EFFECTS OF MUNICIPAL WASTE COMPOSTS ON SOIL AND CROP HEAVY METALS IN GRASS CULTIVATION IN FINLAND

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ABSTRACT

Municipal waste composts, as potential soil improvers and sources of nutrients, were studied in conventional grass cultivation and in organic red clover-grass cultivation during 2000-2002 to determine the impacts on soil and plants of heavy metals in the compost. In both farming systems, a bio-waste compost and a bio-waste-sewage sludge compost were investigated and applied at two phosphorus fertilization levels in 2000. The cereal cover crop was harvested in 2000 and 2-3 cuts of grass were collected during 2001-2002. The composts were compared to mineral fertilizers in conventional farming and to cattle manure compost in organic farming. Compost, soil and plant samples were analysed for nutrients and heavy metals. The lowest metal input came from the mineral fertilizers and the second lowest from the cattle manure compost. During the three-year experiments, at the low rate of compost application the crops took up about 1-5% of the chromium and lead, 10-20% of the cadmium and nickel and 20-30% of the copper and zinc added with the composts. At the high rate of application, metal uptakes by the crops were about half of these. The remainder of the metals added with the compost accumulated in the soil.
Keywords: *bio-waste, sewage sludge, compost, heavy metals.*

INTRODUCTION

Municipal waste, after composting, might be used in agriculture as a soil improver and a source of nutrients in plant production. However, heavy metals in the waste composts added to the soil could be a risk to the food chain, human health and the environment. Therefore, this study aimed to investigate the effects of heavy metals in municipal waste composts on the quality of soil and on the metal uptake by the crops in grass cultivation in conventional and organic farming in Finland.

MATERIALS AND METHODS

All the field experiments were conducted during 2000-2002 in Eastern Finland. The experiments on grass cultivation in conventional farming were carried out in Mikkeli (fine sandy soil, pH 6.1, C 5.4%) and the experiments on red clover and grass cultivation in organic farming in Juva (fine sandy till, pH 6.5, C 3.0%). Soil samples were taken from the experimental fields before compost applications in spring 2000 and afterwards each autumn and spring. The municipal waste composts studied were bio-waste compost (BW) and bio-waste-sewage sludge compost (BWS). They were given in a single application in spring 2000 and compared to mineral fertilization (M) in the conventional farming and to cattle manure compost (CM) in the organic farming. A split-plot experimental design with phosphorus (P) fertilization level in the main plot and compost type in the sub-plot (four replicates) was used with a zero control (no fertilization). Compost samples were taken at the time of application. Two rates of compost application were tested and they corresponded to the two- and four-year P fertilization levels needed for grass or red clover-grass mixture established with a cereal cover crop. 75% of the total P in the composts was assumed to be plant-available. In the conventional farming, the low application rates of BW and BWS were 20 and 22 t/ha and the high application rates 40 and 44 t/ha, respectively. The amounts of nitrogen (N) added in these composts were 277 and 413 kg/ha at the low rate and 544 and 820 kg/ha at the high rate, respectively. In the organic farming, the application rates of CM, BW and BWS were 17, 23 and 9 t/ha at the low rate and 33, 45 and 18 t/ha at the high rate, respectively. The amounts of N added in CM, BW and BWS were 367, 257 and 126 kg/ha at the low rate and 720, 503 and 248 kg/ha at the high rate, respectively. No other nutrients were added in 2000. In 2001 and 2002, mineral N (250 kg/ha/year) and potassium (K) were supplied in the M treatment in the conventional farming. The cereal cover crop was harvested in 2000 and 2-3 cuts of grass and red clover-grass mixture were collected in 2001 and 2002. The crops were sampled at harvest.

