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EFFECTS OF SEWAGE SLUDGE APPLICATION ON SELECTED SOIL PROPERTIES AND YIELD OF MAIZE AND BAMBARA GROUNDNUT

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ABSTRACT

Several studies in the temperate region have indicated that sewage wastes have the potential to improve soil properties but may also cause drastic reductions in soil productivity. We studied the effects of long-term application of dehydrated sewage wastes on soil properties and yield of maize (Zea mays L.) and bambara groundnut (Vigna subterranea) on a sandy Ultisol (Arenic Kandiustult) at Nsukka, Nigeria. The sewage sludge was applied at the rate of about 36 t/year for 40 years before this study was carried out. We sited two profile pits on the site that received the sewage (S/NSK/1 and S/NSK/2) and one pit on the site that did not (NS/NSK) and described them before collecting soil samples from the genetic horizons of each pit for analysis of soil properties. Soil organic carbon (OC), microbial respiration, electrical conductivity (EC), sodium adsorption ratio (SAR) exchangeable sodium percentage (ESP), total N, exchangeable Na and Ca, cation exchange capacity (CEC) and maize performance were significantly ($P < 0.05$) enhanced in the sewage treated soil compared to the non-sewage treated soil. The growth of salt-sensitive bambara groundnut was very poor on the former until the sludge was leached of excess salts with distilled water, after which its yield was identical with that from the control soil. Maize height and dry matter yield after 6 weeks were significantly improved ($P = 0.05$) on the sewage treated soil than the control. These results indicate that the application of sewage sludge on agricultural soils should be done with caution because of its negative effects on soils and crops when used at high rates.

Key words: Sewage sludge disposal; exchangeable bases; electrical conductivity; microbial respiration; salinity levels; sodium adsorption ratio.

INTRODUCTION

Application of sewage sludge on agricultural lands has been practised for decades. According to Johns and McConchie (1994) when disposal rates are not excessive, sewage sludge is beneficial to agricultural soils. However, when they are applied at excessive amounts and the soil is coarse-textured with low concentration of Fe and Al hydroxoxides, extensive leaching of minerals can occur. Some authors agree that short-term land application of sludge wastes improves soil physical conditions (Mbagwu et al., 1991; Mbagwu and Piccolo, 1990; Giusquiani et al., 1995). Angers and N'Dayegamiye (1991) observed that soil organic carbon (OC) content of a sandy loam soil increased from 1.5 to 2.5% after 7 years of applying sewage sludge at the rate of 5 t/ha/yr.

A few studies (Sumner and McLaughlan, 1996; Cameron et al., 1996) reported detrimental effects and/or risks associated with the agricultural land disposal of sewage sludge. Such risks include increased concentration of dissolved P in runoff water, soil build-up of heavy metals, nitrate leaching to ground water, salt concentration and either elevated or extremely low pH. There is however, no quantitative information on changes in these properties with long-term sewage sludge disposal on tropical soils.

With increasing amounts of urban and industrial sewage wastes being disposed of on agricultural lands in the tropics, there is a need to understand their implications for plant nutrition and productivity and for soil quality. The objectives of this study were to characterize the soil chemical and biological properties in response to sewage sludge application for about 40 years, and to assess the beneficial and adverse effects of this sewage sludge application on yield of maize and bambara groundnut. This study will provide valuable input data for managing a land disposal system for sewage sludge in the tropics.

Table 1: Some characteristics of the top 0-30 cm soil used in the green house study

Soil property[1]	Sewage soil		Non-sewage soil
	First planting[2]	Second planting[3]	
Sand (%)	80	83	86
Silt (%)	4	3	4
Clay (%)	16	14	10
Textural class	SL	SL	SL
pH (H_2O)	3.9	4.0	4.0
OM (%)	5.21	5.12	1.98
Total N (%)	0.225	0.216	0.091
Exch.Na (Cmol/kg)	0.18	0.13	0.12
Exch. K (Cmol/kg)	0.16	0.15	0.11
Exch. Ca (Cmol/kg)	2.40	2.40	1.80
Exch. Mg (Cmol/kg)	1.65	1.60	0.90
CEC (Cmol/kg)	8.20	7.50	6.10
Exch. (Al+H) (Cmol/kg)	2.95	3.00	3.30
Aval P. (mg/kg)	15.4	13.4	11.8
Base sat. (%)	54	57	47
SAR	0.13	0.11	0.10
ESP	2.20	2.00	1.97
EC (mmhos/cm)	2.10	0.89	0.08
Salt conc. (mg/l)	1344	570	51.2

1. SAR = sodium adsorption ratio; ESP = exchangeable sodium percentage; EC = electrical conductivity of the soil extract.
2. Without leaching the soil.
3. After leaching the soil with distilled water.

