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Comparative assessment of different poultry manures and inorganic fertilizer on soil properties and nutrient uptake of maize (*Zea mays* L.)

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This study investigated soil physicochemical properties and nutrient uptake of a drought-tolerant maize variety (DT-SR-WC$_2$) in a derived savanna zone of Southwestern Nigeria when different composted poultry manures (CPM) and inorganic fertilizer (IF) were applied. This was with a view to determining the essential trace elements and nutritional quality of the test crop. The experiment was a randomized complete block design with six treatments [cockerel manure (CM), broiler manure (BM), layers manure (LM), equal proportions of cockerel + broiler + layers manures (CBLM), IF)] and zero manure/fertilizer application served as control. Each treatment was replicated three times. Three months after sowing, the maize ears were manually harvested and threshed for analyses. The results show that addition of CPM increased the soil properties, but only significantly ($p < 0.05$) with the soil organic carbon and cation exchangeable capacity when BM was applied. There were no significant ($p > 0.05$) differences among the treatments considered in the proximate compositions of the harvested maize grains. The concentrations of mineral and trace elements in the harvested maize were generally higher during the wet than dry seasons, but with only Cu showing significant ($p < 0.05$) difference among the elements. It was concluded that BM was the best choice among the CPM considered for enhanced soil health and nutrient uptake of maize.

Key words: Maize, cockerel manure, broiler manure, layers manure, quality maize, soil health.

INTRODUCTION

Maize (*Zea mays* L.) is an annual cereal plant of the Poaceae family and native to Mexico (Hugar and Palled, 2008). Maize was introduced into Nigeria in the 16th century by the Portuguese (Osagie and Eka, 1998) and based on the area cropped and quantity produced; maize was the country's first most important crop among other prominent cereals such as rice, wheat, sorghum and millet (Macauley, 2015). In developing countries, where many of the farmers are resource-poor, maize is a good source of income as the crop could be cultivated on the same piece of land two or more times in one year. It is an important cereal crop that is not only rich in carbohydrate,

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but also a potential source of protein and essential minerals. A typical maize variety contains 65% carbohydrate, 10 to 2% protein and 4 to 8% fat (Iken and Amusa, 2004). Maize grain also contains mineral salts and essential trace element containing-compounds (Adeleye and Ayeni, 2010).

The problem of declining soil fertility was already mentioned by Stoorvogel and Smaling (1998) as becoming one of the major challenges for sustainable agricultural production in sub-Sahara African countries. Improving soil fertility management among smallholder farmers is widely recognized as a critical approach to addressing enhanced crop yields and poverty alleviation, especially in sub-Sahara Africa, where the majority of the populations earn their livelihood as smallholder farmers (Donovan and Casey, 1998). Sustained soil fertility management is a requirement for enhanced crop productivity and income in agri-business.

The use of inorganic fertilizer has not been helpful under intensive agriculture, because it is often associated with increased soil acidity, reduced soil organic matter with consequent deterioration of soil physical and chemical properties, soil nutrient imbalance, and reduced crop yield (Ojeniyi, 2000; Adeniyan and Ojeniyi, 2003; Awodun et al., 2007). In Nigeria, the rising cost of inorganic fertilizers coupled with their inability to recondition the soil, has directed attention to organic manures usage in recent times. Makinde et al. (2001) observed that soil degradation is brought about by loss of organic matter accompanied by continuous cropping. This becomes aggravated when inorganic fertilizers are applied repeatedly because crop response to applied fertilizer depends majorly on soil organic matter.

In Nigeria, arbitrary use of poultry manures as soil additives in crop production is on the increase because of availability, nutritive value and inexpensiveness. Poultry manure, in contrast to chemical fertilizer, adds organic matter to soil which improves soil structures, nutrient retention, aeration, soil moisture holding capacity and water infiltration (Boateng et al., 2006). Optimum use of poultry manure requires knowledge of their composition, not only in relation to enhanced crop yield but also for good crop quality (Ayeni and Adetunji, 2010), particularly in developing countries like Nigeria where maize is largely consumed when roasted, boiled or as supplement in many food diets. Dipeolu (2009) observed preference for organic vegetables due to their enhanced nutritional quality as against vegetables from inorganic fertilization.

