Zinc (Zn) Distribution In Selected Rice Soils Of Ebonyi, Southeastern Nigeria

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Abstract

This research work was carried out on the selected rice soils of Ebonyi to determine the distribution of Zn in the upland, lowland and irrigated rice soils at the three agro-ecological zones of Ebonyi, namely; Ebonyi North, Ebonyi Central and Ebonyi South. The location at Ebonyi North was at Amachi Izzi in Abakaliki and designated by AUP, ALP and AIP for Abakaliki Upland, Lowland and Irrigated pits respectively. Ebonyi Central was located at Ikwo and designated by IUP, ILP and IIP for Ikwo Upland, Lowland and Irrigated pits respectively. Ebonyi south located at Ivo and designated by IvUP, IvLP, and IvIP for Ivo Upland, Lowland and Irrigated pits respectively. Each of the rice land utilization types were delineated, and three profile pits dug in each of the rice land uses to investigate the distribution of Zn in the rice soils. Zn distribution in Ebonyi soils ranged between 14.87mg/kg in AIP3 to 68.90 mg/kg in AUP3. Coefficient of variation (CV) indicated that there was moderate (CV>15≤35%) to high (CV>35%) variability of Zn in all the investigated soils except at the Abakaliki irrigated soils and Ikwo lowland and irrigated soils where CV was low (CV<15%). Also, Zn had a positive and significant correlation with clay, bulk density and ECEC at Ebonyi North, Organic matter and total nitrogen at Ebonyi Central but had not significant correlation with any Physical and Chemical property at Ebonyi South. Analysis of variance of Zn for different agricultural zones in Ebonyi state was significant at 5% probability and non significant at the different cropping land-uses of upland, lowland and irrigated soils at 5% level of probability.

Keyword: Micronutrients, Physical and Chemical properties, Rice Soils, Southeastern Nigeria

Introduction

Zinc is one of the essential plant micronutrients and its importance for crop productivity is similar to that of major nutrients (Rattan *et al.,* 2009). Zinc is an important micronutrient essential for plant growth especially for rice grown under submerged condition. Zinc deficiency is prevalent worldwide in temperate and tropical climates (Fageria *et al.,* 2003; Slaton *et al.,* 2005). In plants it promotes growth hormones and starch formation and is involved in seed maturation and production. Grain seed heads often fail to completely fill if zinc is deficient. It is essential for root membrane permeability and moisture absorption into roots. Widespread and extensive Zn deficiency has been reported in the soils of lowland rice cultivation of India, Bangladesh, Pakistan, Philippines, Myanmur, Indonesia, Japan, Korea, Taiwan and Thailand (IRRI, 1978). Studies on Zn fertilizer proved that the application of Zn greatly influences growth, yield and quality of rice (Patnaik *et al.*, 2011 and Rahman et al., 2007). The symptoms of Zn deficiency have been recorded on rice grown in soils of alluvial zone of West Bengal (Mahata *et al.,* 2012). The most important soil factor associated with Zn deficiency is pH, because availability is markedly reduced with increasing soil pH over the agriculturally important range of 5.5-7.0. For this reason over-liming acid soils may severely reduce the Zn availability for the plant.

Highly available P and prolonged waterlogging also reduce availability. Zn is present in soil in different forms, including in soil solution as Zn^{2+}, $ZnCl^{+}$, and $ZnOH^{+}$. These ions are immediately available for plants as exchangeable Zn, in complex with organic matter, occluded by or co-precipitated with oxides and hydroxides of iron, aluminium and manganese held in clay minerals (Hanza 2008). About 30% of the world's human population has diets deficient in zinc. Zinc deficiency in humans affects physical growth, the functioning of the immune system, reproductive health and neurobehavioural development. Therefore, the zinc content of staple foods, such as rice is of major importance (Alloway 2008). There is a rapidly developing field of research on the biofortification of plant foods with zinc. The extent to which the total concentration of a trace element, such as zinc, in a soil is available for uptake by plants or movement down the soil profile depends on a range of soil properties. The range of total zinc concentrations in soils reported in the literature tends to show an overall mean total concentration of around 55 mg Zn kg-1. Kiekens (1995) reported a typical range of zinc in soils of 10-300 mg kg-1 with a mean of 50 mg Zn kg-1.

