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Full Length Research Paper

Variations in sludge effects on selected properties of four soil types and vegetable yield

V. M. Ngole

Faculty of Science, Engineering, and Technology, Walter Sisulu University, Nelson Mandela Drive, P/Bag X1 Mthatha 5117, Eastern Cape Province, South Africa. E-mail: vm.ngole@gmail.com. Tel: +27 (0)766843253. Fax: +27 (0)475022725.

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This study investigated the degree of modification of selected properties of soils in a semi-arid environment as a result of sludge application, in an endeavour to understand variations in percentage improvement with sludge application rate (SAR). Sludge was applied to a calcic luvisol (luvisol 1), a ferric luvisol (luvisol 2) an arenosol, and a vertisol at different rates and after three months, each soil-sludge mixture tested. Spinach (*Spinacea oleracea*) was then planted to test sludge effects on spinach yield. Addition of sludge reduced the pH of luvisol 1, luvisol 2, arenosol and vertisol by an average of 0.8, 1.1, 0.4 and 1.0 pH units, respectively. Mean concentrations of phosphorus, total kjeldahl nitrogen, and plant available nitrogen were highest in luvisol 1 (91.1 mg/kg), vertisol (2.3%), and vertisol (718.3 mg/kg) respectively. Concentrations of all plant nutrients increased with SAR in all soils. Percentage increase however varied, being highest in the luvisols at lower SAR, and shifting to the arenosol as SAR increased. Highest spinach yield was obtained from luvisol 2 with mean values of 49.2 gm, 19.7 gm and 179.7 cm^2 for fresh biomass, dry biomass and leaf area of spinach respectively. Spinach grown on the sludge-amended vertisol had the highest correlation coefficients between leaf area (LA) and SAR (0.92), fresh biomass (FBM) and SAR (0.90) and dry biomass (DBM) and SAR (0.95). Possible causes of the observed differences in sludge effects on the different soil properties are discussed.

Key words: Arenosol, vertisol, luvisol, plant nutrients, sludge application rate.

INTRODUCTION

Application of sewage sludge to soil as a method of disposal has emerged as an economically and environmentally acceptable alternative to disposal through landfill and incineration, because of the high concentrations of plant nutrients contained in sludge (Dolgen et al., 2007; Kidd et al., 2007; Stacey et al., 2001). Sludge application to soil could be for agricultural and reclamation purposes as well as in forestry, but its use in agriculture has been received with mixed feelings because of the concentrations of heavy metals (Alloway, 1995; Krauss and Page, 1997), toxic organic compounds (Wilson, 1997), and pathogenic organisms (Sidhu et al., 1999) that may be contained in the sludge. Research on the risks involved in using sewage sludge for agriculture has presented contrasting views.

Solomon et al. (2002) for example demonstrated systemic uptake of *E. coli* O157:H7 into lettuce plants through roots as a result of the application of manure slurries to soils. Ngole (2007) showed that the health risk presented by vegetables grown on sewage sludge-amended soils in semi-arid and arid environments was low because of the high rates of evaporation in these environments and the sterilising effect of the sun. According to Chimbari et al. (2001), Lou and Christie (1998) and McBride (1995), some sludge contains high concentrations of potentially toxic heavy metals but the total concentrations of heavy metals in the sludge provide little indication of their bio-availability. Sludge application to soil for agricultural purposes is practiced in several countries in Europe (Tlustoš et al., 2000), America (Krauss and Page, 1997), Asia (Wong et al., 2001), and Africa (Röhrs et al., 1999) to improve soil properties. Soil properties influenced by sludge application include porosity, structure, bulk density, aggregation, water holding capacity, concentrations of plant nutrients like nitrogen (N), phosphorus (P), and organic carbon (OC)

(Logan et al., 1996; Krauss and Page, 1997; Fierro et al., 1999; Röhrs et al., 1999; Snyman et al., 2000; Tlustoš et al., 2000; Chimbari et al., 2001; Mbila et al., 2001; Nyamanangara and Mzezewa, 2001; Wong et al., 2001; El-Naim and El-Housseini, 2002; Veeresh et al., 2003). Though the productivity of a soil may be influenced by several soil properties, the yield of crops may depend on a few including soil textural properties, pH, organic matter (OM), P, N, and potassium (K) contents. Whereas sludge will have no immediate influence on soil texture, it directly affects soil pH, OM, P, N, and K.

Modification of these soil properties may have a considerable effect on soil fertility index and consequently on the yield of crops and vegetables grown on such soils. Luvisol, vertisol and arenosol are soil types that are common in arid and semi arid environments. Agricultural activities on these soils are constrained by low water retention capacity and nutrient status (Soil mapping and advisory services Botswana, 1990), which could be improved by sludge application. In Botswana where these soils are common, 70 tons of vegetables are imported from neighbouring countries (Bok et al., 2006). Only 20% of the country's vegetable requirement is produced within the country (Bok et al., 2006). Spinach (*Spinacea oleracea*) is a common vegetable accompaniment in most dishes in Botswana. Improving the productivity of these soils may play a role in the attainment of food security in the country. These soil types vary in their physical and chemical properties. Whereas vertisols have fine texture and comparatively higher organic matter (OM) content, luvisols have medium texture and low OM content (Soil mapping and advisory services Botswana, 1990). The arenosols are sandy with very little OM content. Differences in properties among these soils may affect the manner in which they respond to sludge addition. As a consequence, the effect of sludge addition on vegetable yield on the different soils may not be proportional to the rate of sludge application. This study compares the changes in properties of two luvisols, an arenosol and a vertisol from a semi- arid environment amended with sewage sludge at different rates. It further elucidates the relationship between changes in selected properties, and the yield of spinach grown on these soils after sludge application. It is anticipated that the study will provide more information regarding the use of sewage sludge to improve vegetable production in semi arid environments.

