cm; 26-57 cm and 57-98 cm. Profile C had 5 horizons: 0-15 cm; 15-27 cm; 27-40 cm; 47-57 cm; 57-100 cm and 100-150 cm. The samples were air-dried and sieved through a 2-mm sieve and stored for general characterization, particle size, organic and available phosphorus (P) analyses. Samples for carbon and total nitrogen were crushed and sieved through a 0.5 mm sieve, while samples for available Fe determination were further sieved through a 0.2 mm sieve.

2.3. Soil analyses

The soils were analysed for particle size by the Bouyoucos (1962) hydrometer method. The pH was determined with a glass electrode pH metre using 1:1 soil:water ratio. Exchangeable cations were extracted with normal, neutral ammonium acetate. The Na and K in the extracts were analysed by flame photometry while Ca and Mg were determined by the versenate titration method (Jackson, 1958). The soils were extracted with 1M KCl and the acidity in the extract was determined by titration with 0.1M NaOH, using Phenolphthalein indicator. Effective Cation Exchange Capacity (ECEC) was obtained by summing up the exchangeable bases and total acidity. Organic carbon was determined by the chromate wet oxidation method (Nelson and Sommers, 1992) and used to calculate the organic matter content. The available P in the soils was extracted with Bray P^1 solution (Bray and Kurtz, 1945) and determined by the Murphy and Riley (1962) method. Organic P was determined by the Legg and Black (1957) procedure. The micronutrients were extracted with 0.1M HCl and their contents in the extract determined with the atomic absorption spectrophotometer.

3. Results and discussion

3.1. General characteristics

The general characteristics of the soils are as shown in Table 1. The soils are mostly sandy loam, having relatively high silt contents. This may be due to the nature of the parent material which is sedimentary rock

(Adepoju, 1993). The pH is near-neutral (6.95-7.3) probably due to low level of leaching of exchangeable cations as a result of low rainfall in the study area. The exchange acidity is also low (0.04-0.20). All exchangeable cations are high enough to produce good arable crops, based on the critical values reported by Ayodele (1984) and Adeoye and Agboola (1985). There was no identifiable pattern of distribution of Mg, Ca, Na and ECEC. However, there seemed to be an accumulation of these cations in the third horizons of Profiles A and B, and in the fourth horizon of Profile C. Potassium decreased downward the profile in Profile 1, increased then decreased in Profiles 2 and 3, though the content is generally high enough for arable crop production in all the profiles. Organic matter was expectedly highest at the topsoil of each of the profiles, decreasing downwards.

Table 1. General characteristics of the soils of a toposequence in Mokwa, Niger State, Nigeria

Pedons Depth	pH 1:1 (soil: H_2O)	*O. M. (mk/kg)	Exchange Acidity	Mg	Ca	Na	K	**ECEC (%)
			cmol/kg soil					
A								
0-14	7.30	3.50	0.12	5.6	9.0	1.65	2.41	18.78
14-30	7.10	1.40	0.20	3.6	8.4	1.56	2.05	15.81
30-39	7.27	1.59	0.20	4.0	8.4	1.74	2.77	17.11
39-93	7.27	0.68	0.08	2.6	7.4	1.72	2.57	14.37
B								
0-10	7.17	1.03	0.16	5.4	8.4	1.33	1.92	17.21
10-26	7.11	0.73	0.16	3.0	7.0	1.44	2.06	13.66
26-57	7.14	0.73	0.12	6.8	9.2	1.92	2.01	20.05
57-100	6.95	0.62	0.08	4.4	1.91	1.91	1.56	17.75
C								
0-15	7.04	2.54	0.16	2.4	5.4	1.57	2.13	11.66
15-27	7.08	1.46	0.12	3.6	7.4	1.67	1.47	13.46
27-47	7.06	1.59	0.12	4.0	8.2	1.76	2.09	15.87
47-57	7.12	1.00	0.08	3.6	9.2	1.89	2.95	17.72
57-100	7.15	0.83	0.04	5.4	16.8	1.93	2.58	24.17
100-150	7.15	0.67	0.04	4.8	11.4	2.17	2.56	18.41

3.2. Extractable micronutrients

3.2.1. Iron (Fe)

There was no clear trend of distribution of Fe in Pedons 1 and 2, but it was clearly decreasing in Pedon 3 (Table 2). Though the amount is adequate for the production of most arable crops in the study area, according to Adeoye and Agboola (1985), it is likely to become deficient in the near future if not supplemented in the area around Pedon 3 because it decreased down the profile and would be exhausted over time. Iron is negatively correlated with organic P and organic matter. This implies that organic matter in these soils may bind up or form complex compounds of Fe as chelates, thereby effectively immobilizing it.

3.2.2. Zinc

The soil Zn content decreased down the profiles (Table 2), the lowest value being 0.04 cmol/kg soil in Pedon 2 and the highest of 0.44 cmol/kg soil in Pedon 1. It was high enough in Pedon 1, but too low in Pedons 2 and 3, for adequate for arable crop production, according to the report of Osiname et al. (1973).