Droppings of cockerel, broilers and layer birds have historically been composted into manures to serve as rich sources of plant nutrients and soil amendments (Otitoju, 2014). However, there is dearth of information on the specific type of the poultry manure that could give the best result in terms of quality of product when drought-tolerant maize is the test crop. One of the strategies that are currently being implemented to enhance global poverty reduction due to the impact of climate change on the agro-system is the introduction of drought-tolerant crop varieties to farming systems. This study therefore determined the essential trace elements and nutritional quality of a drought-tolerant maize variety under different poultry manures and inorganic fertilizer applications.

MATERIALS AND METHODS

Location of the study, experimental design and agronomic details

The field experiment was carried out during the dry season (October 2012-January 2013) in the Teaching and Research Farm of the Institute of Agricultural Research and Training, Ilora Substation, Ilora, Afijio Local Government of Oyo State, Southwest Nigeria with latitude 07°48´50.6´´ N and longitude 003°48´55.6´´ E. The experimental plot was cleared manually two times and pre-cropping soil samples (3), within 0 to 15 cm soil depth were taken for soil analysis. The experiment consisted of three, 23.0 × 2.5 m^2 blocks; each block was divided into six plots of 3.0 × 2.5 m^2 with an alley of 1.0 m between blocks and 1.0 m within plots. The experiment was laid out in a randomized complete block design (RCBD) with six treatments, namely: four manures [cockerel only, broiler only, layers only, cockerel + broiler + layers in equal proportion] each applied at 6.0 t ha^{-1}, one inorganic fertilizer (NPK 20-10-10) applied at 0.4 t ha^{-1} and zero manure/inorganic fertilizer application served as control. Each of the treatments was replicated three times to give a total of 18 plots.

The test crop, maize (DT-SR-WC_2), a drought-tolerant and streak resistant variety was planted at three grains per hole using 75 × 50 cm planting distance, and was rain-fed. The maize seedlings were later thinned to two grains per hole at two weeks after planting (WAP) to give a total of 53,333 maize plants population per hectare. A repeat experiment was carried out on the same treatment plots in the subsequent wet season (April-July 2013), but without fertilizer or compost application. Three manual weeding of the plots was carried out at 2, 5 and 7 WAP using hand hoe.

Soil and poultry droppings samples collections, preparation and analyses

Three composite surface soil (0 to 15 cm depth) samples were collected using simple random sampling technique before sowing; air-dried and sieved through a 2-mm mesh to remove debris and stones prior to analyses. Fresh droppings of cockerel, broiler and layer birds from a private poultry farm were separately collected, heaped under a shed and allowed to compost aerobically. The poultry heaps were stirred once in two weeks to enhance aeration and composting. As the decomposing organisms work on the heaped materials, heat was generated which helped to destroy associated fungal diseases and parasites with composts. The heat produced (peak temperature range 62 to 65°C) and moisture provided with addition of water periodically speed up the rate of decomposition. Fully cured dark manures with temperature range of 32 to 34°C were obtained at three months of composting. The poultry composts were air-dried, ground and analyzed for their chemical properties.

The properties of soil and manure samples were analyzed using standard methods (Page et al., 1982). The soil pH was determined in 1:1 soil-1 M KCl suspension using a glass electrode pH meter. Total nitrogen of the soil and manure were determined by the macro-Kjeldahl method. Available phosphorus in the soil and manure were extracted using Bray P1 method and P in the extractants was determined by colorimeter. The organic carbon in

Table 1. Properties of soil and composted poultry manures used for the experiment.

