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QUANTIFYING THE PRODUCTIVITY OF SELECTED SOILS IN NSUKKA AND ABAKALIKI, SOUTHEASTERN NIGERIA USING PRODUCTIVITY INDEX

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ABSTRACT

A study quantifying the productivity of selected soils in Nsukka and Abakaliki areas of Southeastern Nigeria was carried out for two cropping seasons using modified productivity index model. The study involved two modifications of Pierce et al. (1983) productivity index model. Maize was used as test crop. The first involved the exclusion of sufficiencies for aeration and electrical conductivity (PIM_1). The second entailed the inclusion of sufficiencies for organic carbon, available phosphorus and exchangeable aluminium with simultaneous exclusion of sufficiencies for aeration and electrical conductivity ($P1M_2$). Results from the experiment showed a highly significant relationship ($r^2 = 0.92$ at $P < 0.01$) between $P1M_2$ and maize grain yield. However, there was a poor relationship ($r^2 = 0.41$ at $P<0.05$) between $P1M_1$ and grain yield. Similarly, the inclusion of sufficiencies for organic carbon and available phosphorus increased the validity of $P1M_2$.

Keywords: Productivity, modification, exclusion, inclusion, sufficiencies.

INTRODUCTION

Productivity index is an algorithm based on the assumption that crop yield is a function of root – growth, including rooting depth, which is controlled by the soil environment (Lindstrom *et al.,* 1992). Pierce *et al.* (1983) modified the productivity index model of Kiniry *et al.* (1983) by inclusion of new parameters such as sufficiency for aeration and electrical conductivity. The sufficiency term refers to a particular soil factor and normally it is based on a response curve relating a measured value for that factor to a dimensionless sufficiency for root growth between 0 . 0 and 1.0.

According to De Wit and Van Kuelen (1987) simulation models enabled quantitative estimates of the growth and production of the main agricultural crops in many soils. Williams *et al.* (1983) and Pierce *et al.* (1983) corroborated that many models such as universal soil loss equation and erosion-productivity impact calculator had been used to assess the productivity of agricultural lands. However, Neill (1979) and Kiniry *et al.* (1983) pointed out that productivity index was a model which related root growth to soil properties within a profile. The approach assumed that properties of soil within the rooting zone were major factors constraining crop growth and yield (Gantzer and McCarty, 1987). Gantzer and McCarty (1987) assumed that soil suitability for plant growth was the sum of the suitability of each layer of soil.

These models use physical and chemical soil parameters such as bulk density, available water capacity, porosity, pH and nutrient storage to quantify the productivity of soils. Most of these models do not consider all the physical and environmental factors that affect soil productivity. Also their applicability is limited by lack of necessary soil and environmental data that would help increase their authenticity.

According to Lal (1984) and El – Swaify *et al.* (1984), high level of management and replacement of nutrients are not always readily met in developing countries. Thus, they proposed that organic matter and nutrient considerations should form part of the model. Organic carbon available phosphorus and exchangeable aluminium are known to limit the productivity of many tropical soils. Besides, there is paucity of information on the quantification of the productivity of soils in tropical soils and specifically in Nsukka and Abakaliki areas. The productivity index model would permit assessment of the relative productive potential of such soils by using measurable soil characteristics. This will enable periodic evaluation of the continuing ability of these soils to produce food and fiber for the nation. The objective of this work was to quantify the productivity of selected soils in Nsukka and Abakaliki areas of Southeastern Nigeria, using two modifications of the productivity index model of Pierce *et al.* (1983).

MATERIALS AND METHODS

The Productivity Index Model and Its Modification

Neill's (1979) productivity index was modified by Pierce *et al.* (1983). The productivity index was based on the use of simple easily measurable soil properties to predict the effect of soil environment on root growth. This is expressed as follows:

$$PI = \sum_{i=1}^{r} (A_i x B_i x C_i x D_i x E_i x Wf_i) \ldots (1)$$

where;

PI = productivity index

A_i = Sufficiency for available water capacity for the ith soil layer

B_i = Sufficiency for aeration 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

E_i = Sufficiency for electrical conductivity for the ith soil layer

Wf_i = Root weighting factor

r = Number of horizons in the rooting zone.