MATERIALS AND METHODS

This study was carried out at the University of Nigeria, Nsukka (Latitude 06^{0} 52'N and Longitude 07^{0} 24'E) sewage disposal site. Application of sewage sludge at the site had been on for about 40 years. The soil according to Nwadialo (1989) is an *Arenic Kandiustult* (USDA, 1984). Two profile pits sited on the sewage disposal area (S/NSK/1 and S/NSK/2) and one sited on the non-sewage area (NS/NSK) were used for this study. Duplicate soil samples were collected in each horizon for chemical characterization. Some characteristics of the soil are shown in Table 1.

The sewage disposal sites were located at the lowest point in the University whereas the non-disposal site was about 100 m away from the sewage disposal site towards the northeast. It is estimated from the dry mass of sewage sludge added annually by the farmers for improved crop production that the application rate is about 36 t/year, which gives a total of 1440 t for the 40 years before the study was carried out.

FIELD/GREEN HOUSE INVESTIGATION

Differences in soil chemical and biological properties were assessed by comparing values obtained from these sites. Implications for crop production were evaluated in the green house by the performances of maize (*Zea mays* L.) and bambara groundnut (*Vigna subterranea*) on these soils.

In the green house study, bulked soil samples were collected from the 0-30 cm depths in the study areas, maintained at field capacity (20% gravimetric water content) and planted with maize and bambara groundnut in a Completely Randomized Design (CRD) with each treatment replicated 9 times. When the bambara groundnut in the sewage treated soil died within the first two weeks after emergence due to phytotoxic conditions, other soil samples, collected from the sewage site, were leached of the excess salts for 2 weeks with distilled water before replanting the bambara groundnut. The maize height and dry matter yield were recorded at 6 weeks whereas the bambara groundnut pods were harvested at maturity.

Laboratory Determinations

The soil pH was measured in 1:2.5 soil/water suspension ratio (McLean, 1982). Total OM was determined by the Walkley and Black wet dichromate oxidation method (Nelson and Sommers, 1982). Total N was obtained by the macro Kjedahl digestion procedure (Bremner, 1965) and available P by the Bray II method (Bray and Kurtz, 1945). The phosphorus in the extract was measured with a

Table 2: The pH, organic matter, total N and available P of the soil after 40 consecutive years of sewage sludge application

Soil profile	Horizon	Depth (cm)	pH (H_2O)	OM (%)	Total N (%)	Avail P (mg/kg)
S/NSK/1	Ap	0-15	3.9	2.89	0.130	12.4
Sewage soil	AB	15-35	3.8	8.58	0.421	18.4
	Bt1	35-55	3.6	2.31	0.121	16.4
	Bt2	55-105	3.5	0.76	0.041	10.6
	Bt3	105-160	3.5	0.69	0.040	10.4
Mean			3.7	3.05	0.151	13.6
S/NSK/2	Ap	0-15	4.0	3.98	0.140	12.0
Sewage soil	AB	15-35	3.8	5.50	0.210	14.8
	Bt1	35-65	3.6	3.23	0.136	15.6
	Bt2	65-80	3.2	1.36	0.060	15.2
	Bt3	80-160	3.4	0.97	0.030	11.6
Mean			3.6	3.01	0.119	13.8
NS/NSK	Ap	0-14	4.9	2.06	0.096	12.0
Non-sewage soil	AB	14-35	4.5	1.72	0.086	11.6
	E	35-76	4.4	1.52	0.076	10.8
	Bt1	76-90	4.2	1.07	0.056	12.8
	Bt2	90-160	4.2	0.90	0.050	12.4
Mean			4.4	1.45	0.073	11.9

photo-electric colorimeter. Cation exchange capacity (CEC) was determined by the NH_4OAc displacement method (Jackson, 1958) and exchangeable acidity by the titrimetric method after extraction with 1.0 M KCl (McLean, 1982). Exchangeable Na and K were extracted using 1 M NH_4OAC solution and measured with flame photometer and Ca and Mg by atomic absorption spectrophotometer (AAS). Electrical conductivity and salt concentration were measured in 1:2.5 soil/aqueous extract at 25°C as described by Black et al. (1965). Salinity hazards were classified according to Bernstein (1964) groups using sodium adsorption ratio computed as,

$$SAR = Na^+/[0.5(Ca^{2+} + Mg^{2+})] \quad (1)$$

and exchangeable sodium percentage (ESP) as:

$$ESP = (Exch\ Na/CEC) \times 100 \quad (2)$$

Soil microbial respiration was measured by CO_2 evolution and obtained by back titration with 1.0 M HCl after precipitating the carbonates with 3 ml, 1.0 M $BaCl_2$ as described by Blom and Eddhausen (1955). Three hundred grams of the soil were wetted to field capacity, put in flasks and tightly covered after inserting 0.01 M NaOH solution. The evolved CO_2 was trapped in the NaOH solution and then titrated with 1.0 M HCl solution.

