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Potassium distribution as related to sampling depth in rice-producing zones of northern Ebonyi, Nigeria

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ABSTRACT

Potassium (K) is a crucial element for rice production. Thus,understanding the active forms of Kin soils is important for formulating K management policies for rice production. In this study, we evaluated the K forms in the major rice-producing clans (Amasisi, Mgbom, Ibi and Unwana) of Afikpo L.G.A. of Ebonyi State, southeast Nigeria. Representative soil samples were collected in three replicates from each clan at three depths (0-15 cm, 15-30 cm and 30-45 cm). Standard Laboratory procedures were used to analysed the soils for solution, exchangeable, non-exchangeable, mineral, available and total K. The experimental Design was a 4 x 3 factorial in a Randomized Complete Block Design where location and soil depth were the factors under consideration. Results showed the various K forms were significantly influenced by depth and location. Afikpo had the greatest concentration of these K forms with exception of mineral K, which was most in Ibi. The solution, exchangeable and available K forms decreased with soil depth, but the mineral and total K increased with depth. Irrespective of location and depth, the K forms were generally low and this could impede profitable rice production in these zones. Therefore, external K fertilizer addition is crucial to large scale and profitable K production in these regions.

Keywords: *Afikpo, Depth, Potassium, Production and Rice.*

INTRODUCTION

Rice is one of the most consumed grains in the world, with an annual average consumption of above 500 million metric tons [1]. In Nigeria, rice is considered one of the most staple foods consumed massively across all geopolitical zones and socio-economic classes with an estimated annual consumption average of 7-10.5 million metric tons[2]. Ebonyi State is considered one of the major rice-producing states in the southern Nigeria, contributing significantly to the National rice production.

Potassium is considered a crucial element in rice nutrition. It significantly boosts rice growth and yield by enhancing photosynthesis, improving nutrient uptake, strengthening stem, increasing tillers and grain weight, and improving overall grain quality [3]. According to [4], strengthened by [5], the yield of rainfed rice can be significantly increased by adequate K fertilizer application.

In the soil system, K occurs in different forms, otherwise known as K pools [6]. Based on the relative availability to crops, three different K pools can be identified, and these are, according to [7]: readily available, slowly available and difficultly or relatively unavailable K.

The readily available K are the K in solution and exchangeable form and this constitutes only about 1-2% of soil total K. The slowly available (Non-exchangeable) K forms constitute about 1-10% of soil total K and are fixed K in soil secondary minerals such as vermiculites, illites and micas.These are K held at inter-lattice positions and therefore are non-exchangeable [8]. The difficultly available(Mineral structural) K forms constitute 95-98% of total K. They are K fixed by primary soil minerals[9].These minerals are all resistant to weathering and so they release K very slowly.Over 95% of potassium in tropical soils occurs as relatively unavailable forms contained in primary and secondary minerals [10]. In practical soils, there are dynamic equilibrium among the different K forms and this equilibrium determines the dynamics of K reservation/storage and supply to growing plants [11]. According to [12], Non-exchangeable Kis in equilibrium with available forms and consequently acts as an important reservoir of slowly available K. The readily available K pools are often rapidly depleted through agricultural activities, creating a K concentration gradient. This gradient forces K in the non-exchangeable form to become available. Plants generally depend on the available K pool for its nutrition, thus the equilibrium dynamics that promotes the release of K from mineral or non-exchangeable K to available K favours plant K nutrition.

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The dynamic equilibrium between the K forms is influenced by certain soil conditions such cation exchange capacity, pH and concentrations of other ions in the soil [13],[14]. In addition, farming practices such as fertilization and cropping systems could also influence potassium equilibrium in soils [15].

Farmers in Afikpo north have in recent years complained of low rice production despite heavy financial investment in fertilizers, especially NPK fertilizers. Study by Azu et al., [16], described the phosphorus and nitrogen forms in Afikpo and provided practical guides on P and N management in these soils. There is currently dearth of information on K status of these soils. This study was designed to determine the K status, the dynamics of K release and to provide realistic approaches to K fertility management for maximum and sustained Rice production in AfikpoNorth LGA of Ebonyi State.

