World Journal of Research and Review (WJRR)
ISSN:2455-3956, Volume-7, Issue-2, August 2018 Pages 26-31

Evaluation of Soil Erosion Effects on Soil Productivity Using Productivity Index Model in Makurdi, Benue State, Nigeria

AJON A.T., AGBER P.I., ALI A.

Abstract— **A field experiment was conducted at the Teaching and Research Farm of the College of Agronomy, University of Agriculture, Makurdi (Latitude 7o46' – 7o50'N and Longitude 8o36' – 8o40'E) during the 2015 and 2016 cropping seasons. Soil erosion plots (runoff plots) were set up under a slope gradient of 2.5 % to evaluate the effects of soil erosion on soil productivity using modified productivity index (PIm) model under rainfed condition. Soil management practices namely, bare fallow (control), 4 and 8 t/ha mulched maize, maize + cowpea and unmulched maize were replicated three times. The data collected on runoff, soil loss, soil properties and grain yield of maize were analyzed using analysis of variance test based on randomized complete block design (RCBD). Correlation analysis was performed to test the relationship between PIm and erosion parameters, and grain yield of maize. The effects of erosion on soil productivity using the modified productivity index (PIm) model indicated PIm value of 0.20 under 8 t/ha mulched maize management compared to PIm values of 0.10 obtained at the start of the experiment, and 0.03 and 0.04 for bare fallow plots in 2015 and 2016 respectively. These values are low which implies that runoff and soil loss had high effects on soil productivity of the study site. There was no significant correlation between PIm and runoff, and soil loss. The relationship between PIm and grain yield of maize showed significant positive correlation (r = 0.902) in the second cropping season. Differences in soil characteristics as a result of runoff and soil loss affected soil productivity and eventually grain yield of maize.**

Index Terms— **Soil erosion, soil productivity, model, soil loss, yield.**

I. Introduction

The Southern Guinea Savanna Agroecological zone of Nigeria where Benue State is located is characterized by diverse climatic, topographic and soil conditions. This region is one of the areas where soil erosion processes constitute key constraints to soil productivity. Accelerated erosion, drought and soil fertility decline are among the main causes of soil productivity depletion in Benue State (Ajon et al., 2017).

Erosion, according to El-Fring (1983), is not the only process that can damage soil productivity, but it is the most pervasive. Soil erosion has been established to deplete soil productivity. The relationship between soil productivity and soil erosion has generated much interest. However, the relationship is not well defined. Until the relationship is adequately developed, selecting management strategies to maximize long term crop production will be impossible (NSESPPC, 1981). The first model of productivity index was used by Chinese (Kiniry et al., 1983). Researchers are trying to establish the relationship between soil properties and soil productivity (Follet and Stewart, 1985; ASAE, 1985; Agber, 2011). These, according to Gantzer and McCarthy (1987), and Agber (2011), have grown out of the need to increase the knowledge of quantitative relationships between plant growth and soil properties which could be affected by soil erosion. Various approaches are being developed, which attempted to numerically relate soil properties to its productivity. It is established that productivity capacities or expected yields are useful in determining the suitability of any soil for agricultural use (De La Rosa et al., 1982). Consequently, estimates have been made of the productivity of individual kinds of soil in many places. Attempts have been made to key the yields of crops or pastures to limited number of soil properties (De La Rosa et al., 1982; Kiniry et al., 1983; Ngwu et al., 2005; Williams et al., 1983; Agber, 2011) so that the changes in soil productivity are determined in relation to soil erosion. Numerous models currently exist ranging from simple to complex, which describe the effect of soil erosion on productivity.

The original Neill productivity index (PI) model was developed by Neill, (1979). This model was later modified by Pierce et al. (1983) and Agber (2011) for an assessment of long term changes due to soil erosion. The model was based on assumption that the soil is a major determinant of crop yield because of the environment it provides for root growth. Therefore, the presence and degree of expression of these parameters have very significant influence on root proliferation and hence on crop productivity.

The original PI contained sufficiency for available water capacity, pH, bulk
density, clay content. Land slope, organic matter and root weighting factor. However, not enough information available in relation to the effects of soil erosion on soil productivity using modified productivity index (PIm) model in Makurdi area of Benue State, Nigeria.

