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Research Article

Influence of Sesquioxide's and Organic Matter on Phosphorus Release and Cation Exchangeability of Southeastern Nigeria Soils

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Abstract

The study investigated the influence of sesquioxide's (Al2O3 and Fe2O3) and organic matter on phosphorus release and cation exchangeability of southeastern Nigeria soils. Soil samples (undisturbed and disturbed) were collected from five study locations in southeastern Nigeria. Undisturbed soil samples were collected using cylindrical (5×5 cm) cores, followed by disturbed soil samples using soil auger. Soil samples were collected at a depth of 0-20 cm and were analyzed following standard laboratory methods. Data analysis involved correlation and regression analyses using the IBM SPSS statistics computer package. Correlation and regression analyses across the locations show that aluminum oxide (Al2O3) and Iron (III) oxide (Fe2O3) do not have significant effects on both phosphorus release and cation exchangeability of the studied soils. Though; phosphorus release increased significantly with an increase in the effective cation exchange capacity of the soils. A non-significant relationship existed between soil organic matter and phosphorus release. Soil organic matter had a highly significant positive effect on the cation exchangeability of the soils.

Keywords	*Cation Exchangeability; Organic Matter; Phosphorus Release; Sesquioxide's Soil; Southern Nigeria*
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Introduction

Phosphorus is one of the least available mineral nutrients to plants. One unique characteristic of phosphorus is its low availability due to diffusion and high fixation in soils (Asomaning 2020). Its deficiency is more critical in highly weathered soils. The soils of southeastern Nigeria are highly weathered with low amount of plant essential nutrients. Soils within this ecological zone are known for their low phosphorus availability (Igwe, Zarei and Stahr, 2010). Phosphorus is a critical element in natural and agricultural ecosystems (Onweremadu, 2007). It is an essential element required to maintain lucrative crop production. Large amounts of applied phosphorus are fixed in the soil in a form that is not readily available to plants. This is a soil problem and can be worsened with inappropriate phosphorus management. Tropical soils particularly the highly weathered ones like Nigeria soils often have a high phosphorus retention power. This limits the availability of inorganic phosphorus to plants (Osemwotai, Ogboghodo and Aghimien, 2005). Thus, low availability of phosphorus is a major constraint on agricultural productivity. Fixation of plant nutrients is a major concern for economical use of fertilizer (Chatterjee, Datta, and Manjaiah, 2014); most plant nutrients are available to plants in cationic forms; hence the exchangeability of cations is also a matter of apprehension. The cation exchange characteristic is a very important soil chemical property used to characterize soils for classification and fertility assessment (Nwachokor and Molindo, 2007). It determines the capacity of a soil to hold nutrients and eventually release them for plant uptake (Ibrahim and Idoga, 2015).

Sesquioxides and organic matter have the capacity of binding soils into aggregates and are known to influence soil properties. Therefore, determining the influence of sesquioxides and organic matter as they relate to the availability of phosphorus and the cation exchangeability of soils is of paramount importance. This will ensure proper use of soils and also help to give recommendations on practices that will help in maintaining fertility of soils so as to improve crop growth. In addition, for assessing the fertility of these soils, their cation exchangeability is an important criterion. The cation exchange capacity of soils plays a very important role in nutrient availability to crops. Soils with low cation exchange capacity are more likely to develop deficiencies in nutrient cations and this adversely affects crop production. Studies on the influence of sesquioxide's and organic matter on phosphorus release and cation exchangeability of soils especially those of the southeastern Nigeria are still inadequate. Also, since phosphate sorption of soils has serious effect on their cation exchange capacity, there is a great need to investigate the potential of some soil properties especially those that have to do with sesquioxide and organic matter contents of these soils as they relate to phosphorus release and cation exchangeability of soils. This is essential to help determine the processes that will improve cation exchangeability and facilitate the availability of phosphorus in soils on addition as a fertilizer or when already contained in the soil. The major objective of this study was to assess the influence of sesquioxides (Al_2O_3 and Fe_2O_3) and organic matter on phosphorus release and cation exchangeability of southeastern Nigeria soils. The specific objectives were to: (i) investigate the impact of sesquioxides and organic matter on phosphorus release in soils of southeastern Nigeria, (ii) assess the impact of sesquioxides and organic matter on cation exchangeability of southeastern Nigeria soils, (iii) establish if the impact of sesquioxides and organic matter on phosphorus release and cation exchangeability vary with location or can be consistent across locations and (iv) ascertain if application of organic materials may improve phosphorus availability by enhancing organic phosphorus mineralization.

