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Prediction of the productivity of floodplain soils in Taraba state using productivity models

Tanko Bako[1]*, Akila Bardey Istifanus[1], Ezekiel Ambo Mamai[2]

1. Department of Agricultural and Bio-Resources Engineering, Taraba State University, Jalingo, Nigeria
2. Department of Soil Science and Land Resource Management, Federal University, Wukari, Nigeria

Corresponding author e-mail: engbako@gmail.com

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Abstract
A study was carried out to quantify the productivity level of floodplain soils in Taraba state usingNeill's Productivity Index (PI) and Modified Neill's Productivity Index (PI_M). Fields and laboratory experiments were conducted to study the effects of locations on distribution of bulk density, available water capacity, pH, organic matter, available phosphorus, iron oxide and aluminium oxide atdifferentsoildepths, and itseffects on soil productivity. The bulk density and available water capacitywerefound to increase with soil depths while the soilpH, organic matter, available phosphorus, ironoxide and aluminium oxide were found to decrease with soildepthsatall the locations investigated. The results show that soil productivity index was significantly ($P \leq 0.05$) affected by locations of the floodplains.

Keywords
physical, chemical, properties, Productivity Index

Introduction

Floodplain soils constitute the back bone of arable crop production in the semi-arid and arid savannah agro-ecological zones where precipitation (rainfall) is limited for agricultural productivity. The productivity of soil is reduced through soil degradation in form of erosion, contamination, deforestation and dissertation (Nwite, 2013). Accurate estimate of future soil productivity is essential to make agricultural policy decisions and to plan the use of land from field scale to the national level. It is established that productivity capacities or expected yields are useful in determining the suitability of any soil for agricultural use. Different methods have been developed which attempt to numerically relate soil properties to its productivity. These include the Universal Soil Loss Equation (USLE) and Erosion Productivity Impact Calculation (EPCI). However, a simple numerical index model is now preferred to others because of its simplicity and applicability in many soils. The model widely used today in quantification of soil productivity is the productivity index (PI) model modified by Pierce *et al.* (1983). This productivity index is based on the use of physical and chemical properties to predict effect of soil erosion on productivity (Pierce *et al.,* 1983). The Southern Guinea Savanna Agro-ecological zone of Nigeria where Taraba State is located is characterized by diverse climatic, topographic and soil conditions. This region is one of the areas where seasonal flooding and soil erosion processes constitute key constraints to soil productivity. It is worrisome that in spite of the increasing interest in floodplain farming in Taraba State, there has been no studies reported in literature on the fertility assessment of the floodplain nor

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its productivity status, and the need for this data cannot be over emphasized especially when viewed against the realization that such information forms the background to an efficient and judicious use of the soil resources. It is for these reasons that this kind of simulation study was carried out. Therefore, this work was carried out to quantify the productivity status of floodplain soils using productivity index models in Taraba State, North-Eastern Nigeria.

Materials and Methods

Study area

The experiment was conducted in 2017 at the floodplains of Wukari, Taraba State, North Eastern Nigeria, located at latitude $7^0 51'$ North of the equator and longitude $9^0 47'$ East of Greenwich Meridian. It covers an area of about 4,308km^2. Wukari lies within the tropical hinterland climatic region. The natural vegetation of the area is northern Guinea savanna and has two distinct seasons; dry and wet. The wet season starts from April and ends in October, with annual rainfall between 1000 mm to 1500 mm per annum, relative humidity of 50 % to over 80 % and air temperature of 18°Cto 39°C. Figure 1 is the map of Taraba State showing Wukari Local Governmento with map of Nigeria showing Taraba State inset and Figure 2 is the map of Wukari Local Government showing the study area.

