VOL. 7, NO. 11, NOVEMBER 2012 ISSN 1990-6145
ARPN Journal of Agricultural and Biological Science

www.arpnjournals.com

TESTING THE EFFECTIVENESS OF SOIL PRODUCTIVITY INDEX (PI) MODEL FOR SELECTED SOILS IN MAKURDI, NIGERIA

Agber P. I. and B. C. Anjembe
Department of Soil Science, College of Agronomy, University of Agriculture, Makurdi, Benue State, Nigeria
E-Mail: agber_philip@yahoo.com

ABSTRACT

Soil productivity evaluation for a long has been a major hotspot in soil science. In this article, research conducted to evaluate the effectiveness of soil productivity index (PI) in Makurdi Southern Guinea Savanna of Nigeria is reported. The productivity index (PI) model is a measure of soil productivity. The basic assumption of PI model is that crop yield is a function of root development, which in turn is controlled by the soil environment. This research was conducted in 2007 and 2008 at the Teaching and Research (T and R) Farm and the SIWES Farm of the University of Agriculture Makurdi. The factors used in this model included available water capacity, pH, bulk density, land slope, clay content, organic matter content and depth of root zone. Comparisons were made of PI values obtained for the selected sites. Results from the study show that PI model can be used efficiently to characterize soil productivity at specific site if accurate field data are available. Results from the research work revealed significantly higher average seed yield, plant height and leaf area index in the Teaching and Research Farm than the SIWES Farm of the University of Agriculture Makurdi. This coincided with the study location with higher calculated productivity index (PI). The significant correlations which existed between seed yield and PI evaluated showed that this index can actually explain yield variations.

Keyword: productivity index, soil productivity, maize, sorghum, model.

INTRODUCTION

Soil productivity is the capacity of a soil in its natural environment to produce a specific plant or sequence of plants under specific systems of management inputs. Riquier (1970) described soil productivity as the initial soil capacity to produce a certain amount of crop per hectare per annum.

Methods of predicting site quality (soil productivity) have been a topic of much heated discussion since the early 1990s (Milner, 1996). The uses of soil information in the assessment of soil productivity have been stressed (Milner, 1996). In recent years, researches have been interested after the methods for soil productivity evaluation that are directly related to growth factors (Burger, 1996; Kiniry *et al*., 1983; Gale, 1991; Milner, 1996). The productivity index (PI) model developed by Kiniry in 1983 used an integrated approach to describe the relationship between plant productivity and soil properties on optimum vertical root distribution and subsequently on biomass production.

The productivity index (PI) model is a derived measure of soil productivity. Its basic assumption according to Pierce *et al.* (1983) is that crop yield is a function of root development, which in turn is controlled by the soil environment. Compared to other methods, the PI method is based on the logical expression of direct effect of soil and site properties on vertical root distribution. It can be estimated for a wide ranged of forested and non forested sites and in stand that are young or old (Gale, 1991). Many studies (Boje Fu, 1997) have been conducted for selection and creation of an index system, the quantification of index and selection of evaluation method that helped to break away from the descriptive qualifier of before.

In this article, research was conducted to investigate the effectiveness of productivity index (PI) model on the SIWES Farm and Teaching and Research Farm of the University of Agriculture Makurdi, Nigeria.

MATERIALS AND METHODS

Experiments were carried out during the 2007 and 2008 cropping seasons at the Teaching and Research Farm and the SIWES Farm of the University of Agriculture Makurdi, in the southern Guinea savanna zone of Nigeria. Locations selected for evaluation is similar, including the gradient and slope direction, climate, and factors of chemical and physical features.

The study area experiences a warm tropical climate characterized by wet and dry seasons. The wet season lasts from April to October with annual rainfall of about 1137 mm. The soils are underlain by Makurdi sand - stone and normally moderately deep to deep with a few of them being shallow. The soils are generally coarse textured and are well drained to moderately well drained (Fagbami and Akamigbo, 1986).