Other parameters like nutrients, management, climate and genetic factors are presumed to be constant.

Neill's model (1979) did not take care of some soil parameters such as organic carbon, available phosphorus and exchangeable aluminium that exert key influence on the productivity of tropical soils. Consequently, a modifixation was carried out to include these three sufficiencies. The modified expressions are as follows:

$$P1M_i = \sum^{r} (A_i x C_i x D_i x Wfi) \ldots (2)$$

Where:

$P1M_i$ = Modified productivity index that involves the exclusion of sufficiencies for aeration and electrical conductivity.

$$P1M_2 = \sum (A_i x C_i x D_i x J_i x Ki x L_i x Wf_i) \ldots (3)$$

Where:

$P1M_2$ = Modified productivity index that involves the inclusion of sufficiencies for organic carbon, available phosphorus and exchangeable aluminium with simultaneous exclusion of sufficiencies for aeration and electrical conductivity.

Ji = Sufficiency for organic carbon for the ith soil layer

Ki = Sufficiency for available phosphorus for the ith soil layer

Li = Sufficiency for exchangeable aluminium for the ith soil layer

The sufficiencies for available water capacity, bulk density, pH and root weighting factor for this modification were as established by Pierce *et al.* (1983), while other sufficiencies were established in this work.

Sufficiency for Organic Carbon Contents

A sufficiency of 1.0 was assigned for organic carbon content of 2.0 percent in the study area. It is presumed that soil productivity approaches zero at organic carbon content of 0.5 or less (Enwexor *et al.,* 1981).

Table 1: The rating of organic carbon

Organic carbon content (%)	Sufficiency
0.50	0.0
0.65	0.1
0.80	0.2
0.95	0.3
1.10	0.4
1.25	0.5
1.40	0.6
1.55	0.7
1.70	0.8
1.85	0.9
2.0 and above	1.0

Source: Enwezor *et al.(* 1981)

Sufficiency for Available Phosphorus Content

In this study, a sufficiency of 1.0 was assigned for the highest available phosphorus content of 50 Cmol kg^{-1} and it is assumed that soil productivity declines at available phosphorus of 15 cmol kg^{-1} or less (Landon, 1991).

Table 2: Sufficiency rating of available phosphorus

Available phosphorus	Sufficiency
5	0.1
10	0.2
15	0.3
20	0.4
25	0.5
30	0.6
35	0.7
40	0.8
45	0.9
50	1.0

Source: Landon (1991.)

Sufficiency for exchangeable Aluminium

The highest sufficiency of 1.0 was assigned for exchangeable aluminium concentration of 2.8 cmol kg^{-1}. Soil productivity approaches zero at exchangeable aluminium conc entration of 14.0 cmol kg^{-1} and above (Pratt, 1966; Mclean and Gilbert, 1927).

The rating is as follows:

Table3: Sufficiency rating of exchangeable aluminium

Exchangeable aluminium concentration (cmol kg^{-1})	Sufficiency
2.8	1.0
5.6	0.8
8.4	0.6
11.2	0.4
14.0 and above	0.2

Source: Pratt (1966); Mclean and Gilbert (1927)

Site Description

The research was carried out at four locations in the southeastern zone of Nigeria. Two locations were at the Research and Teaching Farm of the Faculty of Agriculture University of Nigeria, Nsukka (06;52^{1}N; 07^0 24^{1}E) in a humid area. The station experiences wet (April to October) and dry (November to March) seasons. The annual total rainfall is about 1700 - 2000 mm and it is bimodally distributed (Obi, 1982). The soil is deep and red to brownish red, and derived from sandy deposits of false bedded sandstone. It is an Ultisol classified as Typic Kandiustult and belongs to the Nkpologu soil series (Nwadialor, 1989).

The other two locations were at the experimental farm of the Faculty of Agriculture, Ebonyi State University, Abakaliki (06^0 04^1 N; 08^0 65^1 E). The annual rainfall is about 1700-2000 mm spread between April and November. The soil is of shale parent material. It is shallow with unconsolidated parent material within one metre of the soil surface; and classified as Tropaquept (Anikwe *et al.,* 1999) and gleyic lixisols (FAO/UNESCO, 1988).