MATERIALS AND METHODS

Soil sampling and preparation

Four different soils types; luvisol 1 (calcic), luvisol 2 (ferric), arenosol and vertisol were collected from Barolong Farms, Tuli Block, Mmamabula and Pandamatenga areas respectively, all located in the eastern part of Botswana. The soil types were chosen because they are the dominant soil types on which arable agriculture in the country is practiced. For each of the four soil types, 10 samples each weighing six kilograms were collected randomly from different sites at depths of between 0 - 50 cm from the respective areas. Samples from the same study area were then homogenised to form a composite sample that was representative of the specific soil type. The mineralogical composition of the soils comprised of quartz and hydromica for both types of luvisol, quartz for the arenosol, and quartz, smectites and albite for the vertisol (Ngole and Ekosse, 2008). Mineralogical composition of the clay fraction of the soils also varied being quartz and kaolinite in luvisol 1 and the arenosol, quartz, kaolinite and biotite for luvisol 2, and smectite (montmorillonite) mainly for the vertisol (Ngole 2005; Ngole and Ekosse, 2008).

These soil composites were each separately mixed thoroughly with a three year old sludge. The sludge was generated from a waste water treatment plant in Botswana through the activated sludge method of waste water treatment and anaerobically digested at 37°C for about 5 days. The digested sludge was then air-dried and piled at the sides of the sludge drying beds in the open. Though no further treatment process is employed to stabilize the sludge, periodic aeration may occur when the sludge pile is moved further from the drying beds to create space for younger sludge piles. Some physicochemical and chemical properties of the soils and sludge used are indicated in Table 1. Soils were mixed with sludge at ratios (v/v %) of 0:100, 5:95, 10:90, 20:80, and 40:60 sludge: soil, and allowed to stabilize for three months (average period between harvesting and planting season in Botswana). Samples were then taken from each soil-sludge mixture for characterisation. The 0:100 sludge: soil mixture of each soil type served as the control for that set of soil-sludge mixtures. The mixtures were homogenized and passed through a sieve with a mesh size of 4 mm (Hammer and Keller, 2002) and then transferred into five (5) different plant pots each measuring 25 cm in diameter. The pots were then transferred to a greenhouse and allowed to acclimatize for three days after which spinach seeds were sown directly into the sludge-amended soil in the pots.

Determination of soil properties after sludge

Each soil-sludge mixture was characterised for its pH, OM, P, total Kjeldahl nitrogen (TKN), plant available nitrogen (NO_3-N + NH_4-N) (PAN), and exchangeable potassium (K). Whereas soil pH was determined in a 1:2.5 soil: water suspension, OM and available P contents in the soils were determined using the wet combustion method and ascorbic acid reduction method respectively (van Reeuwijk, 2002). Available nitrogen was extracted using KCl (Csuros, 1997) while H_2SO_4 and Se were used to digest samples for TKN (USDA 1996). Exchangeable K was determined in the CH_3COONH_4 leachate of the sample (van Reeuwijk, 2002). A Gerhardt Kjeldtherm digestion system equipped with a Gerhardt Turbosorg scrub unit and a Gerhardt Vapodest 30 distilling unit was employed in the determination of TKN, NO_3-N, and NH_4-N, in the samples. Phosphorus and K content in the samples were determined with a SCHIMADZU UV 1601 UV-Visible Spectrophotometer and a Varian SpectrAA 220 FS flame atomic absorption/emission respectively. Each sample was analysed in duplicate.

Determination of the yield of spinach

A total of 12 seeds were sown in each pot. Thinning was carried out when the shoots were about 5 cm tall. Only three spinach seeds were allowed to grow in each pot. The temperature in the greenhouse was maintained between 15 and 20°C throughout growth period. Lighting in the greenhouse was natural. Each pot received 0.5 ml of tap water every two days for 13 weeks, after which spinach was harvested. The yield of spinach was determined

Table1. Properties of soils and sludge used in the study.

Properties	Soil types				Sludge
	Luvisol 1	Luvisol 2	Arenosol	Vertisol	
Sand (wt %)	85.25	83.33	95.97	34.12	-
Silt (wt %)	11.99	11.85	2.29	37.28	-
Clay (wt %)	5.76	4.81	1.75	28.60	-
pH - (H_2O)	6.80	6.54	4.96	7.07	5.70
Electrical conductivity (µs/cm)	211.00	310.20	221.00	270.50	4700.00
Cation exchange capacity (cmolc/kg soil)	7.70	5.10	0.30	72.70	39.02
Organic matter content (%)	1.88	1.83	0.80	2.30	23.10
Exchangeable K ($cmol_c$/kg soil)	1.17	1.01	0.83	10.61	1.40
Exchangeable Ca ($cmol_c$/kg soil)	7.8	3.8	2.0	12	2.54
Exchangeable Mg ($cmol_c$/kg soil)	4.3	5.4	1.2	33	2.27
Exchangeable Na ($cmol_c$/kg soil)	0.59	0.35	0.73	0.42	1.34
Phosphorus (mg/kg)	33.60	19.51	4.45	52.15	7319.00
Total Kjeldahl nitrogen (%)	2.26	2.23	1.03	2.54	4.40
NH_4-N (mg/kg)	314.20	298.50	153.30	280.90	612.20
NO_3- N (mg/kg)	207.10	270.30	173.10	208.40	546.20
Al (%)	0.42	0.46	0.25	3.96	2.98
Fe (%)	1.02	1.08	0.12	7.38	2.94
Cu(mg/kg)	18.01	20.21	10.92	148.75	115.9
Zn (mg/kg)	41.30	27.00	9.60	116.80	400.00

by measuring the leaf area (LA) and determining the fresh biomass (FBM) and dry biomass (DBM) of the spinach leaves at time of harvest. Leaf area was measured with a leaf area meter whereas the fresh and dry biomasses were determined using gravimetric methods. Details of the methods used are described in Tei et al. (1996) and Pierce et al. (1998). Mixing of soils and sludge, and growing of spinach was repeated twice.