II. MATERIALS AND METHODS

A. Study Area

The experimental plots were set up at the Teaching and Research Farm of the College of Agronomy, University of Agriculture, Makurdi, during the 2015 and 2016 cropping seasons. The experiment was conducted under four months' rainfall events from 7th July to 13th October, 2015 and 5th July to 14th October, 2016 during maize production.

AJON A.T. , Department of Crop Production Technology, Akperan Orshi College of Agriculture, Yandev, P.M.B. 181, Gboko, Benue State, Nigeria
AGBER P.I., Department of Soil Science, University of Agriculture, P.M.B. 2373, Makurdi, Nigeria
ALI A. Department of Soil Science, University of Agriculture, P.M.B. 2373, Makurdi, Nigeria.

The area is located at latitude 7o46' – 7o50'N and longitude 8o36' – 8o40'E (Fig. 1) and characterized by tropical climate with wet and dry seasons. The rainfall pattern is bimodal with annual rainfall varied between 900 and 1200mm. The wet season usually begins in April and ends in October/November. Temperature ranges between 21 – 35oC. Vegetation is guinea savannah type. The major crops cultivated in the area are maize, cowpea, yam, cassava, rice, sorghum and millet.

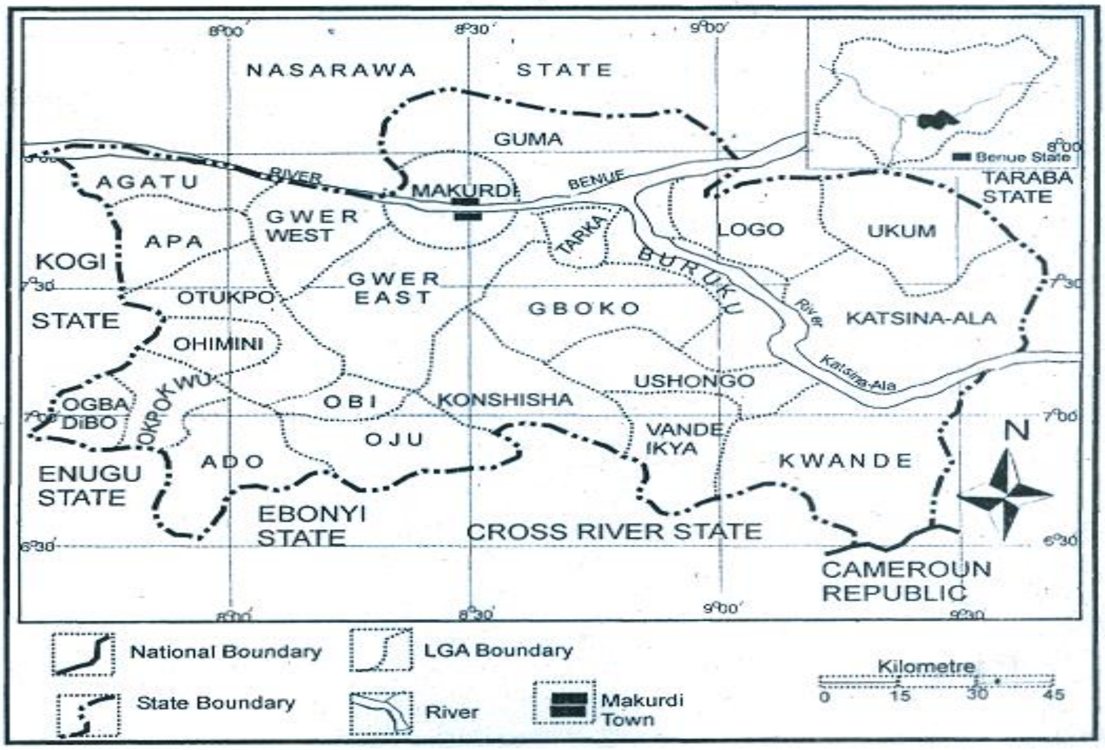

Fig. 1: Map of Benue State showing Makurdi
Source: Ministry of Land and Survey, Makurdi

B. Experimental Plots

The experimental plots were laid out on cultivated lands under a slope gradient of about 2.5% before the onset of the rainfall season. Fifteen (15) runoff plots measuring 20m x 3m (plus 1.5 m^2 triangular downslope end) (i.e 61.5 m^2) each were bordered by corrugated iron sheets which were inserted into the soil to a depth of 20cm leaving 25 cm above the soil surface to prevent lateral flows from the plots to the adjacent area.

