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Effect of long-term application of sewage sludge and farmyard manure on soil properties under mustard-based cropping system

Mahesh C Meena[1*] and KP Patel

Anand Agricultural University, Anand 388 110, Gujarat, India
[1]Division of Soil Science & Agricultural Chemistry, ICAR-IARI, New Delhi 110 012, India
**Corresponding author: mcmeena@gmail.com*

Abstract

The use of sewage sludge in agriculture is being considered as one of the method for recycling of waste in an environmental beneficial manner. Sewage sludge, due to its acidic nature, high organic matter and heavy metals content, had more impact on soil properties. To study the changes in the selected physical and biological properties and accumulation and mobility of heavy metals due to continuous use of sewage sludge, a field experiment was started in year 2000 to evaluate the long-term effect of sewage sludge with or without farmyard manure under pearlmillet (*Pennisetum glaucum* L.) (cv. GHB-526) and Indian mustard (*Brassica juncea* L. Czernj and Cosson) (cv. GM-2) crops sequence. The sewage sludge @10 and 20 tonnes/ha, farmyard manure @ 10 tonnes/ha and farmyard manure + sewage sludge @ 10+2.5, 10+5 and 10+10 tonnes/ha were applied to pearlmillet in *kharif* for direct effect and their residual effect was studied on Indian mustard during *rabi* in randomized block design keeping three replications. Use of sewage sludge increased the heavy metal contents in surface soil as well as plant. The DTPA-extractable heavy metals were higher in sewage sludge than farmyard manure + sewage sludge or farmyard manure treated soil. The farmyard manure + sewage sludge application reduced bulk density and increased saturated hydraulic conductivity, microbial biomass carbon (MBC), microbial biomass nitrogen (MBN) and dehydrogenase activity (DHA) significantly. The microbial activity was decreased by sewage sludge alone compared to farmyard manure + sewage sludge or farmyard manure. The farmyard manure and sewage sludge applications were also found beneficial in increasing yield and quality of grain as direct effect on pearlmillet and as residual effect on succeeding Indian mustard. Application of farmyard manure together with sewage sludge exhibited mitigating effect by lowering the contents of trace and heavy metals in both the crops.

Key words: *Farmyard manure, mustard, sewage sludge, soil properties*

Introduction

The agricultural use of sewage sludge is widely recommended, since it contains organic matter and it rich macro and micronutrients (Meena *et al.,* 2008; Meena *et al.,* 2013). Sewage sludge is a residue from domestic and industrial wastewater treatment. Increasing costs of commercial fertilizers and large amounts of sewage sludge produced worldwide have made agriculture land application of this residue an attractive disposal option. When sewage sludge is applied to soil, it causes alterations in the structure and functioning of the agroecosystems; one of the most sensitive components in the microbial community in soil health. Chemical and biological composition of sewage sludge changes with seasons (Maiti *et al.,* 1992) and pollutants with sources (Brady and Weil, 2002). Usually, it is rich in organic matter and plant nutrients such as nitrogen, phosphorus and calcium (Beri and Gupta, 2003) and can improve soil physical, chemical and biological properties, such as porosity, aggregate stability, bulk density, soil fertility, water movement and retention. In the tropics, where soils are generally poor in minerals with high cation exchange capacity and are low in organic matter, sewage sludge could be an important soil amendment (Golui *et al.,* 2016). A problem to be solved is the management hazardous constituents, such as heavy metals, among them cadmium, cobalt and persistent organic pollutants normally present in sewage sludge. These may cause soil and water pollution and toxicity to crops, animals and humans, affecting the food chain (Rattan *et al.,* 2002; Patel and George, 2005; Golui *et al.,* 2014). The heavy metal concentrations in sewage sludge vary widely, depending on the origin of the sludge and on the processes of treatment in the sewage treatment plant; its uptake by plants depends on the form in the soil and on the plant species. Considering that the aim of this work was to estimate the effect of rates of application of sewage sludge produced by effluent treatment plant (ETP) with or without farmyard manure on the soil physical and biological properties and distribution of heavy metals at different depth of the soil.