Materials and Methods

The study locations which include: Abakaliki Awka, Enugu, Owerri and Umuahia are all in south-eastern Nigeria which stretches from 04°15'N to 07°00'N and between 05°34'E and 09°24'E, and has a total area of approximately 78,612 km^2. Mean annual temperature ranges between 27-32°C. The soils of the zone have isohyperthermic temperature regime and receive average annual rainfalls of between 1600 mm to 4338 mm (Anikwe, 2010). Differences in the parent material guided the choice of the different locations. Soil samples were collected at a depth of 0–20 cm from eight different study sites in each of the five study locations to give a total of 40 soil samples. Undisturbed soil samples were collected using cylindrical (5×5 cm) cores, followed by disturbed soil samples using soil auger. Laboratory analyses on the soils followed standard procedures for physical properties (Dane and Topp, 2002) and chemical properties (Sparks, 1996). Oxide analysis (2003) method as described by the Association of Official and Analytical Chemists (AOAC) was used in determining aluminium oxide and iron (III) oxide. The soil samples were processed and analyzed in the laboratory for particle size distribution, available phosphorus, cation exchange capacity, effective cation exchange capacity, soil organic carbon, soil organic matter, total nitrogen, exchangeable

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acidity, exchangeable bases, electrical conductivity, soil bulk density, hydraulic conductivity, water holding capacity, total porosity, saturation percentage, aluminium oxide and iron (III) oxide. Soil data was subjected to correlation and regression analyses to determine the relationships and the strength of relationships among the studied variables and other soil properties within and across locations. Mean values and the coefficient of variation of the collected data were also determined. The IBM SPSS statistics computer package was used in all statistical analyses.

Table 1: Sesquioxides, Soil Organic Matter, Available Phosphorus, Cation Exchange Capacity and Effective Cation Exchange Capacity of the Studied Soils (0-20 cm)

Sampling site	Location	Al_2O_3	Fe_2O_3	SOM	Avp	CEC	ECEC
		(mg/kg)		(g/kg)	(mg/kg)	(cmol/kg)	
Achara	Abakaliki	0.5	20	20.34	13.99	48	6.23
Agbaja	Abakaliki	2	90	30.17	25.18	44	11.51
Amuzu	Abakaliki	9.5	40	12.64	13.99	36	6.66
Ezzama	Abakaliki	20	60	9.83	29.85	36.8	7.95
Idembia	Abakaliki	10	50	26.67	41.97	39.2	4.94
Onueke	Abakaliki	0.2	60	8.41	11.19	34.4	5.49
Oriuzor	Abakaliki	0.3	60	20.34	23.32	28.8	6.96
Umuezeoka	Abakaliki	1	70	22.45	11.19	36.8	8.01
Amawbia	Awka	2	0	2.1	47.57	20.4	4.6
Isuaniocha	Awka	1	40	4.91	11.19	21.2	4.64
Mbaukwu	Awka	10	110	8.41	66.22	48.8	4.66
Mgbakwu	Awka	2	90	4.91	31.71	39.2	3.63
Nibo	Awka	0.3	0	7.72	22.38	38.8	4.95
Nise	Awka	1	4	10.53	0	48	6.4
Okpuno	Awka	20	0	2.81	2.8	31.2	3.97
Umuawulu	Awka	10	60	5.62	49.43	32	4.89
Alulu	Enugu	2	40	7.02	15.86	34.4	18
Coal camp	Enugu	0.2	40	6.31	4.66	43.6	4.69
Emene	Enugu	100	0	36.48	1.87	43.6	4.2
Ibagwa	Enugu	10	0	10.53	9.33	32.8	19.84
Independence Layout	Enugu	2	40	25.26	0.93	48	8.27
Iva valley	Enugu	4	40	35.08	8.39	48	5.71
New Layout	Enugu	0.1	30	47.7	1.87	48.4	8.12
Ugwuaji	Enugu	6	0	25.96	16.79	49.2	8.09
Avu	Owerri	1	60	18.95	0.93	45.2	7.34
Awaka	Owerri	50	0	12.64	18.65	48.8	8.6
Emekuku	Owerri	20	90	26.67	3.73	49.2	4.88
Eziobodo	Owerri	10	80	11.22	0	39.6	4.56
Ihiagwa	Owerri	5	20	8.41	47.57	39.6	5.48
Obinze	Owerri	0	2	21.76	5.6	47.6	4.92
Okwu uratta	Owerri	0.2	0	13.33	23.32	47.2	4.77
Orji	Owerri	0.5	0	7.02	138.97	44.8	4.67

