Evaluation of Soil Productivity Using Soil Productivity Models in Yandev, Gboko, Benue State

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Abstract

Field experiments were carried out at the Teaching and Research Farms of the Akperan Orshi Polytechnic, Yandev (AOPOLY) (Latitude 7°45' – 8°00'N and Longitude 8°36' – 8°45'E) in September, 2022. The experiment was carried out to assess soil productivity using soil productivity models in Akperan Orshi Polytechnic, Yandev area of Benue State. Soil productivity models considered were: Productivity Index (PI) model, Modified Productivity Index (PIm) model and Riquier index (RI) model. Three agricultural lands located within Akperan Orshi Polytechnic, Yandev namely western, eastern and southern parts of the school farming areas were used for the experiment. A total of 9 soil composite auger samples were collected at depth 0 – 30 cm for physical and chemical analysis across the three locations. The soils of the study area were of dominantly loamy sand textures at western and eastern farm sites while southern farm site was of sandy loam texture. Chemical properties of soils such as organic matter content, total nitrogen, available phosphorus and exchangeable bases contents of the soils were generally low throughout the study areas. Calculated productivity index (PI), modified Productivity Index (PIm) and Riquier Productivity Index (RI) show that Western School Farm site had 0.32, 0.18 and 0.25 values for PI, PIm and RI models respectively. Eastern School Farm site had 0.38 for PI, 0.21 for PIm and 0.25 for RI. Similarly, Southern School Farm site had 0.45 for PI, 0.25 for PIm and 0.31 for RI. The RI values of Western, Eastern and Southern School Farm sites fall under productivity class 3 and rated as 'average productivity'. Generally, PI model had higher values followed by RI and PIm models across the locations. Soil productivity models across the locations generally, could be ranked as Southern Farm>Eastern Farm>Western Farm while ranking on the basis of the models could be PI> RI>PIm.

Key Words: *Productivity, models, soil, index, Agricultural lands*

INTRODUCTION

Soil productivity is the capacity of a soil in its normal environment to produce a particular plant or sequence of plants under a specified management system (Nwite and Nnoke, 2005). It is also considered as initial soil capacity to produce a certain amount of crop per annum, and is expressed as a percentage of the optimum yield per hectare of the same crop grown on the best soil. Soil productivity is a function of the intrinsic properties of a soil, first as determined in the process of describing the soil profile and the crops grown on it, and secondly by laboratory analysis. Soil productivity varies with the type of crop grown. Some plants are able to withstand adverse soil conditions which others cannot. A number of soil properties directly affect soil productivity; these include topsoil thickness, texture distribution, rooting depth, soil fertility and slope.

Assessment of soil quality is the basis for assessing sustainable soil management in the next century (Estrada *et al*., 2017). It is particularly difficult to select factors of soil quality for degraded or polluted soils. Estrada *et al*. (2017) indicated that appropriate sustainable management would require that a technology have five major pillars of sustainability, namely, it should: (1) be ecological protective, (2) be socially acceptable, (3) be economically productive, (4) be economically viable, and (5) reduce risk. Appropriate indicators are needed to show whether those requirements are being met. Some possible soil variables which may define resource management domains are soil texture, drainage, slope and land form, effective soil depth, water holding capacity, cation exchange capacity, organic carbon, soil pH, salinity or alkalinity, surface stoniness, fertility parameters, and other limited properties (Eswaran et al. 1998). The utility of each variable is determined by several factors, including whether changes can be measured over time, sensitivity of the data to the changes being monitored, relevance of information to the local situation, and statistical techniques which can be employed for processing information. Doran and Parkin (1994) have developed a list of basic soil properties or indicators for screening soil quality and health. These include physical, chemical and biological indicators.

Numerous models currently exist, which are used to assess soil productivity, ranging from single to complex: these include Riquier index, Neill index, and cook index (Gantzer and Mc Carty, 1987). Anikwe(2000) evaluated efficiencies of some models on soil productivity in south-east Nigeria. Agber (2011) evaluated the effectiveness of some models in Makurdi.