Reported symptoms of excessive availability of Zn according to Ezeji *et al.,* (2016) who worked on soils of southeastern Nigeria are chlorotic and nicrotic leaf tips, intervenal chrolosis in new leaves and retarded growth of the entire plant. Also, excessive Zinc uptake due to high application could just as easily cause deficiencies of other nutrients such as Phosphorus, resulting in their deficiency symptom being the only apparent symptom (Knox *et al.,* 2000). According to Nagajyoti *et al.,* (2010) accumulation of heavy metals can degrade soil quality, reduce crop yield and the quality of agricultural products, and thus negatively impact the health of human, animals, and the ecosystem irrespective of their sources in the soil. Chen and Lee (2000) noted that Zinc (Zn) toxicity is relatively rare under normal field conditions, however it has been observed after unusually high prolonged applications. Therefore the objective of this research work was to determine the distribution of Zn in selected rice soils of Ebonyi in southeastern Nigeria.

Materials and Methods

Location

The study area is Ebonyi which lies approximately between latitudes 5° 40' and 6° 45' N and longitudes 7° 30' and 8° 30' E. It has a land mass of approximately 5,952 square kilometers and a population of 2.1 million people (Edeh et al., 2011). Ebonyi State is located in the Southeastern Nigeria. The study was carried out in three Local Government Areas located in three rice zones of Ebonyi North, Ebonyi Central and Ebonyi South.

Geology and Geomorphology

Parent materials consist of shale inter-bedded with sand and limestone (Edeh *et al.*, 2011). The geology is mainly from Nkporo shale and Afikpo sandstone which spreads through Abakaliki region and dislocation of the Anambra Platform and Afikpo region. The resulting succession comprises the Nkporo Group, Eze Aku group, Mamu Formation, Ajali Sandstone, Nsukka Formation, Imo Formation and Ameki Group commenced in the Late Eocene as a result of a major earth movement that structurally inverted the Abakaliki region and displaced the depositional axis (Obasi *et al.*, 2016, Obi *et al.*, 2001). The area is generally dominated by plains and lowland and a fairly uniform landform of low relief. These plains and lowlands exhibit a gently rolling top sequence with a characteristic physiographic differentiation of steeped slope usually below or a little above 100 m above sea level (Obasi *et al.*, 2016). The inland valleys at the foot of the top sequences are often used for lowland rice cultivation.

