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Use of Compost and Sewage Sludge with Different Tillage Treatments for Sustained Soil Protection

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ABSTRACT

Organic wastes can be utilized to preserve soil fertility via the input of humic substances. However, pollutants like heavy metals can be introduced to soil through the application of such material. Properties of soils influenced by tillage may determine their capability to cope with the input of heavy metals.

A field trial was designed to show the impacts of soil tillage on the utilization potentialities of sewage sludge and compost as soil amendment. Laboratory experiments served to estimate the tillage effect on changes in substance accumulation, availability, and shifting of sorption capacity. Three tillage treatments, differing in intensity of their impacts on soils were investigated. To measure soil properties, sampling increments of 0 – 3, 3 – 10, and 10 – 25 cm were used. Sewage sludge and compost amendments were added according to German law. Specific accumulation for total Zn and Cu caused by tillage were observed for the Eutric Luvisol. These observations were confirmed by the results of extractions of bioavailable fractions (NH_4NO_3, EDTA) of the same elements. Element specific differences of sorption capacities depending on the soil tillage were found. Due to the differences of the organic matter content non-tilled soils showed higher sorption capacity for Cd than plowed soils. Studies of arsenic showed no differences. Soil properties altered through tillage caused variations, which resulted in different peculiarities of heavy metal accumulation, availability, and sorption. The observations should contribute to improve regulations for sewage sludge and compost utilization on differently tilled soils considering principles of sustained soil protection.

INTRODUCTION

The utilization of compost and sewage sludge offers the potential to recycle plant nutrients and reduce use of mineral fertilizers in agricultural production. The reduction of mineral phosphorus especially contributes to the protection of natural resources. Additionally the agricultural utilization of organic municipal wastes provides a cost effective method of disposal. An indispensable principle must be to minimize heavy metal toxicity when using municipal wastes. Hence, there must be limits of the maximum load of toxic heavy metals delivered to soils. The major principle must be a mass balance between the heavy metals added to soils and their subsequent uptake by harvested plants to avoid accumulations in soils.

German law has fixed limits for seven heavy metals and selected organic pollutants in sewage sludge and compost, and maximum amounts of sludge and compost application (BioAbfV, 1998; AbfKlärV, 1992). The amounts of heavy metals and organic pollutants added often exceed the plant uptake if the maximum amounts of sludge and compost are applied. For long-term soil protection, regulations need to be improved.

The regulations do not consider the different soil types and management systems used. Our hypothesis is that the supplied substances impact soil ecosystems differently if different tillage systems are used. Due to the significant changes of numerous soil properties depending on tillage (Tebrügge et al., 1997), heavy metal accumulation processes in the soils, availability of supplied substances for plants, and the mobility of these substances in the soil profile are likely to be affected. Differences in mobility and availability of heavy metals are expected because of the diversification of the soil biology and chemistry through the tillage treatment (Brümmer et al., 1986). An additional hypothesis is that sorption capacities for the supplied substances differ and thus transfer to the plants and leaching behavior may vary.

Testing these hypotheses, field experiments with long-term tillage systems were designed, and compost and sewage sludge were added according to German law and common agricultural practice. This was accompanied by laboratory studies on substance behavior in the soils under these special conditions. The initial results after two years are presented.

MATERIALS AND METHODS

The field trials using compost and sewage sludge were based on long-term treatments of various soils with different tillage systems over a period of 20 years (Tebrügge and Böhrnsen, 1997). For this study, three soil types and three tillage systems were chosen from the long-term treatment program. The soils were selected because of their distinct differences in physical, biological, and chemical properties (Table 1). The different tillage systems were conventional plow tillage (CT) characterized by topsoil turning, reduced non-inversion tillage by chisel plowing (RT) and no-tillage (NT) practice.

By German law (AbfKlärV, 1992; BioAbfV, 1998), the amounts applied must not exceed 10 t ha^{-1} y^{-1} of compost and 5 t ha^{-1} 3 y^{-1} of sewage sludge. Additionally, limiting values for the concentrations of pollutants in wastes used for

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Table 1. Specific soil properties altered by different tillage systems: no-tillage = NT, reduced tillage = RT, conventional plow tillage = CT.

	Eutric Cambisol			Eutric Luvisol			Eutric Fluvisol		
Tillage system	**Soil sampling depth [cm]**								
	0-3	**3-10**	**10-25**	**0-3**	**3-10**	**10-25**	**0-3**	**3-10**	**10-25**
	Total content of organic carbon [g kg^{-1}]								
NT	11.7	9.0	5.8	27.0	16.7	10.3	23.4	22.2	16.0
RT	7.5	0.7	6.2	1.2	16.0	11.2	23.7	20.7	19.1
CT	5.7	5.6	6.0	11.3	11.6	11.3	18.7	19.3	21.0
	Total content of nitrogen [g kg^{-1}]								
NT	1.2	1.0	0.6	2.3	1.6	1.1	1.9	1.8	1.3
RT	1.3	1.1	0.9	1.6	1.6	1.2	2.0	1.9	1.8
CT	1.0	0.9	0.9	1.2	1.2	1.2	1.7	1.7	1.8
	pH								
NT	5.7	5.4	6.1	6.6	6.6	6.4	6.4	6.4	6.3
RT	5.4	5.3	5.5	6.4	6.5	6.5	6.3	6.5	6.5
CT	5.5	5.4	5.2	6.1	6.1	6.2	6.2	6.5	6.5
	Cation exchange capacity [cmol kg^{-1}]								
NT	9.74	8.99	7.87	19.56	15.85	13.73	23.75	23.44	22.82
RT	5.71	5.61	5.50	17.39	13.63	13.30	22.10	21.45	23.61
CT	4.77	5.34	4.72	14.33	14.72	14.49	21.11	22.51	22.56
	Bulk density [g cm^{-3}]								
NT	1.59	1.69	1.62	1.36	1.46	1.55	1.42	1.58	1.60
RT	1.58	1.58	1.58	1.01	1.22	1.37	1.24	1.44	1.53
CT	1.62	1.62	1.61	1.20	1.25	1.28	1.16	1.28	1.35

Table 2: Heavy metal concentrations and loads in sewage sludge and compost and the maximum values allowed by German law.