Afugiri	Umuahia	0.2	70	49.82	100.73	48	8.83
Amaforo	Umuahia	2	50	30.17	122.18	48	17.38
Ndume	Umuahia	2	0	15.43	116.58	42.4	8.22
Isieke	Umuahia	2	20	28.05	3.73	49.6	8.09
Old Umuahia	Umuahia	50	0	17.53	1.87	48	4.25
Olokoro	Umuahia	1	0	37.19	172.54	48	17.8
Ubakala	Umuahia	4	0	16.14	59.69	42	11.45
Umuawa Alaocha	Umuahia	10	0	39.29	69.02	37.6	7.49
Mean		9.3	33.4	18.65	33.67	41.43	7.53
CV(%)		200.51	99.07	67.05	125.71	18.51	54.54

Table 2: Bulk density, water holding capacity, Total porosity, saturated hydraulic conductivity and Saturation percentage of the studied soils (0-20 cm)

Sampling site	Location	BD	WHC	TP	K_{sat}	Satp
		(g/cm^3)	(%)	(%)	(cm/hr)	(%)
Achara	Abakaliki	1.16	80.81	56.23	4.38	95.86
Agbaja	Abakaliki	1.68	19.52	36.6	1.88	26.42
Amuzu	Abakaliki	1.16	83.05	56.23	7.74	94.93
Ezzama	Abakaliki	1.52	19.08	42.64	61.07	27.34
Idembia	Abakaliki	1.4	17.37	47.17	11.63	25.35
Onueke	Abakaliki	1.87	13.43	29.43	3.76	25.14
Oriuzor	Abakaliki	1.73	19.42	34.72	13.77	27.7
Umuezeoka	Abakaliki	1.59	19.33	40	175.28	26.78
Amawbia	Awka	1.92	16.92	27.55	28.8	22.94
Isuaniocha	Awka	1.97	13.13	26.79	20.36	21.13
Mbaukwu	Awka	1.82	10.98	31.32	75.12	20.87
Mgbakwu	Awka	1.75	16.69	33.96	145.23	23.99
Nibo	Awka	1.65	15.96	37.74	137.72	23.99
Nise	Awka	1.83	17.63	30.94	50.08	22.75
Okpuno	Awka	1.8	17.42	32.08	107.67	24.74
Umuawulu	Awka	1.66	24.4	37.36	313	31.79
Alulu	Enugu	1.69	19.01	36.23	187.8	24.42
Coal camp	Enugu	1.75	17.57	33.96	28.35	26.44
Emene	Enugu	1.38	24.92	47.92	7.27	33.98
Ibagwa	Enugu	1.73	13.47	34.72	2.45	19.66
Independence Layout	Enugu	1.22	79.02	53.96	3.76	87.96
Iva valley	Enugu	1.84	12.24	30.57	5.01	17.23
New Layout	Enugu	1.63	20	38.49	62.78	29.32
Ugwuaji	Enugu	1.63	21.23	38.49	7.51	32.84
Avu	Owerri	1.21	77.21	54.34	43.82	85.28
Awaka	Owerri	1.83	15.88	30.94	25.44	21.1

Emekuku	Owerri	1.66	17.45	37.36	78.51	22.03
Eziobodo	Owerri	1.62	22.98	38.87	210.82	30.55
Ihiagwa	Owerri	1.26	67.06	52.45	159.93	77.93
Obinze	Owerri	1.35	26.67	49.06	407.1	33.18
Okwu uratta	Owerri	1.43	25.08	46.04	130.85	31.45
Orji	Owerri	1.49	24.49	43.77	247.17	34.16
Afugiri	Umuahia	1.53	25.3	42.26	29.08	30.89
Amaforo	Umuahia	1.21	81.74	54.34	81.38	93.39
Ndume	Umuahia	1.47	23.16	44.53	167.2	29.93
Isieke	Umuahia	1.2	68.23	54.72	63.25	77.47
Old Umuahia	Umuahia	1.5	22.11	43.4	79.97	28.4
Olokoro	Umuahia	1.4	21.88	47.17	90.6	27.32
Ubakala	Umuahia	1.3	29.89	50.94	428.91	37.33
Umuawa Alaocha	Umuahia	1.42	26.17	46.42	45.8	34.62
Mean		1.56	29.7	41.29	93.81	37.72
CV(%)		14.9	75.7	21.07	113.85	63.26

