PERIODIC MUNICIPAL COMPOST AND SEWAGE SLUDGE APPLICATION ON ACCUMULATION OF HEAVY METALS IN SOIL AND PLANTS

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ABSTRACT

In arid region, land applications of organic matter, in the form of compost and sewage sludge improve soil physical and chemical properties; and provide a mean for disposal of them. However, the possibility of contamination of arable lands by heavy metals from municipal compost and sewage sludge should be study. Municipal compost and sewage sludge are heterogeneous organic matters that include residual of various disposed materials. The possibility of the presence of heavy metals in municipal compost and sewage sludge even in small quantity increase the risk of soil and plant contamination. A field study carried out in Rodasht Agricultural Research Station, to determine the effects of compost and sludge application on soil and plants. In, a four years sugarbeet, corn, onion and wheat rotation, the effects of the municipal compost and sewage sludge, on accumulation of heavy metals in soil and plant were studied, in a randomized complete block design with three replications. The amendment treatments were two compost rates (25, 50 Mg ha^{-1}) and two sludge rates (15, 30 Mg ha^{-1}) and a check (none). The results showed that application of 50 Mg ha^{-1} compost produce the highest yields, and the other treatments, except 15 Mg ha^{-1} sludge ranked next. However, the highest biological yield produced by 50 Mg ha^{-1} sludge application. The continuous amendment application during the experiment improved soil chemical fertility. The highest available P and K were resulted from the highest level of sludge and compost application rates, respectively. Compost application sharply increased Pb concentration. In 50 Mg ha^{-1} compost treatments, Fe concentration was the highest and in sludge (30 Mg ha-1), soil Cu and Zn reached to the highest level during experiment. Finally, no clear trends of heavy metal accumulation found due to addition of soil amendments.

Keywords: municipal, compost, sewage, heavy metals, sugarbeet, corn, onion, wheat

INTRODUCTION

Composts are different in chemical characteristics. The pH, salinity, maturity and stability, and physical properties, are among characteristics for determination of compost quality (Robin et al., 2001). The various component of municipal solid waste are not only consist of animal and plants residue but, is a heterogeneous material which all of the components are not compostable (Dalzell et al., 1987). Compost may contain mineral and heavy metals that bring about soil contamination and salinity (Chang et al., 1984; ARAR, 1985). One of the most important characteristics of compost and sludge equality is the quantity and the chemical forms of heavy metals (Dalzell et al., 1987). Utilization of compost with high level of heavy metals for agricultural production lead to accumulation of heavy metals in soil and plant, and consequently endanger public health after incorporated into human food chain. Cortellini (1999) reported that in a wheat-corn-sugarbeet rotation, application of compost increased the Zn and Cu concentrations in wheat grain, and sugar-beet roots, respectively. However, Cd, Cr, and Ni concentration did not change.

For prevention of environmental pollution, due to heavy metals and salinity permissible concentration level of heavy metals and maximum allowable compost and sludge application rates in agricultural land have been setups (ARAR, 1985; Chang et al., 1984; Davies et al., 1991; Pescod, 1992). Even with many desirable results, the microbial, chemical, and physical properties of compost and sludge are checked for prevention of harmful effects on soil and agricultural products. The objectives of this experiment were (i) determination of heavy metal concentration in compost and sludge, (ii) effect of periodic compost and sludge application on the accumulation of heavy metals in soil.

MATERIALS AND METHODS

A field experiment was initiated in 1999 to study the effect of compost and municipal sewage sludge application on plants and soil concentrations of heavy metals in a 4- years sugarbeet-corn-onion and wheat rotation. Permanent plots were established, in Roduast Agricultural Experiment Station (32^{o}22' N, 52^{o}11' E; 1200 m elevation) in the old alluvial flood plane of Zayandeh-Roud River on silty clay loam soil. The soil series is Zarandid (fine mixed, Hypertermic, Typic Haplocambid) and a pH of 7.5. The Zarandid series is a deep, moderately drained soils formed in the old alluvial planie of Zayanded-Roud river. Permeability is moderately rapid through out the in the upper part of soil profile. The soil physical and chemical properties at the experimental site are given in table I and II, respectively. The results show that the soil is low in organic matter, with moderate salinity and, pH is slightly alkaline.