The data for evaluating the productivity index (PI) model were obtained from the experiment set up at the Teaching and Research Farm and the SIWES Farm. In each of the site, the field was divided in to 4 blocks; each of the blocks was further divided in to 2 experimental sub-plots of 5.0 m x 5.0 m, with 0.5 m alleys between them. The experiment was laid out in a randomized complete block design (RCBD). There were four (4) treatments each replicated four (4) times. The treatments were:

a) Maize + No application
b) Sorghum + No application
c) Sorghum + NPK (300Kg/ha) + Poultry manure (5 t/ha)
d) Maize + NPK (300Kg/ha) + Poultry Manure (5 t/ha)

Maize was planted manually at two seeds per hole using a spacing of 25 cm (within rows) and 75 cm (between rows). The seedlings were thinned down to one seed per hole one week after emergence. Sorghum, on the other hand, was planted at five seeds per hole at a spacing of 25 cm by 75 cm. The seedlings were also thinned down to two seeds per hole two weeks after emergence. Fertilizer (NPK 15:15:15) was applied at the rate of 300 kg/ha both in the maize and sorghum at 3 WAP. Poultry manure was incorporated into the soil two weeks before planting. The whole plots were kept weed free throughout the growing seasons. The experiment was then repeated the second year.

Bulk composite soil samples were collected from the two farms before planting. Bulk soil samples were also collected from 0 - 15 cm depth before harvest. The soil samples collected from the two locations were analyzed in the laboratory for the physical and chemical properties. Soil pH was determined in 1:2.5 soil/water extract of the composite samples according to Mclean (1965) method. Organic carbon was determined using the Wakley and Black (1934) dichromate oxidation method as reported by Nelson and Sommer (1982). Total N by the Kjeldahl method (Bremmer, 1965) and available P by Bray and Kurtz (1945) method. Exchangeable Na and K were determined by flame photometry and Ca and Mg by EDTA titration method. CEC was obtained by the ammonium acetate technique. Plant height, stem growth, leaf area index (LAI) and seed yield were collected and analyzed using correlation and regression.

DETERMINATION OF PRODUCTIVITY INDEX (PI) MODEL

The Neil productivity Index (PI) model was developed by L. L. Neil, as reported in his unpublished Master of Science thesis (Neil, 1979). This model was later in 1983 employed/modified by Pierce and others, again, as published in Pierce *et al*. (1983) for an assessment of long term changes due to soil erosion. The model was based on the assumption that the soil is a major determinant of crop yield because of the environment it provides for root growth. If a soil/site property is limiting to root growth, changes from the optimum root distribution will occur, negatively affecting the aboveground biomass and reducing site quality. Therefore, the presence and degree of expression of site parameters have very significant influence on root proliferation and hence on crop productivity. The modified equation for PI developed by Pierce *et al*., (1983) is given as:

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

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)
n = number of horizons in the rooting zone (soil layer)

In this PI, these 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 for each property (Kiniry *et al*., 1983) and related the levels of soil properties to their sufficiency. Sufficiencies were assigned to soil properties in the individual horizons. The PI integrates data for all horizons thus overcoming the problem of conflicting results among related properties of individual horizons (Carmean, 1975). Sufficiencies for each depth were multiplied and summed to the number of depth increments (n) to estimate the PI. The sufficiencies for available water capacity, pH, bulk density, clay content, land slope, organic matter content and root weighting factor were adopted and used as described by Pierce *et a*l. (1983).

RESULTS AND DISCUSSIONS

Soil properties of the study sites

The soils were all sandy in texture (Table-1), ranging from loamy sand (0 - 30 and 30 - 60 cm) to sandy loam (60- 90 cm). Sand is the dominant fine earth fraction. The SIWES Farm had higher sand content in all the depths compared to the T and R Farm. The silt and clay contents of the soils ranged from 10 - 13% and 7 - 11% respectively. The Teaching and Research Farm had higher silt contents in the 0 - 30 cm and 30 - 60 cm than the SIWES farm. The total contents of clay + silt fraction in the Teaching and Research Farm was higher than that of the SIWES Farm. Measures of particle size distribution, specifically clay + silt fraction have been found to have good relationship with specific surface area, soil compactibility and compressibility (Smith *et al.,* 1998), all of which affect inherent productivity of the soil. The soils of both sites are coarse, and, therefore, likely to be prone to erosion and leaching.