MATERIALS AND METHODS

Study sites

Four major rice-producing clans in Afikpo North Local Government Area includingAfikpo(latitude 5.51°N and longitude 7.56°E), Amasiri (latitude 5.54°N and longitude 7.54°E), Ibi (latitude 5.47° N and longitude 7.55°E) and Unwana (latitude 5.51°N and longitude 7.55°E) were selected and geo-referenced with the aid of a hand-held global positioning system (GPS) receiver. Afikpo north has mainly ferralitic hydromorphic soils developed from the underlying shale formations. Annual rainfall is usually high with average range of 2000 -2192mm. The mean temperature is between 25.87°C – 35.46°C with a relative humidity of about 74%. The vegetation is a typical rainforest but tending towards savannah due to excessive deforestation and regular bush burning. Apart from cassava, rice is the second most cultivated crop in the study areas.

Soil Sampling

Soil samples from each location were collected in three replications and at three depths (0-15, 15-30, and 30-45cm) using soil Auger. The sampled soils were air-dried, prepared and the different potassium content in each was analysed in the laboratory according ng to standard methods.

Laboratory Analysis of forms of Potassium

Water soluble K was determined using the extraction method of [17] as described by [7].Exchangeable-K concentration was determined using the method described by [7].Non-exchangeable K was determined using the method of[18] as described by [7]. Mineral or Structural Potassiumwas derived as a difference between total K and the summation of other forms of K (non-exchangeable K + exchangeable K + solution K).Available Potassiumwas gotten by summation of solution and exchangeable K as described by [7]. Total K was determined using the method described by [19]. The extractant used was HF – H_2SO_4 digestion as described by Jackson [20].

Experimental Design

The experimental design was a 4 x 3 factorial in Randomized Complete Block Design (RCBD) were the location and soil depth were the two factors under consideration.

Statistical Analysis

Genstat version 2025 was used to perform the analysis of variance (ANOVA) of obtained data and separation of significant means with $Lsd_{(0.05)}$.Correlation studies to establish the relationships between the K forms and other soil properties was performed using SPSS version 16.

Results and Discussion

Fertility status of soils of the studied locations

Some fertility indicators of the soils of the studied locations are shown in table 1. Apart from Ibi (0-15 and 15-30 cm)where the soil textural class is sandy clay loam, other locations had clayey-loam textures. This shows the abundance of clay in the soils of these locations. [16] had previously reported high clay in the hydromorphic soils of shale formations of Afikpo North LGA. The soil separates (sand, silt, and clay) were significantly influenced by location and sampling depth and their interactions. Sand and silt generally decreased with depth, but clay increased with depth.