There is however, inadequate information on the use of these models in assessing the productivity of soil of Yandev area of Benue State, hence, the need for this research work. This work was therefore, design to assess the soil productivity of selected farm sites in Yandev using soil productivity models.

MATERIALS AND METHODS

Study Area

The experiment was conducted at the Teaching and Research Farm of the Akperan Orshi College of agriculture Yandevin September, 2022. The area is located at about 4 km north – east of Gboko Town along Gboko – Makurdi road in Gboko Local Government Area of Benue State. The study area is bounded by longitudes $8^0$36' and $8^0$45'E and latitudes $7^0$45' and $8^0$00'N.

The climate of the study area is tropical savanna. The minimum temperature is 25^0C and maximum is 33.5^0C. The mean monthly temperature is 27.3^0C. The total annual rainfall varies between about 900 and 1200mm. The study area has distinct dry and wet seasons. Rainy season starts in March/April and ends in October/November.

The vegetation in the study area is Guinea Savannah type, characterized by grasses with few scattered shrubs and trees. The land in the study area is used for cultivation of crops such as yam, cassava, guinea corn, maize, millet, groundnut, soyabean, benniseed, rice, melon, and other vegetable crops. Trees crops such as mango, palm trees, citrus, cashew and other economic trees are also found in the area.

Soil Sampling and Analysis

Soil sampling was carried out in the western, eastern and southern parts of the school farms. The random sampling technique was used to collect soil samples from six (6) different points in each location. Soil auger was used for collection of the composite soil samples at the depth of 0 – 30cm at each point. The 6 samples in each location were air dried, bulked accordingly and gently crushed. A total of 3 soil samples from the three locations (western, eastern and southern school farms) were sieved using 2.0 mm sieve for physical and chemical analysis using standard procedures (Udo *et al*., 2009).

Application of Productivity Index (PI) and Modified Neill productivity Index (PIm) Models

The modified equation for PI developed by Pierce *et al*. (1983) is given in equation (1) based on soil properties (soil productivity) indicators. The soil productivity indicators used in the study include available water content, pH, bulk density, clay content, land slope, organic matter content, root weighting factor and phosphorus. Other researchers (Gale and Grigal, 1990; Gale *et al*., 1991; Camacho - Mora, 1991; Agber, 2011), however, pointed out-that the number or soil site properties was expandable, depending on the ability to quantify their effect on growth and the availability of data that quantified this response. In this study, the PI model developed by Pierce *et al*. (1983) was expanded to capture the influence of phosphorus. The modified equation for PI developed by Pierce *et al*. (1983) and expanded by Agber, (2011) is given as:

$$PIm = \sum_{n=i}^{n} Ai \times Ci \times Di \times Fi \times Li \times Ji \times Wfi \times Pi \ \ldots\ldots\ldots\ldots (1)$$

Where; PIm = modified Neill Productivity Index,
Ai = sufficiency for available water capacity for the ith soil depth
Ci = sufficiency for pH for the ith soil depth
Di = sufficiency for bulk density for the ith soil depth
Fi = sufficiency for clay content for the ith soil depth
Li = sufficiency for land slope for the ith soil depth
Ji = sufficiency for organic matter content for the ith soil depth
Wfi = root weighting factor (based on depth of root zone)
Pi = sufficiency for phosphorus content for the ith soil depth
n = number of depths in the rooting zone (0 – 30 cm soil depth), and
i = 0 – 45 cm

In this research, PI and PIm sufficiency rates are assigned to soil properties (soil productivity indicators) based on the soil depth of 0 – 30 cm. These sufficiencies are scored from zero (complete inhibition of root growth) to one (no inhibition of root growth) based on a response function for each property. Ascribed sufficiencies for soil properties in each location were multiplied and summed to estimate the PI and PIm. The sufficiencies for the soil properties were adapted and used as described by Pierce *et al*. (1983), Nwite and Nnoke (2005), and Agber (2011). The higher the PI, the higher the productivity of the soil and vice versa.