Results and Discussion

The values of the sesquioxides (Al_2O_3 and Fe_2O_3), soil organic matter (SOM), available phosphorus (Avp), cation exchange capacity (CEC) and effective cation exchange capacity (ECEC) of the studied soils are presented in Table 1. The values of Al_2O_3 ranged from 0 to 100 mg/kg with a mean value of 9.3 mg/kg and coefficient of variation (CV) of 200.51 %. The values of Fe_2O_3 varied from 0 to 110 mg/kg with an average Fe_2O_3 value of 33.4 mg/kg and CV of 99.07 %. In highly weathered tropical soils, the occurrence of iron and aluminium oxides is very common as weathering products and these products often affect several physicochemical properties of these soils (Igwe *et al.,* 2010). Proper knowledge of the relationships between soil properties and iron and aluminium oxides is important for understanding the physical and chemical characteristics of soils, especially, the highly weathered soils of which they are major components. Table 1 also shows that the SOM values of the soils ranged from 2.1 to 49.82 g/kg with a mean of 18.65 g/kg and CV of 67.05 %. Plants obtain nutrients from soil organic matter. Clay and organic matter (humus) of soils have negatively charged sites on their surfaces which adsorb and hold cations by electrostatic force. This electrical charge is critical to the supply of nutrients to plants because many nutrients exist as cations. In general terms, soils with large quantities of negative charge are more fertile because they retain more cations (McKenzie, Jacquier, Isbell and Brown, 2004).

The Avp values of the soils varied from 0 to 172.54 mg/kg with an average Avp value of 33.67 mg/kg and 125.71 % CV. Tropical soils have suffered drastic reductions in soil organic matter due to soil erosion and inappropriate land uses (Mbagwu, 1992) thereby making phosphorus predictions inconsistent in most tropical soils (Oti, 2002). The CEC values ranged from 20.4 to 49.6 cmol/kg with a mean of 41.43 cmol/kg and CV of 18.51 % while the ECEC values ranged from 3.63 to 19.84 cmol/kg with an average ECEC value of 7.53 cmol/kg and CV of 54.54 %. Cation exchange capacity gives an insight into the nutrient retention capacity and fertility of soil. Soils with low cation exchange capacity are more likely to develop deficiencies in potassium cation, magnesium cation and other cations while high cation exchange capacity soils are less susceptible to leaching of these cations (CUCE, 2007). As shown in Table 1, the highest Al_2O_3 value (100 mg/kg) was recorded in Emene, Enugu; the highest Fe_2O_3 value (110 mg/kg) was recorded in Mbaukwu, Awka; the highest SOM value (49.82 g/kg) was recorded in Afugiri, Umuahia; the highest Avp value (172.54 mg/kg) was recorded in Olokoro, Umuahia; the highest CEC value (49.6 cmol/kg) was recorded in Isieke, Umuahia while the highest ECEC value (19.84 cmol/kg) was recorded in Ibagwa, Enugu. Table 2 shows the values of bulk density (BD), water holding capacity (WHC), total porosity (Tp), saturated hydraulic conductivity (K_{sat}) and saturation percentage (Satp) of the soils studied. The BD values ranged from 1.16 to 1.97 g/cm^3 with an average value of 1.56 g/cm^3 and 14.9 % CV. The WHC values of the soils were between 10.98 % and 83.05 % with a mean value of 29.7 % and 75.7 % CV while the Tp values varied from 26.79 to 56.23 % with a mean of 41.29 % and CV of 21.07 %. Bulk density is an indicator of soil compaction and affects soil properties such as water infiltration, soil porosity and rooting depth. Thus; high bulk density is an indicator of low water infiltration, low soil porosity and poor rooting depth. Soil hydraulic conductivity is an indicator of water movement and pore structure in the soil. Saturated hydraulic conductivity expresses the ease with which pores of a saturated soil transmit water. The K_{sat} values were between 1.88 and 428.91 cm/hr with an average value of 93.81 cm/hr and CV of 113.85 %. The Satp values ranged from 17.23 to 95.86 % with a mean value of 37.72 % and 63.26 % CV. The values of total clay (clay), total silt (silt), total sand (sand), soil organic carbon (SOC) and electrical conductivity (EC) are shown in Table 3. The values of clay varied from 70 to 270 g/kg with an average value of 109 g/kg and CV of 37.84 %. The values of silt ranged from 30 to 390 g/kg with a mean value of 127 g/kg and CV of 74.43 %. Sand is the highest of all the soil separates in all the samples and varied from 480 to 880 g/kg with an average value of 764 g/kg and 16.01 % CV. The textural class of the soils ranged from sand (S) to sandy clay loam (SCL).