Materials and Methods

A field experiment was started in year 2000 with application of farmyard manure and sewage sludge at Agronomy Farm, B.A. College of Agriculture, Anand Agricultural University (AAU), Anand. The soil was contaminated due to sewage sludge application under pearlmillet – cabbage cropping sequence and the same was utilized for further study to generate information on long-term effect of sewage sludge application on crops yield, quality and soil physical and biological properties under pearlmillet (*Pennisetum glaucum* L.) – Indian mustard (*Brassica juncea* L. Czernj and Cosson) cropping sequence. A sandy loam soil (clay, 6.70%; silt, 14.0%; sand, 79.30% in 0 to 15 cm) classified as a Typic Haplustept, was used for applying sewage sludge with or without farmyard manure under pearlmillet- Indian mustard cropping sequence. It was alkaline in reaction with pH 8.6, non-saline with electrical conductivity of 0.17 dS/m and organic carbon content was 3.10 g/kg. The treatments of sewage sludge (10 and 20 tonnes/ha), farmyard manure (10 tonnes/ha) and farmyard manure + sewage sludge (10+2.5, 10+5 and 10+10 tonnes/ha) were applied to pearlmillet in *kharif* for direct effect and residual effect was studied on succeeding Indian mustard in *rabi* with randomized block design keeping three replications. Sewage sludge was obtained from the sewage treatment plant located in Ahmedabad. The farmyard manure collected from locally available at Anand, Gujarat had the average chemical composition given in Table 1.

Table 1: Average chemical composition of sewage sludge and farmyard manure

Parameters	Sewage sludge	Farmyard manure
Total C (%)	14.4	11.2
Total N (%)	1.35	0.52
Total P (%)	0.70	0.43
Total K (%)	0.35	0.48
Cd (mg/kg)	5.30	1.05
Co (mg/kg)	104	0.40
Ni (mg/kg)	96	9.90
Pb (mg/kg)	40	18.7
Cr (mg/kg)	134	4.60

Sewage sludge and farmyard manure were spread on the soil surface annually and incorporated into the top layer before 15 days of sowing date. The recommended doses of N, P and K (pearlmillet: 80-40-0, mustard: 50-50-0) were kept common in all the treatments. Data on yield attributes, yield and oil content of crop grains were recorded as per standard procedures. Protein content of grain of both pearlmillet and Indian mustard was worked out by multiplying nitrogen content with a factor of 6.25 as suggested by Gupta *et al*. (1972). The plant samples were analyzed with standard methods as proposed by Jackson (1973). Important soil physical properties like bulk density and saturated hydraulic conductivity, chemical properties *i.e.* organic carbon (OC), DTPA (Diethyleme Triamine Penta Acetic Acid) extractable heavy metals as well as biological properties were determined as per the standard methods given in Table 2.

Results and Discussion

Soil Properties

Organic carbon

The data on organic carbon content as influenced by farmyard manure and sewage sludge application are given in Table 3. The results revealed that application of farmyard manure and sewage sludge improved organic carbon status of soil significantly at all the depths of soil profile over NPK. The highest organic carbon (4.62 g/kg) content was noted at 0-15 cm under 10 tonnes farmyard manure + 10 tonnes sewage sludge/ha which was on par with rest of the organic treatments. Organic carbon content showed no change at 30-45 cm depth. The improvement in soil organic carbon could be a result of direct addition of organic matter through farmyard manure and sewage sludge as well as its beneficial effect on crop roots as well as on total microbial bio-mass of soil. The tropical/subtropical climate might have not favoured strong build-up in organic carbon inspite of having addition of large quantity of organic matter over years in the soil. However, the organic carbon build-up in 0-15 cm soil layer was comparatively higher than the corresponding organic carbon level at other depths. The build-up of organic carbon in soil is attributed to higher organic loading in the soil due to application of farmyard

Table 2: Methods of soil analysis

Parameter	Extraction method	Reference
Organic carbon (OC)	wet oxidation method	Walkley and Black (1934)
Available heavy metals	0.005 M DTPA (pH 7.3)	Lindsay and Norvell (1978)
Bulk Density	Core sampler method	Blake and Hartage (1986)
Hydraulic conductivity	Saturation method	Klute and Dirkson (1986)
Microbial biomass carbon (MBC) and Microbial biomass nitrogen (MBN)	Fumigation method(0.5 M K_2SO_4)	Jenkinson and Powlson (1976)
Dehydrogenase activity	Formation of triphenyl formazon (TPF)	Klein *et al.* (1971)

Table 3: Effect of farmyard manure and sewage sludge on organic carbon and DTPA- heavy metals (mg/kg) distribution at different soil depth (cm) after mustard