Property	Soil	Cockerel manure	Broiler manure	Layers manure
pH 1: 1 soil-1 M KCl	6.45	nd	nd	nd
Total Nitrogen (g kg^{-1})	0.70	22.40	34.30	24.00
Organic Carbon (g kg^{-1})	9.81	222.50	381.30	248.00
Available P (mg kg^{-1})	9.44	15.50	18.30	16.30
Ca (cmol kg^{-1})	0.75	26.60	31.60	29.30
Mg (cmol kg^{-1})	0.28	34.02	65.10	139.16
Na (cmol kg^{-1})	0.42	15.85	18,25	16.88
K (cmol kg^{-1})	0.35	12.10	13.90	12.50
Zn (mg kg^{-1})	0.14	448.55	475.00	462.85
Fe (mg kg^{-1})	0.20	4,627.65	5,125.70	4,920.50
Mn (mg kg^{-1})	0.17	625.55	643.35	620.95
Cu (mg kg^{-1})	0.27	68.30	75.20	72.09
Co (mg kg^{-1})	0.01	0.10	0.12	0.10
As (mg kg^{-1})	0.01	0.29	0.39	0.32
Pb (mg kg^{-1})	0.09	1.60	1.95	1.83
Cd (mg kg^{-1})	0.02	2.15	2.47	2.16
Textural class	Loamy sand	nd	nd	nd

Nd: Not determined.

soil and manure were determined using Walkley-Black wet oxidation method. Calcium ion, Mg^{2+} and K^+ concentrations in the soil and manure were extracted using 1 M ammonium acetate buffered at pH 7.0 and their concentrations in the extracts were measured using Buck Scientific Model 200 (East Norwalk, Connecticut, USA) Atomic Absorption Spectrophotometer. Also, post-cropping soil analysis was carried out on 54 surface soil samples (3 per plot of 18) to determine the influence of added soil amendments on soil quality after maize harvest.

Maize grains harvesting and analysis

Maize ears were manually harvested at 12 WAP, air-dried inside the maize crib and the field experiment was terminated. The maize grains were manually threshed and weighed. One kilogram of maize grain sample per plot was ground using a stainless-steel milling machine prior to analyses. Nutrient elements and proximate composition of the maize grain were determined using the methods of Association of Official Analytical Chemists (1990).

Statistical analysis

Data collected on the post-cropping soil properties, minerals and trace elements composition, and proximate composition of the harvested maize grains were subjected to analysis of variance at $p < 0.05$ following the procedure of Gomez and Gomez (1984). Test of significance for differences in means was compared using new Duncan's multiple range tests (SAS version 9.1 at $p < 0.05$).

RESULTS

Properties of soil and composted poultry manures

The pre-cropping soil properties and chemical composition of different poultry composts used in the experiment are shown in Table 1. The mean soil pH was 6.45, a slightly acidic soil condition. The soil texture was loamy sand with particle size distribution of 720, 230 and 50 g kg^{-1} for sand, silt and clay proportions, respectively. Soil organic carbon and total N were 9.81 and 0.70 g kg^{-1}, respectively, while available P was 9.44 mg kg^{-1}. However, the organic carbon and total N for the poultry composts ranged from 222.50 to 381.30 g kg^{-1} and from 22.40 to 34.30 g kg^{-1}, respectively, while available P ranged from 15.50 to 18.30 mg kg^{-1}.

Effects of poultry manures and inorganic fertilizer applications on soil properties

Soil properties of the experimental sites after the first and second cultivations of maize are shown in Table 2. Soil properties increased in all treated plots with application of composted poultry manures and inorganic fertilizer, but only significantly ($p < 0.05$) with the soil organic carbon and cation exchangeable capacity when BM was applied. The post-cropping soil pH ranged from 6.20 to 6.33 and from 6.15 to 6.38 in the dry and wet seasons, respectively.

The minerals and trace elements composition in maize

Influence of different poultry manure and inorganic fertilizer applications on the minerals and trace elements uptake by the drought-tolerant maize is shown in Table 3. The concentrations of minerals and trace elements increased when composted poultry manures and inorganic

Table 2. Post-cropping soil properties of the experimental site for the two seasons.