Statistical analyses

Statistical analyses were carried out using SPSS 17.0 for windows. Mann-Whitney test was used to test the difference between means. Percentage change in each property after sludge addition was calculated by comparing them with those of the control samples. The soil with the most modification was identified by summing up the percentage changes in all properties analysed. To determine the effect of sludge addition on the fertility of the soils, the soil fertility index (SFI) of each soil type was calculated at the different sludge application rate (SAR) as directed by Doi et al. (2007). Where: SFI = pH + organic matter (%, dry soil basis) + available P (mg/kg dry soil) + exch K (c eq/kg dry soil) + exch Ca (c eq/kg dry soil) + exch Mg (c eq/kg dry soil) – exch Al (c eq/kg dry soil). Values obtained for FBM, DBM and LA of spinach were also compared to determine how yield varied with soil type and SAR.

RESULTS

pH

Addition of sludge decreased the pH of all soil types with increase in the amount of sludge added (Table 2). No significant differences were observed in pH of the soils at a SAR of 5%, but at SAR > 5%, significant decrease in soil pH was observed in all soils ($P < 0.05$). Mean decrease in pH after sludge addition was highest in luvisol 2 (1.1 pH unit), followed by the vertisol (1.0 pH unit), luvisol1 (0.8 pH unit) and then the arenosol (0.4 pH unit) (Figure 1). Whereas percentage decrease in pH increased with increase in SAR in the vertisol, luvisol 1 and luvisol 2, it decreased with increase in SAR in the arenosol (Figure 1).

Organic matter

Highest OM content was recorded in the vertisol (8.84% at an SAR of 40%) and the lowest in the arenosol (0.63% at an SAR of 5%). The pattern of OM in all soils followed the order vertisol > luvisol1 > luvisol2 > arenosol (Table 2). Though OM content in soils increased with SAR, only increases observed at SAR of 20% were significant ($P < 0.05$). Percentage increase in soil OM after sludge addition increased with increase in SAR and was highest in the vertisol, followed by luvisol1, and luvisol2, then arenosol (Figure 2).

Exchangeable K

Sludge application increased the amount of K in luvisol1,

Table 2. Characteristic of the different soils three months after sludge addition.

Soil type	SAR (v/v %)	pH	OM (%)	K ($cmol_c$/Kg soil)	P (mg/kg)	TKN (%)	NH_4- N (mg/kg)	NO_3- N (mg/kg)	SFI
Luvisol1	0	6.4	3.0	1.2	65.2	0.9	314.2	207.1	14.0
	5	5.7	3.5	1.2	70.2	1.2	347.6	309.7	14.6
	10	5.6	3.7	1.2	63.1	1.3	367.2	289.9	13.4
	20	5.6	3.3	1.2	102.9	1.7	388.9	404.6	22.2
	40	5.5	7.2	1.2	154	2.7	396.4	419.1	33.7
Luvisol2	0	6.9	2.2	1.0	52.3	0.8	298.5	270.3	11.0
	5	6.2	2.4	1.1	58.5	0.9	317.5	333.3	12.1
	10	6.1	2.5	1.0	74.1	1	264.2	339.7	15.3
	20	5.8	2.8	1.0	98.5	1.2	283	351.9	21.3
	40	5.3	3.4	1.0	154.3	1.4	330.3	279.8	33.6
Arenosol	0	6.1	0.9	0.8	47.4	0.4	153.3	173.1	10.3
	5	5.9	1.0	0.9	64.4	0.5	241.1	152.4	14.0
	10	5.6	1.1	1.0	58.8	0.5	227.5	321.9	12.9
	20	5.7	1.3	1.0	81.9	0.6	263.6	270.6	18.3
	40	5.8	1.8	1.1	163.5	1.1	282.7	293.1	36.4
Vertisol	0	7.2	4.1	10.6	61.8	1	280.9	208.4	24.3
	5	6.4	4.7	9.3	74	1.7	313.9	273.9	32.0
	10	6.3	8.2	9.1	104.8	2	394	345.7	41.7
	20	6.1	8.9	8.4	252.6	2.8	460	463.3	52.1
	40	5.9	8.8	6.7	260.2	4	412.2	439.4	56.4

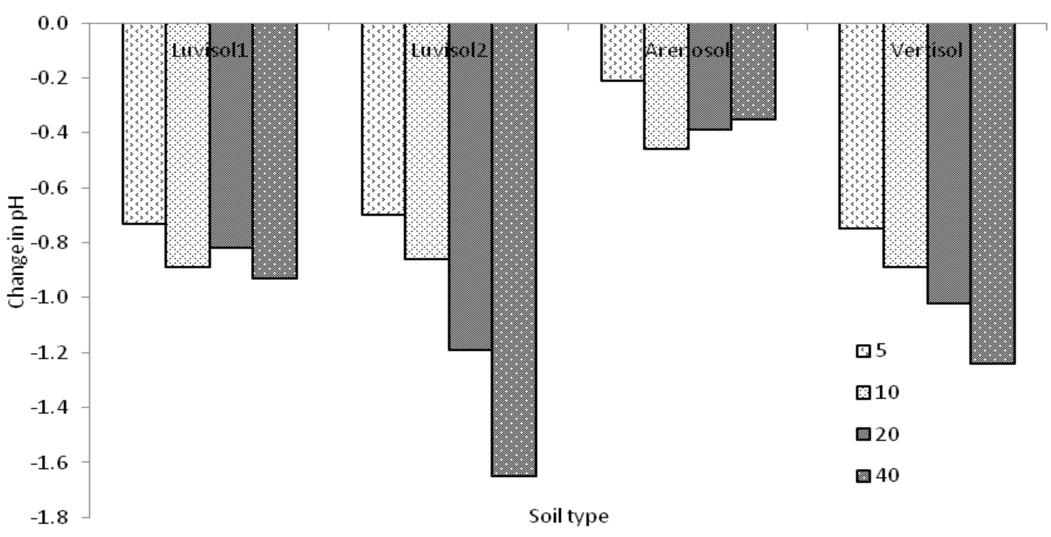

Figure 1. pH of soils three months after sludge addition.

luvisol2 and the arenosol, but reduced it in the vertisol (Table 2). The highest percentage increase in K was recorded in the arenosol followed by both luvisols (Figure 3). Percentage decrease in K in the vertisol increased with increase in SAR (Figure 3). Differences observed in the percentage increase in K in the different soils were insignificant ($P > 0.05$) but the concentration of K in the vertisol was significantly reduced at an SAR of 20% ($P < 0.05$).