Two compost rates of 25 and 50 Mg ha^{-1} (C1, C2) and two sludge rates of 15 and 30 Mg ha^{-1} (S1, S2) and check (no amendment) organized into a randomized complete block design experiment with three replications. The plot size was 10 by 4 meter.

After plots leveling, five random soil sub samples from 0-30 cm were collected and composite. Soil amendments were uniformly hand-applied using shovels and incorporated into 0-25 cm soils depth by a disk cultivator. Fertilizers application were according to the soil test recommendation (Iranian Soil and Water Research Institute) based on the check plot soil test results, with N, P and K in the forms of Urea, Superphosphate triple, and Potassium Sulfate, respectively. The sugarbeet, were sown in April. Irrigation management, pest and weed control and, other cultural practices were typical of commercial practices. At the end of growing season (November), the plant was separated into shoot and roots and was analyzed for heavy metals. Shortly after every crop harvest, soil samples from 0-30 cm collected from each plot, and analyzed for Pb, Cd, Fe, Zn, and Mn, shortly after each crop harvest. Soil samples were air-dried, ground to pass a 2-mm sieve, and analyzed for selected soil parameters. In the following spring the plots were plowed, soil amendment were uniformly applied and incorporated into soil. The second year rotation plant was silage corn. Amendments were applied the same as previous growing season. The third-year crop rotation was onion, but amendments were not applied. The onion sown in early-April and harvested in mid-October. Onion-bulbs and top were sample in each plot.

Winter wheat was sown in mid-November and harvested in mid-June. Grain and straw yields were determined in a 4 by 4 meter area. Composite compost and sludge samples were collected, and analyzed for EC_e, micronutrient, macronutrient, and heavy metals; using standard laboratory methods in each stage of amendment application.

RESULTS AND DISCUSSION

Table I shows the characteristic of compost and sludge and the rotation crops from 2000 to 2004. In 2002, onion planted without amendment application. According to table III, compost and sludge are rich sources of plant nutrient. The EC_e of compost is considerable higher than sludge. In the early growing season, application of sludge compare with compost and check enhanced the vegetative growth and plant vigor. It may have been the results of lower EC_e and higher nutrients availability in sludge treatment compared with compost at the beginning of growing season. However, toward the mid growing season in the compost treatments, plant growth and vigor was higher than sludge amendment treatments, most likely due to improvements of soil physical and chemical properties.

The compost and sludge application increased the soil organic mater content (table II), and the effect of soil amendment application were significant. The differences between the amendments type and application rate were not significant, for most of rotations. Wheat and corn increased soil organic matter compare with onion, which may be due to higher wheat and corn root mass compare with onion.

3.1. First year, sugarbeet 2000

Plant: The effect of amendment on root and top Zn were only significantly higher in S2 treatment than check (Appendix 1).

Soil: The results of soil analysis after harvesting sugarbeet are given in table IV. The effect of amendment application on Mn and Cd were not significant. The Pb, Cu, Fe, and Zn concentration were significantly *($P<0.05$)* higher in C2 and S2 treatment than check. The Pb concentration in C1 treatment was significantly higher than check.

3.2. Second year, corn silage 2001

Plant: The Pb and Cd concentration of leaf, stem, grain, and root were below the instrument detection level (Appendix 1).

Soil: The result of soil Pb, Cu, Fe and, Zn analysis are given in table IV. The Cu and Zn concentration in S2 treatment is significantly higher than other treatments. However, soil Pb concentration is significantly higher in compost compare with sludge or check treatments. Compost and sludge application did not significantly affect Mn and Cd concentrations in soil.

3.3. Third year, onion 2002

Plant: The effect of treatments on onion–bulb Fe, Mn, Zn and concentrations are given in Appendix 1. Only onion-bulb Fe and Zn concentrations were significantly affected by soil amendments.

