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Predicting grain yields of maize in an Ultisol amended with organic wastes using modified productivity index in Abakaliki, Southeastern Nigeria

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Predicting grain yields of maize in soil amended with organic wastes using modified productivity index was studied for three cropping seasons. Soil samples for determination of productivity index and individual productivity indicators for prediction of grain yields of maize were collected from 0 15, 15-30, 30-45, and 45-60 cm depths. Ascribed sufficiency value was assigned to each productivity indicator of bulk density, available water capacity (AWC) pH and depth of rooting zone (DRZ) which were used to calculate productivity index (PI) for each amendment. Highest predictions of grain yields of maize were obtained for sawdust PI=0.39 and grain yield of maize-2.30 t ha^{-1} in 2013 and burnt rice mill waste PI=0.39 and grain yield of maize=2.30 t ha^{-1} and PI=0.37 and grain yield of maize=2.25 t ha^{-1} in 2014 and 2015 cropping seasons, respectively. The prediction of organic wastes for grain yields of maize is as follows BRMW>SD>URMW>C. Calculated productivity index (CPI) predicted highly significant (r=0.92 and r^2=0.84) grain yields of maize. Bulk density more than AWC and pH predicted highly significant (r=0.95 and r^2 = 0.89) grain yield of maize.

Key words: Amended, grain yields of maize, organic wastes, predicting, productivity index.

INTRODUCTION

Maize (*Zea mays* L.) is an important food and industrial cereal that has contributed greatly to the growth of many developing countries (FAO, 1998; Ande et al., 2008). It belongs to the grain under the family Graminae and class of cereals that thrive under a wide range of environmental conditions (Mbah et al., 2009), although, grain yields are affected by nature and physical conditions as well as nutrients storage of the soil.

Physicochemical condition of a soil is fundamental to its productivity. For instance, soil properties have high degree of relationship with its productivity and crop yield (Wallace and Wallace, 2011; Nnaji, 2009). Corroborating (Follet and Stewart, 1985) noted that relationship existed between soil properties and soil's capacity for producing plants or soil productivity. Anikwe (2000) had related bulk density, available water capacity, depth of rooting zone, pH and generally nutrient storage to soil productivity.

Thus, soil productivity which is expressed in form of

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crop yield can be determined using various approaches. Some of these approaches have been developed in an attempt to numerically relate soil properties to its productivity (Anikwe, 2000). These include Universal Soil Loss Equation (USLE) and Erosion Productivity Impact Calculator (EPIC) (National Soil Erosion and Productivity Research Planning Committee NSEPRPC, 1981). However, a simple numerical index model generally preferred and which has received wide acceptability due to its simplicity and applicability in many soils (Nwite and Alu, 2015; Anikwe 2000) is the productivity index (PI). This model is used widely today for prediction of crop yield. The model is based on the use of physical and chemical properties of soil to predict crop yield and soil productivity.

Modification of productivity index arise because of the need to exclude soil parameters peculiar to a region it was originally conceive and to include those relevant in a new ecological regions where the model is to be currently tested for grain yield predictions. This would not only add value but could increase the models acceptability and applicability in new regions. Productivity index is an algorithm that relates crop yield to rooting depth (Lindstrom et al., 1992), which is controlled by soil environment, while prediction of yield is an estimated projection of crop performance under a specified or set of management system usually expressed in terms of harvestable edible parts. Prediction of future crop yield is essential to make agricultural policy decisions and plan on use of soil in order to sustain both local and national food needs of a nation. Even though, studies have been carried out on soil productivity predictions, little or no research has been documented on prediction of grain yields of maize in the study area. Therefore, it is expected that output from this study would arouse the national psyche towards the need for concerted and sound research on characterization of soils for crop yield predictions. Consequently, critical stakeholders, farmers, policy makers, agronomists and probably other land users might find the result of this work useful. The objectives of this study were to use soil selected physicochemical properties to compute productivity indices for predicting grain yields of maize on soil amended with organic wastes using modified productivity index for three cropping seasons.