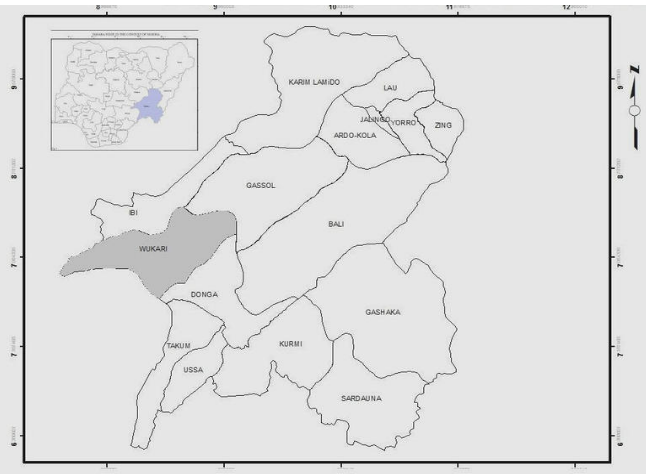

Figure 1. *Map of Taraba state showing Wukari local government with map of Nigeria showing Taraba state inset* (Oko et al., 2017).

Experimental design and statistical analysis

The experimental design for the statistical analysis follows a one-treatment effect (five sample locations) in a Completely Randomized Design (CRD) with three replications per experimental unit giving fifteen (15) observations for the experiment. Statistical differences between soil properties from different locations were tested by Analysis of Variance (ANOVA) at $p \leq 0.05$. When significant difference was observed, treatment means were separated using the Fisher's Least Significant Difference (F-LSD).

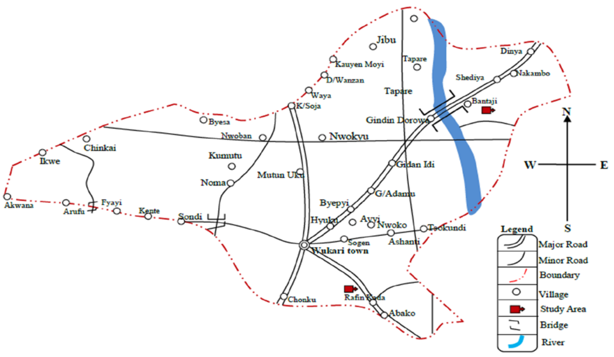

Figure 2. *Map of Wukari local government showing the study area* (Oko et al., 2017).

Determination of soil properties

The soil textures in these areas are mainly clay loam, which is medium texture. Soil samples were collected with auger and core samplers at 0-20cm, 20-40cm and 40-60cm depths in each plot. The soil samples were air-dried for a period of one week in a clean well ventilated laboratory, homogenized by grinding, passed through a 2 mm (10 mesh) stainless sieve and were analyzed for physical and chemical properties using standard procedures. Particle size analysis was done by the hydrometer method (Cheick, 2014). The soil bulk density was determined according to Aikins and Afuakwa (2012). Available water capacity was determined using pressure plate according to Singh *et al.* (2013). Soil pH was measured in a 1:1 soil-water ratio using a glass electrode (H19017 Microprocessor) pH meter as described by Hendershot *et al.* (1993). Soil organic matter was obtained by determining soil organic carbon using the dichromate wet oxidation method and multiplying the organic carbon by 1.724 as described by Bray and Kurtz (1945). Available phosphorus was determined using the conventional method reported by Bray and Kurtz (1945). Extractable iron and aluminium were determined by the sodium citrate, sodium bicarbonate and sodium dithionite (CBD) method described by Parfitt and Childs (1988).

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Application of productivityindexmodels

The Neill Productivity Index (PI) model modified by Pierce *et al.* (1983) was used. This model was based on simple measurable soil properties. The equation is:

$$PI = \sum_{i=1}^{n} A_i \times C_i \times D_i \times F_i \times L_i \times J_i \times Wf_i \qquad [1]$$

Where: PI = Productivity Index, A_i = Sufficiency for available water capacity for the ith soil layer, C_i = Sufficiency for pH for the ith soil layer, D_i = Sufficiency for bulk density for the ith soil layer, F_i = Sufficiency for clay content for the ith soil layer, L_i = Sufficiency for land slope for the ith soil layer, J_i = Sufficiency for organic matter content for the ith soil layer, Wf_i = Root weighting factor (based on depth of root zone) and n = Number of horizons in the rooting zone (soil layer).