RESULTS AND DISCUSSION

ORGANIC MATTER, TOTAL N, AVAILABLE P AND PH

The soil pH (Table 2) was generally extremely low and ranged from 3.2 to 4.0 for the sewage treated soil and strongly to very strongly acid for the non-sewage treated soil (pH 4.2 to 4.9). The extremely acid nature of the former could be attributed to the dissociation of weakly bonded H^+ of the phenolic and amino groups present in sewage OM.

Organic matter content was very low to high in the sewage-treated soil and low to moderate in the control (Table 2). The higher level of OM obtained in the former in contrast to that of the control shows the beneficial effect of sewage sludge application on agricultural soils. Organic matter content in the Ap horizon increased from 2.06% in NS/NSK profile to 3.98% in the S/NSK/2 profile whereas it was up to 8.58% in the AB horizon of S/NSK/1 compared to 1.72% obtained in a similar horizon in the control soil (Table 2). This AB horizon of the sewage-treated soil profile formed a restricting layer for the mobility of OM, especially the dissolved component, which at the high application rates used here increased the OM content and confirms the report of Angers and N'Dayegamiye (1991) that soil OM content increased with sewage sludge application. Total N showed a similar trend to that of OM content (Table 2), being much higher in the treated than in the control soils. Such level of N makes land application of sewage sludge attractive, especially in low OM-soils.

Available P ranged from 10.4 to 18.4 mg/kg, with the highest value recorded in the AB horizon of the sewage soil profile apparently because of reasons given above for OM accumulation in this

Table 3: Exchangeable bases, exchangeable acidity and cation exchange capacity of the soil after 40 consecutive years of sewage sludge application.

Soil profile	Horizon	Depth (cm)	Exchangeable bases (Cmol/kg)				Exch. acidity	CEC
			Na	K	Ca	Mg	Cmol/kg	Cmol/kg
S/NSK/1	Ap	0-15	0.12	0.11	1.8	1.0	2.6	7.5
Sewage soil	AB	15-35	0.18	0.23	2.8	2.0	5.6	8.0
	Bt1	35-55	0.09	0.09	1.0	0.8	3.8	4.5
	Bt2	55-105	0.06	0.06	0.8	0.6	4.0	4.0
	Bt3	105-160	0.06	0.06	0.9	0.6	4.0	4.0
Mean			0.10	0.11	1.5	0.8	4.0	5.6
S/NSK/2	Ap	0-15	0.16	0.12	2.2	1.2	3.2	8.0
Sewage soil	AB	15-35	0.20	0.16	2.6	3.0	2.4	9.0
	Bt1	35-65	0.13	0.09	1.2	0.6	1.6	4.0
	Bt2	65-80	0.09	0.14	2.2	1.0	4.4	6.5
	Bt3	80-160	0.06	0.05	1.0	0.8	4.4	6.0
Mean			0.13	0.11	1.9	1.3	4.2	6.7
NS/NSK	Ap	0-14	0.10	0.09	1.8	0.8	3.6	6.0
Non-sewage soil	AB	14-35	0.12	0.12	1.6	0.8	3.0	6.0
	E	35-76	0.09	0.08	1.2	0.6	3.6	4.5
	Bt1	76-90	0.08	0.08	1.0	0.6	3.2	4.0
	Bt2	90-160	0.06	0.05	0.8	0.8	2.8	4.0
Mean			0.09	0.08	0.6	0.6	3.2	4.9

horizon. The trend in the profiles tends to suggest that there was little or no leaching of P down the profile, probably due to the formation of complex compounds with Fe as a result of the low pH values of the soil (Table 2). Johns and McCouchie (1994) reported the possibility of P fixation at low soil pH levels.

Table 4: Sodium adsorption ratio (SAR), exchangeable sodium percentage (ESP), electrical conductivity (EC) and salt concentration of the soil after 40 consecutive years of sewage sludge application.