MATERIALS AND METHODS

Experimental site

The study was carried out at the Teaching and Research Farm of Faculty of Agriculture and Natural Resources Management, Ebonyi State University, Abakaliki. The area is located by Latitude 06°4/N and Longitude 08°65/E in the derived savannah zone of the southeast agro-ecological area of Nigeria (Figure 1). The rainfall pattern is bimodal (April-July and September-November), with a short dry spell in August normally referred to as "August break". The total annual rainfall in the area ranges from 1500 to 2000 mm, with

Figure 1. Map of Abakaliki, Southeast, Nigeria.

a mean of 1,800 mm. At the onset of rainfall, it is torrential and violent, sometimes lasting for one to two hours (Okonkwo and Ogu, 2002). The area is characterized by high temperatures with minimum mean daily temperature of 27°C and maximum mean daily temperature of 31°C throughout the year. Humidity is high (80%) with the lowest (60%) levels occurring during the dry season between December to April, before the rainy season begins (ODNRI, 1989). The underlying geological material in the area is the sedimentary rocks derived from successive marine deposits of the cretaceous and tertiary periods. According to the Federal Department of Agricultural Land Resources (FDALR, 1987) Abakaliki Agricultural zone lies within 'Asu river group' and consists of olive brown sandy shales, fine-grained sandstones and mudstones. The soils are shallow with unconsolidated parent materials (shale residuum) within 1 m of the soil surface. The soils of the area are acidic due to mainly heavy and frequent rain falls experienced during rainy seasons and belong to the order ultisol and are classified as Typic Haplustut (FDALR, 1987).

The vegetation of the area is primarily derived savannah, with bush regrowth, and scanty economic trees. The site had history of previous cultivation of yam (*Dioscorea* species) and cassava (*Manihot* species). There is grown of native vegetation such as *Tridax* species, *Odoratum* species, *Aspilla africana, Imperata cylindrica, Panicum maximum, Pennisetum purperum, Sporobulus pyramidalis* and other herbs and shrubs. The common farming practices obtained in the area are continuous cultivation and mixed cropping as a result of population pressure as well as to optimize soil resources. These practices act as "drain" on soil nutrients and cause for low farm outputs often recorded in Abakaliki areas.

Field methods

Field design/layout and treatment application

The vegetation was cleared manually using matchet and hoe. The debris left after clearing was removed before seedbed preparation. An area of land that is approximately (0.021 ha) was used for the study. The land was demarcated into plots and replicates. The plots were laid out in Randomized Complete Block Design (RCBD). The plots measured 2 × 2 m with a plot alley of 0.5 spacing. The four replicates were separated by 1 m spaces. The treatments consisted of: control (C), that is, no application of organic wastes; burnt rice mill waste (BRMW) 20 t ha^{-1} equivalent to 8 kg/plot; unburnt rice mill waste (URMW) 20 t ha^{-1} equivalent to 8 kg/plot; sawdust (SD) 20 t ha^{-1} equivalent to 8 kg/plot.

The treatments namely were burnt rice mill waste (BRMW), fresh or unburnt rice mill waste (URMW) and sawdust (SD) were sourced from the agro-rice mill industry and timber shade market, Abakaliki, respectively. Agro-rice wastes and sawdust are generated from numerous rice mills and timber shades that criss cross the state. These wastes are heaped to form artificial mountains causing environmental nuisance as they are not put to any useful use in the area. Furthermore, they are cheap and available to resource poor farmers. The organic wastes of burnt rice mill waste, unburnt rice mill waste and sawdust were spread on the plots. They were incorporated into the soil during seedbed preparation using traditional hoe. The beds were allowed to age for two weeks after incorporation of treatments before planting the test crop. The treatments were replicated four times to give a total of twenty plots in the study.

Maize seed (suwan-1-SR-hybrid variety) sourced from Ebonyi State Agricultural Development Programme (EBADEP) was planted 2 seeds per hole at 5 cm depth and spacing distance of 25 × 75 cm. Two weeks after emergence (WAE), the plants were thinned down to one plant per hole while lost stands were replaced. Weak plants were rogued out and replaced leaving a plant population of approximately 53, 000 stands per hectare. There was application of NPK (20:10:10) fertilizer at 400 kg ha^{-1} to all the plots two weeks after plant emergence (WAPE). The fertilizer was banded and placed 5 cm away from the maize plants. Weeds were removed at three-weekly intervals up till harvest. In the second year, the procedure was repeated while residual effect was tested in the third year of study without fresh application of treatments.

Agronomic data

The cobs were harvested at plant maturity. This was when the husks were dried. The cobs were dehusked and further dried before shelling and grain yield determined at 14% moisture content. Agronomic yield data were taken on twelve tagged plants representation, 25% of plant population per plot.

Soil sampling

Initial soil samples were collected from the 0 to 20 cm depth using auger at different points in the study site before application of organic wastes and cultivation. The auger samples were composited and used for routine laboratory analysis. Core and auger samples were collected at 0 to 15, 15 to 30, 30 to 45 and 45 to 60 cm depths in each plot and used for soil productivity evaluation. Core samples were used to determine some soil physical properties while auger samples were air-dried at room temperature (about 26°C) and passed through a 2 mm sieve. These were used for pH determination.