Phosphorus

Addition of sludge increased P content in the soils at rates which were proportional to the amount of sludge added (Table 2). Though P concentration increased with

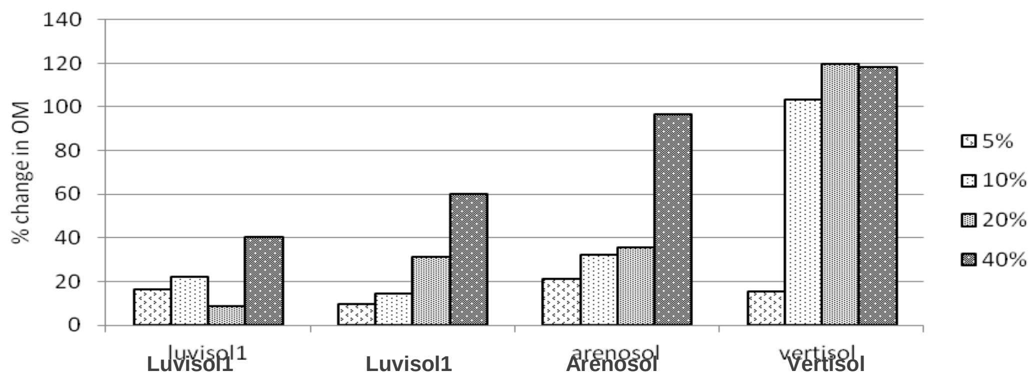

Figure 2. Percentage change in OM of soils three months after sludge addition.

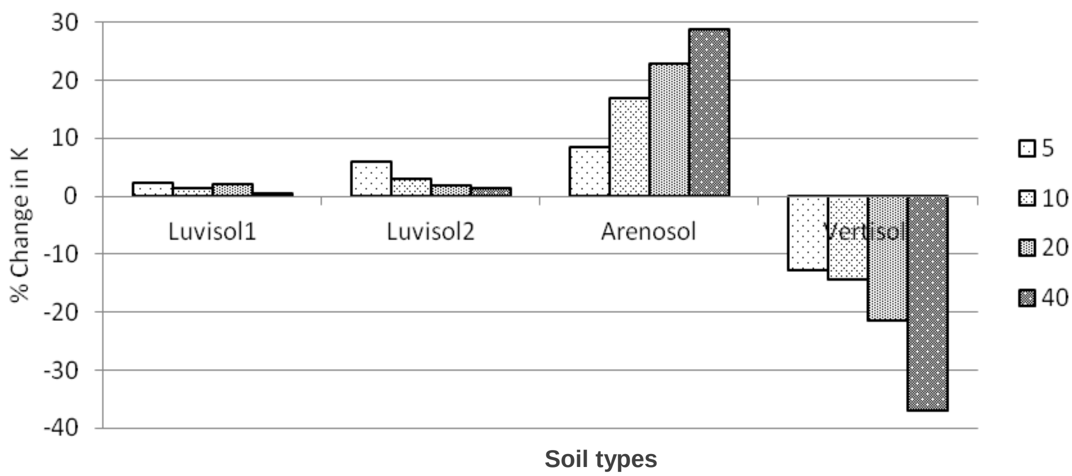

Figure 3. Percentage change in exchangeable K in soils three months after sludge addition.

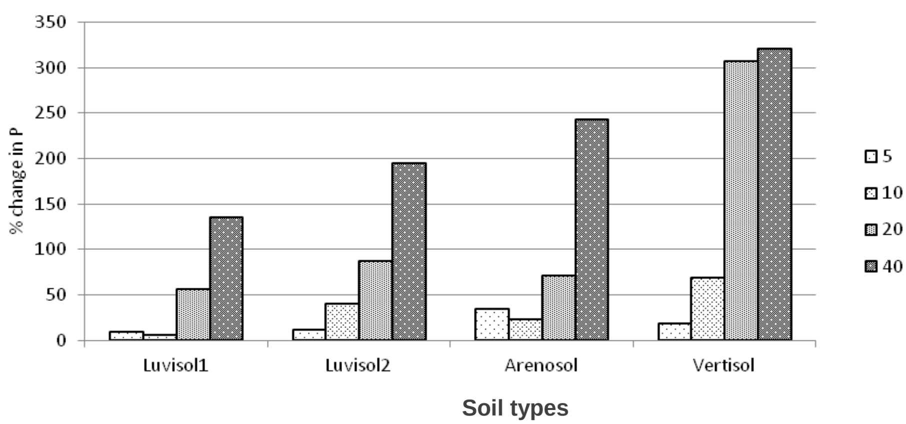

Figure 4. Percentage change in phosphorus in soils three months after sludge addition.

increase in SAR, only increases in P observed at SAR of 20% and 40% were significant ($P < 0.05$). The vertisol showed the highest percentage increase in P followed by luvisol2, then arenosol, and finally luvisol1 (Figure 4).

Nitrogen

Concentrations of NO_3 - N and NH_4 - N in all the soils ranged from 150 mg/kg to 450 mg/kg and were increased

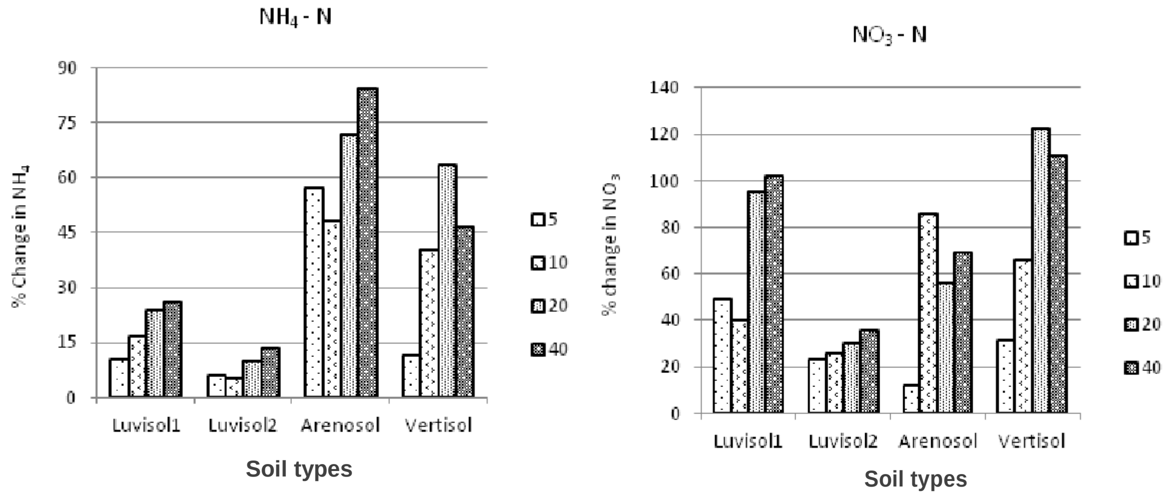

Figure 5. Percentage change in NO_3 - N and NH_4 - N in all soils three months after sludge addition.