Field Methods

The experiment was carried out in the 1999 and 2000 planting seasons at the various locations. The selected sites had been under fallow for four years. At each location a 20 m x 25 m plot (0.05 ha) was cleared and used for the experiment.

The soil was tilled to the depth of about 20 cm using traditional hoes. Maize (Oba super II hybrid variety) was used as a test crop. This was manually planted (two seeds per hole) at 5 cm depth and at 25 cm x 75 cm spacing. The seedlings were thinned down to one seedling per hole, one week after emergence leaving 53,000 plants per hectare. Lost stands were replaced. Fertilizer (NPK 15: 15: 15) was applied at 5 cm depth (banded) and 10-15 cm radius from the plants at the rate of 300 kg ha^{-1}. Weeds were removed with hoes at three-weekly intervals. Grain yield was evaluated at harvest. The cobs were harvested, threshed, dried, weighed and the yield data were adjusted to 14% moisture content.

Soil samples were collected from four locations in each plot. Both undisturbed core samples and auger samples were collected form three depths (0-30 cm, 30- 60 cm and 60 – 90 cm) at each sampling point after planting. The undisturbed core samples were used to determine bulk density, total porosity, pore size distribution, water retained at 60 cm tension and available water capacity. Surface penetration resistance was measured using a pocket penetrometer (0-5 cm) of cone and at 90% cone angle.

Laboratory Methods

Auger soil samples were air dried and sieved with 2 mm sieve. Soil particle size analysis was determined using the method of Gee and Bauder (1968). Bulk density determination was carried out using core method as described by Blake and Hartge (1986). Water retained at 60 cm tension was determined by the hanging column of water technique (Obi, 2000). The pressure plate apparatus was used to determine available water capacity at 10 kpa (field capacity) and 1500 kpa (permanent wilting point) (Stolte, 1998). Total porosity and pore size distribution were determined as described by Obi (2000).

Organic carbon determination was by Nelson and Sommers (1982) method. Bray-2 method as described by Page *et al.* (1982) was used to determine available phosphorus. Exchangeable aluminium was determined by the titrimetric method using 1.0 N KCI extract (Mclean, 1982). The soil pH determination was in soil/water ratio of 1:2.5.

Data Analysis

Relationships between calculated productivity, each productivity indicator and grain yield of maize were determined using correlation analysis as outlined by Steel and Torrie (1980).

Results and Discussions

Soil Properties

The physical properties of the soils of the study sites are presented in Tables 4 and 5. The results show that mean sand contents at Nsukka study locations were 72% and 76% in the topsoil (0-30 cm) for 1999 and 2000 cropping seasons. Similarly, mean topsoil sand contents were 56% and 50% in the top (0-30 cm) soil depth at Abakaliki study sites for 1999 and 2000 cropping seasons. Also, the mean clay contents were 13% and 19% for the two cropping seasons at the 0-30 cm depth zone of the Nsukka study locations. The clay fraction tended to increase down the profiles at Abakalike and Nsukka study locations for 1999 and 2000 cropping seasons at 30-60 cm and 60 – 90 cm depth zones, respectively. The mean values of the clay plus silt fractions were 42% and 52% at Abakaliki soil whereas the values were 16% and 24% at Nsukka study sites for the two cropping seasons respectively. Soil particle size distribution had been found to have good relationship with specific surface area, soil compactability (Smith *et al.,* 1998) and other soil properties like organic matter and cation exchange capacity which affect inherent productivity of the soil.

The mean values for total porosity were 44.6% - 44.9% and 44.3% -44.7% in the top soil (0-30 cm) at both Abakaliki and Nsukka study locations for the two cropping seasons. Similarly, the mean values for macroporosity and microporosity were 28.7%-22.2% and 18.75% - 25.9%, respectively in the top (0-30 cm) depth zones at Abakaliki study locations for 1999 and 2000 cropping seasons. Furthermore at the Nsukka study locations, values of 26.25%-19.6% and 25.1%- 20-6% were recorded for macro-porosity and micro-porosity at the 0-30 cm depth zones in 1999 and 2000 cropping seasons. These results suggest that both macroporosity and microporossity are moderate and not limiting in soil productivity.