Soil Profile	Horizon	Depth (cm)	SAR[1]	ESP[2]	EC[3] (mmhos/cm)
S/NSK/1	Ap	0-15	0.13	2.00	1.04
	AB	15-35	0.12	2.25	3.15
	Bt1	35-55	0.09	2.00	0.38
	Bt2	55-105	0.09	2.00	0.21
	Bt3	105-160	0.07	1.50	0.18
Mean			0.10	2.00	0.99
S/NSK/2	Ap	0-15	0.10	2.00	1.16
	AB	15-35	0.13	2.22	3.05
	Bt1	35-65	0.09	2.25	0.40
	Bt2	65-80	0.10	2.00	0.21
	Bt3	80-160	0.06	1.50	0.20
Mean			0.10	2.00	1.00
N/NSK	Ap	0-14	0.08	1.50	0.09
	AB	14-35	0.10	1.80	0.06
	E	35-76	0.08	1.76	0.03
	Bt1	76-90	0.07	1.50	0.02
	Bt2	90-160	0.06	1.50	0.02
Mean			0.08	1.62	0.04

1. Sodium adsorption ratio.
2. Exchangeable sodium percentage.
3. Electrical conductivity of the soil extract.

EXCHANGEABLE BASES, EXCHANGEABLE ACIDITY AND BASE SATURATION

Table 3 shows that exchangeable Na^+ ranged from 0.06 to 0.20, K^+ from 0.05 to 0.23, Ca^{2+} from 0.8 to 2.80 and Mg^{2+} from 0.60 to 3.00 Cmol(+)/kg for the sewage treated and untreated soils, respectively. The significant changes in CEC were lower than expected from literature reports (Johns and McCouchie, 1994). This was most likely due to the fact that at low pH the metals added to the soil via the sludge can be complexed, thus causing a decrease in the negative surface charge of the OM. Exchangeable Na^+ and Ca^{2+} showed significant ($p<0.05$) increases in the sewage sludge treated soil compared to the untreated soil (Table 3). Exchangeable acidity (Table 3) was high in the AB horizon of the treated soil profile (2.8 Cmol(+)/kg soil) compared to 0.40 Cmol(+)/kg soil in the similar horizon of the control soil.

Sodium Adsorption Ratio, Exchangeable Sodium Percentage, Electrical Conductivity and Salt Concentrations

The sodium adsorption ratio (SAR) values (Table 4) ranged from 0.06 to 0.13, with the highest (0.13) recorded for the sewage soil profile. This indicates that a high percentage of exchangeable Na^+ has been built up in this soil. The long-term application of this waste significantly increased the

Table 5: Statistical tests of difference for some soil characteristics in the sewage and non-sewage disposal areas.

Soil properties	Calculated t-values
OM (%)	2.948*
Total N (%)	2.888*
Exch. Na (Cmol/kg)	2.933*
Exch. K (Cmol/kg)	2.617NS
Exch. Ca (Cmol/kg)	2.937*
Exch. Mg (Cmol/kg)	1.460NS
Exch. Al (Cmol/kg)	0.851NS
Exch. H (Cmol/kg)	1.694NS
CEC (Cmol/kg)	2.980*
EC (mmhos/cm)	2.807*
Salt conc. (mg/l)	2.781*
ESP	3.938*
SAR	3.051*
CO_2 evolution (mg/100g)	2.595*

1. EC = electrical conductivity of the soil extract; ESP = exchangeable sodium percentage; SAR = sodium adsorption ratio.

* Significant at P < 0.05.
NS = not significant.

exchangeable Na^+ concentration in the topsoil (0-15 cm) (by 39%) and in the sub-soil (15-35 cm) (by 19%) when compared to similar horizons in the non-sewage treated soil (Table 4).

Electrical conductivity (EC) values gave similar trends as those of SAR and ESP, being significantly higher ($p<0.05$) in the sewage than non-sewage treated soils (Table 4). The implications of this are that yields of salt-sensitive crops like bambara groundnut for example, may be initially restricted unless the soil is leached of the excess salt.

In Table 5 the statistical tests of differences in some characteristics show that with the exception of exchangeable K, Mg, Al, and H the other soil properties were significantly higher in the sewage than non sewage treated soils.