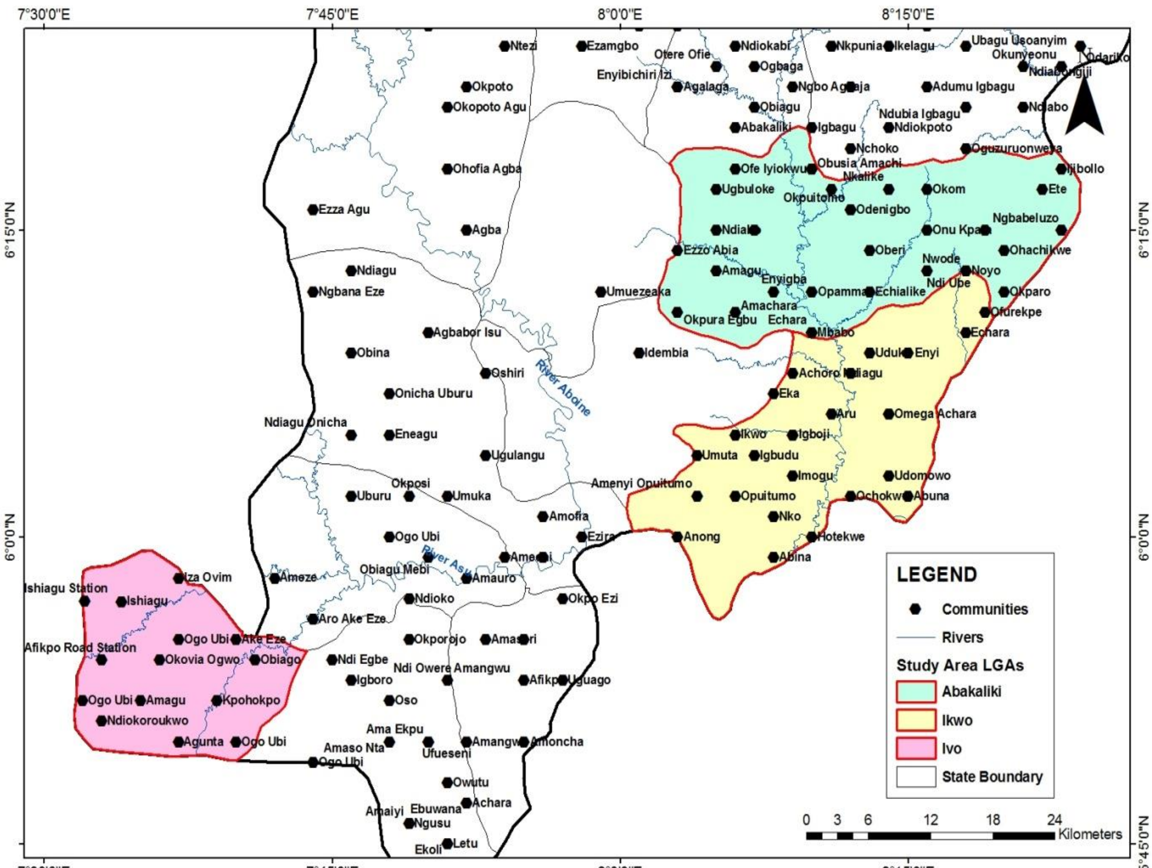

Fig. 1: Map of Ebonyi State showing Study areas, the three major zones in the study area, Rivers and Communities

Source: Ministry of Land Resources Ebonyi State

Climate

The area lies within the humid tropics with Ustic moisture regime. This concept is one of moisture that is limited but is present at a time when conditions are suitable for plant growth. The soil in moisture control section in ustic moisture regime is dry in some or all parts for 90 or more cumulative days in normal year (Soil Survey Staff 2003). Rainfall duration is experienced mostly between April to November with highest intensities occurring between June-September and receives a mean annual rainfall of between 2250mm in the South and 1500mm in the northern part of the zone, average annual temperature of about 27°C with relative humidity of 85% (Nwakpu 2003). Two main seasons prevail in the area- the rainy season, which spans from late April to early November usually with two peaks which occurs at July and September. Short dry period (August break) is usually experienced during the month of August. The dry season, lasts from late November to early April.

Existing Information on Soil

The study area is made up of some upland and lowland soils. The lowlands are usually hydromorphic soils, whose morphology is influenced by seasonal waterlogging caused by underlying impervious shale. The soil texture is clay loam, fairly to poorly drained with gravely subsoil in some locations especially the uplands adjacent to lowland areas. The soils of this class are usually pale-coloured and mottled in the sub-soil (Ekpe 2005). The area consists of undulating to nearly level plains with low ridges and wide shallow valleys where rice is a major crop. Also in the inland valleys, cassava, yam and cocoyam are grown.

The vegetation of the state is a mixture of savanna and semi-tropical forest located in Southeastern Nigerian. The increased activities of man which include bush burning, hunting and increased farming have apparently determined the type of vegetation.

Socioeconomic Activities

The major occupation of the people of Ebonyi is subsistence farming with food crops dominating the practice. The agricultural type is mainly the mixed farming where food crops predominantly planted are cassava, yam and rice. Lowland areas popularly called *fadamas* are largely available and serve as good site for rice production. The rice production on these submerged soils would have enhanced commercial agriculture in the region but has been affected by land fragmentation. The study area has been used both for lowland and upland rice production (Edeh *et al.*, 2011). *Sawah* Technology is practiced in some parts of the state namely Ishiagu in the South and Abakaliki in the northern part of the state. Sawah technology is an irrigation practice in which rice soils are puddled with bunds which can be manipulated for inlet or outlet of water depending on the moisture need of rice plant.