Treatments	OC (g/kg)			Cd			Co		
	0-15	15-30	30-45	0-15	15-30	30-45	0-15	15-30	30-45
Control (NPK)	2.86	2.30	1.80	0.08	0.16	0.09	0.18	0.24	0.23
10 t F	4.10	2.30	1.90	0.89	0.23	0.12	0.29	0.42	0.33
10 t F + 2.5 t SS	4.35	2.50	2.10	1.35	0.23	0.15	0.31	0.44	0.28
10 t F + 5.0 t SS	4.57	2.70	2.30	1.33	0.23	0.18	0.32	0.43	0.29
10 t F + 10 t SS	4.62	3.10	2.30	1.58	0.26	0.21	0.33	0.42	0.33
10.0 t SS	4.23	2.40	2.20	1.43	0.26	0.19	0.32	0.45	0.36
20.0 t SS	4.45	3.00	2.20	1.91	0.28	0.23	0.34	0.46	0.37
LSD (P=0.05)	0.60	0.05	NS	0.44	NS	0.06	0.10	0.09	NS

manure and sewage sludge. These findings are in conformity with the work of Antolin *et al.* (2005) and Meena *et al*. (2006).

Heavy metals

The heavy metals contents of different depth of soil as influenced due to farmyard manure and sewage sludge application after pearlmillet–mustard cropping sequence are presented in Table 3 and 4. It was clearly observed that the contents of DTPA-extractable heavy metals *viz.* Cd and Co were significantly increased due to application of sewage sludge with or without farmyard manure at different depths at the end of the sequence. The contents of heavy metals were increased with increase in rates of sewage sludge application. Application of sewage sludge @ 20 tonnes/ha recorded maximum values of DTPA-heavy metals at all the soil depths. The accumulation and released of Cd in sludge amended soils under varying moisture and temperature were reported by Golui *et al.* (2015). In case of Cd, the highest value was recorded at 0-15 cm (1.91 mg/kg), 15-30 cm (0.28 mg/kg) and 30-45 cm (0.23 mg/kg) under sewage sludge @ 20 tonnes/ha application.

The Co content in soil also increased with increase in rate of sewage sludge application. Similarly farmyard manure application enhanced overall contents of Co over control at different soil depths. The similar trend was observed with other heavy metals (Ni, Pb and Cr) due to application of sewage sludge and farmyard manure in different soil layers. The correlation coefficient also confirmed the positive association of organic carbon with DTPA-Cd (r = 0.842**) and Co (r = 0.951**). The similar results were in case of Ni, Pb and Cr after mustard. These results are in agreement with those reported by Chaudhuri *et al.* (2003) and Usman *et al.* (2004). In general, the external addition of metal in water soluble form finds its way towards the pool which is more easily enriched. Time becomes a factor for relative distribution of heavy metals among the fractions. Accordingly, relatively wider changes in per cent distribution in different forms of heavy metals after mustard could be attributed to less time available for equilibrium.

Bulk density

The results of soil physical properties *viz*., bulk density (BD) and hydraulic conductivity as influenced by the treatments are presented in Table 5. The BD of surface soil was reduced due to farmyard manure and sewage sludge applied to *kharif* pearlmillet. A significant reduction

Table 4: Effect of farmyard manure and sewage sludge on DTPA-heavy metals (mg/kg) distribution at different soil depth (cm) after mustard

Treatments	Ni			Cr			Pb		
	0-15	15-30	30-45	0-15	15-30	30-45	0-15	15-30	30-45
Control (NPK)	0.40	0.31	0.22	0.85	0.19	0.25	1.02	1.41	0.85
10 t F	0.44	0.45	0.32	1.53	1.33	0.47	1.49	1.55	1.58
10 t F + 2.5 t SS	0.47	0.45	0.32	1.29	1.29	0.47	1.75	1.70	1.70
10 t F + 5.0 t SS	0.39	0.42	0.37	1.32	1.32	0.43	1.71	1.75	1.55
10 t F + 10 t SS	0.48	0.43	0.37	1.37	1.34	0.24	1.95	1.53	1.62
10.0 t SS	0.48	0.44	0.36	2.31	1.39	0.49	1.94	1.61	1.51
20.0 t SS	0.48	0.47	0.44	2.53	1.55	0.51	1.99	1.82	1.60
LSD (P=0.05)	NS	0.10	0.15	0.68	0.45	0.22	0.65	NS	0.62

Table 5: Effect of farmyard manure and sewage sludge on surface soil properties (0-15 cm) after mustard