Soil: The effect of amendment levels on heavy metals concentration were more than amendment types. The highest Zn concentration was found in C2 but was not significantly different from S2 treatment. Zn concentration in S1 and C1 were not significantly different. Considering the compost and sludge Zn concentration (390 vs. 662) and, application rates (50 vs. 30) the total Zn for compost and sludge application are similar (19500 vs. 1986). The Mn and Cd concentrations were not, and Pb, Cu, Fe and, Zn were significantly affected by amendments. Pb concentration in C2, S2, and C1 were similar and significantly different from S1 and check. The S2 resulted in greatest Cu, followed by S1, C1. The Cu concentration in sludge is six times greater than compost. Fe concentration in S2 and C2 are similar. The effects of soil amendments on Zn concentration were significant and separated into four groups ($p<0.05$). The S2 resulted in the highest Zn concentration, followed by S1 and C2 then by C1, and finally the check, respectively. There was no difference between S1 and C2, and C1 resulted in higher Zn than check. Even though, the Zn addition for C2 and S2 are similar, the S2 heavy metals concentration is higher than C2, which may be due to lower sludge pH, which increase the solubility of heavy metals.

3.4. Forth year, wheat 2003

The EC_e of compost is considerably higher than sludge. At the beginning of the growing season, growth vigor in sludge treated soil was higher than compost, and check. However, the plant growth in compost treatments exceeded sludge treatments toward the end of growing season.

Plant: The results of wheat grain, straw, and roots analysis show that the highest grain macronutrient concentrations (N, P, and K) were in sludge treated soil, but the micronutrient concentration did not show any specific trend (Appendix 1). For wheat straw, only P concentration is significantly higher in S1, and other macronutrient does not show any specific trends. In roots, the highest concentrations of N and P observed in S1 and S2, and the macronutrients concentrations did not follow any specific trend. In none of plant parts, Cd and Pb concentration were in the detectable range of instruments (Appendix I).

Soil: In 2003, the soil Cd was not significantly affected and Pb, Cu, Mn, Fe, and Zn were significantly ($P<0.05$) affected by amendment application, respectively (table IV). The Pb concentrations in C1 and C2 treatment are similar, and are significantly different from Check. The Mn, Fe, and Zn were significantly affected by amendment, but their concentrations were not effected by type and amount of amendment. The Cu concentration was effected by amendment type, and is higher for sludge then compost treatments.

CONCLUSION

The municipal compost and sewage sludge application increase the soil organic matter content. However, the high concentration of heavy metals especially Pb in compost and sludge shows a corresponding increase in soil. In none of the treatments, the plant Cd and Pb concentrations have increased above permissible levels of 5 to 30 and 20 to 100 mg kg^{-1} soil, respectively (Allaway, 1990; Pendias and Pendias, 1992). Monitoring the changes in soil pH and concentration of heavy metals are necessary for application of compost and municipal sludge.

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Table I. Soil physical properties at the experimental site.

Soil depth (cm)	Soil texture	FC (g g^{-1})	PWP (g g^{-1})	□b
00-20	clay loam	30.3	15.6	1.4
20-40	clay loam	32.2	16.0	1.3
40-60	Clay loam	33.0	18.0	1.4
60-80	clay	39.4	19.0	1.34

FC = Field capacity
PWP= Permanent wilting point
r_b = bulk density

Table II. Soil chemical properties at the experimental site.

Soil property		Depth (cm)		
		0-20	20-40	40-60
EC_e	(dS m^{-1})	6.2	5.2	5.9
SP	(g g^{-1})*100	46	47	52
pH		7.6	7.6	7.7
Na^+	(me l^{-1})	27	21	34
Ca^{2+}+Mg^{2+}	(me l^{-1})	55	51.2	50
So4^{2-}	(me l^{-1})	51	53	67.4
Cl^-	(me l^{-1})	27.4	14.4	11.8
Hco3$^-$	(me l^{-1})	2.9	2.8	2.6
Gypsum	(me 100 g soil^{-1})	65	80	35
Exchangeable Na	(me 100 g soil^{-1})	2.6	2.1	3.0
CEC	(me 100 g soil^{-1})	14.5	14	17
SAR	(me l^{-1})$^{1/2}$	5.2	4.2	6.8
ESP	Percent	18	15	17.6

SP = saturated percent

TABLE I

Characteristics of applied compost and sludge amendments from 2000 to 2003 period.