Field Work

A reconnaissance visit was carried out with the aid of location map of the study area to identify three major rice zones in the state and each of the three rice zones was mapped out. A combination of target and random sampling techniques was used. The target sampling technique was used to identify the three major rice areas in each of the three zones. Random sampling technique was used to identify the three rice land use types (LUTs). The rice land use types include; lowland, upland and local irrigated rice production (*Sawah* Technology). In each of the land use types three pedons was sunk, making a total of 9 pedons per zone and 27 pedons in the three zones of the state. Samples were collected from pedons according to horizon differentiation. Samples were carefully labeled and sent for soil analysis.

Laboratory Soil Analysis

Zinc (Zn) Analysis

Pre-extraction of cation with dithionite – citrate carbonate according to the methods of (Hesser 1977) as follows: two and half grams (2.5g) of each air dried sample were weighed into a beaker and the same quantity of sodium dithionite was added. This was prepared by adding 88.23g of sodium citrate to 21.02g of citric acid in two liter flask and made to mark with distilled water to give exactly 0.15M, sodium citrate and 0.5M citric acid are essential for this extraction. The beaker was shaken over height in a shaking machine and later filtered with whatman no.42 filter paper. Twenty five milliliters of the extracts was pipette into a 200ml beaker and 5ml of 30% H_2O_2 was added after the beaker was covered with watch glass. The sample was then allowed to cool. At this stage 10ml of HNO_3 – $H2SO_4$ acid mixture was added in a fume chamber with the sample, again digested for $3^1/_2$ hours until the extract becomes clear. The extract was allowed to cool and diluted with distilled water and made to 100ml in a volumetric flask. Concentrations of zinc were determined thereafter using Perkin Elmer model 2280/2380 Atomic Absorption Spectrophotometer.

Statistical Analysis

Coefficient of Variation (CV) was used to estimate the degree of variability existing among soil properties in the study site. Coefficient of variation (C.V.) ranked as follows; Low variation ≤15%, Moderate variation >15≤35%, High variation >35% was used as outlined by Wilding, (1985). Comparisons were drawn from the results of the laboratory analysis of the pedons in the three rice zones. Analysis of variance (ANOVA) was used to analyse the variability of cation ratios across the three rice zones using 3x3 factorial RCBD and mean separation performed using LSD (Wahua, 1999) to evaluate the cation ratios of the rice soils in Ebonyi.

Results and Discussion

The Zn distributions of Ebonyi North Soils were as shown in Table 1. At Abakaliki upland mapping unit, Zn indicated a decreasing trend in all investigated pedons of Abakaliki soils in Ebonyi north except at the at the Abakaliki lowlands where ALP2 rather indicated increase down the profile. The means of 30.68, 64.88 and 69.90 mg/kg were recorded in the three respective upland pedons of AUP1, AUP2 and AUP3. Also the means at the Ebonyi north lowland pedons were 15.95, 35.88 and 26.64 mg/kg in ALP1, ALP2 and ALP3 respectively, while at the irrigated soils of Abakaliki soils had means of 29.21, 62.53 and 14.87 mg/kg at the AIP1, AIP2 and AIP3 respectively. However, at the uplands coefficient of variation CV varied highly (CV>35%) at AUP1 and AUP3 and moderate (CV>15≤35%) at AUP2. At the lowland soils of Abakaliki, soil varied moderately (CV>15≤35%) at ALP1 and ALP2 while highly (CV>35%) at ALP3. Also, at the irrigated soils, Soils varied lowly (CV<15%) at the AIP1, highly (CV>35%) at the AIP2 and moderately (CV>15≤35%) at the AIP3.