The mean values for the surface resistance to penetration were 0.78kg m^{-2} and 0.86-89kg m^{-2} respectively at both Nsukka and Abakaliki study locations for 1999 and 2000 cropping seasons. Surface resistance to penetration had been found to correlate with bulk density (Grossman, 1981). Obi (2000) noted the force needed by a germinating seed to break through crusted soil.

Table 4. Some Properties of the Soils of the study in 1999 Cropping Season

Soil Properties	*Abakaliki I*			Abakaliki II			Mean of	Nsukka I			*Nsukka II*			Mean of
	0-30,	30-60,	60-90(cm)	0-30,	30-60,	60-90(cm)	(0-30cm)	0-30,	30-60	60-90(cm)	0-30,	30-60,	60- 0(cm)	(0-30cm)
Sand %	44	36	56	68	55	52	56	78	67	68	84	77	70	74
Silt %	24	31	18	12	13	14	18	6	6	5	4	5	5	3
Clay %	32	32	26	20	32	34	26	14	26	12	12	19	25	13
Total porosity %	45.0	44.4	54.6	44.2	36.1	30.9	54.6	45.3	36.3	31.9	44.1	36.9	32.5	44.7
Macroporosity %	21.8	21.5	22.2	22.6	18.9	18.1	22.2	24.2	21.5	17.1	28.2	18.4	18.4	26.2
Microporosity %	33.2	25.1	28.7	24.2	20.0	18.0	28.7	20.5	15.2	14.0	18.7	13.1	13.1	19.6
Penetration Resistance (Kgm^{-2})	0.74	1.50	0.86	0.97	1.65	2.74	0.86	0.77	1.51	2.18	0.78	1.55	1.55	0.78

Table 5. Some Properties of the Soils of the study Sites in 2000 Cropping Season

Soil Properties	*Abakaliki I*			*Abakaliki II*			Mean of	*Nsukka I*			*Nsukka II*			Mean of
	0-30	, 30-60,	60,90(cm)	0-30,	30-60	,60-90(cm)	(0-30cm)	0-30,	30-60,	60-90(cm)	0-30,	30-60,	60-90(cm)	(0-30cm)
Sand %	42	42	50	44	57	53	50	73	74	67	79	75	77	76
Silt %	27	31	26	30	24	14	16	6	5	3	4	5	2	5
Clay %	31	33	36	33	20	33	34	21	23	31	17	20	22	19
Total porosity %	44.6	37.1	34.9	33.5	45.2	39.1	34.3	44.8	35.4	30.3	43.	35.2	30.0	44.3
Macroporosity %	18.0	12.4	18.7	12.2	19.7	16.7	15.2	24.0	20.4	18.2	22.	20.2	19.2	23.1
Microporosity %	26.4	25.5	25.9	21.3	25.3	22.2	19.5	20.2	15.2	12.5	21.	15.6	11.8	20.6
Penetration Resistance (Kgm^{-2})	0.81	1.33	0.89	2.27	0.96	1.88	2.84	0.78	1.58	2.70	0.78	1.58	2.60	0.78

Soil Productivity Index Parameters and Ascribed Sufficiency Values

Tables 6,7,8 and 9 show the soil properties, ascribed sufficiency values and predicted productivity indices for Nsukka and Abakaliki study locations. The soil properties and their individual sufficiency values were used in the computation of productivity indices.