Amendment characteristic	2000 - sugar-beat		2001 - corn silage		2003 - wheat	
	compost	sludge	compost	sludge	compost	sludge
EC_e, dS m^{-1}	20.8	8.2	23	16	18.8	7.5
PH	7	7.2	6.9	6.3	7.1	7.2
N, %	2.47	1.46	1.42	3.31	1.2	2.7
P, %	0.92	0.25	0.11	0.45	0.4	0.4
K, %	0.27	1.75	1.1	0.35	1	0.6
Na, %	0.22	0.69	1.01	0.18	nd	nd
Ca, %	4.6	5.1	nd*	Nd	4.2	4.8
Mg, %	0.67	0.62	nd	Nd	0.65	0.61
Fe, mg kg^{-1}	9240	6260	7500	10000	1240	1144
Mn, mg kg^{-1}	349	352	268	244	194	144
Zn, mg kg^{-1}	1212	492	390	622	158	184
Cu, mg kg^{-1}	564	156	158	636	156	490
Pb, mg kg^{-1}	134	134	80	100	12	12

* Not detectable

TABLE II

The effect of compost and sludge application rates on organic matter content of soil in the 0-30 cm soil depth.

Year, crop in	Check	compost		Sludge	
	0	25	50	15	30
	Mg ha^{-1}				
	O.C. %				
corn silage, 2001	0.62b	0.86a	0.86a	0.83a	1.01a
Onion, 2002	0.5c	0.6bc	0.67ab	0.67ab	0.77a
Wheat, 2003	0.85b	1.07ab	1.11ab	0.95ab	1.14a

TABLE III

Effect of compost and sludge application rates on concentrations of Pb, Cu, Mn, Fe, and Zn, in 2000- 2003, in 0-30-cm soil depth at harvest time.

Year, crop in rotation	Element	check	compost		Sludge	
		0	25	50	15	30
		------------------------------ Mg ha^{-1} ------------------------------				
2000, sugar-beat	Pb, mg kg^{-1}	1.98c	2.9b	2.72a	2.2bc	2.8b
	Cu, mg kg^{-1}	1.8c	2.4bc	2.8b	2.2bc	6.8a
	Fe, mg kg^{-1}	5.8c	7.6abc	8.8a	6.1bc	8ab
	Zn, mg kg^{-1}	1.11c	2.5bc	5.5b	2.11c	9.2a
2001 corn silage	Pb, mg kg^{-1}	2b	3.47a	3.53a	2.40b	2.67b
	Cu, mg kg^{-1}	1.53c	277bc	2.63bc	4.18b	8.27a
	Fe, mg kg^{-1}	5.60c	8.07ab	7.87ab	7.33bc	9.93a
	Zn, mg kg^{-1}	0.2c	3.29b	3b	3.62b	11.60a
2002 onion	Pb, mg kg^{-1}	1.3c	2abc	2.9a	1.6bc	2.5ab
	Cu, mg kg^{-1}	1.7d	2.3cd	2.9bc	3.8b	6.4a
	Fe, mg kg^{-1}	7b	8.2b	9bc	8.6b	10.7a
	Zn, mg kg^{-1}	0.6d	1.7c	2.7b	2.6b	4.5a
2003 wheat	Pb, mg kg^{-1}	1.6c	3.9ab	4.9a	2.6bc	2.89bc
	Cu, mg kg^{-1}	1.6c	3.5c	4.2bc	6.8b	9.96a
	Mn, mg kg^{-1}	5.2b	7.0ab	8.3a	7.7a	6.8ab
	Fe, mg kg^{-1}	7.0b	11.8a	11.7a	11.1a	12.7a
	Zn, mg kg^{-1}	0.4b	4.8a	5.9a	5.7a	8.1a

For each year, within rows, means followed by the same letter are not significantly different by Duncan multiple test at $p < 0.05$.

Appendix I

Effect of compost and sludge application rates on sugarbeet, corn, onion and wheat heavy metal concentration.