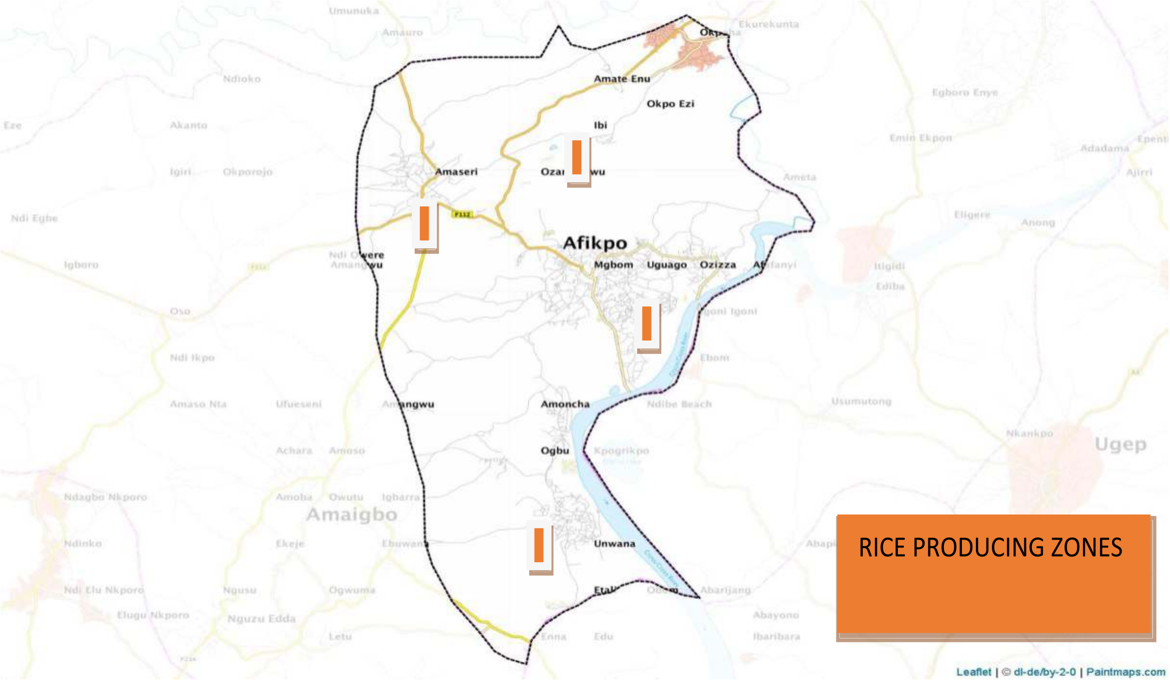

Figure 1: Map of Afikpo North LGA showing the rice producing zones

Table 1: Some of properties of the soils used for the study

Location	Depth	Sand	Silt	Clay	pH	OM	TN	AP	TEB	TEA	ECEC
	(cm)	%	%	%	H$_2$0	%	%	mgkg^{-1}	Cmolkg^{-1}		
Afikpo	0-15	59.33	11.67	29.00	6.00	1.05	0.12	14.10	5.70	2.48	8.18
	15-30	53.33	10.00	36.67	5.07	0.70	0.12	13.33	4.81	3.61	8.42
	30-45	50.19	9.85	39.96	5.00	1.22	0.11	9.97	3.90	3.88	7.78
Amasiri	0-15	55.47	12.38	32.15	4.47	0.52	0.12	13.77	4.57	2.25	6.82
	15-30	55.28	11.66	33.06	5.51	1.15	0.11	11.67	3.96	3.77	7.73
	30-45	50.76	10.14	39.10	5.26	0.87	0.10	10.26	3.00	3.77	6.77
Ibi	0-15	65.33	10.67	24.00	5.00	0.17	0.11	9.93	3.53	2.17	5.70
	15-30	63.20	9.70	27.10	5.00	1.19	0.10	10.00	3.24	2.93	6.17
	30-45	53.46	9.57	36.97	4.84	0.49	0.08	6.87	2.91	3.51	6.42
Unwana	0-15	69.37	12.67	17.96	5.60	1.15	0.09	11.11	4.77	3.33	8.10
	15-30	50.33	9.67	40.00	5.63	0.84	0.08	10.13	4.41	3.79	8.20
	30-45	50.00	9.45	40.55	4.11	0.87	0.06	8.25	4.19	3.96	8.15
LSD$_{0.05}$											
Location		0.33	0.23	0.45	0.06	0.02	NS	0.24	0.01	0.13	136.1
Depth		0.29	0.20	0.39	0.05	0.02	NS	0.21	0.01	0.09	117.9
L X D		0.58	0.39	0.77	0.11	0.05	0.01	0.42	0.01	0.23	235.8

Other studies have previously reported this trend in the profile distribution of soil separates [21] which could be attributed to clay migration down the soil profile [22]. The soils were strongly acidic irrespective of location and depth which is consistent with soils of southeastern Nigeria [23]. Organic carbon varied significantly (0.05) with location, depth and their interactions. Organic carbon, which ranged from 0.28% in Ibi to 0.70% in Afikpo was generally low and below the critical value of about 12.5% proposed by [24]. The total nitrogen and available P were generally low and below the critical threshold for tropical soils. Leaching of nitrogen due to heavy tropical rains [25]. The concentration of the exchangeable bases and ECEC in the soils were relatively high [16] observed high cation content in soils of Ebonyi State and they attributed this to the underlying shale parent material and high clay content.

Forms and Distribution of Potassium in the Soils Studied

The K distribution in the major rice producing clans of Ebonyi State is presented in table 2. Location, depth and their interaction statistically influenced the solution K. In Afikpo and Amasiri, solution K increased at 15-30cm depth and then decreased at 30-45cm depth, thus the highest concentration of solution K (0.1cmolkg^{-1}each) occurred at 13-30cm depth in Afikpo and Amasiri. However, the solution K decreased with depth in Ibi and Unwana.The mean values of solution K indicate that Afikpo and Amasiri had the largest value (0.08 cmolkg^{-1}each), followed by Ibi (0.04 cmolkg^{-1}) and then Unwana (0.03 cmolkg^{-1})

Exchangeable K ranged from 0.08 cmolkg^{-1} in Unwana to 0.14 cmolkg^{-1} in Afikpo and Amasiri and concentrations with exception of Unwana increased with depth.The intensification of clay minerals, especially 2: 1 mineral down the soil profile could be used to explain this observation.[26], noted that illite and montmorillonite are the predominant clay minerals in most soils of Ebonyi State. These minerals are capable of attracting and releasing cations such as K at the exchange sites [7]. It can be inferred that exchangeable K increased with depth due to increased concentration of clay minerals.