The values of SOC varied from 1.22 to 28.9 g/kg with a mean of 10.82 g/kg and CV of 67.04 % while the EC values ranged from 3 to 10 µʃ/cm with an average value of 5.8 µʃ/cm and 37.49 % CV. Table 4 shows the values of total nitrogen (N), exchangeable acidity (EA) and exchangeable bases (Na^+, K^+, Mg^{2+} and Ca^{2+}) of the studied soils. The table shows that the total nitrogen values of the soils ranged from 0.11 to 0.35 % with a mean of 0.22 % and CV of 28.06 %. The EA values of the soils varied between 0.6 and 1.8 cmol/kg with an average value of 1.07 cmol/kg and 30.09 % CV. The exchangeable sodium (Na^+) values ranged from 0.02 to 0.06 cmol/kg with a mean of 0.04 cmol/kg and 20.1% CV. The exchangeable potassium (K^+) values ranged from 0.01 to 0.22 cmol/kg with a mean value of 0.09 cmol/kg and 59.85 % CV. The values of exchangeable magnesium (Mg^{2+}) ranged from 0 to 3.38 cmol/kg with an average value of 1.15 cmol/kg and 76.13 % CV while the exchangeable calcium (Ca^{2+}) values ranged from 1.35 to 15.19 cmol/kg with a mean value of 5.18 cmol/kg and 71.03 % CV. Table 5 shows the correlation between AvP, CEC, ECEC, SOM, Al_2O_3, Fe_2O_3, N, EC, EA and other soil properties across the studied locations. Al_2O_3 and Fe_2O_3 had negative correlations with Avp 'r' = -0.21 and -0.11 respectively. Al_2O_3 correlated positively with CEC 'r' = 0.11 while Fe_2O_3 correlated negatively with CEC 'r' = -0.02. Thus; the sequioxides (Al_2O_3 and Fe_2O_3) had no significant relationship with available phosphorus and cation exchange capacity of the soils. Therefore, they do not have any significant influence on phosphorus release and cation exchangeability of the soils across the studied locations. Positive and highly significant correlation existed between SOM and CEC 'r' = 0.52**. There was a positive and significant correlation between Avp and ECEC 'r' = 0.35*. Thus; Soil organic matter had highly significant positive relationship with cation exchange capacity of the soils implying that it has positive and significant influence on cation exchangeability of the studied soils across locations. Also, the availability of phosphorus increased significantly with an an increase in the effective cation exchange capacity of the soils.

Table 3: Particle size distribution, textural class, soil organic carbon and electrical conductivity of the studied soils (0-20 cm)

Sampling site	Location	Clay	Silt	Sand	Textural	SOC	EC
		(g/kg)	(g/kg)	(g/kg)	Class	(g/kg)	(µʃ/cm)
Achara	Abakaliki	130	110	760	LS	11.8	6
Agbaja	Abakaliki	150	110	740	SL	17.5	10
Amuzu	Abakaliki	110	170	720	SL	7.33	5
Ezzama	Abakaliki	110	150	740	SL	5.7	5
Idembia	Abakaliki	130	130	740	LS	15.47	4
Onueke	Abakaliki	110	190	700	SL	4.88	4
Oriuzor	Abakaliki	110	210	680	SL	11.8	5
Umuezeoka	Abakaliki	90	190	720	LS	13.02	6
Amawbia	Awka	90	50	860	LS	1.22	5
Isuaniocha	Awka	90	50	860	LS	2.85	4
Mbaukwu	Awka	90	50	860	LS	4.88	7