Laboratory determination

Dry bulk density was determined as described by Blake and Hartge (1986). Particle size distribution was determined by the hydrometer method as described by Gee and Or (2002). The result from particle size distribution was reported as percentage sand, silt and clay respectively.

Moisture retained at -10 and -1500 Kp_a matric potentials were estimated based on the saturation water percentage (S_p) models of Mbagwu and Mbah (1998). The models are: available water capacity (AWC) was computed as the difference between moisture retained at 10 and 100 kp_a matric potentials, where

$$\Theta.01\ (FC) = -6.22 + 0.79\ (S_p) \quad (1)$$

$$\Theta\ .100 = -\ 10.95 + 0.65\ (S_p) \quad (2)$$

$$\Theta\ .15\ (PWP) = -\ 8.65 + 0.51\ (S_p) \quad (3)$$

where FC is the field capacity, S_p is the saturation percentage, and PWP is permanent wilting point.

The pH determination of the soil was in duplicates both in distilled water and in 0.1N KCL solution using a soil/water ratio 1:2.5. After stirring for 30 min, the pH values were read off using a Beckman zeromatic pH meter (Peech, 1995). The total nitrogen was determined using the micro-Kjedhal distillation method of Bremner (1996). The ammonia from the digestion was distilled with 45% NaOH into 2.5% boric acid and determined by titrating with 0.05N KCL. Available phosphorus determination was done according to by the Bray-2 method as described in by Page et al. *(*1982). This method involved weighing 2 g of soil sample into a test tube. 20 ml of 0.03 NH_4F in 0.1N HCL was added to the sample of soil in the test tube. Then, the test tube was closed and shook for a minute. It was allowed to settle and filtered. 1 ml of the filtrate was pipetted into a 50 ml of volumetric flask. 7 ml of distilled water and 1 ml of NH_4 molybdate and 1 ml of ascorbic acid were added to the sample. The flask was made up to the mark with distilled water and allowed to stand for 15 min before taking the reading using 608 filter paper.

The available phosphorus was read off from the standard curve obtained from optical density using a colorimeter. Organic carbon determination was done by using the method described by Nelson and Sommer (1982). Calcium (Ca) and magnesium (Mg) were determined by titration method (Mba, 2004). Cation exchange capacity (CEC) was determined by ammonium acetate (NH_4OC) displacement method (Jackson, 1958).

The burnt rice mill waste, unburnt or fresh rice mill waste and sawdust organic wastes were analyzed for calcium (Ca), magnesium (Mg), nitrogen (N), phosphorus (P), organic carbon (OC) and C:N ratio using the method of Juo (1983).

Soil productivity index and its modification

The Pierce et al. (1983) productivity index is expressed thus:

$$PI = \sum_{i=1}^{r} (A_i x B_i x C_i x D_i x E_i x W f_i) \quad (4)$$

where PI is the productivity index, Ai is the sufficiency for available water capacity for the ith soil layer, B_i is the sufficiency for aeration for the ith soil layer, $C_i$is the sufficiency for pH for the ith soil layer, D_i is the sufficiency for bulk density for the ith soil layer, E_i is the sufficiency for electrical conductivity for the ith soil layer, Wf_i is the root weighting factor, and r is the number of horizons in the rooting zone

Modified Pierce et al. (1983) productivity index

Pierce et al. (1983) productivity index model as used in this work was modified to exclude sufficiency for aeration since it could be predicted from bulk density and sufficiency for electrical conductivity which is not common under humid conditions. Hence, the modified productivity index.

$$PI_M = \sum_{i=1}^{r} (A_i x C_i x D_i x W f_i) \quad (5)$$

where PI_M is the modified productivity index, Ai is the sufficiency for

Table 1. Some properties of soil at initiation of study.

Soil properties	Unit	Value
pH KCL	-	5.1
Organic carbon	%	1.84
Nitrogen	%	0.16
Available P	$mgkg^{-1}$	4.70
Calcium	$cmolkg^{-1}$	5.20
Magnesium	$cmolkg^{-1}$	3.80
Cation exchange capacity	$cmolkg^{-1}$	10.3

Table 2. Some properties of amendment materials.