The PI model developed by Pierce *et al.* (1983) was expanded to capture the influence of phosphorus (P), iron oxide (FeO) and aluminum oxide (Al_2O_3) by Agber (2011) as follows:

$$(PI_M) = \sum_{i=1}^{n} A_i \times C_i \times D_i \times F_i \times L_i \times J_i \times Wf_i \times P_i \times Fe_i \times Al_i \qquad [2]$$

Where: (PI_M) = Modified Neill productivity index, P_i = sufficiency for phosphorus content for the ith soil layer, Fe_i = sufficiency for iron oxide content in the ith soil layer and Al_i = sufficiency for aluminum oxide content in the ith soil layer.

Determination of productivity index value

In these productivity indexes, the productivity terms were normalized to range from 0.0 (complete inhibition of root growth) to 1.0 (no inhibition of root growth) based on a response function foreach property (Kiniry *et al.*, 1983) and related the levels of soil properties to their sufficiency. Sufficiencies were assigned to soil properties. The sufficiencies for available water capacity, pH, bulk density, claycontent, land slope, organic matter content and root weighting factor were adopted and used as described by Pierce *et a*l. (1983), the sufficiency for available phosphorus was adopted and used as described by Aduayi *et al.* (2002) and the sufficiencies for Extractable iron and aluminium were adopted and used as described by Ogunsola *et al.* (1989). Sufficiencies for each location were multiplied to estimate the productivity indexes.

Results and Discussion

Properties of the floodplain soils

Tables 1 and 2 show the mean soil physical and chemical properties of the floodplain soils. The soil textures in these areas are mainly clay loam, which is medium texture. It was observed from the result that bulk density values increased with soil depth in all the floodplain locations investigated. The bulk density values of the flood plains were lower than 1.6 g/cm^3, thus rated medium, a range considered not to impede root penetration (Donahue *et al.*, 1990). Therefore bulk density will not be a retarding factor for crop cultivation in the study area. The ANOVA showed that bulk density of the floodplain soils were statistically insignificant for all the soil sample depths at $P \leq 0.05$ level of significance. The results show that available water capacity increased with soil depth in all the floodplain locations investigated. Generally, the available water capacity of these soils is very high according to Landon (1991) ratings (>21 % very high, 18-21 % high, 12-18 % medium, 8-12 % low and < 8 % very low). The ANOVA showed that available water capacity of the floodplain soils were statistically insignificant for all the soil sample depths at $P \leq 0.05$ level of significance. The soil pH values decreased with soil depth in all the floodplain locations investigated. Soil reaction was slightly acidic to neutral (Malgwi, 2007). The soil organic matter content is generally low in the soils according to Landon (1991) ratings (>20 % very high, 10-20 % high, 4-10 % medium, 2-4 % low and < 2 % very low). The low organic matter content of the flood plain soils has been attributed to factors such as continuous cultivation, frequent burning of farm residues commonly carried out by farmers in the area which tends to destroy much of the organic materials that could have been added to the soil (Yakubu, 2006). The Analysis of Variance (ANOVA) of the soil organic matter content test confirm the observed variations, in that, the differences amongst the different flood plain locations are statistically significant at 0.05 probability level for all the soil depths. The available phosphorus content of the floodplain soils decreased with increased in soil sample depths at all the locations examined. The available phosphorus content is generally at the medium range in the soils according to Cottenie (1980) ratings (>25mg kg^{-1} very high, 18-25mg kg^{-1} high, 10-17mg kg^{-1} medium, 5-9mg kg^{-1} low and< 5mg kg^{-1} very low). The Analysis of Variance (ANOVA) of the soil available phosphorus shows that the differences among the different flood plain locations are statistically significant

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at 0.05 probability level at the soil depths of 0-20 cm and 20-40 cm but not statistically significant at the soil depth of 40-60 cm. The results showed that in all the floodplain locations, extractable iron oxide tend to decrease at the lower depth.