Application of Riquire Productivity Index (RI) Model

Riquire productivity index (RI) (Riquire, 1970) put forward a formula for expressing productivity as a resultant of various factors at play. This productivity index is concerned basically with soil characters that govern its utilization and productive capacity. This considers only intrinsic factors such as slope and erosion. Riquire productivity index is given as:

$$Pa = H \times D \times P \times T \times Fa \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where:
Pa = Soil Productivity
H = Soil moisture based on number of wet/dry months.
D = Drainage
T = Soil texture/structure

Fa = Actual fertility index consisting of several factors such as
(i) = Organic matter
(ii) = pH
(iii) = Base saturation
(iv) = Exchangeable capacity of clay $Cmol^{(+)}$ Kg^{-1}
(v) = Total soluble salts (s)

Actual Fa was calculated separately using equation 3 and the final factor incorporated into equation 2 (Pa).

Fa = O x pH x N x C x S ……………………… (3)

Where
O = Organic matter
pH = Soil reaction (pH)
N = Base saturation
C = Nature of clay taken as (EC Kg Clay)
S = Soluble Salt content.

Each factor is rated on a scale from 0 – 100, the actual percentages being multiplied each other. The resultant index of productivity also lying between 0 and 100 is set against a scale placing the soils in one of the five productivity classes. Soil characteristics used to determine Riquier productivity index and their ratings for crop production are presented in Table 1.

Table 1: Scale of Productivity (P), Rating, RI – Range and Potentiality (Pi)

P	Rating	RI – Range	Pi
1	Excellent	65–100	I
2	Good	35–64	Ii
3	Average	20–34	Iii
4	Poor	8–19	Iv
5	Extremely poor to Nil	0–7	V

Source: Riquier *et al*. (1970)

Data Analysis

The data generated from the soil samples (soil productivity indicators) in the three locations were assigned to soil productivity sufficiency rates. Soil productivity of the three locations was evaluated using PI, PIm and RI models.

RESULTS AND DISCUSSION

Soil Productivity Assessment using Productivity Index (PI) and Modified Productivity Index (PIm)

Tables 2, 3 and 4 show the soil property, ascribed sufficiency values and calculated productivity index (PI) and Productivity Index modified (PIm) for AOPOLY Western, Eastern, and Southern Farm sites respectively. The soil properties and their individuals sufficiency of a particular soil property/indicator was based on a response curve relating the measured value for that indicator to a dimensionless sufficiency for each depth was multiplied and summed to the number of depth increments (n), where 0.0 meant an absolutely limiting level of the soil property and a value of 1.0 indicates optimum level (Kiniry *et al*., 1983).

Results obtained show that the values for soil pH in AOPOLY Western and Eastern farm sites were slightly alkaline and the values were 7.3 and 7.2 respectively. Slightly acidic soil pH of 6.8 was recorded in AOPOLY Southern farm site. High sufficiencies of 1.0 for both PI and PIm were recorded for soil pH in all locations. The sufficiency of 1.0 indicates that there could be optimum level of nutrient uptake in all locations. The sufficiency curves for pH were based on the effect that pH influences nutrient up take of plants and thus, will affect yield of crops across the locations. Moderate values of CEC of the study sites were recorded. AOPOLY Western farm site had 6.54 Cmol/kg, 6.92 Cmol/kg for Eastern farm site and 7.62 Cmol/kg for Southern farm site. Sufficiency for CEC in all the sites was 0.8. This moderate CEC could be as a result of moderate soil exchangeable cations and less leaching of soil minerals. The slope of all the study sites were found to be on 0 – 2 % slope gradient and all had the same value of sufficiency for land slope as 1.0 and thus indicating good slope for crop farming. The organic matter of study sites was moderate and their values were 1.07 % for western farm, 1.41 % for southern farm and 1.75 % for southern farm site. The sufficiencies for O.M in the study sites were 0.50, 0.60 and 0.70 for western, eastern and southern farm sites respectively. The soil depth of 90 cm and the value for sufficiency for root weighting factor of 0.8 was used for the three study sites. This implies that the sites had little soil depth limitation for crop productivity. Deep soils without limitation promote root proliferation and as such plant roots can explore more area for nutrients and water. Phosphorus of the soils of the study sites was low, 2.80 % phosphorus was recorded for western farm, 2.83 % for western farm and 3.20 % for southern farm. Sufficiency values for western, eastern and southern school farms were 0.55.