Treatment	Parameter	Unit	Value
Burnt rice mill waste	Organic carbon	%	6.92
	Nitrogen	%	0.30
	Phosphorus	$mgkg^{-1}$	14.00
	Calcium	$cmolkg^{-1}$	1.17
	Mg	$cmolkg^{-1}$	0.27
	C:N	-	23
Unburnt rice mill waste	Organic carbon	%	16.39
	Nitrogen	%	0.48
	Phosphorus	$mgkg^{-1}$	7.00
	Calcium	$cmolkg^{-1}$	0.50
	Mg	$cmolkg^{-1}$	0.12
	C:N	-	34
Sawdust	Organic carbon	%	8.99
	Nitrogen	%	0.28
	Phosphorus	$mgkg^{-1}$	3.00
	Calcium	$cmolkg^{-1}$	0.30
	Mg	$cmolkg^{-1}$	0.10
	C:N	-	32

available water capacity for the ith soil layer, C_i is the sufficiency for pH for the ith soil layer, D_i is the sufficiency for bulk density for the ith soil layer, Wf_i is the root weighting factor, and r is the number of horizons in the rooting zone.

Data analysis

The data collected from this experiment were subjected to Statistical Analysis System (SAS, 1985) method. Significant treatment effect was reported at 5% probability level. Correlation and regression analysis according to Steel and Torrie (1980) were used to determine the relationship between soil productivity indicators and yield data.

RESULTS

Table 1 shows some properties of soil at initiation of study. The pH in KCL was 5.1. The respective percentage organic carbon and nitrogen were 1.84 and 0.16%. Available phosphorus was low with a value of 4.70 $mgkg^{-1}$. Calcium and magnesium of the soil were 5.20 and 3.80 $cmolkg^{-1}$ in the exchange complex of soil. The cation exchange capacity was 10.3 $cmolkg^{-1}$.

Some properties of amendment materials are shown in Table 2. Organic carbon and total N ranged from 6.92 to 16.39 and 0.28 to 0.48%, while available phosphorus ranged from 3.00 to 14.00 $mgkg^{-1}$ and calcium and magnesium ranged from 0.30 to 1.17 $cmolkg^{-1}$ and 0.10 to 0.27 $cmolkg^{-1}$ in the organic wastes. Carbon-nitrogen ratio for the organic wastes were 23, 32 and 34 for burnt rice mill waste, sawdust and unburnt rice mill waste, respectively.

Tables 3 to 5 show soil properties, ascribed sufficiency values and calculated productivity index for each of the treatments for 2013, 2014 and 2015 cropping seasons.

Table 3. Soil properties, ascribed sufficiency value and calculated productivity indices for 2013

Control	**…………..Measured property soil…………..**				**……….2013 Ascribed sufficiency of soil……….**			
Soil depth (cm)	**BD (mgm^{-3})**	**AWC (cm^{-})^{1}**	**pH (kcl)**	**RWF (cm)**	**BD (mgm^{-3})**	**AWC (cm^{-1})**	**pH (kcl)**	**RWF (cm)**
0-15	1.66	0.17	3.5	60	0.13	0.65	0.25	1.00
15-30	1.68	0.18	3.6	60	0.11	0.70	0.21	1.00
30-45	1.70	0.19	3.3	60	0.09	0.78	0.16	1.00
45-60	1.78	0.20	3.0	60	0.02	0.79	0.14	1.00
PI					0.28			

URMW	**……..…..Measured property of soil………….**				**………..Ascribed sufficiency of soil………..**			
Soil depth (cm)	**BD (mgm^{-3})**	**AWC (cm^{-1})**	**pH (kcl)**	**RWF (cm)**	**BD (mgm^{-3})**	**AWC (cm^{-1})**	**pH (kcl)**	**RWF (cm)**
0-15	1.51	0.18	4.0	60	1.00	0.70	0.47	1.00
15-30	1.62	0.19	3.7	60	0.96	0.78	0.34	1.00
30-45	1.64	0.20	3.5	60	0.92	0.79	0.25	1.00
45-60	1.66	0.21	3.5	60	0.81	0.80	0.25	1.00
PI					0.36			

BRMW	**…………..Measured property of soil…………..**				**…..……Ascribed sufficiency of soil……..…**			
Soil depth (cm)	**BD (mgm^{-3})**	**AWC (cm^{-1})**	**pH (kcl)**	**RWF (cm)**	**BD (mgm^{-3})**	**AWC (cm^{-1})**	**pH (kcl)**	**RWF (cm)**
0-15	1.62	0.18	3.7	60	0.60	0.70	0.34	1.00
15-30	1.64	0.18	3.6	60	0.58	0.70	0.30	1.00
30-45	1.65	0.19	3.5	60	0.50	0.78	0.25	1.00
45-60	1.66	0.20	3.4	60	0.48	0.79	0.16	1.00
PI					0.38			

