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Changes in Soil Properties Following Application of Composted Sludge on an Isohyperthermic Kandiudult*

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Abstract: Growing sewage sludge production in urban and peri-urban areas in Nigeria without hygienic disposal necessitated this study. Three experiments were conducted in 2004-2006 cropping seasons at the Teaching and Research farm of the Federal University of Technology Owerri, Southeastern Nigeria for the purpose of investigating the effects of composted sludge on soils of the area and yield of Amaranth (*Amaranthus cruentus* L.). Rates of compost application were 0, 2, 4, 6 and 8 t ha^{-1} and with 3 replications in a Randomized Complete Block Design RBBD. Results indicated significant ($p<0.05$) increases in crop performance and reduced cadmium and mercury concentrations in composted sludge when compared with the un-composted sludge. Soil properties were highly improved as residual effects of composted sludge.

Key words: Amaranth, amendment, composting heavy metals, sewage sludge, tropical soils

INTRODUCTION

In many developing countries including Nigeria, several registered industrial plants are known to produce wastewater, which contain heavy metals, organics and corrosive metal wastes. A good quantity of the wastewater may not be treated before disposal and may not be safely discarded as some end in agricultural lands. Some scholars (Cameron *et al*., 1995; Summer and Mclaughlan, 1996; Mbagwu *et al*., 2001) reported detrimental effects and risks associated with agricultural land disposal of sewage sludge to include increased concentration of dissolved P in runoff water, building-up of heavy metals in soils, nitrate leaching to groundwater, salt concentration and extremes of soil pH. Composting of activated sludge is considered as a technique of decreasing risks of heavy metals contamination on agricultural lands (Planquart *et al*., 1999). During the composting process, most of the oxygen demand of the sludge is met and the organic materials contained in the sludge are converted to more stable products, such as humic acids while carbon (iv) oxide, ammonia and water vapour are evolved (Inbarr *et al*., 1993). Composting is an accelerated process of breakdown as gathering sludges conserves part of the heat of fermentation which raises the temperature of sludge mass as well as rate of chemical reaction (Biddlestone and Gray, 1985). Applying municipal wastewater biosolids to agricultural land is an effective way of recycling soil nutrients to benefit crop production (Cogger *et al*., 2004).

Sewage sludge is rich source of plant nutrients and organic matter (Martinez *et al*., 2003) and these improve the physicochemical properties of soils (Mckay and Moffat, 2001). The uncertainties as to

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the nature of many of the organic chemical found in the sludge as well as the cumulative nature of the metals problem, dictate continued caution in the regulations governing applications of sludge to croplands (Brady and Weil, 1999). But in composting sewage sludge, soil pathogens are eliminated (Inbar *et al*., 1993) and soil properties are improved including reduced leaching of basic cations (Garcia *et al*., 1991).

Activated sludge-derived compost increases macro-and micro-nutrients status of soil (Caravaca *et al*., 2002). It has high potential for supplying nitrogen to the soil (Cogger *et al*., 2004) but with little residual effects (Cogger *et al*., 1999). In addition to nitrogen, phosphorus, potassium, iron, zinc and humic substances contained in activated sludge derived compost, it improve soil physical properties (Wong *et al*., 1995). In this study, Amaranth (*Amaranthus cruentus* L.) was used a test crop. Amaranth belongs to the Amaranthaceae and is widely used as a vegetable. The leaves are used in preparing soup and yam porridges. It is used to garnish popular foods. It is commonly grown near homesteads and flat beds. It has high degree of survivability through its numerous seeds and characteristic high germination percentage. It fits into dry season agriculture with irrigation. Based on the above, it is hypothesized that compost manure derived from activated sludge influences soil properties and macronutrients. This study was aimed to investigate the effects of compost manure obtained from activated sludge on properties of sandy soils of Owerri in Southeastern Nigeria.

MATERIALS AND METHODS

Study Areas

The study was conducted at the experimental farm of the Federal University of Technology Owerri in 2004-2006 cropping seasons. The site is located on latitude 5°27^{1}50^{11}. 230 N and longitude 7° 02^1 49^{11}. 330 E, with an elevation of 55 m above mean sea level (Handheld Global Positioning System-GPS) receiver (Garmin Ltd., Kansas, USA). The predominant parent material underlying the study area from which soils are derived is coastal plain sands (Benin Formation) of the Oligocene-Miocene geological era. Earlier soils were classified as Isohyperthermic Arenic Kandiudult (Onweremadu *et al*., 2006) using Soil Survey Staff (2003). The study area is predominated by rainforest vegetation with 27-29°C mean annual temperature. Farming is mainly practised at subsistence level with traditional slash-and burn-system. Soil fertility is regenerated by bush fallowing. Cassava-based mixed cropping system is common.