Treatment	pH	OC (g kg^{-1})	N (g kg^{-1})	P (g kg^{-1})	K (cmol kg^{-1})	CEC (cmol kg^{-1})	As (mg kg^{-1})	Zn (mg kg^{-1})
Dry season								
CM	6.20	10.59^{b}	1.35	11.70	0.61	4.24^{b}	0.02	1.30
BM	6.27	13.89^{a}	1.48	11.48	0.58	5.49^{a}	0.01	1.20
LM	6.20	11.62^{b}	1.40	11.85	0.81	4.37^{b}	0.02	1.36
CBLM	6.27	12.10^{b}	1.45	11.65	0.62	3.89^{b}	0.02	1.18
IF	6.20	11.15^{b}	1.37	11.40	0.61	4.06^{b}	Bdl	1.32
CT	6.33	10.80^{b}	1.26	11.47	0.54	3.06^{b}	Bdl	1.17
Wet season								
CM	6.15	10.22^{b}	1.30	12.00	0.75	3.31^{b}	0.02	1.42
BM	6.27	12.97^{a}	1.39	12.02	0.66	4.84^{a}	0.02	1.48
LM	6.27	11.10^{b}	1.36	12.03	0.86	3.30^{b}	0.02	1.46
CBLM	6.20	10.49^{b}	1.31	12.17	0.65	3.44^{b}	0.02	1.31
IF	6.28	10.05^{b}	1.26	11.90	0.72	3.08^{b}	Bdl	1.41
CT	6.37	9.73^{b}	1.20	11.35	0.61	2.83^{b}	Bdl	1.20
Interaction								
CM × BM × LM × CBLM × IF × CT	ns	*	ns	ns	ns	*	ns	ns

Mean with the same superscript within the same column do not differ significantly at $p < 0.05$ by new Duncan multiple range test. CM, Cockerel manure; BM, broiler manure; LM, layers manure; CBLM, cockerel + broiler + layers manure; IF, inorganic fertilizer; CT, control; ns, no significant interaction; Bdl, below detection level.

Table 3: Influence of soil amendments on the minerals and trace elements composition (mg kg^{-1}) of a drought-tolerant maize

Treatment	Ca	Mg	K	Mn	Zn	Fe	Co	Cu	As	Pb
Dry season										
CM	5.88	155.90	404.00	5.09	1.75	2.39	0.01	1.13^{a}	0.01	0.01
BM	5.70	153.70	371.20	5.50	2.21	2.60	0.01	1.20^{a}	0.01	0.01
LM	5.87	156.40	379.70	5.33	2.06	2.40	0.01	1.10^{a}	0.01	0.01
CBLM	5.62	157.30	411.20	5.28	1.93	2.39	0.01	1.07^{a}	0.01	0.01
IF	6.05	155.20	419.50	4.63	1.89	2.53	0.01	0.97^{a}	Bdl	Bdl
CT	5.24	147.20	400.00	5.28	1.78	2.44	0.01	0.43^{b}	Bdl	Bdl
Wet season										
CM	6.46	162.93	428.10	4.43	2.48	2.81	0.01	1.39^{a}	0.01	0.01
BM	6.70	167.05	419.30	4.77	2.31	2.77	0.01	1.48^{a}	0.01	0.01
LM	6.50	168.13	431.10	4.79	2.29	2.75	0.01	1.30^{a}	0.01	0.01
CBLM	6.13	162.90	438.90	4.52	2.36	2.52	0.01	1.64^{a}	0.01	0.01
IF	6.15	163.80	425.30	4.10	2.37	2.55	0.01	0.96^{a}	Bdl	Bdl
CT	6.20	159.08	410.30	4.34	2.43	2.60	0.01	0.47^{b}	Bdl	Bdl
Interaction										
CM × BM × LM × CBLM × IF × CT	ns	ns	ns	ns	ns	ns	ns	*	ns	ns