SD	**……….…..Measured property of soil……………**				**………..Ascribed sufficiency of soil………..**			
Soil depth (cm)	**BD (mgm^{-3})**	**AWC (cm^{-1})**	**pH (kcl)**	**RWF (cm)**	**BD (mgm^{-3})**	**AWC (cm^{-1})**	**pH (kcl)**	**RWF (cm)**
0-15	1.63	0.18	3.7	60	0.61	0.70	0.34	1.00
15-30	1.64	0.18	3.6	60	0.58	0.70	0.30	1.00
30-45	1.65	0.19	3.5	60	0.50	0.78	0.25	1.00
45-60	1.65	0.20	3.4	60	0.50	0.79	0.16	1.00
PI					0.39			

C-control, B- burnt rice husk dust, U- Unburnt rice husk dust, S- Sawdust, PI- productivity index.

Table 4. Soil properties, ascribed sufficiency value and calculated productivity indices for 2014

Control	**……………Measured property of soil……………**				**………2014 Ascribed sufficiency of soil………**			
Soil depth (cm)	**BD (mgm^{-3})**	**AWC (cm^{-1})**	**pH (kcl)**	**RWF (cm)**	**BD (mgm^{-3})**	**AWC (cm^{-1})**	**pH (kcl)**	**RWF (cm)**
0-15	1.67	0.16	3.5	60	0.12	0.60	0.25	1.00
15-30	1.66	0.18	3.5	60	0.05	0.70	0.25	1.00
30-45	1.80	0.19	3.3	60	0.04	0.78	0.16	1.00
45-60	1.80	0.20	3.0	60	0.04	0.79	0.14	1.00
PI					0.26			

URMW	**…………Measured property of soil…………**				**…………Ascribed sufficiency of soil…………**			
Soil depth (cm)	**BD (mgm^{-3})**	**AWC (cm^{-1})**	**pH (kcl)**	**RWF (cm)**	**BD (mgm^{-3})**	**AWC (cm^{-1})**	**pH (kcl)**	**RWF (cm)**
0-15	1.78	0.16	4.3	60	0.10	0.65	0.64	1.00
15-30	1.79	0.18	4.0	60	0.11	0.70	0.47	1.00
30-45	1.80	0.18	4.0	60	0.04	0.70	0.47	1.00
45-60	1.83	0.18	3.7	60	0.01	0.70	0.34	1.00
PI					0.36			

Table 4. Contd.

BRMW	…………Measured property of soil…………				…………Ascribed sufficiency of soil…………			
Soil depth (cm)	**BD (mgm^{-3})**	**AWC (cm^{-1})**	**pH (kcl)**	**RWF (cm)**	**BD (mgm^{-3})**	**AWC (cm^{-1})**	**pH (kcl)**	**RWF (cm)**
0-15	1.78	0.17	4.4	60	0.10	0.65	0.62	1.00
15-30	1.78	0.19	4.1	60	0.10	0.78	0.47	1.00
30-45	1.84	0.20	4.0	60	0.01	0.79	0.47	1.00
45-60	1.80	0.20	4.0	60	0.01	0.79	0.47	1.00
PI					0.39			

SD	…………Measured property of soil…………				…………Ascribed sufficiency of soil…………			
Soil depth (cm)	**BD (mgm^{-3})**	**AWC (cm^{-1})**	**pH (kcl)**	**RWF (cm)**	**BD (mgm^{-3})**	**AWC (cm^{-1})**	**pH (kcl)**	**RWF (cm)**
0-15	1.74	0.18	3.7	60	0.10	0.70	0.34	1.00
15-30	1.78	0.19	3.6	60	0.80	0.78	0.30	1.00
30-45	1.80	0.19	3.5	60	0.08	0.78	0.25	1.00
45-60	1.80	0.20	3.5	60	0.07	0.80	0.25	1.00
PI					0.34			

C-control, B- burnt rice husk dust, U- Unburnt rice husk dust, S- Sawdust, PI- productivity index.

Table 5. Soil properties, ascribed sufficiency values and calculated productivity indices for 2015.