Treatments	Physical		Biological		
	BD (Mg/m^3)	HC (cm/hr)	MBC (µg/g)	MBN (µg/g)	DHA(µg TPF/g/24 hr)
Control (NPK)	1.40	1.42	213	33.4	8.7
10 t F	1.36	1.62	311	50.7	11.4
10 t F + 2.5 t SS	1.34	1.65	366	58.5	12.0
10 t F + 5.0 t SS	1.32	1.68	356	57.0	12.4
10 t F + 10 t SS	1.29	1.72	337	54.6	11.9
10.0 t SS	1.35	1.61	263	45.3	10.6
20.0 t SS	1.33	1.69	242	41.7	9.2
LSD (P=0.05)	0.04	0.10	35	4.8	0.7

in BD was observed under the highest rate of sewage sludge @ 20 tonnes sewage sludge/ha (1.33 Mg/m^3) followed by 10 tonnes farmyard manure + 5.0 tonnes sewage sludge/ha (1.32 Mg/m^3) over NPK (1.40 Mg/m^3), while the effect of farmyard manure alone was non-significant. Further, the maximum reduction in BD was noticed under 10 tonnes farmyard manure + 10 tonnes sewage sludge/ha (1.29 Mg/m^3) which was at par with rest of treatments, while maximum BD was recorded under NPK (1.40 Mg/m^3) treatment. Application of farmyard manure and sewage sludge increased organic carbon and aggregate stability, resulting in a decrease in the BD of soils. This has been confirmed by significant negative correlation between organic carbon and BD of soil (r= -0.752*). Reduction in BD due to sewage sludge application has earlier been reported by Veeresh *et al.* (2003).

Hydraulic conductivity

Addition of organic matter reduces bulk density and thereby increases macro and micro pores of soil, which improve the hydraulic conductivity of soil. The results given in Table 5 showed that application of 10 tonnes farmyard manure + 10 tonnes sewage sludge/ha caused significantly higher saturated hydraulic conductivity of soil (1.72 cm/hr) than NPK (1.42 cm/hr). The highest improvement in saturated hydraulic conductivity was by 21 per cent recorded under 10 tonnes farmyard manure + 10 tonnes sewage sludge/ha over control, which was on par with other farmyard manure and sewage sludge combinations.

In general, saturated hydraulic conductivity of soil increased with increasing rates of farmyard manure and sewage sludge application. The farmyard manure application also significantly increased saturated hydraulic conductivity over control as revealed from the data given in Table 5. This has been proved by the significant negative correlation between bulk density and saturated hydraulic conductivity (r = -0.914**). Garcia *et al.* (2005) and Moffet *et al.* (2005) reported that the addition of organic matter reduces bulk density and thereby increases macro and micro pores of soil, which improve the saturated hydraulic conductivity of soil.

Soil microbial biomass

Microbial biomass carbon (MBC) and microbial biomass nitrogen (MBN) constitutes a transformation matrix for organic matter in a soil and act as an active reservoir for plant available nutrients. Microbial biomass carbon responds much more rapidly than does the total organic matter to any change in eco-system and thus, its measurement is a valuable tool for understanding and predicting the effect of farmyard manure and sewage sludge. It is well known fact that addition of farmyard manure or any organic material changes microbial population in the soil. The results of this study (Table 5) revealed that MBC and MBN were significantly influenced by farmyard manure as well as sewage sludge applied to *kharif* pearlmillet. The improvement in MBC and MBN was by 72 and 75 per cent, respectively due to 10 tonnes farmyard manure + 2.5 tonnes sewage sludge/ha over NPK (213 and 33.4 µg/g, respectively) which was at with other combinations of farmyard manure and sewage sludge.

The MBC and MBN were significantly decreased under sewage sludge application alone over combined application at all the rates of application. In an evaluation of the effect of sludge on the biomass, Chander and Brookes (1991) reported that the microbial biomass decreased in soils treated with sludge that was rich in heavy metals and that the reduction was greater in sandy than in clayey soils. Similar results were also observed by Khan and Scullion (2000).

Soil enzymatic activity

Dehydrogenase is a metabolic enzyme used to measure the metabolic activity of soil biomass. It is reflects the total range of oxidative activity of soil microflora and consequently may be a good indicator of microbial activity. The sewage sludge and farmyard manure increased dehydrogenase activity (DHA) during the experiment at maturity stage of mustard under pearlmillet–mustard sequence during 2006-07. The DHA values ranged from 8.7 to 12.4 µg TPF/g soil/24 hr in the surface soil due to the different treatments. The DHA values significantly differed due to sewage sludge with or without farmyard manure and the effect of rates was at par. The highest improvement (77%) in DHA was recorded under 10 tonnes farmyard manure + 10 tonnes sewage sludge/ha, which was at par with other combinations of sewage sludge and farmyard manure. The results also indicated that sewage sludge application without farmyard manure caused less increase in DHA (10%) under 20 tonnes sewage sludge/ha as shown in Table 5. Several anthropogenic factors might affect enzymatic activity in the soil, and the major problems would be associated with the presence of heavy metals, salts and pesticides, which are components of sewage sludge (Gianfreda and Bollag, 1996).