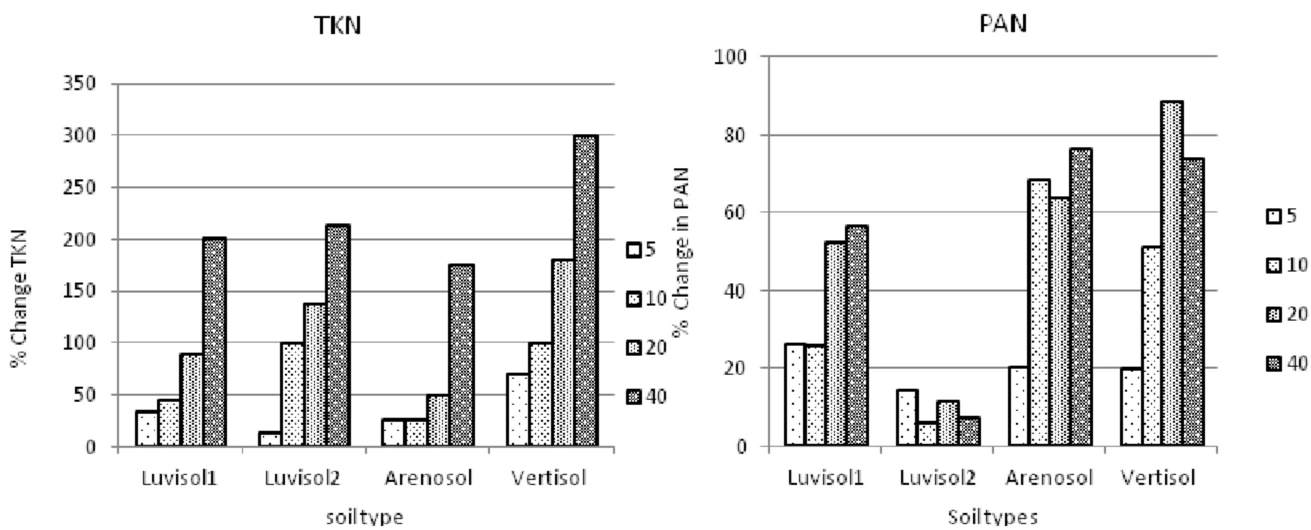

Figure 6. Percentage change in TKN, and PAN in soils three months after sludge addition.

as a result of sludge addition (Table 2). Percentage change in NO_3 - N in the vertisol was similar to that of luvisol1but higher than those of luvisol 2 and arenosol (Figure 5). The arenosol had the highest percentage change in NH_4 - N followed by the vertisol, luvisol 1 and luvisol 2 (Figure 5). Differences in percentage change in NO_3 - N and NH_4 - N were reflected in the changes observed in plant available nitrogen (PAN) in all soil types (Figure 6). The vertisol contained the highest amount of TKN while the arenosol contained the least (Table 2). Differences observed in TKN in the sludge- amended soils and the respective control samples were significant at an SAR of 40% in luvisol1 and arenosol, and 20% and 40% in luvisol2 and vertisol ($P < 0.05$). Percentage increase in TKN in soils followed the order vertisol > luvisol2 > luvisol1 > arenosol (Figure 6). These differences were also insignificant.

Soil modification with SAR

The extent to which the soils were modified varied with soil types and with SAR. At an SAR of 5%, luvisol2 was least modified by sludge addition whereas the arenosol was the most modified (Figure 7). The vertisol showed the highest percentage modification at SAR of 10, 20 and 40%. The fertility index of the soils also changed with changes in SAR as indicated in Figure 8. Luvisol 2 and vertisol showed increase in SFI with increase in SAR. For luvisol1 and the arenosol, a decrease was observed at an SAR of 10% but SFI increased with increase in SAR thereafter. The vertisol showed the highest increase in