Control	…………Measured property of soil…………				………2015 Ascribed sufficiency of soil………			
Soil depth (cm)	**BD (mgm^{-3})**	**AWC (cm^{-1}**	**pH (kcl)**	**RWF (cm)**	**BD (mgm^{-3})**	**AWC (cm^{-1}**	**pH (kcl)**	**RWF (cm)**
0-15	1.80	0.16	4.3	60	0.08	0.60	0.61	1.00
15-30	1.82	0.17	4.0	60	0.05	0.65	0.47	1.00
30-45	1.85	0.17	3.8	60	0.04	0.65	0.38	1.00
45-60	1.87	0.18	3.6	60	0.03	0.70	0.30	1.00
PI					0.21			

URMW	…………Measured property of soil…………				…………Ascribed sufficiency of soil…………			
Soil depth (cm)	**BD (mgm^{-3})**	**AWC (cm^{-1})**	**pH (kcl)**	**BD (mgm^{-3})**	**AWC (cm^{-1})**	**pH (kcl)**	**BD (mgm^{-3})**	**AWC (cm^{-1})**
0-15	1.78	0.17	4.3	60	0.10	0.64	0.64	1.00
15-30	1.79	0.18	4.3	60	0.11	0.70	0.64	1.00
30-45	1.80	0.19	4.0	60	0.08	0.78	0.47	1.00
45-60	1.81	0.19	3.8	60	0.07	0.78	0.38	1.00
PI					0.35			

BRMW	…………Measured property of soil…………				…………Ascribed sufficiency of soil…………			
Soil depth (cm)	**BD (mgm^{-3})**	**AWC (cm^{-1})**	**pH (kcl)**	**BD (mgm^{-3})**	**AWC (cm^{-1})**	**pH (kcl)**	**BD (mgm^{-3})**	**AWC (cm^{-1})**
0-15	1.80	0.17	4.4	60	0.08	0.65	0.65	1.00
15-30	1.82	0.18	4.3	60	0.07	0.70	0.64	1.00
30-45	1.83	0.18	4.3	60	0.04	0.70	0.64	1.00
45-60	1.85	0.19	4.0	60	0.04	0.78	0.47	1.00
PI					0.37			

SD	…………Measured property of soil…………				…………Ascribed sufficiency of soil…………			
Soil depth (cm)	**BD (mgm^{-3})**	**AWC (cm^{-1})**	**pH (kcl)**	**BD (mgm^{-3})**	**AWC (cm^{-1})**	**pH (kcl)**	**BD (mgm^{-3})**	**AWC (cm^{-1})**
0-15	1.75	0.17	4.4	60	0.12	0.65	0.65	1.00
15-30	1.78	0.17	4.3	60	0.10	0.65	0.64	1.00
30-45	1.80	0.18	4.2	60	0.08	0.70	0.65	1.00
45-60	1.82	0.18	4.0	60	0.06	0.70	0.47	1.00
PI					0.32			

C-control, B- burnt rice husk dust, U- Unburnt rice husk dust, S- Sawdust, PI- productivity index.

Table 6. Productivity Index and Grain Yield of Maize.

Treatment	PI	Grain yield of maize (t ha^{-1})
Control	0.28	2.20
Control	0.26	2.15
Control	0.21	2.00
BRMW	0.38	2.26
BRMW	0.39	2.30
BRMW	0.37	2.25
SD	0.39	2.30
SD	0.34	2.22
SD	0.32	2.18
URMW	0.36	2.24
URMW	0.36	2.24
URMW	0.35	2.23
Total	5.14	26.57
Mean	0.42	2.21

BRMW: Burnt rice mill waste; URMW: unburnt rice mill waste; SD: sawdust.

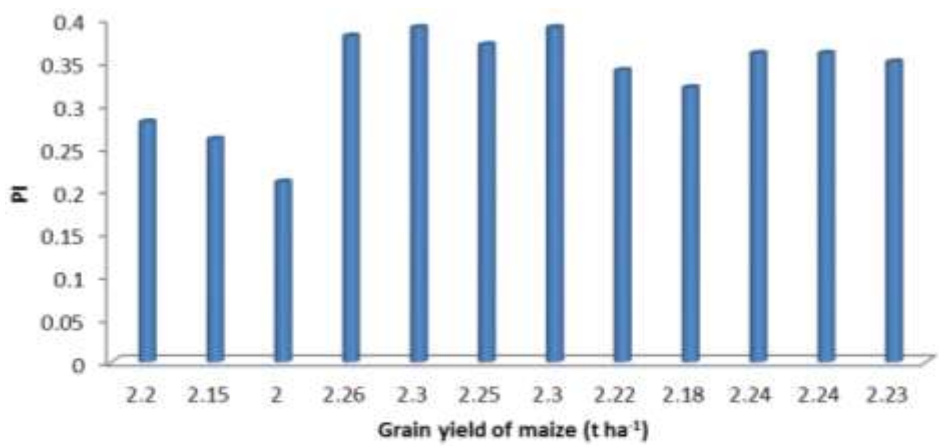

Figure 2. Productivity index and grain yield of maize.