Mean with the same superscript within the same column do not differ significantly at $p < 0.05$ by new Duncan multiple range test. CM, Cockerel manure; BM, broiler manure; LM, layers manure; CBLM, cockerel + broiler + layers manure; IF, inorganic fertilizer; CT, control; ns, no significant interaction.

fertilizer were applied, though with no significant ($p > 0.05$) difference, except for Cu. The minerals in the maize grains ranged from 5.24 to 6.70 mg kg^{-1} for Ca, 147.20 to 168.13 mg kg^{-1} for Mg and 371.20 to 438.90 mg kg^{-1} for K.

Table 4. Influence of soil amendments on the proximate composition (g 100 g^{-1}) of a drought-tolerant maize.

Treatment	CPT	CFB	CFT	TAH	CHO	TSG	RSG	VitC
Dry season								
CM	10.33	1.50	1.60	2.75	73.82	5.63	3.63	1.22
BM	10.49	1.53	1.59	2.66	74.30	5.10	2.98	1.24
LM	10.16	1.52	1.61	2.71	74.00	4.86	3.46	1.24
CBLM	9.90	1.40	1.45	2.69	75.04	5.37	3.40	1.24
IF	9.93	1.49	1.60	3.07	73.35	5.72	3.53	1.33
CT	9.90	1.31	1.36	2.55	74.88	5.32	3.95	1.23
Wet season								
CM	11.20	1.52	1.64	2.90	72.08	6.32	4.70	1.30
BM	10.90	1.55	1.60	2.90	73.18	5.80	4.01	1.28
LM	10.47	1.54	1.65	2.87	73.47	5.72	4.01	1.49
CBLM	10.71	1.49	1.51	2.87	73.43	6.32	3.99	1.32
IF	10.90	1.54	1.65	3.28	72.46	6.60	4.21	1.36
CT	10.15	1.35	1.47	2.21	73.56	6.06	4.38	1.33
Interaction								
CM × BM × LM × CBLM	ns	ns	ns	ns	ns	ns	ns	ns
IF × CT	-	-	-	-	-	-	-	-

Mean within the same column do not differ significantly at $p < 0.05$ by new Duncan multiple range test. CM: Cockerel manure; BM, broiler manure; LM, layers manure; CBLM, cockerel + broiler + layers manure; IF, inorganic fertilizer; CT, control; CPT, crude protein; CFB, crude fibre; CFT, crude fat; TAH, total ash; CHO, carbohydrate; TSG, total sugar; RSG, reducing sugar; VitC, vitamin C; ns, no significant interaction.

Proximate composition of a drought-tolerant maize variety

The effects of different poultry manure and inorganic fertilizer as soil amendments on the proximate composition of drought-tolerant maize are presented in Table 4. Except for the carbohydrate, other proximate compositions (crude protein, crude fiber, crude fat, total ash, reducing sugar, vitamin C) of the harvested maize grains when no soil amendment was applied were the least and with no significant ($p > 0.05$) difference among the treatments. The carbohydrate content ranged from 73.35 to 75.04 g 100 g^{-1}, in the dry season and from 72.46 to 73.56 g 100 g^{-1}, in the wet season. Zero manure/fertilizer application had least values of 9.90 g 100 g^{-1} crude protein, 1.31 g 100 g^{-1} crude fiber, 1.36 g 100 g^{-1} crude fat and 2.55 g 100 g^{-1} total ash.