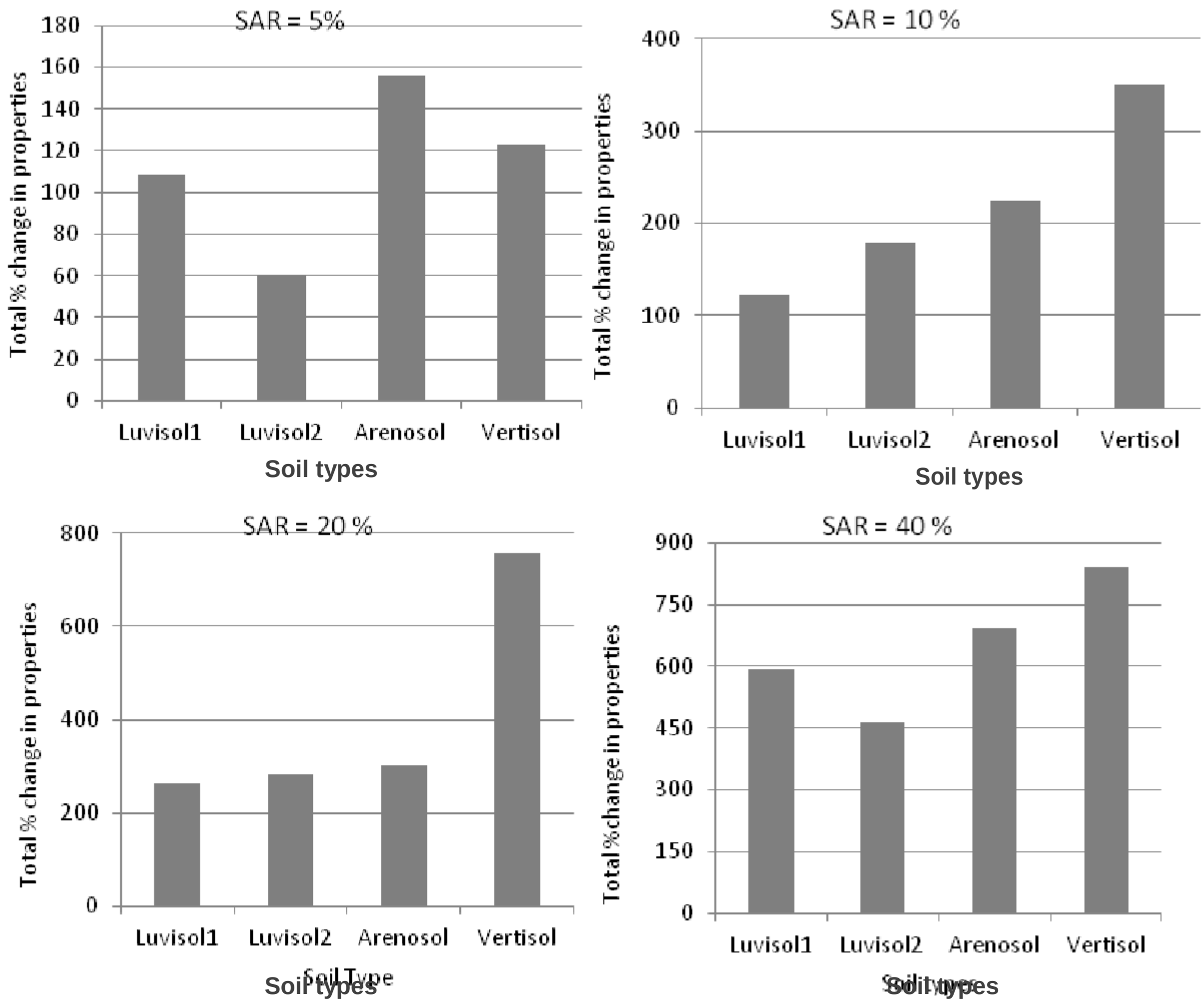

Figure 7. Percentage change in soil properties at different SAR.

SFI at all SAR (Figure 8).

Spinach yield

Fresh and dry biomass as well as the leaf area of spinach increased with increase in SAR (Table 3). Spinach grown on luvisol2 amended with sludge had the highest mean FBM (54.9 g), whereas those grown on the arenosol had the lowest (33.5 g). Mean DBM on the other hand was highest in spinach from the vertisol (26.2 g) and also lowest in spinach from the arenosol (12.2 g). Mean spinach LA followed the order spinach from luvisol1 (204.5 cm^2) > spinach from luvisol2 (200.4 cm^2) > spinach from vertisol (196.7 cm^2) > spinach from arenosol (129.6 cm^2). Details of the FBM, DBM and LA of the spinach at the different SAR are presented in Table 3. Spinach from the arenosol had significantly lower FBM, DBM and LA than those from luvisol 1, luvisol 2 and vertisol ($P < 0.05$). Only increases observed in FBM, DBM, and LA of spinach from all soil types with an SAR of 20% were significant ($P < 0.05$).

The highest percentage increase in FBM was observed in spinach from luvisol 2 followed by spinach from luvisol1, then spinach from the arenosol and finally those from vertisol. Percentage increase in DBM and LA of spinach followed the order spinach from luvisol 1 > spinach from luvisol 2 > spinach from arenosol > spinach from vertisol. Percentage increase in LA, FBM and DBM increased with increase in SAR for all soil types.

DISCUSSION

Effect of sludge on soil properties

Variations in sludge effect on soil OM

Except for K, in the vertisol, which had a higher concentration than that in the sludge used, the sludge had higher values for all other properties analysed. This

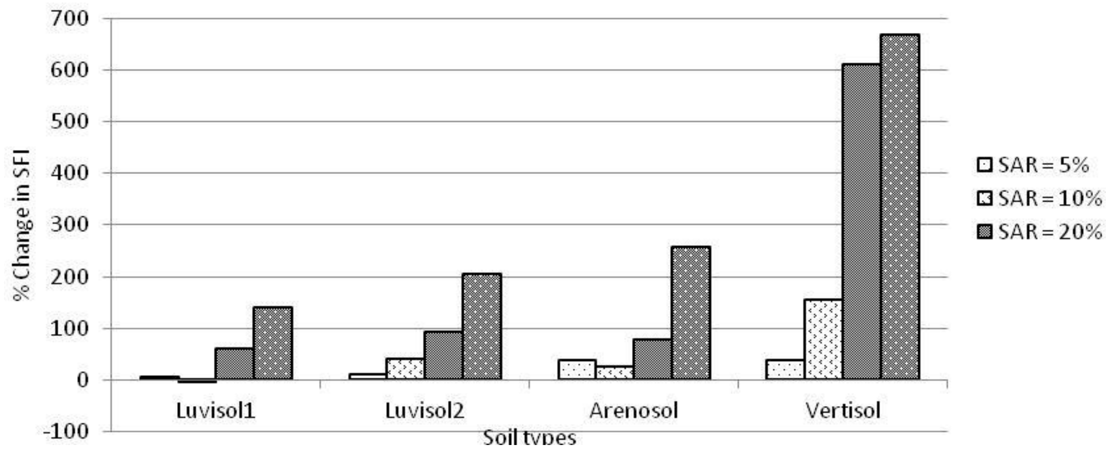

Figure 8. Percentage change in fertility index of the different soils with increase in Sludge application rate.

Table 3. Fresh and dry biomass and leaf are of spinach from the different soils.