Field Studies

Composting

Activated sludge was collected from a wastewater plant in Owerri municipality, southeastern Nigeria. Farmers grow vegetables on soils of the sludge disposal sites and this promotes dry season farming. Preservation of the sludge was conducted before the commencement of the experiment. Compost was produced from the above sludge with green wastes (½) by volume and municipal sewage sludge (½) by volume using the aerated pile method according to the procedure of Wilson *et al*. (1980). The produced compost as well as the sludge were characterized for organic matter, total nitrogen, total organic carbon, copper, cadmium and mercury content.

Experiment

Three field experiments were conducted in 2004-2006 cropping seasons to compare the effects of 2, 4, 6 and 8 t ha^{-1} of composted activated sludge on Amaranth (*Amaranthus cruentus* L.). In all, 5 rates of activated sludge compost, namely O t ha^{-1} (control), 2, 4, 6 and t ha^{-1} replicated 3 times in a randomized complete block design (RCBD) were used in each cropping season's experiment. Seeds of Amaranth were sown in the greenhouse and nursed in trays containing sandy loam soil. At the end of 2 weeks, seedlings were transplanted at a spacing of 20×15 cm to each of the 15 plots. The plot area was 4 m^2. After 7 days after transplanting, ring method of sludge compost application was done. The same plots were used for the 3 years: 2004-2006 experiments. Performance parameters, namely plant height, root length, root weight and number of leaves were measured weekly for 4 weeks after application of activated sludge compost. Roller tape was used in measuring plant height and root length while Salter weighting balance was used in measuring root weight. Number of leaves per plant was counted. Fresh and dry matter yields were determined at harvest and in all determinations, 5 plants were taken per plot.

A profile pit was dug, described and sampling (FAO, 1998) for the purposes of characterization and classification.

Soil and Plant sampling

Three auger soil samples were collected from each treated soil and bulked to produce 5 composite soil samples, representing soils treated with 4 rates of activated sludge compost plus the control soil sample. These soil surface samples were air-dried and sieved using 2 mm sieve and bagged in black polyethylene bags before laboratory determinations. Leaf samples were harvested at 4 and 8 WAP stages. These leaves were oven-dried, crushed and sieved using 2 mm sieve in readiness for laboratory analysis.

Laboratory Analyses

Particle size distribution was determined by hydrometer method as described by Gee and Or (2002) while bulk density was estimated by core method (Grossman and Reinsch, 2002). Soil pH was determined electrometrically in a soil/liquid ratio of 1: 2.5 according to Hendershot *et al.* (1993). Cation exchange capacity was estimated according to the procedure of Anderson and Ingram (1998a). Soil organic carbon was determined by acid dichromate digestion (Anderson and Ingram, 1998b.) Total nitrogen in sludge and compost materials were measured by micro-Kjeldahl method (Bremner, 1996). Ground leaf samples from Amaranth were digested with nitric-per chloric-sulphuric acid mixture and the resulting aliquot was used to estimate phosphorus, calcium, magnesium and potassium contents (AOAC, 1990). Mercury (Hg) was determined by atomic absorption analysis (NF EN 1483) while copper (Cu) and cadmium (Cd) were analysed by emission spectrometry-ICP (NF EN ISO 11885).

Statistical Analysis

Data were analyzed statistically using analysis of variance (ANOVA). Thereafter, means were separated by least significant difference (LSD) at 5% level of probability.

RESULTS AND DISCUSSION

The experiments were conducted on sandy, acidic soils with low values of cation exchange capacity, silt-clay ratio and soil organic carbon (Table 1). Soils of the study site are highly weathered as shown by low silt-clay ratios as well as highly degraded indicated by low values of CEC and OC. Sandiness and acidity of soils could be attributed to the nature of parent materials (Coastal Plain Sands) climate and land use history. Bulk density was high before compost application (Table 1) but reduced numerically (Table 6) possibly due to increased OC. Results on characterization of activated sludge and its composted form are shown in Table 2, indicating that values of total organic carbon, total nitrogen, cadmium, copper and mercury were higher in activated sludge than in the resultant compost. However, carbon-nitrogen ratio increased to 12.7 in compost form when compared with non-composted form of the sludge. The total OC in the sludge material (341.0 g kg^{-1}) decreased to 206.0 g kg^{-1} in the compost, suggesting that during composting, micro organisms used these carbon