Yield and quality of crops

Grain and straw yield of pearlmillet was affected significantly due to farmyard manure and sewage sludge application. The highest grain yield was observed under the treatment 10 tonnes farmyard manure + 10 tonnes sewage sludge/ha (1.16 tonnes/ha) and the percentage improvement over control (0.70 tonnes/ha) was upto 66. However, it was comparable with that of 10 tonnes farmyard manure + 5 tonnes sewage sludge/ha (1.13 tonnes/ha). Application of farmyard manure or sewage sludge alone also increased the grain yield significantly over control (Table 6). The results indicated that farmyard manure + sewage sludge application could supply more of the nutrients to plants for better growth and yield (Gondek, 2005). The straw yield was also improved significantly over control due to combined application of farmyard manure and sewage sludge, like grain, the highest straw yield (2.91 tonnes/ha) was noted with the application of 10 tonnes farmyard manure + 10 tonnes sewage sludge/ha and the percentage improvement over control was to the tune of 38. This was followed by that of 10 tonnes farmyard manure + 2.5 tonnes sewage sludge/ha (2.72 tonnes/ha). The increase in yield of crops due to farmyard manure and sewage sludge application has also been reported by some other workers (Antolin *et al.*, 2005 and Mohammad and Athamneh, 2004).

The maximum improvement in mustard seed yield was by 18 per cent under 10 tonnes farmyard manure + 10 tonnes sewage sludge/ha over control (1.47 tonnes/ha) followed by 10 tonnes farmyard manure + 5 tonnes sewage sludge/ha (1.71 tonnes/ha). The results revealed that yield improvement was higher when sewage sludge was applied together with farmyard manure than their sole application. The effect of the treatments on straw yield also depicted similar trend where highest yield (5.42 tonnes/ha) was recorded under 10 tonnes farmyard manure + 10 tonnes sewage sludge/ha treatment followed by 10 tonnes farmyard manure + 5 tonnes sewage sludge/ha. Application of farmyard manure and sewage sludge were found beneficial in improving mustard straw yield over NPK (4.40 tonnes/ha). The beneficial effect of farmyard manure and sewage sludge application in improving mustard yield has been reported by several workers (Maiti and Singh, 2003 and Khan *et al.*, 2003).

The oil and protein contents of pearlmillet grain were significantly increased with farmyard manure and sewage sludge application. The highest value of oil (5.97%) was recorded with 10 tonnes farmyard manure + 10 tonnes sewage sludge/ha, while the minimum was under NPK

Table 6: Effect of farmyard manure and sewage sludge application on yield and grain quality of crops (Pooled of two years)

Treatment	Pearlmillet				Mustard			
	Yield (t/ha)		Oil	Protein	Yield (t/ha)		Oil	Protein
	Grain	Stover	(%)	(%)	Seed	Stover	(%)	(%)
Control (NPK)	0.70	2.11	4.69	6.54	1.47	4.40	37.00	16.18
10 t F	0.95	2.34	5.50	9.58	1.62	5.20	36.95	23.42
10 t F + 2.5 t SS	1.04	2.72	5.59	11.87	1.69	5.31	37.05	23.91
10 t F + 5.0 t SS	1.13	2.59	5.71	12.21	1.71	5.36	37.06	24.69
10 t F + 10 t SS	1.16	2.91	5.97	12.13	1.73	5.42	37.01	26.40
10.0 t SS	0.92	2.62	5.50	10.91	1.63	5.09	36.84	23.71
20.0 t SS	0.93	2.63	5.08	10.51	1.59	5.09	36.82	22.66
LSD (P=0.05)	0.08	0.43	0.26	1.56	0.07	0.41	NS	2.59

(4.69%). In case of protein content of grain, 10 tonnes farmyard manure + 5 tonnes sewage sludge/ha treatment registered the maximum values of 12 per cent. Further, it was observed that the oil content in seed decreased with increasing level of sewage sludge when applied alone. Similar observations were made by Tsakou *et al.* (2001) in cotton where they observed detrimental effect of sewage sludge application on cotton seed oil content.