DISCUSSION

Sobulo and Osiname (1987) earlier recommended 17.40 g kg^{-1} organic carbon, 1.50 g kg^{-1} total nitrogen, 8 to 10 g kg^{-1} available phosphorus and 0.20 cmol kg^{-1} exchangeable K as nutrient critical level for maize production in Southwestern Nigeria. Therefore, for the soil organic carbon (9.81 g kg^{-1}) and total nitrogen (0.70 g kg^{-1}) obtained; each value was approximately half of the recommendation, hence were considered very low while the available phosphorus (9.44 g kg^{-1}) obtained was adequate for maize production within the same agro-ecological western zone of Nigeria. In this study, composted broiler manure gave the highest N, P and K concentrations of 34.3, 18.3 and 13.9 g kg^{-1}, respectively while composted cockerel manure had the least values. A previous study by Farhad et al. (2009) gave the N, P and K concentrations in poultry manure as 20.4, 20.6 and 18.6 g kg^{-1}, respectively. The birds are raised for different purposes; hence, quality of their feeds varied. Broilers were primarily raised for meats; fast-growing formulated feeds rich in protein formed bulk of their food. The chemical compositions of poultry manures therefore depended very much on the quality and quantity of the feeds the birds ate. This fact agreed with the observation of Oyedeji et al. (2014) that the protein constituent in the poultry feeds had a direct relationship with manure nitrogen.

Studies by Hirzel et al. (2007), Farhad et al. (2009) and Ayeni and Adetunji (2010) had similar results when poultry manure was added to soil as amendment and maize was the test crop; although poultry manures from different birds were not considered by these authors. There was slight increase in soil acidity of the post-cropped soil which must have been brought about by the addition of composted poultry manures and inorganic fertilizer when compared with the pre-cropped soil pH value (6.85). Comparable results of increase in soil acidity as a result of addition of poultry manure were obtained by Gupta and Charles (1999). The treatments, though with single application, had positive influence in the post-cropped soil values of N, P and K. In a similar study by Boateng et al. (2006), enhanced soil physical properties and increased values of these macro-nutrients (N, P and K) were obtained. The values obtained after the second (wet season) harvest of maize were relatively lower than the first (dry season) and with no significant ($p > 0.05$) difference, except for soil organic carbon and cation exchangeable capacity. The treatments residual effect and maize biomass from the first cropping which was incorporated into the soil during land preparation for the second cropping could be attributable to these relatively comparable values. The residual effect of added organic materials and incorporation of crop residues into soil have been well documented in many studies (Nottidge et al., 2005; Ayeni et al., 2009).

Lower values of these minerals were obtained by Hirzel et al. (2007), while Mg and K values obtained by Iken et al. (2002) were higher. This disparity in the results could be attributed to differences in the treatments considered and maize varietal differences. Also, the trace element concentrations in the maize grains were in the order: Mn > Fe > Zn > Cu with greater values in the wet than dry seasons. The influence of composted poultry manures treatments on the concentration of Co, As or Pb in the maize grains did not exceed 0.01 mg kg^{-1} and their concentrations were below detection levels for IF and control treatments. The available compound forms of Co, As and Pb that could enhance their mobility from either the soil or added treatments might be presumably not very mobile. The ability to form insoluble carbonate by Pb and arsenate by As in the soil medium would reduce their mobility (Khan et al., 1982). Generally, relatively higher values of these minerals and trace elements were obtained in the wet than dry seasons. Generally, wet season favored enhanced proximate compositions of maize grains, except for carbohydrate that increased marginally across all the treatments in the dry season. Wet season values of other properties (crude protein, crude fiber, crude fat, sugar and vitamin C) were also marginally higher.

Availability of moisture in the form of rain water during the wet season favored soil nutrients mobility and nutrient uptake by the maize plants. Enhanced nutrients uptake by crops has direct relationship with the crop quality (Warren et al., 2006).

Conclusion

Composted poultry manures, particularly broilers manure had positive and superior influence on soil organic carbon and cation exchangeable capacity when compared with inorganic NPK fertilizer, composted cockerel or layers manures. The proximate composition of maize was enhanced by poultry manures as soil amendments than with chemical or zero manure/fertilizer application. It could be concluded that composted broiler manure had superior effect on nutrient uptake of maize, and particularly in the wet season.

Conflict of Interests

The authors declared that there was no conflict of interests in respect of this paper.

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