The results of the computation of the PI and PIm based on ascribed sufficiencies for the different soil properties for the study sites are presented in Tables 36, 37 and 39 for AOPOLY Western, Eastern and Southern School Farms respectively. The PI values for the locations are: Western farm site (0.32), Eastern farm site (0.38) and Southern farm site (0.45). Similarly, computed PIm values were 0.18 for Western farm site, 0.21 for Eastern farm site and 0.25 for Southern farm site. Generally, the locations on the basis of their PI and PIm could be ranked as: Southern Farm>Eastern Farm> Western Farm. These results show that the soil of Southern Farm site is more productive than other two locations. Similarly, the models on the basis of productivity rating could be rank as: PI>PIm. This indicates that higher values of soil productivity were obtained under PI and therefore could be ranked higher than the PIm.

The Phosphorus contents of the three (3) locations were low. The inclusion of P in the PI reflected the true fertility status of the soils and hence their productivity. This therefore, increases the precision of the PI model. This agree with the findings of Agber (2011) who reported similar effects of P, aluminium oxide and iron oxide on the accuracy of the PI model .The results also agree with that of Ajon *et al*. (2018) who concluded that soil properties of PI and PIm are good indicators for assessing the productivity of the soils within the sub humid zone since they influenced soil productivity status.

Table 2: Soil Properties, Ascribed Sufficiency, Productivity Index (PI) and Modified Productivity Index (PIm) for Western School farm site

		Ascribed Sufficiency	
Soil Properties	values	PI	PIm
Soil pH (H_2O)	7.30	1.0	1.0
CEC (Cmol/kg)	6.54	0.80	0.80
Land slope	2	1.0	1.0
O.M (%)	1.07	0.50	0.50
RWF	90	0.80	0.80
Phosphorus (%)	2.80	-	0.55
Total Sufficiency		0.32	0.18

Table 3: Soil Properties, Ascribed Sufficiency, Productivity Index (PI) and Modified Productivity Index (PIm) for Eastern School farm site

		Ascribed Sufficiency	
Soil Properties	values	PI	PIm
Soil pH (H_2O)	7.20	1.0	1.0
CEC (Cmol/kg)	6.92	0.80	0.80
Land slope	2	1.0	1.0
O.M (%)	1.41	0.60	0.60
RWF	90	0.80	0.80
Phosphorus (%)	2.87	-	0.55
Total Sufficiency		0.38	0.21

Table 4: Soil Properties, Ascribed Sufficiency, Productivity Index (PI) and Modified Productivity Index (PIm) for Southern School farm site

		Ascribed Sufficiency	

Soil Properties	values	PI	PIm
Soil pH (H_2O)	6.80	1.0	1.0
CEC (Cmol/kg)	7.62	0.80	0.80
Land slope	2	1.0	1.0
O.M (%)	1.75	0.70	0.70
RWF	90	0.80	0.80
Phosphorus (%)	3.20	-	0.55
Total Sufficiency		0.45	0.25

Soil Productivity Assessment using Riquier Productivity Index (RI)

Soil properties, ascribed sufficiencies for the soil of the study sites and their calculated Riquier Productivity Index (RI) are shown in Tables 5 – 7. The results show that the ascribed sufficiency values for soil moisture, drainage, soil depth, soil texture, organic matter, soil pH, CEC and base saturation were 0.8, 0.95, 1.0, 0.5, 0.9, 0.8, 0.9 and 1.0, respectively for Western and Eastern School Farm sites. Ascribed sufficiency values at Southern School Farm site were 0.80, 0.95, 1.0, 0.5, 0.9, 1.0, 0.9 and 1.0 for soil moisture, drainage, soil depth, soil texture, organic matter, soil pH, CEC and base saturation, respectively.