Mineral N (ammonium N + nitrate N) in the compost and soil samples, which were stored frozen, were determined by extracting the samples with 2 M KCl and by measuring the concentrations from the extracts by a spectrophotometer (Mulvaney, 1996). After defrosting, the soil and compost samples were air-dried and sieved (particle size < 2 mm). The samples were analysed for N and carbon (C) content using a dry combustion method (Leco CN-2000 auto-analyser). A wet combustion (nitric acid) method was used for determination of the P and K contents. The measurements were made by ICP-AES. Compost and soil samples taken in spring and autumn 2000 were digested in *aqua regia* (ISO 11466). The cadmium (Cd) and lead (Pb) contents were determined by GFAAS, and the chromium (Cr), copper (Cu), nickel (Ni) and zinc (Zn) contents by ICP-AES. In addition, all the soil samples were extracted in acid ammonium acetate-EDTA (1 M ammonium acetate + 1 M acetic acid, pH 4.65, 1 h; 0.02 M EDTA). Heavy metals (HM) in the extracts were measured by ICP-AES. A wet combustion (nitric acid) method was used for the determination of Cd, Cr, Cu, Ni, Pb and Zn in plant samples and concentration measurements were made by ICP-AES (Huang & Schulte, 1985).

The statistical analyses were based on the SAS Mixed procedure. The differences between the treatments were reported only if the level of significance was higher than $p<0.05$. A normal distribution and an equality of variance were determined with univariate analysis. The zero control was not included in the analysis due to the structure of the experiment.

RESULTS AND DISCUSSION

The chemical characteristics of the composts at the time of application are presented in Table 1. The highest total content of P was in BWS, while the highest concentration of soluble P was in the CM. The total N content was roughly the same in the different composts, but the concentration of mineral N varied. CM contained much more K and a little more C than the other composts. The heavy metal contents of all four municipal waste composts were below the national limit values, but clearly higher than the metal contents of CM. The lowest metal contents of all the composts were in CM and the highest in BWS.

The lowest metal input came from the mineral fertilizers and the second lowest from the cattle manure compost (Table 2). The amounts of heavy metal added to the soil with the municipal waste composts were considerably higher than those added with the cattle manure compost or the mineral fertilizers. In both farming systems, heavy metal uptake by the harvest products (Table 2) was not markedly affected by the heavy metal doses supplied by the compost applications. During the three-year experiments, the crops took up about 1-5% of the Cr and Pb, 10-20% of the Cd and Ni and 20-30% of the Cu and Zn added in the composts at the low rate of application. At the high rate of compost application, the metal uptake percentages by the crops were about half of these.

***Table 1**. Chemical characteristics of the composts applied to grass in conventional farming and to red clover-grass mixture in organic farming in 2000 (BW = bio-waste compost, BWS = bio-waste-sewage sludge compost, CM = cattle manure compost, Tot = total, Min = NH_4-N + NO_3-N, Sol = soluble) and initial contents of total heavy metals in experimental soils prior to compost applications.*

	Nutrient concentration						pH	Heavy metal content					
	N		P		K	C	(H_2O)	Cd	Cr	Cu	Ni	Pb	Zn
	Tot	Min	Tot	Sol	Tot								
	g/kg DM							mg/kg DM					
Conventional													
BW	27	2.1	6.9	1.7	9.5	288	6.8	0.48	27	58	9	23	192
BWS	22	1.1	14	0.5	5.9	311	6.4	0.59	42	128	19	32	402
Organic													
CM	26	0.7	6.9	4.4	41	425		0.13	8	25	4	3	124
BW	25	2.2	5.2	2.5	9.9	315	6.9	0.35	20	44	8	37	197
BWS	24	1.8	12	0.4	4.4	304	6.4	0.58	45	150	22	34	433
Fine sandy soil (Conventional)								0.13	45	16	12	8	34
Fine sandy till soil (Organic)								0.20	18	22	8	8	82

In this study, only minor changes in the total contents of heavy metals in the soil were observed after compost applications. In conventional farming, the changes in the untreated zero control and M control were generally at the same level as the compost plots. The percentage changes were low on average, with at most 12% increases and 13% decreases being observed. In organic farming, the zero control and CM produced the same or even higher percentage increases as the waste composts, in particular for Cu, Ni and Zn. The percentage changes were generally low, with at most 13% increases and 20% decreases being observed. The total contents are not very sensitive to the metal doses supplied by a compost application. Instead, a better indicator might be the concentration of readily soluble metals in the soil. In conventional farming, BWS at the high rate of application significantly increased the soil concentration of soluble Zn. In organic farming, BW increased the soil concentrations of soluble Pb, Cd and Cu in some samples at the high rate of application. In this study, also decreases in the soil concentrations of soluble heavy metals occurred after compost applications.