Mgbakwu	Awka	70	90	840	LS	2.85	6
Nibo	Awka	70	50	880	S	4.48	7
Nise	Awka	90	70	840	LS	6.11	6
Okpuno	Awka	90	50	860	LS	1.63	3
Umuawulu	Awka	70	50	880	S	3.26	6
Alulu	Enugu	70	90	840	LS	4.07	9
Coal camp	Enugu	150	210	640	SL	3.66	4
Emene	Enugu	130	390	480	L	21.16	4
Ibagwa	Enugu	70	210	720	SL	6.11	9
Independence Layout	Enugu	270	210	520	SCL	14.65	6
Iva valley	Enugu	110	350	540	SL	20.35	5
New Layout	Enugu	150	250	600	SL	27.67	5
Ugwuaji	Enugu	210	310	480	L	15.06	5
Avu	Owerri	90	70	840	LS	10.99	10
Awaka	Owerri	110	90	800	LS	7.33	7
Emekuku	Owerri	130	50	820	LS	15.47	4
Eziobodo	Owerri	90	30	880	S	6.51	3
Ihiagwa	Owerri	70	50	880	S	4.88	4
Obinze	Owerri	110	30	860	LS	12.62	3
Okwu uratta	Owerri	90	50	860	LS	7.73	3
Orji	Owerri	70	50	880	S	4.07	5
Afugiri	Umuahia	170	290	540	SL	28.9	4
Amaforo	Umuahia	110	90	800	LS	17.5	9
Ndume	Umuahia	70	50	880	S	8.95	9
Isieke	Umuahia	130	210	660	SL	16.27	5
Old Umuahia	Umuahia	130	70	800	LS	10.17	3
Olokoro	Umuahia	70	70	860	LS	21.57	10
Ubakala	Umuahia	70	70	860	LS	9.36	9
Umuawa Alaocha	Umuahia	90	70	840	LS	22.79	8
Mean		109	127	764		10.82	5.8
CV(%)		37.84	74.43	16.01		67.04	37.49

Table 4: Total nitrogen, exchangeable acidity and exchangeable bases of the studied soils (0-20 cm)

Sampling site	Location	N	EA	Na^+	K^+	Mg^{2+}	Ca^{2+}
		(%)	(cmol/kg)				
Achara	Abakaliki	0.28	1	0.05	0.11	0.68	4.39
Agbaja	Abakaliki	0.29	0.8	0.06	0.18	3.38	7.09
Amuzu	Abakaliki	0.21	1	0.05	0.2	2.03	3.38
Ezzama	Abakaliki	0.18	1	0.04	0.16	0	6.75
Idembia	Abakaliki	0.24	0.8	0.04	0.05	0	4.05
Onueke	Abakaliki	0.24	1	0.02	0.08	0	4.39
Oriuzor	Abakaliki	0.29	0.8	0.04	0.04	1.35	4.73
Umuezeoka	Abakaliki	0.08	0.8	0.03	0.09	1.69	5.4
Amawbia	Awka	0.15	0.8	0.04	0.04	0.68	3.04
Isuaniocha	Awka	0.24	0.8	0.04	0.08	1.69	2.03
Mbaukwu	Awka	0.17	0.8	0.05	0.1	0	3.71
Mgbakwu	Awka	0.14	0.8	0.06	0.07	0	2.7
Nibo	Awka	0.11	0.8	0.05	0.05	1.01	3.04
Nise	Awka	0.13	0.8	0.04	0.16	1.69	3.71
Okpuno	Awka	0.18	1	0.04	0.22	0.68	2.03
Umuawulu	Awka	0.15	0.8	0.03	0.01	0.34	3.71
Alulu	Enugu	0.13	0.6	0.04	0.14	2.03	15.19
Coal camp	Enugu	0.17	1.2	0.03	0.09	1.01	2.36
Emene	Enugu	0.28	1	0.04	0.08	1.35	1.73
Ibagwa	Enugu	0.18	0.8	0.04	0.1	2.7	16.2
Independence Layout	Enugu	0.25	1.4	0.05	0.07	0.34	6.41
Iva valley	Enugu	0.25	1.2	0.06	0.06	0.34	4.05
New Layout	Enugu	0.27	1.2	0.04	0.13	1.69	5.06
Ugwuaji	Enugu	0.25	1.2	0.03	0.11	1.69	5.06
Avu	Owerri	0.2	1.2	0.04	0.02	0.34	5.74
Awaka	Owerri	0.2	1	0.04	0.13	1.35	6.08
Emekuku	Owerri	0.25	1.4	0.03	0.08	1.01	2.36
Eziobodo	Owerri	0.21	1.8	0.05	0.01	1.35	1.35
Ihiagwa	Owerri	0.18	1	0.05	0.04	1.35	3.04
Obinze	Owerri	0.24	1.8	0.04	0.04	1.35	1.69
Okwu uratta	Owerri	0.25	1	0.04	0.02	1.35	2.36
Orji	Owerri	0.2	1.2	0.04	0.05	0	3.38
Afugiri	Umuahia	0.34	2	0.04	0.04	2.36	4.39
Amaforo	Umuahia	0.29	1	0.04	0.14	2.36	13.84
Ndume	Umuahia	0.17	1	0.04	0.09	0.34	6.75
Isieke	Umuahia	0.21	1.2	0.04	0.1	1.01	5.74
Old Umuahia	Umuahia	0.22	1.8	0.04	0.04	0.34	2.03
Olokoro	Umuahia	0.28	0.8	0.04	0.08	3.04	13.84