Soil management practices were as follows: (T1) bare fallow; (T2) 4 t ha^{-1} surface mulch + maize; (T3) 8 t ha^{-1} surface mulch + maize; (T4) maize + cowpea; (T5) maize. The experiment was laid out in randomized complete block design (RCBD) of five (5) treatments and replicated three (3) times.

Soil samples were collected from the site at the depth of 0 – 30 cm during the land preparation and after harvest and analyzed for physical and chemical properties using standard procedures (Udo *et al*., 2009).

C. Runoff and Soil Loss Collection

Runoff and soil loss were collected in barrels at the lower outlet of the plots and measured after each rainfall event. The sediment yield (amount of soil washed by runoff from the plots) was determined after oven-drying an aliquot sample of the runoff and weighing the sediments.

D. Application of the Modified Neill Productivity Index (PI)m Model

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.

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

Where; PIm = modified Neill Productivity Index,

A_i = sufficiency for available water capacity for the ith soil depth

C_i = sufficiency for pH for the ith soil depth

D_i = sufficiency for bulk density for the ith soil depth

F_i = sufficiency for clay content for the ith soil depth

L_i = sufficiency for land slope for the ith soil depth

J_i = sufficiency for organic matter content for the ith soil depth

Wf_i = root weighting factor (based on depth of root zone)

P_i = 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 – 30 cm

In this research, 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 soil management practice (treatment) were multiplied and summed to estimate the PI. The sufficiencies for the soil properties were adapted and used as described by Pierce et al. (1983), Nwite, (2005), and Agber, (2011). The higher the PI, the higher the productivity of the soil and vice versa. If the PI of a soil increases, it indicates decrease in erosion effects on soil and vice versa.

E. Statistical Analysis

The observed data were analyzed using the IBM SPSS version 20. Correlation analyses were performed to test the relationships between the modified productivity index (PIm) model and runoff, soil loss, and grain yield of maize under various soil management practices.

III. RESULTS AND DISCUSSION

A. Grain Yield of Maize, Runoff and Soil Loss

The results of grain yield of maize, runoff and soil loss is shown in Table 1. The results indicated that the lower the runoff and soil loss, the higher the grain yield of maize obtained during the experiments. In 2015, the higher grain yield (2.55 t/ha) of maize was obtained under 8 t/ha mulched maize management with decreased runoff (15.26 mm) and soil loss (2.62 t/ha/yr) followed by 4 t/ha mulched maize of grain yield (1.9 t/ha) with runoff (18.3 mm) and soil loss (4.25 t/ha/yr), and maize + cowpea of grain yield (1.72 t/ha) with increasing runoff (26.4 mm) and soil loss (4.6 t/ha/yr). The lower grain yield (1.45 t/ha) of maize was obtained under unmulched maize treated plot with higher runoff (37.48 mm) and soil loss (9.19 t/ha/yr).

In 2016, the higher grain yield (3.06 t/ha) of maize was obtained under 8 t/ha mulched maize management with decreased runoff (1.4 mm) and soil loss (0 t/ha/yr) followed by 4 t/ha mulched maize of grain yield (2.39 t/ha) with runoff (6.54 mm) and soil loss (0.12 t/ha/yr), and maize + cowpea of grain yield (2.06 t/ha) with increasing runoff (14 mm) and soil loss (0.49 t/ha/yr). Lower grain yield (1.57 t/ha) of maize was obtained under unmulched maize treated plots with higher average runoff (49.43 mm) and soil loss (1.83 t/ha/yr). Generally, higher grain yield of maize with lower values of runoff and soil loss were observed in 2016 compared to 2015 results (Table 1).