Table 1: Zn Distribution in Ebonyi North (Abakaliki) Soils (mg/kg)

Horizons	Pedon 1	Pedon 2	Pedon 3
	Uplands Soils (AUP)		
1	48.50	85.70	104.0
2	29.60	65.90	120.8
3	16.80	56.10	38.80
4	27.80	51.80	12.00
Mean	30.68	64.88	68.90
CV	42.91	23.23	75.27
Rank	***	**	***
	Lowland Soils (ALP)		
1	18.80	23.50	37.60
2	15.10	33.70	30.14
3	12.30	41.20	32.60
3	17.60	45.10	6.20
Mean	15.95	35.88	26.64
CV	18.06	26.51	52.47
Rank	**	**	***
	Irrigated Soils (AIP)		
1	60.50	105.0	41.60
2	40.40	65.10	8.32
3	15.90	48.60	4.36
4	0.05	31.40	5.20
Mean	29.21	62.53	14.87
CV	10.03	61.72	21.54
Rank	*	***	**

* = Low variability, ** = moderate variability and *** = high variability

The Zn distribution of Ebonyi Central (Ikwo Soils) was as shown in Table 2. There was consistent decrease in Zn distribution down the profile in virtually all investigated pedons of the mapping unit except at IIP3 where there was an increase down the pedon. Means at the uplands were; 55.36, 65.93 and 51.27 mg/kg in IUP1, IUP2 and IUP3 respectively. Means at Ikwo lowlands were 87.32, 53.98 and 51.22mg/kg at ILP1, ILP2 and ILP3 respectively, whereas at the irrigated Ikwo soils, means were 77.97, 38.78 and 54.36 mg/kg at IIP1, IIP2 and IIP3 respectively. Coefficient of variation (CV) indicated that the soils varied highly (CV>35%) in all upland pedons of Ikwo soils. At the lowland soils of Ikwo, ILP1 varied lowly (CV<15%) while ILP2 and ILP3 varied highly (CV>35%). However at Ikwo Irrigated soils, IIP1 varied lowly (CV<15%), IIP2 varied highly (CV>35%) while IIP3 varied moderately (CV>15≤35%).

Table 2: Zn Distribution in Ebonyi Central (Ikwo) Soils (mg/kg)

Horizons	Pedon 1	Pedon 2	Pedon 3
	Uplands Soils (IUP)		
1	90.70	112.8	76.00
2	39.60	41.60	26.20
3	35.80	43.40	51.60
Mean	55.36	65.93	51.27
CV	55.37	61.57	48.57
Rank	***	***	***
	Lowland Soils (ILP)		
1	92.07	79.20	84.15
2	93.40	56.80	51.05
3	91.01	46.40	36.41
4	72.80	33.50	33.26
Mean	87.32	53.98	51.22
CV	11.14	35.81	45.45
Rank	*	***	***
	Irrigated Soils (IIP)		
1	86.70	56.70	42.08
2	71.60	11.60	65.40
3	75.60	48.03	55.60
Mean	77.97	38.78	54.36
CV	10.03	61.72	21.54
Rank	*	***	**

* = Low variability, ** = moderate variability and *** = high variability

The Zn distribution of Ebonyi South (Ivo Soils) was as shown in Table 3. There was a decrease in Zn distribution down the profile in Ivo upland pedons 1 and 2 (IvUP1 and IvUP2) while there was an increase in pedon 3 (IvUP3). In the lowlands of Ivo soils, there was a decrease in pedons 2 and 3 (IvLP2 and IvLP3) while there was an increase down the profile in lowland pedon 1 (IvLP1). The same trend was observed in Ivo irrigated soils where pedon 1 (IvIP1) recorded an increase down the profile while pedons 2 and 3(IvIP2 and IvIP3) showed a decreased Zn distribution down the horizons. Means were 39.28, 25.38 and 43.95 mg/kg at the uplands and pedons IvUP1, IvUP2 and IvUP3 respectively. At the lowlands, means were 48.30, 65.19 and 62.27 mg/kg at the three respective pedons of IvLP1, IvLP2 and IvLP3 respectively, while at the irrigated soils means were 31.75, 12.23 and 63.54 mg/kg all in IvIP1, IvIP2 and IvIP3 respectively. Coefficient of variation (CV) was high (CV>35%) in IvUP1, IvUP3 and IvIP3 while all other investigated pedons in the mapping unit all varied moderately (CV>15≤35%).