Table 1. *Mean soil physical properties of the floodplain soils at different locations*

Soil Depth (cm)	Location	Particle Size Distribution			Textural class	ρ_d	AWC
		% sand	% Silt	% clay		(g/cm^3)	m/m
0-20	NWRS	34.9	28.5	36.6	CL	1.32	0.25
	TSRS	37.8	26.2	36.0	CL	1.31	0.26
	RKRS	36.0	27.0	37.0	CL	1.32	0.26
	GIRS	35.7	27.5	36.8	CL	1.31	0.25
	GDRS	35.0	27.3	37.7	CL	1.30	0.26
F-LSD $_{0.05}$		-	-	0.55	-	-	-
20-40	NWRS	34.8	28.5	36.5	CL	1.32	0.26
	TSRS	36.7	27.7	35.8	CL	1.31	0.26
	RKRS	36.0	27.3	36.7	CL	1.32	0.26
	GIRS	36.7	26.7	36.7	CL	1.31	0.26
	GDRS	36.1	26.9	37.0	CL	1.32	0.26
F-LSD $_{0.05}$		1.08	0.85	-	-	-	-
40-60	NWRS	35.0	28.5	36.5	CL	1.33	0.26
	TSRS	36.3	28.0	36.3	CL	1.32	0.27
	RKRS	36.3	27.7	36.0	CL	1.33	0.27
	GIRS	36.3	26.3	36.7	CL	1.31	0.27
	GDRS	36.1	26.7	37.3	CL	1.32	0.27
F-LSD $_{0.05}$		0.82	0.81	-	-	-	-

The extractable iron oxide obtained is generally low in the soils according to Ogunsola *et al.* (1989) ratings (3.6 g/kg Low and 13.3 g/kg High). The Analysis of Variance (ANOVA) of the soil extractable iron oxides shows that the differences among the different flood plain locations are statistically significant at 0.05 probability level at all the soil depths investigated. The aluminium oxide value decreased with increasing soil depth. Values of extractable aluminium oxide obtained in the soils are low according to Ogunsola *et al.* (1989) ratings (0.2 g/kg Low and 3.0 g/kg High). The ANOVA of the aluminium oxide contents of the floodplain soils showed that the differences among the different flood plain locations are statistically significant at 0.05 probability level at the soil depths of 0-20 cm and 20-40 cm but were statistically insignificant at the soil depth of 40-60 cm.

Productivity of the floodplain soils

Tables 3 shows the average soil properties for determining sufficiency, Table 4 show ascribed sufficiency values for calculating soil productivity index and Table 5 shows the soil productivity index using productivity models. The physical and chemical properties of the studied soils were used to quantify the productivity of the floodplain soils. The sufficiency of the soil properties for each floodplain location was multiplied to estimate the PI and PI_M where, a value of zero indicates an absolutely limiting level of a soil property and a value of 1.0 indicated the optimum level (Kiniry *et al.*, 1983). According to Nwite and Obi (2008), high soil productivity index is a good indicator of soil capacity to support crop production for long period of time. The data showed that the mean values of PI calculated were 0.418, 0.446, 0.432, 0.422 and 0.413 for Nwuko, Tsokundi, Rafin-Kada, Gidan-Idi and Gindin-Dorowa floodplains respectively and the mean values of PI_M calculated were 0.261, 0.288, 0.283, 0.272 and 0.235 for Nwuko, Tsokundi, Rafin-Kada, Gidan-Idi and Gindin-Dorowa floodplains respectively. The variation in PI values is depending on the initial properties of each soil, within the root zone, which affect the sufficiency of each soil property.

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Table 2. *Mean soil chemical properties of the floodplain soils at different locations*

Depth (cm)	Location	pH (H_2O)	OM (%)	Avail P (%)	FeO (g/kg)	Al_2O_3 (g/kg)
0-20	NWRS	7.37	2.53	17.06	3.9	1.0
	TSRS	7.03	2.66	16.61	5.8	0.6
	RKRS	6.87	2.64	16.74	4.0	0.7
	GIRS	6.81	2.53	16.72	5.4	0.6
	GDRS	7.06	2.46	16.92	5.6	1.1
F-LSD $_{0.05}$		-	0.08	0.111	0.56	0.30
20-40	NWRS	7.34	2.46	16.20	3.6	0.7
	TSRS	7.00	2.66	16.49	5.5	0.5
	RKRS	6.87	2.63	16.70	3.8	0.7
	GIRS	6.68	2.53	16.66	5.3	0.5
	GDRS	6.76	2.45	16.89	5.4	0.8
F-LSD $_{0.05}$		-	0.04	0.502	0.45	0.373
40-60	NWRS	6.88	2.45	16.19	3.6	0.7
	TSRS	6.88	2.65	16. 32	5.3	0.4
	RKRS	6.77	2.60	16.67	3.6	0.5
	GIRS	6.62	2.49	15.85	5.1	0.4
	GDRS	6.67	2.45	16.89	5.4	0.7
F-LSD $_{0.05}$		-	0.14	-	0.44	-