Table 1. Grain Yield of Maize, Runoff and Soil Loss under Various Management Practices

Treatments	Maize Yield (t/ha)	Runoff (mm)	Soil Loss (t/ha/yr)
2015			
(T1) Bare fallow	**-**	88.79	31.80
(T2) 4 t/ha mulch + maize	1.90	18.30	4.25
(T3) 8 t/ha mulch + maize	2.55	15.26	2.62
(T4) Maize + cowpea	1.72	26.40	4.60
(T5) Maize	1.45	37.48	9.19
2016			
(T1) Bare fallow	-	127.02	13.90
(T2) 4 t/ha mulch + maize	2.39	6.54	0.12
(T3) 8 t/ha mulch + maize	3.06	1.40	0.00
(T4) Maize + cowpea	2.06	14.00	0.49
(T5) Maize	1.57	48.43	1.83

B. Modified Neill Productivity Index (PIm) and its Ascribed Sufficiency

Soil properties, ascribed sufficiencies and calculated modified productivity index (PIm) for the study site is shown in Tables 2, 3 and 4.

Results of the investigation show that the ascribed sufficiency values for available water capacity (AWC) and soil pH in the study site at the start of the experiment (before planting) in 2015 and 2016 cropping seasons were 1.0. The sufficiency values for bulk density, clay content, land slope, organic matter, rooting weighting factor and phosphorus at the start of the experiment were 0.8, 0.8, 0.8, 0.45, 0.4 and 0.65, respectively (Table 2). The sufficiency values for AWC, soil pH, bulk density, clay content, land slope, organic matter, rooting weighting factor and phosphorus in each treatment ranged from 0.4 to 1.0 in 2015 and 2016 cropping seasons (Tables 3 and 4).

The computed PIm shows that at the start of the experiment the PIm value was 0.10 (Table 2). In 2015 cropping season, the computed PIm values were 0.03, 0.10, 0.20, 0.10 and 0.10 for bare fallow, 4 t/ha mulched maize, 8 t/ha mulched maize, maize + cowpea and unmulched maize plots, respectively (Table 3). In 2016, the results of computed PIm values were 0.04, 0.12, 0.20, 0.10 and 0.10 for bare fallow, 4 t/ha mulched maize, 8 t/ha mulched maize, maize + cowpea and unmulched maize treated plots respectively (Table 4).

Table 2. Soil Properties, Ascribed Sufficiencies and Calculated Modified Productivity Index (PIm) for the Experimental Site at the Start of the Experiment in Makurdi (2015)

Soil Properties	Values	Ascribed Sufficiency
AWC (g/m^3)	23.8	1.00
pH (H_2O)	6.29	1.00
B.D (Mg/m^3)	1.4	0.80
Clay content (Coml/kg)	17.2	0.80
Land Slope (%)	2.5	0.80
Organic Matter (%)	0.86	0.45
RWF (cm)	30	0.40
P (mg/kg)	5.2	0.65
Calculated PIm =	0.10	

Table 3. Soil Properties, Ascribed Sufficiencies and Calculated PIm for the Experimental Site after Harvest in Makurdi (2015)

Soil Properties	Values					Ascribed Sufficiency				
	T1	T2	T3	T4	T5	T1	T2	T3	T4	T5
AWC (g/m^3)	19.1	18.1	17	19.6	18.1	1.0	1.0	1.0	1.0	1.0
pH (H_2O)	6.06	6.12	6.19	6.54	6.26	1.0	1.0	1.0	1.0	1.0
B.D (Mg/m^3)	1.4	1.27	1.22	1.31	1.34	0.8	1.0	1.0	0.8	0.8
Clay Content (Cmol/kg)	13.2	13.53	15.87	12.53	11.87	0.6	0.8	0.8	0.8	0.6
Land slope (%)	2.5	2.5	2.5	2.5	2.5	0.8	0.8	0.8	0.8	0.8
Organic matter (%)	0.71	1.52	3.05	1.23	1.16	0.45	0.65	1.0	0.55	0.55
RWF (cm)	30	30	30	30	30	0.4	0.4	0.4	0.4	0.4
P (mg/kg)	1.8	3.25	3.25	3.24	2.16	0.50	0.60	0.60	0.60	0.55
Calculated PIm =						0.03	0.10	0.20	0.10	0.10

NOTE: (T1) bare fallow; (T2) 4 t ha^{-1} surface mulch + maize; (T3) 8 t ha^{-1} surface mulch + maize; (T4) maize + cowpea; (T5) maize.