The mean sufficiency values for dry bulk density, soil pH, organic carbon content and available phosphorus were generally high at the top (0-30 cm) soil depth zone except for exchangeable aluminium and decreased down the horizon at Nsukka and Abakaliki study sites (Tables 6-9). This indicates that dry bulk density, available water capacity, soil pH, percent organic carbon and available phosphorus as productivity indicators would not be limiting to maize production in the topsoil. Pierce *et al.* (1983) corroborated that bulk density, soil pH, available water capacity and soil depth values respectively were high at the top-soil and not limiting to soil productivity. However, the decrease in mean sufficiency values of these parameters down the profiles in both Nsukka and Abakaliki study sites implied that the assessed productivity indicators could be limiting to maize production in the subsoil. The mean sufficiency value for available water capacity at Abakaliki study locations consistently remained the same (0.90) in the topsoil and subsoil in 1999 and 2000 cropping seasons. At Nsukka study sites, the mean sufficiency value for available water capacity was 0.60 in the topsoil (0-30 cm) and slightly appreciated to 0.62 in the subsoil for the two cropping seasons. The results indicated more available water in Abakaliki study soils. Available water would not be considered limiting to soil productive opacity for maize grain yield at Abakaliki but could be limiting in Nsukka soils. Furthermore, the results showed higher productivity indices which explained higher mean grain yields of maize (2.35 t ha^{-1} and 2.27 t ha^{-1} respectively) for the two cropping seasons at Abakaliki study locations. Low available water in Nsukka study soils could be attributed to porous nature of the soils, low clay content as well as low organic carbon content of the soil (Table 4). The ascribed mean sufficiency values for soil depth were 1.00 respectively for Nsukka and Abakaliki study sites at the top (0-30 cm) soil depth in 1999 and slightly reduced to 0.90 at the subsoil at Abakaliki study sites and 2000 cropping seasons. The result indicates that soil depth was not limiting in all the study location. Deep soils without limitations had been noted by Anikwe (2000) to promote root proliferation. This would enable plant root to explore more area for nutrients and water.

The productivity indices were 0.32 and 0.24, 0.23 and 0.30 for Abakaliki clay loam (Abakaliki 1) and Abakaliki sandy clay loam

(Abakaliki II) study locations, respectively, for the two cropping seasons.(Table 10) Similarly, the productivity indices for the Nsukka sandy clay loam soil (Nsukka I) and Nsukka sandy loam (Nsukka II) study sites were 0.04 and 0.15, 0.01 and 0.06, respectively for 1999 and 2000 cropping seasons.(Table10) These results show that Abakaliki study soils have comparatively higher productive potential. The results further suggest that Abakaliki clay loam soil (Abakaliki I) which has the highest productivity index rating is more suitable and can sustain maize production for a longer period under similar management practices compared to the Nsukka sandy loam and sandy clay loam soils.

Table 6: Soil Property, Ascribed Sufficiencies and calculated productivity index for Abakaliki I study site

Soil Properties	**1999 measured property (soil depth)cm**			**Ascribed sufficiency**			**1999 measured property (soil depth) cm**			**Ascribed sufficiency**		
	0-30,	**30-60,**	**60-90**	**0-30,**	**30-60,**	**60-90**	**0-30,**	**30-60,**	**60-90**	**0-30,**	**30-60,**	**60-90**
Bulk density (Mgm^{-3})	1.38	1.53	1.78	0.98	0.45	0.00	1.44	1.54	1.79	0.75	0.45	0.00
Available water Capacity (cm/cm)	0.21	0.22	0.23	0.89	0.90	0.96	0.22	0.22	0.24	0.90	0.90	0.98
PH in KCl	4.0	3.9	4.0	0.47	0.43	0.47	4.0	3.5	3.3	0.47	0.25	0.16
Organic Carbon (%)	1.20	0.80	0.37	0.40	0.20	0.00	1.70	0.76	0.71	0.80	0.10	0.10
Available Phosphorus (cmol kg^{-1})	78	23	18	1.00	0.43	0.38	54	30	20	1.00	0.60	0.40
Exchangeable aluminium (cmol kg^{-1})	81	290	324	0.00	0.00	0.00	68	292	392	0.00	0.00	0.00
Root weighting factor (cm) (Depth of rooting zone)	90	90	90	0.90	0.90	0.90	90	90	90	0.90	0.90	0.90
Calculated P I			0.32						0.32			

Table 7: Soil Property, Ascribed Sufficiencies and calculated productivity index for Abakaliki II study site