Table 3: Zn Distribution in Ebonyi South (Ivo) Soils (mg/kg)

Horizons	Pedon 1	Pedon 2	Pedon 3
	Uplands Soils (IvUP)		
1	75.13	27.89	32.80
2	43.10	33.64	27.23
3	22.65	23.42	72.45
4	16.23	16.56	43.32
Mean	39.28	25.38	43.95
CV	67.48	28.43	45.82
Rank	***	**	***
	Lowland Soils (IvLP)		
1	45.69	88.32	71.20
2	43.12	66.10	40.87
3	38.80	48.30	72.60
4	65.60	58.02	64.40
Mean	48.30	65.19	62.27
CV	24.59	26.16	23.62
Rank	**	**	**
	Irrigated Soils (IvIP)		
1	23.41	68.10	74.16
2	45.16	53.60	14.09
3	34.20	64.80	69.29
4	34.26	62.17	52.51
Mean	31.75	62.17	63.54
CV	31.75	12.23	63.54
Rank	**	**	***

* = Low variability, ** = moderate variability and *** = high variability

Table 4: Analysis of variance of Zn for Agricultural Zones and different Land uses in the study area

Agric. Zones	Zn	Land use	Zn
Ebonyi North	44.5	Upland rice	53.4
Ebonyi Central	61.5	Lowland rice	51.5
Ebonyi South	48.9	Irrigated rice	50.0
L.S.D (0.05)	10.08	L.S.D (0.05)	NS

Zn distribution in Ebonyi soils ranged between 14.87mg/kg in AIP3 to 68.90 mg/kg in AUP3. Kiekens (1995) gave a critical level of Zn to be 10 mg/kg and toxicity level at above 300 mg/kg suggesting that all soils investigated were within acceptable Zn range in the three agricultural zones of Ebonyi state. Hamza (2008) noted that most important soil factor associated with Zn deficiency is pH, because availability is markedly reduced with increasing soil pH over the agriculturally important range of 5.5-7.0. Highly available P and prolonged water-logging also reduce availability. Plant species and selections within species vary widely in their tolerance to Zn deficiency as well as toxicity (Alloway 2008). Gorny *et al.* (2000) reported the following median zinc concentrations on German soils: sandy soils 27.3 mg kg-1, loam/silt soils 59.2 mg kg-1, and clay soils 76.4 mg kg-1. This result agrees with that obtained at the soils of Ikwo and Ivo as their means are close to that of Gorny et al.

(2000) and more so as the rice soils were mostly of clay and shale parent material. This also suggests the greater ability of clay-rich soils to adsorb and retain zinc and other elements relative to soils with lower percentages of clay and higher percentages of sand.

The lowest Zn distributions were obtained at ALP1 (15.95 mg/kg) and AIP3 (14.87 mg/kg). Although these were within the acceptable limits (Kiekens 1995) but a number of factors may have affected its concentration in soils solution which invariably affects its availability to crops. Alloway (2008) noted that zinc which is available to plants is that present in the soil solution, or is adsorbed in a labile (easily desorbed) form. The soil factors affecting the availability of zinc to plants are those which control the amount of zinc in the soil solution and its sorption-desorption from/into the soil solution. These factors include: the total zinc content, pH, organic matter content, clay content, calcium carbonate content, redox conditions, microbial activity in the rhizosphere, soil moisture status, concentrations of other trace elements, concentrations of macro-nutrients, especially phosphorus and climate. Also, waterlogged soils, such as paddy rice soils, reducing conditions result in a rise in pH, high concentrations of bicarbonate ions, sometimes elevated concentrations of magnesium ions and the formation of insoluble zinc sulphide (ZnS) under strongly reducing conditions. The reducing conditions in periodically waterlogged soils also give rise to increased concentrations of divalent ferrous (Fe2+) and manganese (Mn2+) ions, from the dissolution of their hydrous oxides, and these could compete with zinc ions for availability for crops.