The application of farmyard manure and sewage sludge to the preceding crop of pearlmillet significantly increased oil and protein contents of mustard seed over control due to its residual effect. The lower oil (36.74%) content of seed was observed under sewage sludge @ 5 tonnes sewage sludge/ha application, while the higher oil content (37.06%) of mustard seed was noticed with 10 tonnes farmyard manure + 5 tonnes sewage sludge/ha. The oil content of mustard seed decreased with increasing level of sewage sludge alone. The protein content (26.40%) of mustard seed was significantly higher in 10 tonnes farmyard manure + 10 tonnes sewage sludge/ha and the percentage improvement over control (16.18%) was 63 (Table 6). The beneficial role of combined application of sewage sludge and farmyard manure in increasing leaf protein content of barley was earlier reported by Antolin *et al.* (2005).

Heavy metals concentration in crops

The analysis of grain and straw of pearlmillet and mustard for heavy metals (Cd, Co, Ni, Pb and Cr) content carried out in both the years to study the effect of treatments on accumulation of toxic metals in soil vis-à-vis their content in crops grain and straw revealed that there was a significant increase in contents of heavy metals in grain and straw of crops due to the treatments over respective control. The maximum values of metals content (Cd: 0.59, Co: 2.02, Ni: 5.79, Pb: 4.30 and Cr: 2.54 µg/g) in pearlmillet grain (Table 7) was under higher rate of sewage sludge *i.e.* 20 tonnes sewage sludge/ha. In general, the metal contents were comparatively higher in treatments of sewage sludge application alone followed by farmyard manure + sewage sludge treatments.

The residual effect of farmyard manure and sewage sludge on heavy metal content in mustard seed and straw was significant over control. The content of Cd and Co under 20 tonnes sewage sludge/ha was about 3 times higher in mustard seed than that recorded under control (Cd: 0.34 and Co: 1.15 µg/g) (Table 8). Similarly, the contents were also double in straw, respectively. Similar trend was also found in other metals in mustard. The values under treatment of farmyard manure + sewage sludge combinations were comparable with farmyard manure alone which indicated that heavy metal contamination in grain and straw of the test crops due to addition of sewage sludge @ 2.5 tonnes/ha along with farmyard manure application @ 10 tonnes/ha was at minimum risk.

The findings of the present investigation suggest that the sewage sludge could be a better source of nutrients besides organic matter for higher crop yields and quality, if applied at lower levels *i.e.* 2.5 or 5.0 tonnes/ha combined with farmyard manure at 10 tonnes/ha in pearlmillet-mustard sequence. The soil application of sewage sludge alone containing higher quantity of heavy metals viz., Cd, Pb, Ni, Cr and Co might pose serious threat in terms of contamination of soil-water-plant system to adversely affect crop growth and soil quality in a long run. Therefore, the sewage sludge could be utilized safely together with farmyard manure at lower rates (2.5 tonnes sewage sludge + 10 tonnes farmyard manure/ha) with regular monitoring of soil for higher crop yields and quality with a minimum risk to soil health.

Considering that agricultural use is the best option for

Table 7: Effect of farmyard manure and sewage sludge on heavy metal content in pearlmillet (Pooled of two years)

Treatment	Heavy metal (µg/g)									
	Cd		Co		Ni		Pb		Cr	
	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw
Control (NPK)	0.20	0.40	0.90	1.69	2.94	5.38	2.03	13.89	1.34	2.58
10 t F	0.33	0.48	1.38	2.17	4.62	6.45	3.58	15.00	1.68	4.21
10 t F + 2.5 t SS	0.42	0.50	1.45	2.63	4.93	5.83	3.62	15.46	2.01	4.91
10 t F + 5.0 t SS	0.47	0.60	1.53	3.02	4.96	7.64	3.92	15.62	2.03	5.49
10 t F + 10 t SS	0.46	0.66	1.66	2.51	5.49	8.90	4.30	15.37	2.28	5.56
10.0 t SS	0.56	0.56	1.93	2.98	5.12	6.50	3.99	15.84	2.37	5.87
20.0 t SS	0.59	0.79	2.02	3.28	5.79	6.62	4.47	15.63	2.54	6.18
LSD (P=0.05)	0.08	0.07	0.27	0.52	0.66	1.65	0.71	0.48	0.42	0.67

Table 8: Residual effect of farmyard manure and sewage sludge on heavy metal content in mustard (Pooled of two years)