Soil Properties	**1999 measured property (soil depth) cm**			**Ascribed sufficiency**			**Mean sufficiency 0-30cm 1999-2000**	**2000 Measured property (soil depth)cm**			**Ascribed sufficiency**			**Mean sufficiency 0-30cm 1999-2000**
	0-30,	**30-60,**	**60-90**	**0-30,**	**30-60,**	**60-90**		**0-30,**	**30-60,**	**60-90**	**0-30,**	**30-60,**	**60-90**	
Bulk density (Mgm^{-3})	1.44	1.72	0.99	1.00	0.20	0.00	0.99	1.54	1.76	1.77	0.78	1.10	0.03	0.77
Available water Capacity (cm/cm)	0.21	0.21	0.89	0.89	0.89	0.9	0.89	0.22	0.21	0.23	0.90	0.89	0.96	0.90
pH in KCl	4.7	4.4	0.63	0.79	0.65	0.63	0.63	4.3	4.0	3.8	0.61	0.47	0.38	0.54
Organic Carbon (%)	1.28	1.20	0.40	0.50	0.40	0.10	0.40	1.84	1.24	0.94	0.80	0.40	0.20	0.80
Available Phosphorus (cmol kg^{-1})	26	19	0.76	0.56	0.39	0.24	0.76	42	33	28	0.82	0.63	0.53	0.91
Exchangeable aluminium (cmol kg^{-1})	79	122	0.00	0.00	0.00	0.00	0.00	68	162	270	0.00	0.00	0.00	0.00
Root weighting factor (cm) (Depth of rooting zone)	100	100	100	1.00	1.00	1.00	1.00	100	100	100	1.00	1.00	1.00	1.00
Calculated P I				0.32						0.32				

Table 8: Soil Property, Ascribed Sufficiencies and calculated productivity index for Nsukka I study site

Soil Properties	1999 measured property (soil depth)cm			Ascribed sufficiency			1999 measured property (soil depth)cm			Ascribed sufficiency		
	0-30,	30-60,	60-90	0-30,	30-60,	60-90	0-30,	30-60,	60-90	0-30,	30-60,	60-90
Bulk density (Mgm^{-3})	1.31	1.50	1.70	1.00	0.90	0.30	1.43	1.54	1.72	1.00	0.82	0.20
Available water Capacity (cm/cm)	0.16	0.18	0.18	0.60	0.70	0.70	0.18	0.19	0.19	0.70	0.75	0.75
pH in KCl	3.2	3.2	3.4	0.12	0.12	0.21	4.1	4.2	4.0	0.52	0.56	0.47
Organic Carbon (%)	0.72	0.46	0.44	0.10	0.00	0.00	0.94	0.67	0.50	0.20	0.10	0.00
Available Phosphorus (cmol kg^{-1})	85	14	13	1.00	0.24	0.23	80	53	32	1.00	1.00	0.62
Exchangeable aluminium (cmol kg^{-1})	122	167	167	0.00	0.00	0.00	189	207	230	0.00	0.00	0.00
Root weighting factor (cm) (Depth of rooting zone)	100	100	100	1.00	1.00	1.00	1.00	100	100	1.00	1.00	1.00
Calculated P I				0.04					0.15			

Table 9: Soil Properties, Ascribed sufficiencies and calculated productivity index for Nsukka II Study site

Soil Properties	1999 measured property (soil depth)cm			Ascribed sufficiency			Mean sufficiency 0-30cm	2000 Measured property (soil depth)cm			Ascribed sufficiency			Mean sufficiency 0-30cm
	0-30,	30-60,	60-90	0-30,	30-60,	60-90	1999-2000	0-30,	30-60,	60-90	0-30,	30-60,	60-90	1999-2000
Bulk density (Mgm^{-3})	1.30	1.64	1.70	1.00	0.06	0.40	1.00	1.32	1.68	1.73	1.00	0.40	0.30	1.00
Available water Capacity (cm/cm)	0.15	0.14	0.16	0.55	0.50	0.60	0.58	0.15	0.15	0.17	0.55	0.55	065	0.63
pH in KCl	3.0	3.0	3.0	0.03	0.03	0.03	0.08	3.3	3.3	3.0	0.16	0.16	0.03	0.34
Organic Carbon (%)	0.70	0.44	0.44	0.10	0.00	0.00	0.10	0.80	0.54	0.42	0.20	0.00	000	0.20
Available Phosphorus (cmol kg^{-1})	53	31	11	1.00	0.60	0.21	1.00	92	88	60	1.00	1.00	1.00	1.00
Exchangeable aluminium (cmol kg^{-1})	144	162	207	0.00	0.00	0.00	0.00	170	216	270	0.00	0.00	0.00	0.00
Root weighting factor (cm) (Depth of rooting zone)	100	100	100	1.00	1.00	1.00	1.00	100	100	100	1.00	1.00	1.00	1.00
Calculated P I			0.01								0.06			