Ubakala	Umuahia	0.24	1.2	0.04	0.09	1.01	9.11
Umuawa Alaocha	Umuahia	0.35	1	0.04	0.04	1.01	5.4
Mean		0.22	1.07	0.04	0.09	1.15	5.18
CV(%)		28.06	30.09	20.1	59.85	76.13	71.03

Table 5: Correlation coefficients for the relationships between AvP, CEC, ECEC SOM, Al_2O_3, Fe_2O_3, N, EC, EA and other soil properties across locations

	AvP	CEC	ECEC	SOM	Al_2O_3	Fe_2O_3	N	EC	EA
N	0.21	0.29	0.13	0.73**	0.1	-0.02	1	-0.03	0.37*
EA	-0.09	0.46**	-0.24	0.35*	0.1	0	0.37*	-0.44**	1
SO	0.18	0.52**	0.25	1	0.11	0.03	0.73**	0.11	0.35*
AvP	1	0.11	0.35*	0.18	-0.21	-0.11	0.21	0.40**	-0.09
CEC	0.11	1	0.07	0.52**	0.11	-0.02	0.29	0.08	0.46**
ECE	0.35*	0.07	1	0.25	-0.17	-0.1	0.13	0.72**	-0.24
EC	0.40**	0.08	0.72**	0.11	-0.21	0	-0.03	1	-0.44**
Na^+	-0.01	0.13	-0.03	0.05	-0.07	0.16	0.04	0.17	-0.04
K^+	-0.12	0.03	0.31	-0.05	0.07	-0.01	-0.1	0.2	-0.32*
Ca^2	0.37*	0.03	0.98**	0.16	-0.18	-0.09	0.05	0.76**	-0.33*
Mg	0.12	0.05	0.65**	0.36*	-0.08	-0.08	0.27	0.33*	-0.07
Al_2	-0.21	0.11	-0.17	0.11	1	-0.2	0.1	-0.21	0.1
Fe_2	-0.11	-0.02	-0.1	0.03	-0.2	1	-0.02	0	0
Ksa	0.21	0	-0.03	-0.25	-0.16	-0.13	-0.29	0.03	0.18
** Correlation is significant at the 0.01 level									
* Correlation is significant at the 0.05 level									

Table 4 shows the correlation between Avp, CEC, ECEC, SOM, Fe_2O_3 and Al_2O_3 within locations. The availability of applied phosphorus is controlled by sorption and desorption characteristics of the soil (Osemwotai *et al.*, 2005). Within all the five locations (Abakaliki, Awka, Enugu, Owerri and Umuahia), aluminium oxide and iron (III) oxide had no significant correlations with available phosphorus and cation exchange capacity. In other words, aluminium oxide and iron (III) oxide did not affect phosphorus release and cation exchangeability of the studied soils within locations. This is also the same with the relationships between these variables across the locations. Within all the locations, soil organic matter had no significant correlation with available phosphorus just as it was seen across the locations. Soil organic matter correlated significantly with cation exchange capacity in Awka but, non-significantly in other locations. Iron (III) oxide correlated significantly with effective cation exchange capacity in Abakaliki 'r' = 0.71*. Adequate knowledge of the cation exchangeability of soils is essential, as cation exchange capacity influences soil structural stability, nutrient availability, soil pH and the soil's reaction to fertilizers and other ameliorants (Hazelton and Murphy, 2007). Soil Organic Matter Correlated significantly with both cation exchange capacity and effective cation exchange capacity in Awka, 'r' = 0.83* and 0.73* respectively. A significant correlation existed between available phosphorus and effective cation exchange capacity in Umuahia, 'r' = 0.77*. There was no significant correlation among the studied variables in Enugu and Owerri. The inconsistence in the relationships among these variables within locations could be attributed to differences in the contents of the studied soils and the nature of parent materials from which they were formed.