The site parameters and their respective ratings of RI indicate that all the locations had well drained characteristics where the water table was sufficiently low enough not to impede crop growth in the areas. The soil depth ratings show that the soils were deep enough without limitations to enhance roots proliferation of crops. The rating for organic matter in Southern School Farm site was higher than in the other two locations. This could influence crop productivity in Southern School Farm site positively than in the other locations.

The calculated Actual Productivity values for Riquier Productivity Index (RI) of the soils show that the highest calculated Actual Productivity value of 0.31 was recorded at the Southern School Farm site followed by Western and Eastern School Farm sites with 0.25. The RI values of Western, Eastern and Southern School Farm sites fall under productivity class 3 and rated as ‘average productivity’. The actual productivity results particularly that of Southern School Farm site show that this land might have been used with maximum management practices for some few years. Higher RI values obtained in Southern School Farm site further show that the soils of Southern School Farm site are more productive than those of Western and Southern School Farm sites.

Table 5: Soil Properties, Ascribed Sufficiency and Riquier Productivity Index (RI) for Western School Farm site

S/N	Parameters	Soil Properties	Rating
1	Soil Moisture duration	5 dry months	0.80

2	Drainage	Well drained	0.95
3	Soil Depth (cm)	90	1.00
4	Soil Texture	Loamy sand	0.50
5	Organic Matter (%)	1.07	0.90
6	Soil pH (H_2O)	7.30	0.80
7	CEC ($Cmol^{(+)}$ Kg^{-1})	6.54	0.90
8	Base Saturation (%)	84.60	1.00
	Actual Productivity (RI)		0.25

Table 6: Soil Properties, Ascribed Sufficiency and Riquier Productivity Index (RI) for Eastern School Farm site

S/N	Parameters	Soil Properties	Rating
1	Soil Moisture duration	5 dry months	0.80
2	Drainage	Well drained	0.95
3	Soil Depth (cm)	90	1.00
4	Soil Texture	Loamy sand	0.50
5	Organic Matter (%)	1.41	0.90
6	Soil pH (H_2O)	7.20	0.80
7	CEC ($Cmol^{(+)}$ Kg^{-1})	6.92	0.90
8	Base Saturation (%)	85.50	1.00
	Actual Productivity (RI)		0.25

Table 7: Soil Properties, Ascribed Sufficiency and Riquier Productivity Index (RI) for Southern School Farm site

S/N	Parameters	Soil Properties	Rating
1	Soil Moisture duration	5 dry months	0.80
2	Drainage	Well drained	0.95
3	Soil Depth (cm)	90	1.00
4	Soil Texture	Sandy loam	0.50
5	Organic Matter (%)	1.75	0.90
6	Soil pH (H_2O)	6.80	1.00
7	CEC ($Cmol^{(+)}$ Kg^{-1})	7.62	0.90
8	Base Saturation (%)	86.70	1.00
	Actual Productivity (RI)		0.31

Comparison of the Productivity Indices

Results of the entire calculated productivity index (PI) and Productivity Index modified (PIm) and Riquier Productivity Index (RI) is presented in Table 8. The findings show that Western School Farm site had 0.32, 0.18 and 0.25 values for PI, PIm and RI models respectively. Eastern School Farm site had 0.38 for PI, 0.21 for PIm and 0.25 for RI. Similarly, Southern School Farm site had 0.45 for PI, 0.25 for PIm and 0.31 for RI. Generally, PI model had higher values followed by RI and PIm models across the locations.

Soil productivity models across the locations generally, could be ranked as Southern Farm>Eastern Farm>Western Farm while ranking on the basis of the models could be PI> RI>PIm.

Table 8: Comparison of Productivity Models

Location	PI	PIm	RI
Western School Farm	0.32	0.18	0.25
Eastern School Farm	0.38	0.21	0.25
Southern School Farm	0.45	0.25	0.31

Productivity index (PI), modified productivity index (PIm) and Riquier productivity index (RI)

CONCLUSION

The effect of continuous cultivation can be a decline in soil productivity as a result of changes in soil physical and chemical properties. The soils at AkperanOrshi Polytechnic, Yandev were investigated in order to characterise them with view to recommending better management strategies that will enhance sustainable use of the soil resources under continuous cultivation in the area.