Table 1: Soil properties of studied site

Horizon	Depth (cm)	Sand (g kg^{-1})	Silt (g kg^{-1})	Clay (g kg^{-1})	SCR	pH (KCl)	CEC (cmo kg^{-1})	OC (g kg^{-1})	BD (mg m^{-3})
A	0-11	870	20	110	0.18	4.2	4.4	11	1.40
E	11-23	880	10	110	0.90	4.0	2.8	4	1.41
EB	23-76	850	20	130	0.15	4.1	3.2	3	1.45
Bt_1	76-119	880	10	110	0.09	4.5	3.6	2	1.47
Bt_2	119-185	900	10	90	0.11	4.3	2.6	1	1.50

SCR = Silt Clay Ratio, CEC = Cation Exchange Capacity, OC = Organic Carbon, BD = Bulk Density

Table 2: Properties of sludge and derived compost (dry basis)

Properties		Sludge	Compost
Total organic carbon	(g kg^{-1})	341.0	206.00
Organic matter	(g kg^{-1})	587.8	355.10
Total nitrogen	(g kg^{-1})	39.1	16.20
CNR		8.7	12.70
Cadmium	(mg kg^{-1})	3.9	0.50
Copper	(mg kg^{-1})	136.2	20.80
Mercury	(mg kg^{-1})	0.1	0.02

CNR = Carbon Nitrogen ratio

compounds as sources of energy and in building their own structures. It is also possible that soil microbes used part of the initial soil carbon in the synthesis of other related substances (Charest *et al*., 2003) Yet, these transformations result in the loss of soil bioavailable soil carbon in form of CO_2 and water. Total nitrogen decreased to 16.2 g kg^{-1} in compost from 39.1 g kg^{-1} initially contained in activated sludge. This can be attributed to the action of proteolytic bacteria and high temperatures (Bertran *et al*., 2004) characteristic of the humid tropics. But some manures act as net suppliers of nitrogen while others may result in net immobilization of nitrogen (Calderon *et al*., 2004) and this may be related to carbon-nitrogen ratio of manure materials used. Sorensen (1998) reported net N-Immobilization in manure sources rich in very free fatty acids (VFA).

Beauchamp and Paul (1989) suggested that manures with carbon-nitrogen ratios below 15 are likely to result in positive N mineralization after application to soil. In this study, the carbon nitrogen ratio of the compost was 12.7, indicating positive impact on the soil on application.

Decreased content of cadmium and mercury in the compost suggests reduced bio accessibility of these heavy metals to human through the food chain. This advantage is further enhanced at post harvest use of soils with increased pH since low pH promotes heavy metals solubility and mobility (He *et al*., 2004). By this, sludge compost can be used in the remediation of soils polluted with cadmium and mercury for bio-safety and general environmental health.

Soil-Crop Relationship

Sludge compost significantly ($p\leq 0.05$) influenced plant height, root weight and number of leaves in 2004-2006 cropping seasons possibly due to high nutrient status of composted sludge while there was significant difference in root length of Amaranth only during the third experiment in 2006 (Table 3). Application of sludge compost had a significant ($p\leq 0.05$) influence on the increases in leaf content of nitrogen, phosphorus, potassium, calcium and magnesium (Table 4). This is consistent with the findings of Mbagwu *et al.* (2001), implying that sludge has high fertility potentials. There were significant ($p\leq 0.05$) differences in both fresh and dry matter yield of Amaranth in the three years of field experimentation. This suggests that the essential nutrients contained in the composted sludge were available for use by Amaranth for its growth and yield performances. Highest fresh and dry matter yields were recorded at rates of 6 and 8 t ha^{-1} in 2004, 4 and 8 t ha^{-1} in 2005 and 6 and 8 t ha^{-1} in 2006 cropping season at both growth and maturity stages of *Amaranthus cruentus* L. (Table 5). The percentage differences between performance parameters at different treatments are shown in Table 6. Net losses in growth and yield parameters were observed in all the

Table 3: Temporal variability in Amaranth performance indices as affected by sludge-compost (Plot data)