Table 2. Forms of phosphorous and micronutrient content of the soils of a Toposequence in Mokwa, Niger State, Nigeria

Pedons Depth (cm)	Fe	Zn (ppm)	Mn	Cu	Org. P (mg/kg)	Avail. P
A						
0-14	0.17	0.37	0.34	0.03	5.11	3.1
14-30	0.25	0.31	0.30	0.09	5.46	2.2
30-39	0.10	0.30	0.21	0.05	5.11	0.4
39-93	0.32	0.44	0.18	0.04	2.30	0.2
B						
0-10	0.12	0.07	0.14	0.09	6.93	1.5
10-26	0.31	0.04	0.49	0.10	6.51	0.5
26-57	0.45	0.08	0.30	0.03	1.82	0.3
57-100	0.27	0.06	0.35	0.03	0.84	0.1
C						
0-15	0.44	0.16	0.25	0.06	4.48	3.2
15-27	0.37	0.07	0.44	0.05	4.48	3.0
27-47	0.35	0.07	0.43	0.05	6.18	1.5
47-57	0.32	0.07	0.34	0.03	3.92	0.4
57-100	0.29	0.10	0.51	0.03	2.59	0.1
100-150	0.27	0.08	0.27	0.03	1.61	0.1

There is need to supplement Zn in the soils at the lower end of the toposequence. Extractable Zn positively correlated with organic matter (r = 0.423**), suggesting that Zn is released as organic matter mineralizes.

3.2.3. Copper

Extractable Cu was low, ranging from 0.03 to 0.10 ppm. It decreased down the depths in all the Pedons (Table 2) and correlated positively and significantly with organic-P (r = 0.753**) and available-P (r = 0.254, Table 3). This may be due to the formation of organic chelates with P in the soil. Copper availability may likely be boosted by the application of organic manures in these soils.

Table 3. Phosphorous in the soils of a toposequence in Mokwa, Niger State, Nigeria

	Fe	Zn	Mn	Cu	Avail. P	Org. P	Org. Matter
Fe		-0.348	0.344	-0.198	0.206	-0.337	-0.147
Zn			-0.454	-0.053	0.146	-0.042	0.423**
Mn				-0.072	-0.055	0.022	-0.050
Cu					0.254	0.753	-0.029
Avail.P						0.426	0.786***
Org. P							0.410**

3.2.4. Manganese

The level of Mn in the soils ranged from 0.14 cmol/kg in the topsoil of Pedon 2 to 0.51 in the subsoil of Pedon 3 (Table 2). There was no noticeable trend in its distribution throughout the three profiles studied. However, the levels observed are adequate for crop production in the near future. Supplementation may become necessary after a few years of continuous cropping.

3.3. Forms of phosphorous (P)

Organic and available forms of P were low and distributed almost evenly throughout each profile, but the lowest values were recorded in the lowest horizons of each profile (Table 2). Lasagne et al. (2000), in their study of forms and profile distribution of P in Alpine Inceptisols and Spodosols, concluded that since most forms of P are insoluble, the migration of P along the profile is dependent on the migration of organic compounds (humic acids), Fe and Al minerals or organo-mineral compounds. Though these savannah soils are inherently low in P, the organic P was higher than available P, suggesting that more P will be released for crop uptake as organic matter mineralizes. Also, there is a positive and significant correlation between available P and organic matter (r = 0.786***). This implies that the more the organic matter in these soils, the more the available P released for plant use as organic matter mineralizes. The importance of organic matter as a major supplier of P in these soils cannot be over-emphasised because it correlated highly and positively with organic P and available P in this study (r = 0.410** and r = 0.786*** respectively). This agrees with earlier reports by Agboola and Ayodele (1983) and Akinrinde and Obigbesan (2000) that organic P is a significant determinant of P availability in tropical soils. Morris et al. (1992) also reported a positive relationship between organic P and P uptake by millet in a Sri Lankan Alfisol. Brady and Weil (1999) had observed that organic P is important in the mineralization and uptake of P by plants. Both organic and available forms of P followed the same trend of decreasing down the profiles in all the three pedons studied. The generally low level of both organic and available forms of P shows the limited capacity of these soils to supply P to cultivated crops from the native pool.

4. Conclusion

The soils were found to be adequate in exchangeable cations and micronutrients, had almost neutral pH values and are inherently low in available and organic P, both in the topsoil and subsoil. The availability of phosphorous and other nutrients to crop plants on these soils would be boosted by the application of organic and/or farmyard manure, with or without the application of inorganic P fertilizer. Efforts should be made to maintain a high level of organic matter because P availability in these soils is highly influenced by it. Organic matter would also mitigate the effects of the free oxides as it would act as a chelating agent to bind them up and release them slowly over time. Activities that hasten up the mineralization of organic matter, such as overgrazing, bush burning and tillage that expose the soil without any soil cover should be minimized. Iron (Fe) and Manganese (Mn) are presently adequate for crop production, but may require supplementation over time. However, Copper (Cu) and Zinc (Zn) are grossly inadequate for optimal crop production and will need to be supplemented for good crop yields. The application of organic manure will improve zinc availability in these soils. Soil testing is recommended before fertilizer use to prevent nutrient toxicity or imbalance.

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