The PI, indicates to be an improvement over the PIm model. It is also an indication that this model (PI) could give reliable results than PIm in the study areas. Soil properties of PI, PIm and RI are good indicators for assessing the productivity of the soils within the sub humid zone since they influenced soil productivity status. The RI values of Western, Eastern and Southern School Farm sites fall under productivity class 3 and rated as ‘average productivity’. Generally, PI model had higher values followed by RI and PIm models across the locations. The results imply that differences in locations as influenced by soil characteristics could affect soil productivity and eventually crop yield.

REFERENCES

Agber, P.I. (2011). Testing the effectiveness of soil productivity assessment models in Makurdi, Benue State, Nigeria. Ph.D Thesis, Department of Soil Science, University of Agriculture, Makurdi. Pp. 25 – 45.

Anikwe, M.A.N. (2000). Use of Numerical Index Methods for Quantifying the Productivity of some Soils in Southeastern Nigeria. Deparment of Soil Science, University of Nigeria Nsukka. www.oer.unn.edu.ng

Camacho-Mora, P. (1991). A productivity index for Leucaena Leucocephala in Central America.Unpublished Ph.D Thesis, Department of Crop Science, University of Missouri, Columbia. Pp. 121 – 128.

Doran, J.W., and Parkin, T.B. (1994). Defining and assessing soil quality. In: Defining Soil Quality for a Sustainable Environment, J.W. Doran, D.C. Coleman, D.F. Bezdicek, and B.A. Stewart (Eds.). Soil Science Society of America, Special Publication, Madison, Wisconsin, USA, No. 35, Pp. 3-21.

Estrada, I.R., Hidalgo, C., Guzmán, R., Almaraz, J.J.,Hermilio Navarro, H., and Etchevers, J.D. (2017). Soil quality indicators to evaluate soil fertility. *Agrociencia*, 51 (8): 372 – 389**.**

Eswaran, H., Beinroth, F., and Reich, P. (1998). Biophysical considerations in developing resource management domains. In: Proceedings of Conference on Resources Management Domains, J.K. Syers (Ed.). Kuala Lumpur, Malaysia, Published by International Board for Soil Research and Management (IBSRAM). Proceedings No. 16: 61-78.

Gale, M.R., and Grigal, D.F. (1990). Development of a soil and root base productivity index model for trembling aspen. In: R.K Dixon (Ed) Process modeling of forest growth responses to environmental stress. Timber press, Portland. Pp. 303-309.

Gale, M.R., Grigal, D.F. and Harding, R.B. (1991). Soil productivity index. Predictions of site quality for white spruce plantation. *Soil Science Society of America Journal*, (15): 1701-1709.

Gantzer, C.J. and McCarty, T.R. (1987). Predicting Corn yields on a clay using a soil productivity index. *Trans. ASAE*, 30: 1347-1352.

Kiniry, L.M., Scrivener, C.L., and Keener, M.E. (1983). A soil productivity index based on water depletion and root growth. Research Bulletin 105, Colombia University of Missouri. P. 89.

Nwite, J.N., and Nnoke, F.N. (2005). Productivity assessment of floodplain in Abakaliki, south east Nigeria. *Nigeria Journal of Soil Science*, 15 (2): 51-56.

Pierce, F.J., Larson, W.E., Dowdy, R.H., and Graham, W.A.P. (1983). Productivity of Soils. Assessing long term changes due to erosion. *Soil and Water Conservation*, 38: 39-44.

Riquier, J., Cornet, J.P., and Braniaso, D.L. (1970).A new system of soil appraisal in terms of actual and potential productivity. 1st Approx. World Soil Research, FAO. P. 44.

Udo, E.J., Ibia, T.O., Ogunwale, J.A., Ano, A.O., and Esu, I.E. (2009). Manual of Soil, Plant and Water Analysis, 1st Edition.Sibon Book Ltd, Lagos. Pp. 17 – 76.