Rate (t ha^{-1})	Plant height (cm)	Root length (cm)	Root weight (g)	No. of leaves
2004				
0	16.9	13.6	6.0	26.4
2	36.9	14.8	17.9	80.8
4	40.5	16.8	22.5	85.7
6	48.6	15.3	24.9	95.2
8	52.0	17.3	39.8	113.1
$LSD_{(0.05)}$	21.0	NS	8.6	49.8
2005				
0	12.3	2.2	5.5	23.6
2	38.1	16.6	18.6	81.2
4	42.6	18.4	22.7	84.9
6	53.3	21.3	23.2	96.1
8	59.3	22.1	37.6	115.1
$LSD_{(0.05)}$	23.4	NS	2.3	50.3
2006				
0	11.2	11.2	5.1	19.2
2	39.9	17.8	19.2	83.1
4	44.6	19.2	25.3	84.9
6	56.1	21.8	38.9	91.6
8	61.6	23.1	40.2	111.8
$LSD_{(0.05)}$	22.8	4.2	3.4	42.6

LSD = Least Significant Difference, NS = Not Significant

Table 4: Changes in nutrients contents of Amaranth leaves

Rate (t ha^{-1})	N (g kg^{-1})	P (g kg^{-1})	K (g kg^{-1})	Ca (g kg^{-1})	Mg (g kg^{-1})
2004					
0	30	2.0	10	2.0	0.1
2	46	5.0	30	2.5	0.7
4	47	5.0	32	3.1	1.0
6	48	6.0	31	3.0	1.1
8	40	7.0	25	3.0	1.2
$LSD_{(0.05)}$	9	0.9	4	2.7	0.1
2005					
0	18	1.0	11	0.3	0.1
2	47	4.0	38	1.0	0.4
4	47	3.0	40	3.6	1.0
6	49	4.0	41	4.4	1.2
8	48	5.0	30	4.5	1.4
$LSD_{(0.05)}$	10	1.0	8	4.0	0.1
2006					
0	15	1.0	9	2.0	0.1
2	46	4.0	20	2.8	0.6
4	46	5.0	30	3.0	1.0
6	50	6.0	35	3.8	1.1
8	44	5.0	25	0.4	0.4
$LSD_{(0.05)}$	8	1.0	6	0.4	0.2

LSD = Least Significant Difference

years at 0 t ha^{-1} and losses increased with time. However, there was variability in net losses among parameters with plant height, fresh and dry matter yields being more responsive to the treatments. With increasing rates of the treatment, performance parameters improved but declined at 8 t ha^{-1}, showing that 6 t ha^{-1} is the optimal rate of composted sludge. Uptake of Cd and Hg by Amaranth is presented in Table 7. Cadmuim uptake by the test crop via the leaves and roots was significant ($p<0.05$) temporally while there was non significant uptake of Hg by the same crop. Mainville *et al.* (2006) attributed this non-significance to the fixing and retaining of Hg by high organic matter content, which composted sludge provided in the studied soils.

Soil pH, cation exchange capacity and organic carbon increased significantly ($p\leq 0.05$) at 2, 4, 6 and 8 t ha^{-1} while there were decreases in these soil properties (Table 8) when compared with preplanning soil properties (Table 1). Bulk density was not significantly influenced by the application

Table 5: Changes in leaf yield

Rates (t ha^{-1})	Fresh matter yield (t ha^{-1}) 4 WAP	Fresh matter yield (t ha^{-1}) 8 WAP	Dry matter yield (t ha^{-1}) 4 WAP	Dry matter yield (t ha^{-1}) 8 WAP
2004				
0	6.2	9.8	1.9	2.6
2	17.9	28.1	8.3	17.1
4	36.8	54.8	8.6	14.1
6	42.3	56.2	8.8	14.3
8	46.4	60.3	8.6	15.6
$LSD_{(0.05)}$	8.2	10.6	2.2	2.9
2005				
0	5.9	7.0	1.6	2.1
2	18.6	27.6	8.4	6.7
4	38.1	55.2	8.7	14.4
6	44.3	53.8	8.9	13.7
8	49.6	58.9	9.3	14.8
$LSD_{(0.05)}$	8.6	12.6	1.2	5.4
2006				
0	4.3	3.9	1.1	0.9
2	16.8	26.7	6.3	6.3
4	38.6	56.8	7.9	14.5
6	45.1	59.2	7.8	15.4
8	50.3	64.1	8.1	15.8
$LSD_{(0.05)}$	8.8	11.8	0.6	3.7

WAP = Weeks After Planting

Table 6: Percentage performance differences among treatments (3 years)