The changes in soil organic matter content influenced PI values. The PI values were obviously higher than those values of PI_M. These results showed that when three more parameters, i.e. available phosphorus (P), iron oxide (FeO) content and aluminium oxide (Al_2O_3) content were included in the model, the values of PI_M decreased as compared with PI values. Contributions of iron and aluminium oxides to the soil productivity are decreasing with their contents. The sufficiencies of iron and aluminium oxides are low therefore, restricted the soil productivity. The results also showed that the highest mean PI_M of 0.288 was obtained in Tsukundi floodplain while the lowest mean PI_M of 0.235 was obtained in Gindin-Dorowa floodplain. High productivity index indicated soil with improved soil properties; therefore, the most productive soil is Tsukundi floodplain soil. Evaluation of soil productivity was done according to Fernando (2002).

Table 3. *Mean soil properties for determining sufficiency*

Soil Property	Location				
	Nwuko	Tsokundi	Rafin-Kada	Gidan-Idi	Gindin-Dorowa
AWC (m/m)	0.26	0.26	0.26	0.26	0.26
pH (H_2O)	7.20	6.97	6.84	6.70	6.83
Bulk density (g/cm^3)	1.32	1.31	1.32	1.31	1.31
Clay content (%)	36.53	36.03	36.57	36.73	37.33
Land slope (%)	2	2	2	2	2
Organic matter (%)	2.48	2.66	2.62	2.52	2.45
Root weighting factor (cm)	60	60	60	60	60
Phosphorus (%)	16.48	16.47	16.70	16.41	16.90
Iron oxide (g/kg)	3.70	5.53	3.80	5.27	5.47
Aluminium oxide (g/kg)	0.80	0.50	0.63	0.50	0.87

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Table 4. *Ascribed sufficiency for calculating productivity index*

Soil Property	Location				
	Nwuko	Tsokundi	Rafin-Kada	Gidan-Idi	Gindin-Dorowa
AWC (m/m)	1.0	1.0	1.0	1.0	1.0
pH (H_2O)	1.0	1.0	1.0	1.0	1.0
Bulk density (g/cm^3)	0.8	0.8	0.8	0.8	0.8
Clay content (%)	1.0	1.0	1.0	1.0	1.0
Land slope (%)	1.0	1.0	1.0	1.0	1.0
Organic matter (%)	0.87	0.93	0.90	0.88	0.86
Root weighting factor (cm)	0.6	0.6	0.6	0.6	0.6
Phosphorus (%)	1.0	1.0	1.0	1.0	1.0
Iron oxide (g/kg)	0.80	0.75	0.80	0.75	0.75
Aluminium oxide (g/kg)	0.78	0.86	0.82	0.86	0.76

Table 5. *Soil productivity index using productivity models*

Productivity Index	Locations					$F\text{-}LSD_{0.05}$
	Nwuko	Tsokundi	Rafin-Kada	Gidan-Idi	Gindin-Dorowa	
PI	0.418	0.446	0.432	0.422	0.413	0.00651
PI_M	0.261	0.288	0.283	0.272	0.235	0.00081

Comparing the calculated PI and PI_M values with the relative data of productivity index, the productivity of floodplain soils obtained with PI is high (0.31 - 0.50) whereas with PI_M all the floodplain soils have moderate productivity (0.11 - 0.30)(Fernando, 2002). The results showed that PI values were higher than PI_M values; therefore, the PI_M model did not reflect the actual productivity level. Productivity index (PI) provides a single scale on which soils may be rated according to their suitability for crop production. The results indicated that soil physical and chemical properties could be limiting or non-limiting factors on the productivity of soils.

Conclusions

The result of this study indicated that the productivity status of Taraba state floodplain soils could be quantified using productivity index models. Sufficiency values of soil properties such as available water capacity, bulk density, rooting depth and soil pH could be used to quantify productivity index of soil.

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