The non-exchangeable K was not statistically influenced by both location and depth. However, the interaction between depth and location had a significant effect (P>0.05) on the non-exchangeable K. Values ranged from 0.15 cmol/kg in Afikpo to 0.12 cmol/kg in Amasiri. These values fall within the low non-exchangeable category and less than the value of 50-150mg/kg reported by [27] for most tropical soils.

Table 2: Forms and Distribution of Potassium in the Soils Studied

Location	Depth	Solution K	Exchangeable K	Non exchangeable K	Available K	Mineral K	Total K
	Cm	Cmolkg^{-1}					
	0-15	0.09	0.13	0.14	0.22	0.22	0.58
Afikpo	15-30	0.10	0.14	0.15	0.24	0.21	0.60
	30-45	0.06	0.13	0.15	0.19	0.23	0.57
	Mean	0.08	0.13	0.15	0.22	0.22	0.58
	0-15	0.07	0.12	0.12	0.19	0.21	0.52
Amasiri	15-30	0.10	0.12	0.12	0.22	0.22	0.56
	30-45	0.08	0.14	0.12	0.22	0.23	0.57
	Mean	0.08	0.12	0.12	0.21	0.22	0.55
	0-15	0.05	0.09	0.13	0.14	0.27	0.54
Ibi	15-30	0.04	0.08	0.13	0.12	0.32	0.57
	30-45	0.04	0.10	0.14	0.14	0.33	0.61
	Mean	0.04	0.09	0.13	0.13	0.31	0.57

Unwana	0-15	0.04	0.09	0.12	0.13	0.21	0.46
	15-30	0.03	0.08	0.13	0.11	0.22	0.46
	30-45	0.02	0.08	0.13	0.10	0.24	0.47
	Mean	0.03	0.08	0.13	0.11	0.22	0.46
LSD$_{0.05}$							
Location		0.157	0.005	NS	0.036	NS	0.017
Depth		0.136	0.004	NS	0.023	NS	0.015
L X D		0.272	0.008	0.002	0.016	0.002	0.029

Available K which is the summation of Exchangeable and Solution K ranged from 0.10 to 0.24Cmol/kg. The order of abundance of Available K is:Afikpo>Amasiri>Ibi>Uwana. Available K generally decreased with depth across locations. Farming system such as fertilization could influence the available form of K as earlier reported by[28].Irrespective of location and depth, available K was generally very low.

Structural / Mineral K values ranged from 0.21 to 0.33 cmol/kg and only the interaction between depth and location showed a significant influence on mineral K concentration. Mineral K decreased with depth and 30-45 cm depth had the highest value of mineral K. This result corroborates the findings of.[29] who revealed that the highest amount of mineral K was found in the sub-surface soils than surface soils and they attributed thisto intense weathering of K minerals at the surfaces than the sub-surface. While Ibi had the highest concentration of mineral K, Unwana had the least value. The present values of mineral K fall below the range of 5000-25,000 mg/kg reported by [30].

Total K content of the soil ranged from 0.46 to 0.6Cmol/kg and varied with depth in Afikpo and increased with depth across all other 3 locations with mean concentrations of 0.58, 0.55, 0.57 and 0.46Cmol/kg for Afikpo, Amasiri, Itim, and Uwana respectively. This variation of total K could be attributed to agricultural practices and land use type [31][7]

The Correlation between Potassium Forms and Soils Physical Properties

The result shows that solution k had positive highly significant correlation (r = 0.944**, 0.932**) with bulk density and moisture contents of the soil which implies that increased in bulk density and moisture contents increases solution k rapidly, that's increase in one increases the other. Solution k also had a slight negative relationship (r = -0.877*) with total porosity of the soil. Showing that increase in one decreases the other.

Exchangeable k had highly significant positive correlation with bulk density and moisture content (r = 0.935**, 0.938**), meaning that an increase in either exchangeable k or bulk density and moisture content increases the other vice versa. Exchangeable k also exhibits a highly significant negative correlation with soil total porosity (r = -0.983**), indicating that increase in one decreases the other at a very high rate. Several studies revealed that any activity associated with a change in land use and agricultural management practices can affect soil properties and K dynamics [32]. But the exchangeable and extractable K status of tropic soil K forms are unsatisfactory measures of nutrient availability since their concentration in the soil at any time is small in relation to long-term losses by crop removal and leaching and they give little indication of reserves of non-exchangeable but potentially available K.