Table 4. Soil Properties, Ascribed Sufficiencies and Calculated PIm for the Experimental Site after Harvest in Makurdi (2016)

Soil Properties	Values					Ascribed Sufficiency				
	T1	T2	T3	T4	T5	T1	T2	T3	T4	T5
AWC (g/m^3)	16.5	19.8	23.0	19.9	18.3	1.0	1.0	1.0	1.0	1.0
pH (H_2O)	6.9	6.8	6.8	6.8	6.6	1.0	1.0	1.0	1.0	1.0
B.D (Mg/m^3)	1.46	1.28	1.22	1.29	1.33	0.8	1.0	1.0	0.8	0.8
Clay Content (Coml/kg)	14.8	12.07	14.64	12.97	16.64	0.6	0.8	0.8	0.8	0.6
Land slope (%)	2.5	2.5	2.56	2.5	2.5	0.8	0.8	0.8	0.8	0.8
Organic matter (%)	0.87	1.85	3.3	1.57	1.17	0.5	0.75	1.0	0.65	0.55
RWF (cm)	30	30	30	30	30	0.4	0.4	0.4	0.4	0.4
P (mg/kg)	1.87	3.0	3.2	3.1	2.7	0.5	0.6	0.6	0.6	0.55
Calculated PIm =						0.04	0.12	0.20	0.10	0.10

NOTE: (T1) bare fallow; (T2) 4 t ha^{-1} surface mulch + maize; (T3) 8 t ha^{-1} surface mulch + maize; (T4) maize + cowpea; (T5) maize.

The soils at the start of the experiment, the bare fallow and unmulched maize plots had higher mean soil bulk density compared to the cover management treated plots. These results showed that maize roots could encounter less resistance to penetration under the cover management plots than in the unmulched maize plots. Crops growth in the cover management plots could explore wider rhizospheric area for nutrients and water. Sufficiency values for soil available water content, pH, clay content, land slope, root weighting factor, phosphorus and depth to rooting zone were not different amongst the treatments in the two seasons. The results of the computed PIm based on ascribed sufficiencies for the different soil properties for the two planting seasons (2015 and 2016) indicated that, the soil properties determined in 2015 and 2016 had higher PIm value of 0.20 under 8 t/ha mulched maize management compared to other treatments. Treatments like 4 t/ha mulched maize, maize + cowpea and unmulched maize maintained the same PIm value of 0.10 with that obtained at the start of the experiment. The PIm value under the bare fallow reduced from 0.10 at the start of the experiment to 0.03 and 0.04 for 2015 and 2016 cropping seasons respectively, which indicate high erosion effect on soil productivity. The higher PIm values of the soil properties observed under 8 t/ha mulched maize may be attributed to conservation practices. This reflected the true fertility status of the soils and hence their productivity and therefore, increase the precision of the model. The PIm values between 0.10 and 0.20 obtained in 2015 and 2016 indicated improvement or maintenance of soil productivity capacity while using the land, which is the main purpose of soil conservation.

Generally, the values of PIm are low. The normal range is 0 – 1 (Pierce *et al*., 1983; Agber, 2011). This implies that water erosion had high effect on soil productivity of the study site especially under bare fallow and unmulched maize plots. These results are in agreement with that of Agber (2011) who concluded that soil properties of PIm are good indicators for assessing the productivity of the soils within the Makurdi sub humid zone since they influenced soil productivity status.

C. Relationships between PIm and Runoff, Soil Loss, and Grain Yield of Maize

The relationships between PIm and runoff, and soil loss for the study site are presented in Table 5. The relationships between PIm and runoff, and soil loss for the study site were not significantly correlated. Though, their correlation coefficient exhibited negative insignificant correlation between them.

The relationship between PIm and grain yield of maize was not significant in 2015, while that of 2016 showed positive correlation (r = 0.902) between PIm and grain yield of maize. This means that grain yield of maize increased with increase in the productivity of the soil. The result further showed that PIm model could explain about 90 % of maize grain yield variation in the second season of the study site. The PIm could explain to a greater extent yield variations and give more reliable results in the Makurdi agro ecological area as also reported by Agber (2011). The result implies that difference in soil characteristics as a result of soil erosion could affect soil productivity and eventually grain yield of crop.