Kiekens and Alloway (1995) stated that there appeared to be two different mechanisms involved in the adsorption of zinc by clays and organic matter and these affect its availability to crops. One mechanism operates mainly in acid conditions and is closely related to cation exchange, and the other mechanism operates in alkaline conditions and mainly involves chemisorption and complexation by organic ligands. Apart from reversible adsorption by cation exchange, zinc can also be sorbed irreversibly by lattice penetration in clay minerals. The latter mechanism fixes amounts of zinc in excess of the cation exchange capacity and may be due to sorption of zinc in a hydrolysed form and precipitation of $Zn(OH)_2$. This ‘fixation’ of zinc tends to increase over time and can affect the long-term availability of zinc to crops for uptake.

Analysis of variance of Zn for different agricultural zones in Ebonyi state was significant at 5% probability and non significant at the different cropping land-uses of upland, lowland and irrigated soils at 5% level of probability (Table 4).

Table 5: Regression Model of Zn against selected Physico-chemical properties in the three agro-ecological Zones

Agric Zones	Model (n=27)	r	r^2	Significant
Ebonyi North (Abakaliki)	Zn = 72.83 – 1.90 Clay	0.41	0.17	*
	Zn = -194.6 + 163.5 BD	0.45	0.20	*
	Zn = 51.1 -1.54pH	0.03	0.001	NS
	Zn = 37.6 + 3.26 OM	0.11	0.01	NS
	Zn = 38.24 + 59.02 TN	0.10	0.01	NS
	Zn = 65.9 – 2.35 AP	0.17	0.03	NS
	Zn = 136.7 – 22.49 ECEC	0.52	0.27	**
Ebonyi Central (Ikwo)	Zn = 78.01 – 604 Clay	0.23	0.05	NS
	Zn = -31.6 + 68.98 BD	0.19	0.04	NS
	Zn = 27.85 + 5.47 pH	0.19	0.04	NS
	Zn = 27.48 +14.27 OM	0.52	0.27	***
	Zn = 20.46 + 363.56 TN	0.59	0.35	***
	Zn = 59.6 + 0.86 AP	0.04	0.00	NS
	Zn = 53.29 + 855 ECEC	0.16	0.03	NS
Ebonyi South (Ivo)	Zn = 57.42 – 0.31 Clay	0.22	0.05	NS
	Zn = 23.38 + 18.5 BD	0.09	0.01	NS
	Zn = 60.28 – 1.95 pH	0.02	0.00	NS
	Zn = 48.45- 0.11 OM	0.01	0.00	NS
	Zn = 48.8 + 0.46 TN	0.27	0.07	NS
	Zn = 73.8 – 0.17 AP	0.27	0.07	NS
	Zn = 53.9 – 0.688 ECEC	0.08	0.01	NS

* Significant, ** Very Significant, *** Very Highly Significant, NS = non-significant

Table 5 displays the regression model of Zn against selected physic-chemical properties in the three agro-ecological zones of Ebonyi state. In Ebonyi north Zn was significant with clay (r = 0.41), bulk density (r = 0.45) and ECEC (0.52) and non significant with pH (r = 0.03), organic matter (r = 0.11), total nitrogen (r = 0.10) and available P (r = 0.17). Regression model in Ebonyi central indicated that Zn had a significant relationship with organic matter (r = 0.52) and total nitrogen (r = 0.58) and non significant with clay (r = 0.23), bulk density (r = 0.19), pH (0.19), available P (r = 0.04) and ECEC (r = 0.16). The model at Ebonyi south indicated that Zn had a fairly significant relationship with total nitrogen (r = 0.27) and available P (r = 0.27) and non significant relationship with clay (r = 0.22), bulk density (r = 0.09), pH (r = 0.02), organic matter (r = 0.01) and ECEC (r = 0.08).

Conclusion

Zn distribution in Ebonyi soils were within the acceptable range but liming of rice soils should be done with caution as excessive application of lime on acid soils may affect availability of Zn to crops. Coefficient of variation (CV) indicated that there was moderate to high variability of Zn in all the investigated soils except at the Abakaliki irrigated soils and Ikwo lowland and irrigated soils where CV was low. Also, Zn had a positive and significant correlation with clay, bulk density and ECEC at Ebonyi North, Organic matter and total nitrogen at Ebonyi Central but had not significant correlation with any Physical and Chemical property at Ebonyi South.

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