Treatment	Heavy metal (µg/g)									
	Cd		Co		Ni		Pb		Cr	
	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw
Control (NPK)	0.34	0.61	1.15	2.37	5.32	6.25	12.5	13.6	5.21	9.3
10 t F	0.54	0.82	1.88	3.13	6.02	8.33	18.3	15.8	7.04	13.9
10 t F + 2.5 t SS	0.66	0.90	2.36	3.25	6.33	8.35	17.7	16.8	7.53	14.0
10 t F + 5.0 t SS	0.76	0.99	2.41	3.62	6.89	9.27	15.0	17.9	7.68	14.7
10 t F + 10 t SS	0.84	1.05	2.66	3.63	6.73	9.67	16.2	18.2	8.80	16.8
10.0 t SS	0.85	0.81	2.91	3.66	6.53	8.73	19.2	16.0	7.35	17.6
20.0 t SS	0.93	1.26	3.00	3.88	6.76	9.8	20.5	18.8	9.50	20.4
LSD (P=0.05)	0.14	0.17	0.35	0.51	0.66	0.74	3.3	2.0	1.9	3.6

sewage sludge disposal and having observed an increase in crop yield and quality of grain, soil fertility status, physical and biological properties (biomass C and N and soil enzymatic activity) improved under farmyard manure and sewage sludge application, we recommend that the amount of sludge must be calculated based on the heavy metal contents and application should not exceed soil capacity, returning to the same area not more frequently than alternate year. Finally, we stress the importance of this pioneer study with long-term effects of continued sewage sludge application under Indian conditions.

References

Antolin MC, Pascual I, Garcia C Polo A and Sanchez DM. 2005. Growth, yield and solute content of barley in soils treated with sewage sludge under semiarid Mediterranean conditions. *Field Crops Res* **94**: 224-237.

Beri V and Gupta AP. 2003. Recycling of rural and urban organic wastes-a review. Department of Soils, PAU, Ludhiana, pp. 103-105.

Blake GR and Hartage KH. 1986. Bulk density, in Methods of Soil analysis Part 1. A. Klute (ed.) Agronomy No.9 Ammarican Soceity of Agronomy, Madison, USA.

Brady NC and Weil RR. 2002. 13th Edition of The Nature and properties of soils. Published by Pearson Education Asia, pp. 819.

Chander K and Brookes PC. 1991. Microbial biomass dynamics during the decomposition of glucose and maize in metal-contaminated and non-contaminated soils. *Soil Biol Biochem* **23**: 917-925.

Chaudhuri D, Tripathy S, Veeresh H, Powell MA and Hart BR. 2003. Mobility and bioavailability of selected heavy metals in coal ash- and sewage sludge-amended acid soil. *Environ Geo* **44**: 419-432.

Garcia OF, Guerrero C, Mataix SJ, Navarro PJ, Gomez I and Mataix BJ. 2005. Factors controlling the aggregate stability and bulk density in two different degraded soils amended with biosolids. *Soil Tillage Res* **82**: 65-76.

Gianfreda L and Bollag JM. 1996. Influence of soil natural and antropogenic factors on enzyme activity in soil. In: Stotzky, G., Bollag, J.M. (Eds.), Soil Biochemistry vol. 9. M. Dekker, New Yark, pp.123-193.

Golui D, Datta SP, Rattan RK, Dwivedi BS and Meena MC. 2014. Predicting bioavailability of metals from sludge amended soils. *Environ Monit Assess* **186**: 8541–8553.

Golui D, Datta SP, Rattan RK, Dwivedi BS, Meena MC and Bandyopadhayay KK. 2016. Release of metals from sludge amended acid and alkaline soils under different levels of moisture and temperature. *Proc Natl Acad Sci, India Sec B: Biol Sci* **86**: 1037-1047.

Golui D, Datta SP, Rattan RK, Dwivedi BS, Meena MC and Bandyopadhayay KK**.** 2015. Release of zinc and cadmium from sludge amended soils as influenced by varying levels of moisture and temperature. *J Environ Biol* **36**: 979-984.

Gondek K. 2005. The influence of soil treatment by untreated and composted tannery sludge on yield, nutrient status, and chromium content in selected crops. *Plant Soil Environ* **51**: 179-192.

Gupta BR, Patak RK, Bhan S and Singh A. 1972. Effect of NPK on yield, nutrient uptake and quality of toria (*B. compestries* Var. toria). *Indian J Agron* **17**: 88-91.

Jackson, MC 1973. *Soil Chemical Analysis*, Prentice Hall, New Delhi.