Calculated Modified Productivity Index and Grain Yield

The calculated productivity indices and grain yields are presented in Table 10 for both Abakaliki and Nsukka study locations for the two cropping seasons. The results indicate that mean productivity indices at Abakaliki study sites were higher by 91% and 61% than those at the Nsukka study soils for 1999 and 2000 cropping seasons respectively. Similarly, mean grain yields at harvest were 47% higher at the Abakaliki study sites for the two cropping seasons respectively. The highest average mean grain yield of maize (2.37 t ha^{-1}) for two cropping seasons was recorded in the Abakaliki location (Abakaliki I) that had the highest calculated mean productivity index of for the two years of study. The results, further, showed that predicted productivity indices decreased with decrease in grain yields.

Table 10: Ascribed Modified productivity index and grain yield in the fourstudy locations

Location	Year	Productivity Index	Grain Yield (t ha^{-1})
Abakaliki I (Clay Loam)	1999	0.32	2.40
Abakaliki I (Clay Loam)	2000	0.24	2.30
Abakaliki II (Sandy Clay Loam)	1999	0.23	2.20
Abakaliki II (Sandy Clay Loam)	2000	0.30	2.34
Nsukka I (Sandy Clay Loam)	1999	0.04	1.30
Nsukka I (Sandy Clay Loam)	2000	0.15	1.04
Nsukka II (Sandy Loam)	1999	0.01	1.18
Nsukka II (Sandy Loam)	2000	0.06	1.35

Table 11: Relationship between the two modifications of Pierce *et al.*(1983) Productivity index (P1M$_1$ and P1M2 (x) and grain yield (Y)correlation (r)

Dependent crop yield parameter	Regression Model	Coefficient of Determination (r^2)	
Grain yield (t ha$^-$)	Y=4.286x + 1.09	$R^2 = 0.92$**	P_1M_2
Grain yield (t ha^{-1})	Y=0.79x + 1.39	$R^2 = 0.41^{NS}$	P_1M_1

**R^2 Value significant at P = 0.01
NS: Not significant

Two modifications of Pierce *et al.* (1983) Productivity index (P1M$_1$ and P1M$_2$) and grain yield.

The relationship between the two modifications of the productivity index of Pierce *et al.* (1983) namely P1M$_1$ and P1M$_2$ is presented in Table 11. The result showed a highly significant relationship (R^2 = 0.92 at P <0.01) between P1M$_2$ and grain yield. However, there was a poor relationship (r^2 = 0.41) between P1M$_1$ and grain yield. This result indicates that a better relationship was established using P1M$_2$ than P1M$_1$. This further indicates that P1M$_2$ with inclusion of organic carbon and available phosphorus increased the sufficiencies is a better predictor of grain yield and, consequently, soil productivity than P1M$_1$. When Neill's (1979) productivity index was modified, there was increment of relationship between P1M$_2$ and grain yields as determined by R^2 from 0.41 to 0.92. This represents 55% increase the relationship between P1M$_2$ and grain yields as by R^2 and grain yields determined by R^2 from 0.41 to 0.92. This represents 55% increase is the relationship between P1M$_2$ and grain yield. The results also showed that exclusion of sufficiencies for organic carbon and available phosphorus contents reduced the relationship between P1M$_2$ and grain yield as measured by R^2 from 0.92 to 0.29 and 0.77 respectively. These accounted for 68% and 16% reductions in R^2, respectively. Similar results were corroborated by Gantzer and McCarty (1987) and Wolman (1995) in relationships between productivity index and grain yield as determined by R^2. The inclusion of ascribed sufficiency for exchangeable aluminium did not influence P1M$_2$ the four study locations. This could be due to the values for exchangeable aluminium, which were too high. Exchangeable alumunium is known to limit soil productivity and might have contributed to the poor grain yields especially at Nsukka study locations.

CONCLUSION

The results of this study indicate that soil physical and chemical properties could be used to quantify the productivity of soils. Though, Pierce *et al.* (1983) productivity index was effective in quantifying soil productivity, its modification proved to be more efficient. This owes to the fact that inclusion of sufficiencies especially for organic carbon and available phosphorus increased the validity of model.

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