SAR (%)	Mean fresh biomass (gm)			
	Luvisol 1	**Luvisol 2**	**Arenosol**	**Vertisol**
0	26.20	26.40	19.60	29.30
5	39.82	41.65	24.28	35.46
10	48.62	52.11	33.96	35.44
20	60.23	59.24	37.57	45.96
40	62.36	66.61	38.03	49.99
Mean dry biomass (gm)				
SAR (%)	**Luvisol1**	**Luvisol2**	**Arenosol**	**Vertisol**
0	5.60	8.60	6.80	16.10
5	13.23	15.68	8.80	20.53
10	14.83	21.13	11.21	24.17
20	20.04	25.32	12.98	26.42
40	24.76	27.77	15.73	33.54
Leaf area (mm^2)				
SAR (%)	**Luvisol1**	**Luvisol2**	**Arenosol**	**Vertisol**
0	111.00	97.30	77.70	140.30
5	174.25	169.30	108.22	165.95
10	188.17	186.72	108.22	179.65
20	209.25	223.88	142.72	208.63
40	246.42	221.55	159.06	232.74

justifies the increase observed in OM, P, TKN, NO_3 - N and NH_4 - N in all soil types with increase in SAR. However, the extent to which these properties were altered varied. These variations could be attributed to differences in the properties of the different soil types used. The soils had different textural properties which may have affected several processes in the soils including the rate of sludge-added OM decomposition. The role of soil textural properties in OM decomposition has been reported by Krull et al. (2001) and Plante et al. (2006). Organic matter in the vertisol with higher clay content may have bonded with the clayey particles to form clay-bound organic matter which decomposes slower than soil organic matter. Ratnayake et al. (2008) and Skene et al. (1996) have reported that OM in clayey soils is protected by intimately associating with clay to form organomineral complexes which decompose less easily.

In addition, clayey soils including vertisol are characterised by microspores which reduce aeration thereby retarding the activities of decomposers in the soil, further slowing down the rate of OM decomposition.

Slower rates of OM decomposition in the vertisol may therefore be responsible for the higher percentage increase in OM observed. It also explains why the vertisol was the most modified soil at high rates of SAR where the amount of sludge-added OM was very high. Decomposition of OM in the arenosol and the luvisol is likely to have progressed under aerobic conditions because of the presence of macropores that are characteristic of coarse-textured soils. Under aerobic conditions, OM decomposition progresses faster resulting in less OM accumulation in the soil and would have caused the lower percentage change in OM observed in the arenosol and both luvisols.

Variations in sludge effect on soil pH

The observed reduction in pH with increase in SAR in all soils could be attributed to the accumulation of organic acids generated during the process of OM decomposition (Veeresh et al., 2003). Under conditions of reduced oxygen, decomposition would result in accumulation of more organic acids due to incomplete breakdown of OM. Accumulation of these acids is more likely to occur in clayey soils like the vertisol with micropores than in the luvisols and arenosol with sandy texture. Though luvisol 1, luvisol 2 and the arenosol were sandy, the arenosol contained less weight percent silt and sand than both types of luvisol. Porosity of the arenosol is therefore likely to be more than in both luvisols, resulting in higher rates of OM decomposition, and less accumulation of organic acids in the arenosol compared to the luvisols. This may explain the decrease in percentage increase in pH with increase in SAR in the arenosol. Further to this, the initial pH of the arenosol before sludge addition was slightly acidic. Acidification caused by sludge-borne OM decomposition may have had little impact on the pH of the arenosol.

Variations in sludge effect on soil P

Differences in the mineralogical composition of soils may have influenced the percentage change in P, TKN, and PAN of all soils after sludge addition. Studies by Zia et al., (1992) indicated that kaolinite will fix more P than montmorillonite. With the vertisol having montmorillonite ($Na0.3(AlMg)\ 2Si_4O10OH_2\ .6H_2O$) as the dominant mineral both in the clay fraction and whole soil (Ngole, 2005), its ability to fix P may therefore be lower than luvisol1, luvisol2 and the arenosol, which are dominated by kaolinite. This may explain the higher percentage increase in P observed in the vertisol compared to the luvisols and arenosol. In addition to the mineralogy, the presence of Ca in luvisol1 (calcic luvisol) and Fe in luvisol 2 (ferric luvisol) may have resulted in the formation of insoluble phosphates further reducing P availability. Hence the low percentage increases in Olsen P in both luvisols. The potential of Ca and Fe to adsorb P in soil has been reported by Maguire et al. (2000) and Maguire et al. (2001).

Variations in sludge effect on soil N

Whereas kaolinite is a better fixer of P compared to montmorillonite (Zia et al., 1992), Kiliç et al. (1999) have indicated that montmorillonite will fix NH_4^+ more than kaolinite. Loss of NH_4-N in soils through volatilization has also been reported in sludge-amended soils by Gilmour and Skinner (1999). Considering that volatilization of N in soils is favoured by low clay and OM contents which was characteristic of the luvisols and arenosol, and that their mineralogical composition is dominated by kaolinite, the low percentage increase in NH_4 - N in these soils is explained. Textural properties of both luvisol and arenosol favoured mineralisation of organic N contained in the soils to NO_3-N (Gilmour and Skinner, 1999). However, NO_3-N being the most soluble form of N in soils may have been volatilized and/or leached out during the three months period, resulting in the lower percentage increase in NO_3-N in the arenosol and luvisols compared to the vertisol. Despite these changes in PAN, there were no significant differences in TKN of all four soil types.

Variations in sludge effect on soil modification

The observed differences in the extent to which the soils were modified can be explained by the differences in properties. At an SAR 5%, the percentage change in pH, K, OM, P, and NH_4 - N of the arenosol was the highest. Though the arenosol had the highest percentage increase in pH, K, NH_4 - N and NO_3 - N, and the vertisol the highest percentage change in OM, P and TKN at SAR of 10 and 20%, the percentage change in OM and TKN in the vertisol were respectively triple and double that of the arenosol, resulting in the vertisol being the most modified by sludge addition at SAR of 10 and 20%. At an SAR of 40% the vertisol was still the most modified because of the percentage increase in TKN and OM.