Jenkinson DS and Powlson DS. 1976. The effect of biocidal treatments on metabolism in soil -1. Fumigation with chloroform. *Soil Biol Biochem* **8**: 167-177.

Khan MA, Rahim M and Ali S. 2003. Sewage sludge effect on soil fertility and yield of maize as compared to poultry litter, farmyard manure, and chemical fertilizers. *Pak J Arid Agric* **6**: 69-77.

Khan M and Scullion J. 2000. Effect of soil on microbial responses to metal contamination. *Environmental Pollution*, **110**: 115-125.

Klein DA, Loh TC and Goulding RL. 1971. A rapid procedure to evaluate dehydrogenage activity of soils low in organic matter. *Soil Biology and Biochemistry* **3**: 385-387.

Klute A and Dirkson C. 1986. Hydraulic Conductivity and diffusivity: Laboratory methods. In: Methods of Soil analysis. Part 1, Kulte, A. (ed.) Agronomy No.9 American Society of Agronomy, Madison, USA.

Lindsay WL and Norvell WA. 1978. Development of DTPA soil test for zinc, iron, manganese and copper, *Soil Science Society of American Journal* **42**: 421-428.

Maiti D and Singh A. 2003. Effect of sewage-sludge and heavy metals and their combinations on yield and content of Indian mustard (*Brassica juncea* L.). *Ann Agril-Res* **24**: 914-920.

Maiti PS, Sah KD, Gupta SK and Banerjee SK. 1992. Evaluation of sewage and sludge as a source of irrigation and manure. *J Indian Soc Soil Sci* **40**: 168-172.

Meena MC, Patel KP and Rathod DD. 2006. Effect of Zn and Fe enriched FYM on mustard yield and micronutrients availability in loamy sand soil (Typic Haplustept) of Anand. *J Indian Soc Soil Sci* **54**: 495-499.

Meena MC, Patel KP, Dhyan-Singh and Dwivedi BS. 2008. Long-term effect of sewage sludge and farmyard manure on grain yields and availability of zinc and iron under pearlmillet (*Pennisetum glaucum*)-India mustard (*Brassica juncea*) cropping sequence. *Indian J Agric Sci* **78**: 1028-1032.

Meena, MC, Patel, KP and Ramani VP. 2013. Effect of FYM and sewage sludge application on yield and quality of pearl millet-mustard cropping system and soil fertility in a Typic Haplustept. *J Indian Soc Soil Sci* **61**: 55-58.

Moffet CA, Zartman RE, Wester DB and Sosebee RE. 2005. Surface biosolids application: effects on infiltration, erosion, and soil organic carbon in Chihuahuan Desert grasslands and shrublands. *J Environ Qual* **34**: 299-311.

Mohammad MJ and Athamneh BM. 2004. Changes in soil fertility and plant uptake of nutrients and heavy metals in response to sewage sludge application to calcareous soils. *J Agron* **3**: 229-236.

Parat C, Chaussod R, Leveque J, Andreux F. 2005. Long-term effects of metal-containing farmyard manure and sewage sludge on soil organic matter in a fluvisol. *Soil Bio Biochem* **37**: 673-679.

Patel KP and George V. 2005. National Seminar on "Developments in Soil Science-2005" from Sept.,28-Oct.,1, 2005 held at TNAU, Coimbatore,

Rattan RK, Datta SP, Suresh-Chandra and Neelam-Saharan 2002. Heavy metals and environmental quality-Indian scenario. *Fertiliser News* **47**: 21-26.

Tsakou A, Roulia M and Christodoulakis NS. 2001. Growth of cotton plants (*Gossypium hirsutum*) as affected by water and sludge from a sewage treatment plant: II. Seed and fiber yield and heavy metal accumulation. *Bullet Environ Contam Toxicol* **66**: 743-747.

Usman ARA, Kuzyakov Y and Stahr K. 2004. Dynamics of organic C mineralization and the mobile fraction of heavy metals in a calcareous soil incubated with organic wastes. *Water, Air Soil Poll* **158**: 401-418.

Veeresh H, Tripathy S, Chaudhuri D, Ghosh BC, Hart BR and Powell MA. 2003. Changes in physical and chemical properties of three soil types in India as a result of amendment with fly ash and sewage sludge. *Environ Geo* **43**: 513-520.

Walkley A and Black IA. 1934. An experimentation of the Degtjareff method for determination soil organic matter, and a proposed modification of the chromic acid titration method. *Soil Sci* **37**: 29-38.