CARBON DIOXIDE EVOLUTION

The cumulative CO_2 evolution from the top 0-30 cm of these soils is shown in Table 6. High microbial respiration rates were recorded for the sewage-treated soil, indicating that the sewage OM was still undergoing rapid decomposition. The CO_2 evolved in the non-sewage treated soil was relatively low. The fact that organic compounds in the sludge waste are highly bio-degradable or biologically active agrees with the high rates of microbial respiration observed here. This result further confirmed the findings of Boyle and Paul (1989) that the decomposition of sewage sludge was generally

Table 6: *Carbon dioxide evolution (mg/100 g soil) during incubation of sewage treated and non-sewage treated soils at Nsukka, Nigeria.*

Site/location	Incubation time (weeks)					
	1	3	6	9	12	Means
S/NSK/1	125	290	420	480	530	369.0
S/NSK/2	120	250	350	375	390	297.0
N/NSK	20	25	50	60	65	44.0
Means	88.3	188.3	273.3	305.0	328.3	-

LSD (0.05):
Soils (S) = 38.0
Incubation time (I) = 26.1
SxI = NS

fast as a result of flush of biological activity.

Such high rates of CO_2 evolved, coupled with the very low pH, in the sewage-amended top soil could be detrimental to soil fertility. This is so because the excess C can cause unavailability of N and P and increased microbial growth rates in the soil (Boyle and Paul, 1989). Ayuso et al. (1996) observed that increased solubility of CO_2 at low pH had a major negative influence on the rates of photosynthesis of plants, availability of NH_4^+ ions and P and on the rates of growth of micro- organisms and the mobility of heavy metals, particularly Cu in soils.

CROP PERFORMANCE

Maize plant height was significantly higher in the sewage than non-sewage sludge treated soils (Table 7) due most probably to the high nutrient status of the sewage treated soil. The performance of bambara groundnut in the sewage treated soil was initially restricted. The high N content and salt concentration in the sewage soil could have been partially responsible for this low performance. Palozzo and Jekins (1979) observed a decline in the concentration of K in legumes over a 4-year period of land application of sewage effluent, and related it to the K:N ratio of the sewage effluent used which contained more than twice as much N as K.

Furthermore, the salts could have interfered with the absorption of water by the bambara groundnut through reduction in the soil water potential and thus decrease the amount of water that would be readily available for plant uptake. This assertion agrees with the observations of Magesan et al. (1996) that high salt concentrations developed via heavy application of municipal effluents interfered with the absorption of water by soybean through reduction in the soil water potential.

Table 7: Maize plant height (cm) in unleached sewage and non-sewage treated soils at Nsukka, Nigeria.

Treatments	Weeks after germination						
	1	2	3	4	5	6	Means
Sewage soil	15.0	35.2	43.8	57.6	76.0	82.7	51.7
Non-sewage soil	7.0	20.1	27.0	32.4	35.0	37.5	26.5
Means	11.0	27.7	35.4	45.0	55.5	60.1	-

LSD (0.05):
Soils (S) = 16.7
Weeks after planting (W) = 9.2
S x W = NS

Table 8: Maize and bambara groundnut performances in the leached sewage and non-sewage soils

Plant parameter	Maize[1]			Bambara groundnut[2]		
	Sewage soil	Non-sewage soil	t-cal	Leached sewage soil	Non-sewage soil	t-cal
Dry matter yield (g/pot)	317.2	109.4	7.077**	197.7	210.0	2.094 NS
Fresh seed yield (g/pot)	-	-	-	94.0	96.4	1.689 NS
Dry seed yield (g/pot)	-	-	-	82.7	83.9	1.256 NS
Plant height (cm)	82.7	37.5	3.549*	-	-	-

** Significant at $P < 0.01$
- Significant at $p < 0.05$

NS Not significant
1. Harvested at 6 weeks
2. Harvested at maturity.

When the soil was leached of excess salt and replanted with bambara groundnut, an appreciable yield response was recorded (Table 8) showing that leaching removed appreciable quantities of the soluble salts present in the sewage sludge (Table 1). These salt concentrations were detrimental to the growth of bambara groundnut but not that of maize. This suggests that maize and bambara groundnut differ in their tolerance to soil salinity. According to the classification of Bernstein (1964), legumes are more sensitive to soil salinity than cereals.

CONCLUSION

The conclusions that can be drawn from this study are:

(1) Long-term disposal of sewage sludge and effluents on the Ultisol significantly improved the OM, exchangeable bases and CEC as well as the growth of maize;

(2) The sludge had detrimental effects on the growth and yield of bambara groundnut initially because of its high salt concentration. The yield was improved only when the sewage sludge was leached of excess salt; and

(3) High salt concentrations are a major limiting factor to long-term application of the sludge waste on agricultural lands in Nigeria.

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