CONCLUSIONS

This study showed that much more heavy metals were added to the soil with the municipal waste composts than with mineral fertilizers or cattle manure compost. Only a minor part of the heavy metals added was taken up by the harvest crops which means that a major part of the added metals remained in the soil. It appears that some immobilisation of soluble metals in the soil occurred after compost applications. Most probably this resulted from the increase in organic matter content in the soil after compost applications. Organic matter is known to immobilise effectively soluble heavy metals in soil. However, the metal mass balance in these soils seems to be positive. Long-term agricultural use of municipal waste composts would increase total contents of heavy metals in cultivated soils. Metal accumulation in soil is likely to gradually generate health and environmental risks. In order to guarantee the safety of agricultural products and to protect arable land, the heavy metal concentrations in composts and particularly heavy metal loading rates into the soil have to be followed up in detail both in conventional and organic farming.

***Table 2**. Amounts of heavy metals (g/ha) added to the soil by compost applications in 2000 and taken up by harvest products from grass in conventional and from red clover-grass mixture in organic farming during 2000-2002. Statistically significant differences in uptake are represented by different letters for each metal within P fertilization levels (* p<0.05, ** p<0.01, *** p<0.005).*

Conventional farming	Cd ***	Cr	Cu	Ni *	Pb	Zn	Cd *	Cr	Cu *	Ni *	Pb	Zn **
No fertilization												
Uptake	0.3	2.4	82	9	1.5	230						
	Phosphorus for 2 years						**Phosphorus for 4 years**					
Mineral NPK (M)												
Supply*	0.2	12	12	12	3.5	12	0.4	20	20	20	6	20
Uptake	1.0[a]	5	192	17[a]	3.2	558	1.0[a]	7	180[b]	18[a]	3.6	521[b]
Bio-waste compost (BW)												
Supply	5	284	602	98	241	1998	10	559	1184	193	474	3932
Uptake	0.8[b]	5	192	14[b]	3.1	547	0.8[b]	7	191	14[b]	3.5	573[b]
Bio-waste-sludge compost (BWS)												
Supply	11	775	2393	355	600	7499	22	1539	4751	705	1191	14886
Uptake	0.8[b]	5	193	15	3.2	563	0.8[b]	6	199[a]	14[b]	3.5	662[a]
*Based on maximum concentrations certified by producer												
Organic farming	**Cd**	**Cr** *	**Cu**	**Ni** *	**Pb**	**Zn**	**Cd** *	**Cr**	**Cu** *	**Ni** *	**Pb** *	**Zn** *
No fertilization												
Uptake	0.5	1.9	152	13	1.3	677						
	Phosphorus for 2 years						**Phosphorus for 4 years**					
Cattle manure compost (CM)												
Supply	1.9	105	343	59	40	1740	3.6	206	673	116	78	3411
Uptake	0.5	2.2[a]	140	11[b]	1.3	663	0.6[a]	2.1	138	10[a]	1.7[a]	695[a]
Bio-waste compost (BW)												
Supply	3.6	212	466	84	391	2064	7.1	415	911	164	765	4039
Uptake	0.5	1.7[b]	144	10[b]	1.2	688	0.5[b]	1.7	121[b]	8[b]	1.2[b]	600[b]
Bio-waste-sludge compost (BWS)												
Supply	3.1	233	784	114	175	2265	6.0	458	1538	223	344	4446
Uptake	0.6	1.9	152	14[a]	1.3	686	0.6	2.1	145[a]	12[a]	1.4	668[a]

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