From the result Mineral K highly correlated negatively with sand at (r= -0.924**), this entails that increase in sanddecreases mineral k content of soil or an increase in mineral k decreases sand content. Hence, significantly correlates positively with clay (r = 0.897*) content of the soil, which implies that increase in one also increases the other. Despite its abundance, only less than 2 to 3% of soil K is available to plants in free soluble form because the rest remains bound to other soil minerals, constituting an estimated 95% of soil potassium [33]

Total k contents of the soil had significant positive correlation with bulk density and moisture content (r = 0.851*, 0.865*), showing that an increase in moisture content and bulk density also influence total k content of the soil positively. Thus, correlates significantly negative with total porosity (r = -0.807*). Meaning that an increase in bulk density decreases total k content of the soil vice versa.

Table 3: Correlation between the soil textural properties and forms of Potassium

	Sand	Silt	Clay
Solution K	0.525	0.007	-0.128
Exchangeable K	-0.716	0.448	0.447
Non-exchangeable K	-0.055	-0.624	0.413
Mineral K	-0.924**	0.730	0.897*
Total K	-0.016	-0.281	0.945*

Correlation is significant at the 0.05% level (2-tailed) Correlation is significant at the 0.01% level (2-tailed)*

The Correlation between Potassium Forms and Soil Chemical Properties

From the results Solution K had a highly significant positive correlation with base saturation (r = 0.934**) Indicating that an increasing soil base saturation increases the solution k, and this may be attributed the basic cation dominance of the soil.

Exchangeable Kexhibits highly significant positive correlation with pH and available phosphorus at (r = 0.911**, 0.974**) indicating that increase of one also increases the other respectively. These results agreed with [9]who indicated that exchangeable K was significantly and positively correlated to Available phosphorus, indicating that as the amount and surface area of exchange complex increases the exchangeable K increases.

Exchangeable K also has positive correlation with soil total nitrogen at (r = 0.870*) meaning that increase in exchangeable k increases the total nitrogen content of the soil or the increased in total nitrogen content of the soil increases the exchangeable k contents of the soil. The result corroborates with [34] also reported that increase in soil pH could be associated with enhanced carbonate levels and less weathering rates,[35] the degree of potassium fixation depends on the type of clay mineral and it charged density, degree of interlaying, moisture content, concentration of k ions as well as concentration of competing cations and the pH of the ambient solution bathing the soil.

Table 4: Correlation between the soil chemical properties and forms of Potassium

	pH	OC	TN	AV. P	TEB	TEA	ECEC
Solution K	0.058	0.512	0.787	0.765	0.505	-0.005	-0.934
Exchangeable K	0.911**	0.521	0.870*	0.974**	0.416	-0.031	0.753
Non-exchangeable K	-0.094	-0.329	-0.233	-0.135	-0.451	0.073	0.260
Mineral K	-0.794	-0.940**	-0.086	-0.738	-0.868*	0.824*	-0.598
Total K	-0.099	0.359	0.500	0.146	0.515	0.123	0.732

**Correlation is significant at the 0.05% level (2-tailed)*
*** Correlation is significant at the 0.01% level (2-tailed)*

Mineral K had highly significant negative correlation with organic carbon content of the (r = -0.940**) showing that an increased in organic carbon decreases the mineral k vice versa. Mineral K also possess moderate positive relationship total exchangeable acidity (TEA) of the soil (r = 0.824*) and negative correlation with total exchangeable bases (TEB) of the soil at (r = 0.868*) which implies that increased in total exchangeable acidity favours the increase in mineral k, consequently, increased mineral K decreases total exchangeable bases content of the soil and vice versa.[36] explained further that the use of K chemical fertilizers results in a strong adsorption of K to the minerals K fixation and thereby making them inaccessible for the plants.

Conclusion and Recommendations

Potassum is an important element for rice production. Understanding the various K forms and the dynamics of K retention and release is essential in soil K modelling and fertilizer K management in the rice producing zones of Afikpo. Results from this study indicates that the various forms of K were generally low and below the critical threshold for optimum rice production. This implies that maximum and profitable rice production in these areas could only become possible where there is conscious effort to add adequate amount of K fertilizers to these soils. Reducing soil acidity through liming could help to free up adsorbed K in the mineral particles for plant use.

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