The soil pH (H_20) was higher in the T and R Farm than in the SIWES Farm at all the depths. The pH decreased down the profile in all the farms. This might be due to the effect of cultivation, and leaching of nutrients down the soil profile. Enwezor *et al*. (1988) stated that leaching of Ca and Mg is largely responsible for development of acidity. Nwite *et al*. (2005) also reported a general decrease in pH values in the lower profile. The organic matter contents of the soils were generally low, mostly less than 2%. The low organic matter obtained may be partly due to the effect of high temperature and relative humidity which facilitate rapid mineralization of organic matter. Soil organic matter decreased with depth. The decrease may be due to illuviation or leaching. This finding agrees with that of Umeugochukwu *et al*. (2012). The low organic matter especially at the SIWES Farm might also be connected to long term effect of degradation arising from continuous cultivation. This low organic matter content in both farms cannot sustain crop production programme. Therefore, organic matter content has to be substantially increased through effective crop residue management.

The total Nitrogen and available P followed the same pattern as that of organic matter. This might be due to low organic matter content earlier observed. The 0-30 cm soil depth generally contained higher levels of N and P. The soils have very low CEC reflecting their intensely weathered status. The low CEC values of these soils coupled with low organic matter and total nitrogen are indications of low inherent soil fertility status, which underscore the need for improved soil management techniques.

Table-1. Some physical and chemicals properties of the soils of the study sites at the start of experiment.

	Soil depth (cm)					
Soil property	**Site A** (SIWES Farm)			**Site B** (Teaching Res. Farm)		
	0 - 30	30 - 60	60 - 90	0 - 30	30 - 60	60 - 90
Sand (%)	81	81	80	80	80	79
Silt (%)	11	10	10	13	12	10
Clay (%)	8	9	10	7	8	11
Textural classes	LS	LS	SL	LS	LS	SL
pH in H_2O	6.1	5.8	5.2	6.2	6.0	6.2
pH in KCl	5.7	5.6	5.1	5.7	5.5	5.1
OC (%)	0.4	0.3	0.2	0.5	0.3	0.2
N (%)	0.1	0.1	0.04	0.2	0.2	0.1
Na (Cmol $^{(+)}$ Kg^{-1}	0.2	0.2	0.2	0.2	0.2	0.2
K “	0.19	0.15	0.13	0.22	0.17	0.14
Ca “	2.8	2.0	1.9	2.5	2.1	1.9
Mg “	2.3	2.0	1.8	2.5	2.1	1.9
CEC “	6.5	5.4	5.2	7.5	6.7	5.4
Avail. P. (Mg Kg^{-1})	5.1	4.3	4.0	6.2	4.5	3.9
Bulk density (g/cm^3)	1.3	1.4	1.3	1.2	1.3	1.2
Total porosity (%)	49	48	49	53	52	53

LS = Loam Sand
SL = Sandy Loam
OC = Organic carbon

Soil productivity index (PI) model

Soil properties, ascribed sufficiencies and calculated productivity index (PI) for the SIWES Farm and Teaching and Research Farm are presented in Tables 2 and 3, respectively. The soil properties and their individual sufficiency values were used in computation of PI. The sufficiency of a particular soil factor was based on a response curve relating the measured value for the factor to a dimensionless sufficiency for root growth between 0.0 and 1.0 (Pierce *et al.*, 1983). Results of the investigations showed that the sufficiency value for available water capacity (AWC) in the SIWES Farm and Teaching and Research Farm ranged between 0.56 - 0.76. The sufficiency values for bulk density in the SIWES Farm were 0.60, 0.62 and 0.64 for 0 - 30, 30 - 60 and 60 - 90 cm, respectively (Table-2), while in the Teaching and Research Farm, the values were 0.83, 0.80 and 0.64 for 0 - 30, 30 - 60 and 60 - 90 cm, respectively (Table-3). The sufficiency values for soil pH in the two Farms were 1.00. The percent slope for the two sites was 5.0. Their sufficiency value was therefore, 0.8 for both the SIWES Farm and the Teaching and Research Farm. The computed PI showed that SIWES Farm had PI of 0.14 (Table-2) while the Teaching and Research Farm had the PI of 0.19 (Table-3).

The soil of the SIWES Farm had higher mean soil bulk density compared to the Teaching and Research Farm. This result showed that maize and sorghum roots could encounter less resistance to penetration in the Teaching and Research Farm than in the SIWES Farm.

ARPN Journal of Agricultural and Biological Science

www.arpnjournals.com

Crops grown in the Teaching and Research Farm could explore wider rhizospheric area for nutrients and water. Sufficiency values of soil organic matter, pH, clay content, land slope and depth to rooting zone were not different amongst the two farms. The results of the computation of the PI based on ascribed sufficiencies for the different soil properties for the two planting seasons (2007 and 2008) indicated that the Teaching and Research Farm had higher PI (0.19) than SIWES Farm which had PI of 0.14 (Tables 2 and 3). These results showed that Teaching and Research Farm is more productive than the SIWES Farm.