Table 6: Correlation coefficients for the relationships between, Avp, CEC, ECEC, SOM, Fe_2O_3, and Al_2O_3 within locations

	AvP	CEC	ECEC	SOM	Fe_2O_3	Al_2O_3
Location (Abakaliki)						
Al_2O_3	0.55	-0.06	-0.05	-0.34	-0.07	1
Fe_2O_3	0.16	-0.24	0.71*	0.32	1	-0.07
SOM	0.39	0.42	0.41	1	0.32	-0.34
AvP	1	0.02	-0.03	0.39	0.16	0.55
Location (Awka)						
Al_2O_3	0.04	0.03	-0.36	-0.31	0.08	1
Fe_2O_3	0.64	0.37	-0.35	0.18	1	0.08
SOM	-0.07	0.83*	0.73*	1	1.18	-0.31
AvP	1	0.08	-0.24	-0.07	0.64	0.04
Location (Enugu)						
Al_2O_3	-0.32	-0.03	-0.31	0.3	-0.55	1
Fe_2O_3	-0.19	0.16	-0.14	-0.11	1	-0.55
SOM	-0.45	0.7	-0.54	1	-0.11	0.3
AvP	1	-0.34	0.51	-0.45	-0.19	-0.32
Location (Owerri)						
Al_2O_3	-0.22	0.37	0.67	0.05	0.01	1
Fe_2O_3	-0.48	-0.2	-0.15	0.47	1	0.01
SOM	-0.63	0.62	0.01	1	0.47	0.05
AvP	1	-0.15	-0.24	-0.63	-0.48	-0.22
Location (Umuahia)						
Al_2O_3	-0.58	0.09	-0.57	-0.37	-0.33	1
Fe_2O_3	0.17	0.47	0.2	0.61	1	-0.33
SOM	0.36	0.13	0.23	1	0.61	-0.37
AvP	1	-0.04	0.77*	0.36	0.17	-0.58
* Correlation is significant at the 0.05 level						

Table 7: Regression model summary and coefficients for the relationship between available phosphorus and soil organic matter, aluminium oxide and iron (III) oxide across locations

Model Summary					
Model	R		R Square	Adjusted R	Std. Error of the
				Square	Estimate
1	.333[a]		.111	.037	41.53376
Predictors: (Constant), iron (III) oxide, soil organic matter, aluminium oxide					
Coefficients[a]					
Model	Unstandardized	Coefficients	Standardized	t	Sig.
			Coefficients		
	B	Std. Error	Beta		
(Constant)	32.888	14.017		2.346	.025
Soil organic matter	.721	.536	.213	1.345	.187
Aluminium oxide	-.602	.367	-.265	-1.643	.109
Iron (III)oxide	-.211	.206	-.165	-1.028	.311
Dependent Variable: Available phosphorus					

Table 7 presents the regression model summary and coefficients for the relationship between available phosphorus and the following three variables: soil organic matter, aluminium oxide and iron (III) oxide while Table 8 shows the regression model summary and coefficients for the relationship between cation exchange capacity and the earlier mentioned variables (soil organic matter, aluminium oxide and iron (III) oxide). In Table 7, the result shows that there was no significant relationship between available phosphorus and the following: soil organic matter, aluminium oxide and iron (III) oxide. As shown in Table 8, cation exchange capacity is related significantly to soil organic matter. There was no significant relationship between cation exchange capacity and aluminium oxide. Iron (III) oxide also had a non-significant relationship with cation exchange capacity.

Table 8: Regression model summary and coefficients for the relationship between cation exchange capacity and soil organic matter, aluminium oxide and iron (III) oxide across locations

Model Summary					
Model	R		R Square	Adjusted R	Std. Error of the
				Square	Estimate
1	.521[a]		.271	.210	6.81359
Predictors: (Constant), iron (III) oxide, soil organic matter, aluminium oxide					
Coefficients[a]					
Model	Unstandardized	Coefficients	Standardized	T	Sig.
			Coefficients		
	B	Std. Error	Beta		
(Constant)	35.620	2.300		15.490	.000
Soil organic matter	.315	.088	.514	3.584	.001
Aluminium oxide	.018	.060	.044	.301	.765
Iron (III)oxide	-.007	.034	-.030	-.206	.838
Dependent Variable: Cation exchange capacity					

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Conclusion

The sesquioxides (aluminium oxide and iron (III) oxide) did not have any significant effect on both phosphorus release and cation exchangeability of the studied soils within and across locations. Across the studied locations, phosphorus release increased significantly with an increase in the effective cation exchange capacity of the soils. Soil organic matter had a highly significant positive effect on the cation exchangeability of the soils. It did not significantly relate to phosphorus release. Thus; the application of organic material to the soil may not improve phosphorus availability. Though; the addition of organic material to the soil can increase the cation exchangeability of soils.

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