Relationship between SAR and spinach yield

Leaf area, FBM and DBM of spinach from all soil types increased proportionately with increase in SAR (Figure 9). Improvement in the yield of vegetables as a result of sludge application has also been reported by Logan et al. (1997), Tlustoš et al. (2000), Nielsen et al. (1998), Ozores-Hampton and Peach (2002) and Wong et al. (2001). The relationship between spinach yield parameters and SAR was most liner in spinach from the vertisol and least in spinach from luvisol2 as indicated by

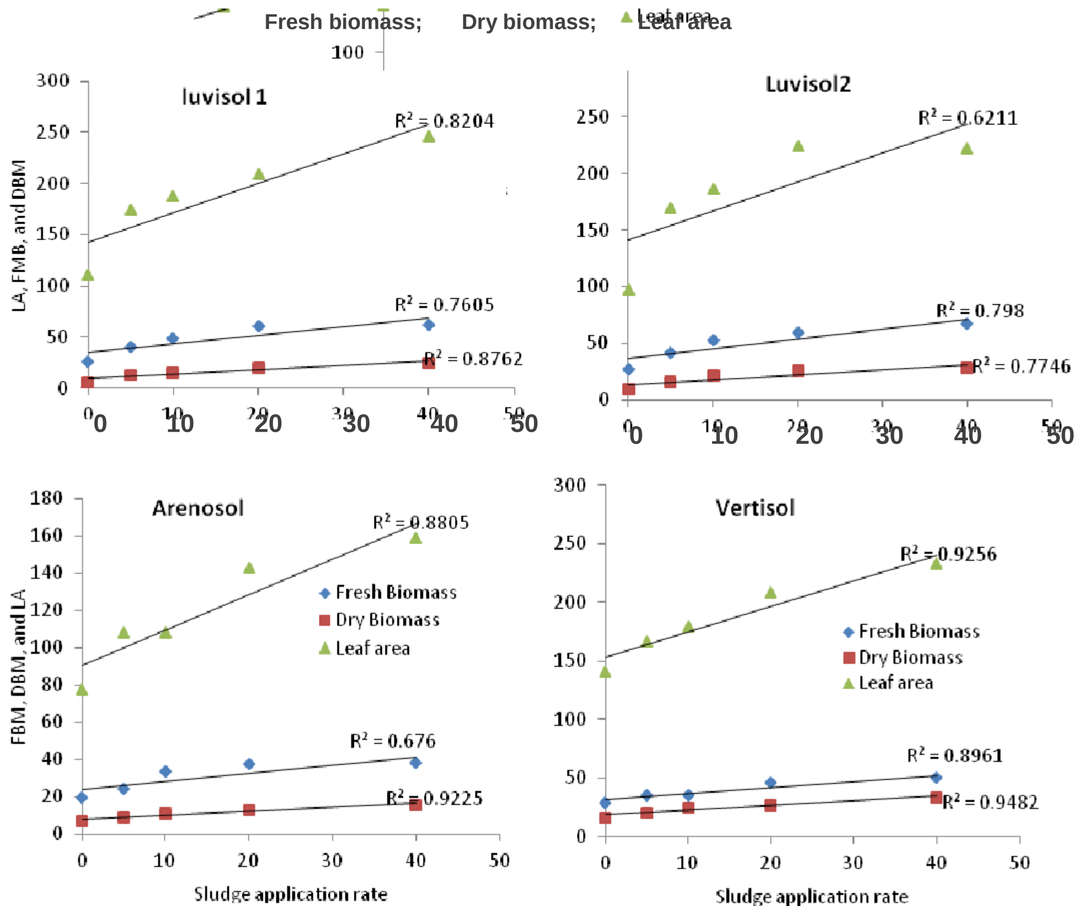

Figure 9. Relationship between spinach fresh and dry biomass and leaf area with sludge application rate.

Table 4. Correlation coefficients of PAN and leaf area, fresh and dry biomass of spinach from the different soils.

Soil type	Fresh biomass	Dry biomass	Leaf area
Luvisol1	0.98	0.98	0.96
Luvisol2	0.44	0.44	0.62
Arenosol	0.97	0.92	0.83
vertisol	0.90	0.86	0.94

the value of R2 in the equation of the trend line in each (Figure 9). The observed linear relationship can be attributed to the increase in the nutrient content of the soils after sludge addition. Nitrogen for example plays an important role in plant growth because it forms a major component of chlorophyll and protein, which influences the rate of photosynthesis. It also influences vegetative growth in plants and would result in an increase in fresh and dry biomass. Studies by Van Delen et al. (2001), Ewert (2004) and Yin et al. (2003) have also shown that LA expansion especially at the latter stages of growth is closely related to N availability. The large leaves are able to intercept photosynthetically active radiation (Ewert, 2004; Van Delen et al., 2000), increasing biomass production. The validity of this explanation in justifying the increase in LA, FBM and DBM is based on the high correlation coefficients between these parameters and PAN in the different soils (Table 4).

Differences observed in percentage increase in yield of spinach on different soils after sludge addition can be explained by the initial nutrient status of the soils and the changes in fertility index as a result of sludge application. According to data presented in Table 2 and Figure 8, the vertisol had a high fertility index which may have been appropriate for the growth of spinach. Adding sludge to the vertisol was therefore not likely to cause very significant changes in the yield. The arenosol on the other hand had the lowest fertility index which was significantly improved by sludge addition explaining the high percentage increase observed in the yield of spinach from the arenosol.

Conclusion

Addition of sludge to soils may result in improvement of the soil properties but the extent of improvement varies with soil type and SAR. Whereas sludge addition affected the soils to different extent, the effect on the yield of vegetables was similar. The degree of modification varied with soil type, being highest in soils with medium texture like the luvisols at low rates of sludge application. At higher rates of sludge application, the sandy soils are most modified. In most cases of sludge application to soil, the nutrient requirement of the crop is considered in determining sludge application rates but results from this study have shown that sludge has different effects on different soils types. Considering that P and N availability in sludge amended soil may depend on the mineralogical composition of the soil, sludge application rates for different crops should be decided according to soil types in addition to crop type. This may maximize the use of sludge as a soil amendment in soils in arid and semi arid environments.

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