Results of the calculated PI and seed yields and growth parameters of maize and sorghum are presented in Table-4. At the SIWES Farm, PI was 0.14. Results on yield and growth parameters showed that maize recorded 2.8 t/ha, 0.20 and 150 cm of seed yield, LAI and plant height respectively, while sorghum recorded 3.08 t/ha, 0.30 and 105 cm of seed yield, LAI and plant height respectively. Relationship between PI for maize at the SIWES Farm was significant (Table-5). The relationship between PI and seed yield of sorghum for the SIWES Farm also showed significant correlations (P = 0.001) with $R^2 = 0.97$ (Table-5).

At the Teaching and Research Farm, result of productivity index was 0.19. Results on yield and yield parameters of maize showed 3.4 t/ha, 0.28 and 173 cm for seed yield, LAI and plant height respectively (Table-4), while sorghum had 3.21 t/ha, 0.38 and 108 cm for seed yield, LAI and plant height respectively. There were significant correlation (p = 0.001) between seed yields of maize and sorghum and PI. The correlation coefficient value (R^2) of maize and sorghum seed yield with soil productivity index was 0.97 (Table-5).

Results also showed that PI model could explain about 97% of maize and sorghum seed yield variation both in the SIWES Farm and Teaching and Research Farm respectively (Table-5).

Table-2. Soil properties, ascribed sufficiencies and calculated productivity index for the SIWES Farm.

Soil property	**Soil depth** (cm)			**Ascribed sufficiency**		
	0-30	30-60	60-90	0-30	30-60	60-90
AWC (g/g)	0.14	0.16	0.18	0.56	0.68	0.76
Bulk density (g/cm^3)	1.50	1.54	1.56	0.60	0.62	0.64
pH (H_2O)	6.00	6.20	6.20	1.0	1.0	1.0
Clay content ($cmol(+)Kg^{-1}$	6.0	8.0	10	0.4	0.4	0.4
Land slope (%)	5.0	5.0	5.0	0.8	0.8	0.8
Organic matter (%)	0.78	0.88	0.19	0.45	0.45	0.40
Root weighting factor (cm)						
Depth to rooting zone (cm)	80	80	80	0.8	0.8	0.8
Calculated PI =				0.14		

Table-3. Soil properties, ascribed sufficiencies and calculated productivity index (PI) for the Teaching and Research Farm

Soil Property	**Soil depth** (cm)			**Ascribed sufficiency**		
	0-30	30-60	60-90	0-30	30-60	60-90
AWC (g/g)	0.14	0.16	0.16	0.56	0.68	0.76
Bulk density (g/cm^3)	1.32	1.34	1.37	0.83	0.8	0.76
pH (H_2O)	6.30	6.30	6.20	1.0	1.0	1.0
Clay content ($Cmol(+)$ Kg^{-1}	6.0	6.0	12	0.4	0.4	0.4
Land slope (%)	5.0	5.0	5.0	0.8	0.8	0.8
Organic matter (%)	1.25	0.78	0.30	0.55	0.45	0.40
Root weighting factor (cm)						
Depth to rooting zone	80	80	80	0.8	0.8	0.8
Calculated PI =				0.19		

ARPN Journal of Agricultural and Biological Science

Table-4. Productivity index (PI) and growth of maize and sorghum.

			Growth parameters and seed yield		
Location	**Crop**	**PI**	**LAI**	**plant ht.** (cm)	**seed yield** (t/ha)
SIWES Farm	Maize	0.14	0.20	150	2.82
SIWES Farm	Sorghum	0.14	0.30	105	3.08
TR Farm	Maize	0.19	0.20	173	3.45
TR Farm	Sorghum	0.19	0.32	108	3.21

TR = Teaching and research farm
RI = Riquier index
LAI = Leaf area index

Table-5. Relationship between Productivity Index (PI) and seed yield of maize and sorghum.