The prediction of grain yield of maize was the highest under sawdust amended plot in 2013 cropping season. This was 28 and 30% higher in prediction of grain yields of maize than control and other organic wastes amended plots.

Even though in 2014 cropping season, productivity index (PI) generally declined, BRMW amended plot predicted highest grain yields of maize. These were 33, 8 and 13% higher in prediction of grain yields of maize than control, URMW and SD amended plots. During residual studies, P1 decreased in all the plots. The predictions in grain yields of maize were 7 and 13% lower for control and sawdust amended plots for 2014 cropping season. Similarly, predictions in grain yields of maize were 25, 3, 3 and 18% respectively higher than the values obtained for 2015 cropping season. Ascribed sufficiency value is a dimensionless curve which relates measured soil property to assigned value between 0.0 and 1.0, while calculated productivity index is the value obtained from computation of sufficiency values of individual soil productivity indicators.

The calculated productivity index (CPI) and grain yield of maize is shown in Table 6 and Figure 2. Results showed that mean PI and grain yield of maize were 0.42 and 2.21 t ha^{-1}, respectively. The plots supplemented with organic wastes had higher predictions of grain yields of maize than control. Of all the amended plots, the one receiving BRMW amendment had higher prediction of mean of grain yield of maize compared to values obtained for URMW, sawdust and control, respectively. The prediction of grain yields of maize in the treatments followed the trend of BRMW>SD>URMW>C. Generally,

Table 7. Relationship between calculated productivity index, individual productivity index and grain yield of maize.

Dependent crop parameter	Regression model	r	r^2	N=128
PI VS grain yield of maize	Y =1.68x=1.63	0.92**	0.84**	-
BD VS grain yield of maize	Y=5.64x-2.16	0.95**	0.89**	-
AWC VS grain yield of maize	Y=5.18x+1.24	0.75**	0.57*	-
pH VS grain yield of maize	Y=0.34x+0.51	0.76**	0.58*	-

PI: Productivity index; BD: Bulk density; AWC: Available water capacity. **Significant at 1%, *Significant at 5%, VS: versus, N: number.

Table 8. Relationship between individual productivity indicators and calculated productivity index.

Dependent crop parameter	Regression model	r	r^2	N=128
BD VS Productivity index	Y=2.01x-1.05	0.83**	0.70**	-
AWC VS Productivity index	Y=2.77x-0.18	0.74**	0.55ns	-
pH VS Productivity index	Y=0.18x-0.57	0.75**	0.56*	-

BD: Bulk density, AWC: available water capacity, RWF: root weighting factor, *Significant at 5%, **Highly significant at P>0.01, VS: versus, N: number of samples.

prediction of grain yields of maize followed the trends of productivity index.

Table 7 shows relationship between calculated productivity index (CPI) as well as individual productivity indicators (IPI) and grain yield of maize. There were positive and highly significant relationships between Calculated Productivity Index and Individual Productivity Index and grain yield of maize except for r^2 relationship between pH and grain yield of maize. Calculated productivity index predicted highly significant (r=0.92 and r^2<0.84 at P<0.01) grain yield of maize. The individual productivity indicators predicted highly significant (r=0.95 and r^2=0.89 at P<0.01) for bulk density and (r= 0.75 and r^2=0.57 at P<0.05) for AWC as well as (r =0.76 and r^2 = 0.58 at P<0.05) and grain yields of maize, respectively. In other words, bulk density explained 89 to 95% in soil variations in predicting grain yields of maize. This implies that bulk density rather than AWC, rooting depth or pH influenced soil productivity and grain yields of maize in the soil.

Table 8 shows relationship between calculated productivity index and individual productivity indicators. Result showed positive relationships between Individual productivity indicator and calculated productivity index. Significantly (P<0.01) higher correlation coefficients were obtained between Individual productivity indicators and calculated productivity index.

These were r=0.83 for bulk density and calculated productivity index, r=0.74 for AWC and calculated productivity index and r=0.75 for pH and calculated productivity index, respectively. The coefficient of determination relationship between bulk density and calculated productivity index was significantly (r^2=0.70 at P<0.01) higher than the value obtained for AWC and calculated productivity index (r^2 =0.55 at P<0.05) and pH and calculated productivity index (r^2 = 0.56 at P<0.05).