Parameters	Treatments (t ha^{-1}) 0	2	4	6	8
2004					
Plant height	-15	+7	+15	15	+14
Root length	-6	+9	+13	+14	+14
Root weight	-9	+6	+14	+17	+18
Number of leaves	-2	+3	+7	+7	+8
Fresh matter yield	-12	+10	+12	+19	+20
Dry matter yield	-10	+9	+11	+16	+18
2005					
Plant height	-35	+12	+18	+16	+15
Root length	- 17	+10	+14	+16	+14
Root weight	- 19	+11	+15	+20	+19
Number of leaves	- 13	+6	+9	+8	+9
Fresh matter yield	-18	+18	+14	+20	+21
Dry matter yield	-15	+17	+14	+18	+18
2006					
Plant height	-53	+19	+19	+17	+15
Root length	- 21	+15	+15	+16	+14
Root weight	- 21	+12	+16	+20	+20
Number of leaves	- 14	+18	+10	+9	+9
Fresh matter yield	-29	+25	+15	+20	+22
Dry matter yield	-23	+23	+16	+17	+17

of sludge compost. However, pH increased while BD decreased as in Table 8. The increase in soil pH with increasing rates of compost application could be due to released basic cations contained in the compost while reduced BD is attributable to increased macroaggregation of soils by organic matter in composted sludge.

Improved performance of Amaranth following the application of different rates of sludge compost implied that fertility potentials of this organic fertilizer positively influenced this vegetable crop. Directly, the bio fertilizer possibly supplied calcium and phosphorus (Lisk *et al*., 1992) which is marginally available in humid tropical soils due to fixation by sesquioxides.

Table 7: Uptake of Cd and Hg

Cd ($mg\ kg^{-1}$)				Hg ($mg\ kg^{-1}$)			
Rate ($t\ ha^{-1}$)	Leaves	Stems	Roots	Rate ($t\ ha^{-1}$)	Laves	Stems	Roots
2004							
0	0.01	0.00	0.02	0	0.00	0.00	0.00
2	0.07	0.01	0.05	2	0.00	0.01	0.01
4	0.11	0.03	0.06	4	0.01	0.00	0.01
6	0.16	0.02	0.16	6	0.01	0.01	0.00
8	0.25	0.03	0.19	8	0.01	0.01	0.00
LSD	0.09	NS	0.02	LSD	NS	NS	NS
2005							
0	0.03	0.00	0.02	0	0.00	0.00	0.00
2	0.09	0.00	0.03	2	0.00	0.01	0.01
4	0.16	0.02	0.09	4	0.01	0.00	0.01
6	0.25	0.03	0.15	6	0.01	0.01	0.01
8	0.22	0.02	0.25	8	0.01	0.01	0.00
LSD	0.05	NS	0.03	LSD	NS	NS	NS
2006							
0	0.01	0.00	0.02	0	0.00	0.00	0.04
2	0.11	0.00	0.11	2	0.00	0.00	0.01
4	0.17	0.01	0.11	4	0.01	0.00	0.01
6	0.26	0.03	0.23	6	0.01	0.01	0.03
8	0.26	0.02	0.27	8	0.01	0.01	0.06
LSD	0.06	NS	0.08	LSD	NS	NS	NS

LSD = Least Significant Differences; NS = Not Significant

Table 8: Residual effects of activated sludge compost on selected soil properties (surface soils)

Rates ($t\ ha^{-1}$)	pH (KCl)	CEC ($cmol\ kg^{-1}$)	OC ($g\ kg^{-1}$)	TN ($g\ kg^{-1}$)	CNR	BD ($mg\ m^{-3}$)
0	3.5	2.6	3.2	0.1	32.0	1.38
2	4.6	4.7	11.6	0.8	10.7	1.36
4	5.3	5.8	12.6	0.9	12.8	1.35
6	5.8	7.9	13.4	1.1	12.2	1.33
8	6.3	8.6	13.4	1.2	11.4	1.31
$LSD_{(0.05)}$	0.9	1.2	2.3	0.1	3.6	NS

CEC = Cation Exchange Capacity, OC = Organic Carbon, TN = Total Nitrogen, CNR = Carbon Nitrogen Ratio, BD = Bulk Density, LSA = Least Significant Difference

With the exception of bulk density, there were significant ($p< 0.05$) and positive residual effects of sludge compost on soil properties. There were elevated values of soil pH at all rates of sludge compost treatment and this portends greater availability of essential plant nutrients such as phosphorus, nitrogen and calcium. On the other hand these raised pH values may reduce Cd and Hg concentrations in soils as they are more soluble and mobile at extreme soil acidity.

CONCLUSION

The study revealed that composted form of activated sludge has profound implication on agronomy and general environmental health. Growth and yield of Amaranth were promoted while soil properties were improved. Finally, high quality of Amaranth was produced since less Cd and Hg were found in the composted sludge used in its production.

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