Table 5. Correlation Coefficient and P-value Between PIm and Runoff, Soil Loss, and Grain Yield of Maize in Makurdi for 2015 and 2016 Cropping Seasons

Relationships	Corr. Coeff. (r)	p-value
2015		
PIm vs. runoff	- 0.708	NS
PIm vs. soil loss	- 0.628	NS
PIm vs. yield	0.816	NS
2016		
PIm vs. runoff	- 0.797	NS
PIm vs. soil loss	- 0.678	NS
PIm vs. yield	0.902*	0.037

NS = Not Significant at (P=0.05), * = Significant at (P=0.05)

IV. CONCLUSION

The values of runoff varied from 1.4 – 127.02 mm and soil loss from 0 – 31.8 t/ha/yr during the two cropping seasons. These losses may greatly contribute to soil productivity depletion and low crop yield as a result of nutrients losses through runoff and soil loss. The low values of the modified productivity index (PIm) model imply that runoff and soil loss had high effects on soil productivity in the study site. Differences in soil characteristics as a result of runoff and soil loss affected soil productivity and eventually grain yield of maize.

From the results of the study, the modified productivity index (PIm) model was found useful in evaluating soil productivity within Makurdi area of Benue State.

REFERENCES

[1] Agber, P.I. (2011). Testing the effectiveness of soil productivity assessment models in Makurdi, Benue State, Nigeria. Ph.D Thesis, Dept. of Soil Sci. Univ. of Agric., Makurdi.

[2] Ajon, A.T., Agber, P.I., and Ali, A. (2017). Runoff, soil loss and nutrient losses from an agricultural field in Makurdi, Benue State, Nigeria. *International Journal of Innovative Research and Development,* 6 (7): 118 – 125.

[3] ASAE. (1985). Erosion and Soil Productivity. Proceedings of National Symposium. Erosion and Productivity. New Orleans LA 10-11 Dec. 1984. America Society of Agriculture Engineering, St. Joseph, M, 149085. Pp. 80 – 89.

[4] Camacho-Mora, P. (1991). A productivity index for LeucaenaLeucocephala in Central America. Unpublished Ph.D Thesis. Univ. of Missouri, Columbia.

[5] De La Rosa, Cardona, D.F., and Almorza, J. (1982). Crop yield predictions based on properties of soils in Sevilla, Spain. *Geoderma,* 25: 267-274.

[6] El-fring, C. (1983). Land productivity and agricultural technology: A study by the office of technology assessment. *Journal of Soil and Water Conservation*, 38: 39-44.

[7] Follet, R. F., and Stewart, B.A. (1985). Soil Erosion and Crop Production. *America Society of Agronomy*. Madison. Wisconsin, USA. Pp. 261 – 274.

[8] 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.

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

[10] Gantzer, C.J., and McCarty, T.R. (1987). Predicting corn yields on a clay pan using a soil productivity index. *Trans America Society of Agricultural Engineering*, 30: 1347-1352.

[11] 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.

[12] National Soil Erosion- Soil productivity Planning Committee (NSESPPC). (1981). Soil erosion effects on soil productivity. A research perspective. *Journal of Soil and Water conservation*, 36: 82-90.

[13] Neill, L.L. (1979). An Evaluation of soil productivity based on Root Growth and water depletion. Unpublished M.Sc. Thesis, University of Missouri. P. 78.

[14] Ngwu, O.E., Obi, M. E., and Mbagwu, J.S.C. (2005). Effects of desurfacing on soil and maize yield. *Nigeria Journal of Soil Science*, 15 (2): 148-150.

[15] Nwite, J.N. (2005). Productivity assessment of floodplain in Abakaliki, Southeast Nigeria. *Nigeria J. Soil Sci.,* 15 (2):51 – 56.

[16] 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.

[17] 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. Sidon Book Ltd, Lagos. Pp. 17 – 76.

[18] Williams, J, R., Dyke, P.T., and Jones, C.A. (1983). EPIC-A model for assessing the effect of erosion on soil productivity. Proceedings of 3rd International Conference on State of the Art in Ecology Modeling; May 24-28 Fort Collins Co, USA. Pp. 315 – 321.