Location	Regression model	Coefficient of determination (R^2)
SIWES Farm (Maize)	3.123 + 0.207 X	0.97**
SIWES Farm (Sorghum)	2.442 + 0.883 X	0.97**
TR Farm (Maize)	3.069 + 0.969 X	0.97**
TR Farm (Sorghum)	3.04 + 0.917 X	0.97**

TR = Teaching and Research Farm

CONCLUSIONS

The effectiveness of soil productivity index (PI) model on two sites in Makurdi was examined. The productivity index (PI) model is a derived measure of soil productivity. The basic assumption of the PI model is that crop yield is a function of root development, which in turn is controlled by the soil environment. The results of this study indicated that PI model can be used efficiently to characterized soil productivity at specific site if accurate data are available. The study location (Teaching and Research Farm) with higher grain yield was shown to have higher calculated PI values. Significant correlations was also shown to exist between grain yield and PI values.

RECOMMENDATION

PI model is hereby recommended for soil productivity assessment within Makurdi, southern guinea savanna zone of Nigeria. It is also recommended as a means of explaining crop yield variations.

REFERENCES

Bray RH and Kurt LT. 1945. Determination of total, organic and available forms of phosphorus in soils. Soil Sci. 59: 39-45.

Bremmer JM. 1965. Nitrogen availability indexes total. In: Black CA (ed). Methods of Soil Analysis, part 2, 2nd edition. Agronomy. 9: 1324-1345 Madison Wisconsin.

Boje Fu, Lixing Cheng and Cheng Ma. 1997. Index system and method for the evaluation of Land sustainable utilization. Journal of Natural Resource. 12(2): 112-118.

Burger J. A. 1996. Limitations of bioassays for monitoring forest soil productivity. Rationale and example. Soil Sci. Soc. Am. J. 60: 1674-1678.

Carmean W.H. 1975. Forest site quality evaluation in the United States. Advances in Agronomy. 27: 209-269.

Enwezor EO, Ohiri AC, Opuwariho EE and Udoh EJ. 1988. A Review of Soil Fertility Investigations in Southeastern Nigeria. Vol. II, Federal Ministry of Agriculture and Rural Development, Fertilizer Procurement and Distribution Division, Lagos, Nigeria. p. 163.

Fagbami A. and Akamigbo F. O. R. 1986. Soils of Benue state and their capabilities. Proceedings of the 14th Annual conference of Soil Sci. Soc. Nigeria held in Makurdi, between 4th to 7th November.

Gale M.R., D.F. Grigal and R.B. Harding. 1991. Soil productivity index. Predictions of site quality for white spruce plantation. Soil Sci. Soc. Am. J. (15): 1701-1709.

Kiniry L. M, C. L. Scrivener and M. E. Keener. 1983. A soil productivity index based on water depletion and root growth. Res. Bull. 105 Colombia University of Missouri. p. 89.

Mclean E O. 1965. Aluminum methods of soil analysis part 2. Ed. CA Black: AM. Soc. of Agronomy.

Milner K. S, Running S. W and Coble D. W. 1996. Biopsical soil - site model for estimating potential productivity of forested landscape. Can. J. 55: 228-234.

Neill L. L. 1979. An Evaluation of Soil Productivity Based on Root Growth and Water Depletion. Unpublished M.Sc. Thesis, University of Missouri, USA. p. 78.

Nelson DW and Sommer LE. 1982. Total carbon, organic carbon and organic matter. In: Page, A. L. (ed.). Methods of soil Analysis. Part 2. Chemical and microbiological properties, 2nd edition. American Society of agronomy. Madison. pp. 539-577.

Nwite J. N. and Nnoke FN. 2005. Productivity Assessment of Floodplain Soils in Abakaliki, Southeast Nigeria. Nig. J. Soil Sci. 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 Cons. 38: 39-44.

Umeugochukwu OP, Ezeaku PI, Chude VO and Nnaji GU. 2012. Impact of Soil erosion on land degradation in Uga Southeastern Nigeria. Nig. J. Soil Sci. 22(1): 26-36.

Riquier J, Cornet JP. and Braniao DL. 1970. A new system of soil appraisal in terms of actual and potential productivity. 1st Approx. World Soil Res. FAO. p. 44.

Smith CW, Johnston MA. and Lorentz S. 1998. Assessing the compaction susceptibility of South African forest Soils. II. Soil properties affecting compatibility and compressibility. Soil and Tillage Research. 43: 337-356.

Walkley A and Black C. A. 1934. Determination of organic matter in soils. Soil Sci. 37: 29-38.