DISCUSSION

The soil was strongly acidic in line with FMARD (2002) bench mark for tropical soils. Nitrogen and available phosphorus were rated low in the soil (Enwezor et al., 1981). Cation exchange capacity was rated low according to Asadu and Nweke (1999) bench mark for soils of sub-Sahran Africa. This preliminary investigation indicates that the soil was acidic and of low fertility trend. This could be attributed to inherent properties of tropical soils. Tropical soils had been reported (Asadu et al., 2008) to suffer degradation and poor mineralization of nutrients due to high temperatures.

The Carbon-Nitrogen ratio fell within moderate values as recommended by Biswas and Murkherjee (2008) to enhance decomposition and release of nutrients. Organic carbon and total N in the organic wastes were rated high (Landon, 1991) while available phosphorus was low using critical values established for tropical soils by FMARD (2002). Calcium and magnesium in the organic wastes were rated low (Asadu and Nweke, 1999) according to ratings established for African soils.

Higher prediction of grain yields of maize in organic wastes amended plots compared to control could be attributed to improvement in soil properties due to amended materials. This corroborates the report of Puget et al. (2000) that organic wastes contained valuable materials that improved soil productivity. The decrease in predictions of grain yields of maize in 2014 cropping season and during residual season could be due to continuous cropping on one hand and low impact of residual effect of organic wastes amendment in third season. Mbah et al. (2009) noted that continuous cropping was depletive on soil nutrients and caused low soil productivity. The superiority of BRMW amendment relative to other amendments in prediction of grain yields of maize could be linked to higher mineralization of nutrients and generally improved soil properties which enhanced predictions of grain yields maize.

Higher predictions of grain yields of maize in plots amended with organic wastes compared to control could be attributed to positive impacts of the amendment materials on soil. It further implies that these materials could improve soil properties and cause increase in grain yield of maize. This study is supported by Mbah et al. (2009) and Adeleye et al. (2010) report that organic wastes amendment improved soil properties and increased its productivity. The generally superior prediction of grain yield of maize obtained in BRMW amended plot could be due to on one hand higher mineralization of nutrients to soil and on the other greater surface area that increased microbial action in degradation of the waste to release nutrients. The results on trend of productivity index and grain yield of maize had been observed by Anikwe (2000) and Nwite and Obi (2008) who reported that grain yields of maize followed the trend of productivity index.

The highly significant prediction of grain yield of maize obtained from calculated productivity index suggests that parameters used to compute productivity index strongly influenced grain yield of maize. This observation was noted by Anikwe and Obi (1999) in their studies that productivity index influenced and determined grain yield of maize. The significantly high prediction of grain yield of maize by productivity index could be further attributed to effectiveness and efficiency of organic wastes amendment in improving soil productivity and grain yield of maize. Superior prediction of grain yield of maize obtained in bulk density compared to AWC, rooting depth and pH could be as a result of its indirect influence on soil moisture status and nutrient storage and supply which also governs crop yield. Furthermore, improvement of soil bulk density could in turn positively influence nutrients storage and generally soil productivity.

The positive relationship between calculated productivity index and individual productivity indicator implies that individual productivity indicator influenced the productivity indices used in predicting the grain yields of maize. This corroborates the findings of Nwite (2013) that individual productivity indicators influenced productivity index in predictions. Significantly higher correlation coefficient obtained between the individual productivity indicator and calculated productivity index tends to suggest that there was synergy among the productivity indicators in promoting prediction of grain yields of maize. Molua and Lambi (2006) reported that available water was the most critical factor determining yield. The highly significant coefficient of determination obtained between bulk density and calculated productivity index compared to AWC and pH and calculated productivity index implies that high soil bulk density could mask influence of AWC and pH on soil productivity and hence reduce crop yield.

Conclusion

This study had shown that grain yields of maize could be predicted using modified productivity index. Generally, organic wastes amended plots predicted higher grain yields of maize than control. Burnt rice mill waste had superior prediction of grain yields of maize when compared to other wastes amendment. There were positive and significant predictions of grain yields of maize by calculated productivity index and individual productivity indicators. Bulk density influenced prediction of grain yields of maize more than available water capacity, pH and rooting depth. The research indicates that agro-wastes from rice mills and timber shades could be used to improve soil properties for higher productivity. This would be useful alternative way for engaging materials ordinarily abandoned to constitute environmental pollution with its attendant health hazards. Furthermore, modified productivity index gained acceptance and applicability in a new region as it could be used for future projection of food needs of a country. This would help policy makers in moving the country to make provisions in periods of shortfall to avert food crisis.

Conflict of Interests

The authors have not declared any conflict of interests.

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