Year, crop in rotation	Element	check	compost		Sludge	
		0	25	50	15	30
		Mg ha^{-1}				
2000, sugar-beet	Roots					
	Fe, mg kg^{-1}	86.3	104.3	122	136	212
	Mn, mg kg^{-1}	420.5	59.5	50	38	39.6
	Zn, mg kg^{-1}	8.3	10.1	12.5	14	19.7
	Cu, mg kg^{-1}	5.7	5	5	6.5	6.6
	Tops					
	Fe, mg kg-1	226	238	290	234	198
	Mn, mg kg^{-1}	96	103	203	183	186
	Zn, mg kg^{-1}	21	32	56	121	64
	Cu, mg kg^{-1}	5	6	8	8.6	8
2001, corn silage	Leaf and Stem					
	Fe, mg kg^{-1}	75	154.7	232	153.3	170
	Mn, mg kg^{-1}	87	102	189	83.3	109.3
	Zn, mg kg^{-1}	29	48	87	36	53
	Cu, mg kg^{-1}	6	6	6.67	6	6
	Ear					
	Fe, mg kg^{-1}	51.3	24.3	30	33	61
	Mn, mg kg^{-1}	22	18	18.32	18.6	18
	Zn, mg kg^{-1}	29.3	34	34	30.67	36.67
	Cu, mg kg^{-1}	8.67	6.67	8.33	10	7.33
	Roots					
	Fe, mg kg^{-1}	2543	2303	2370	2530	2650
	Mn, mg kg^{-1}	74	71	74	104	115
	Zn, mg kg^{-1}	23	24	36	32	26
	Cu, mg kg^{-1}	13	12	15.3	12	21

Appendix I- continue ……..

Year, crop in rotation	Element	check	compost		sludge	
		0	25	50	15	30
		---------------------------- Mg ha^{-1}				
Onion, 2002	Bulb					
	Fe, mg kg^{-1}	4.2a	20.0b	2.70ab	2.3b	2b
	Mn, mg kg^{-1}	1.0a	0.8a	1a	1.2a	1.13a
	Zn, mg kg^{-1}	2.1b	1.9b	3.7a	2.3b	3.23ab
	Cu, mg kg^{-1}	0.7a	0.57a	0.53a	0.87a	0.83a
	Shoot					
	N, (%)	1b	1.15ab	1.17ab	1.0b	1.4a
	Fe, mg kg^{-1}	78.3a	65a	62a	67.7 a	70.7a
	Mn, mg kg^{-1}	38.6a	26a	36.7a	32.7a	32a
	Zn, mg kg^{-1}	10.87b	15a	14a	14.3a	15.3a
	Cu, mg kg^{-1}	5a	5.1a	3.8a	5.4a	4.4a
Wheat, 2003	Grain					
	Fe, mg kg^{-1}	186.8a	129.6a	146.2a	115.8a	169.6a
	Mn, mg kg^{-1}	55.13a	46.9a	51.8a	51.3a	63.7a
	Zn, mg kg^{-1}	12.6b	22.9ab	38.3a	33.6ab	43.9a
	Cu, mg kg^{-1}	7.7a	3.4bc	6.1ab	2.5bc	1.2c
	Shoot					
	Fe, mg kg^{-1}	235.1a	204.7a	199.3a	159. 9a	179.5a
	Mn, mg kg^{-1}	2.7ab	14.7b	12.2b	28.3a	18.6ab
	Zn, mg kg^{-1}	8.8a	11.3a	9.7a	8.9a	6 a
	Fe, mg kg^{-1}	235.1a	204.7a	199.3a	159.9a	179.5a
	Roots					
	Fe, mg kg^{-1}	21340a	20373a	13067a	7356a	18033a
	Zn, mg kg^{-1}	32.2a	61.1a	39.8a	31.9a	56.9a
	Cu, mg kg^{-1}	42.86a	40.0ab	31.2ab	23.2b	55.5a
	Fe, mg kg^{-1}	21340a	20373a	13067a	7356a	18033a

For each year, within rows, means followed by the same letter are not significantly different by Duncan multiple test at $p < 0.05$.