	Sewage sludge					
	Maximum application masses: 5 t dm ha^{-1} 3yr^{-1}					
	Zn	**Pb**	**Cd**	**Ni**	**Cr**	**Cu**
Concentration [mg kg^{-1}]	1320.60	96.61	2.88	61.59	88.27	278.89
Load [g 3yr^{-1} ha^{-1}]	6603.01	483.05	14.39	307.97	441.34	1394.46
Limiting value [mg kg^{-1}]	2500	900	10	200	900	800
	Compost					
	Maximum application masses: 10 t dm ha^{-1} yr^{-1}					
	Zn	**Pb**	**Cd**	**Ni**	**Cr**	**Cu**
Concentration [mg kg^{-1}]	261.13	46.39	0.68	42.34	53.69	38.10
Load [g 3yr^{-1} ha^{-1}]	2611.25	463.87	6.80	423.44	536.87	380.97
Limiting value [mg kg^{-1}]	300	100	1	35	70	70

Table 3: Extraction methods to determine different fractions of heavy metals in the soil.

Element	Fraction	Extraction solution and – procedure	soil : solution ratio	Reference
heavy- metals	total content	aqua regia, 2.5 h at 160°C	1 : 20	VDLUFA (1991)
	mobile	NH_4NO_3 (1 M); horizontal shaking; 16 h	1 : 10	Zeien (1995) (modified)
	potentially available	EDTA (0.025 M); horizontal shaking; 90 min	1 : 10	Zeien (1995) (modified)

organic amendment are regulated by law. The materials used in this study were digested municipal sewage sludge influenced mainly by domestic sewage and low amounts of industrial waste water and finished compost out of a mixture of yard wastes and separately collected organic domestic waste.

The field trials, with the first application of the organic amendments, were started in 1997 and will last over three growing seasons. This means at the beginning of the next two growing seasons the application of compost will be repeated. For the sewage sludge additions, two different approaches were used. One approach was a single application at the beginning of the experiment with no further organic amendments during the next two years, in accordance with German law. The other one was to have three annual applications (5 t ha^{-1} y^{-1}) to estimate effects of accumulation with repeated applications of sewage sludge.

On each of the three field sites, 36 m^2 plots were designed. The treatment was conducted in duplicate for each manure treatment and control on each tillage treatment

(Table 2).

Soils were sampled at three increments: 0 –3, 3 – 10, and 10 – 25 cm depth, following the stratification of each soil. Conventional tillage (CT) reached down to 25 cm. The wing share cultivator (RT) had two working depths. The primary aggregates work down to 25 cm with less intensity than CT. The secondary implement worked at a depth of 10 cm. The no-tillage-practice (NT) had almost no mechanical impact on the soil. There was small but negligible disturbances due to planting. Under these conditions the sampling increments covered the complete spectrum of working depths of the tillage systems.

After the first application, total contents of six heavy metals (Cd, Cr, Cu, Ni, Pb, Zn) and the metalloid As were determined (Table 3).

In addition, amounts of bioavailable portions were determined (Table 3: mobile and potentially available fraction, respectively). The procedures were chosen according to Zeien (1995).

The assumption that different tillage systems effect the sorption capacities of soils was examined in laboratory studies. To assess these differences, sorption isotherms for As and Cd were developed by increasing amounts of the surveyed element, dissolved in a neutral salt solution, added to air-dried, sieved (< 2 mm) soil samples (50 g), and the distribution of the elements between the solid and liquid phases of the system were measured after equilibration (16 h) while shaking. The two phases were separated by centrifugation and micro-filtration. Cadmium content were measured by radioanalytic determination after addition of ^{109}Cd to the sorption experiments (Schug et al., 1999). This provided much lower detection limits than conventional heavy metal analysis by atomic absorption spectrometry.

RESULTS AND DISCUSSION

Results after the first of three applications of sewage sludge and compost were obtained. At this point, tendencies should be observed for whether different substances accumulate or their availabilities and sorption behaviors shift due to tillage system used or not.

Total Heavy Metal Contents

Differences in the total heavy metal contents depending on the tillage in the long term experiments were seen. Copper, lead, and zinc showed accumulations in the upper layer (0 – 3 cm) of the Eutric Fluvisol and Eutric Luvisol no-till plots, as compared to the plots under reduced and conventional tillage, respectively. These results partially agree with Shuman and Hargrove (1985), who found increased Mn and Zn concentrations in the top-most layer (0 – 2 cm) of non-tilled soils compared to conventional tilled soils. For As, Cd, Cr, and Ni no differences were seen. No differences in the accumulation of any element could be ascertained in the Eutric Cambisol.

These differences are considered to be influenced by atmospheric deposition, manure, and fertilizer additions since the tillage treatment program was initialized (Alloway, 1995; Kabata-Pendias, 1992). Conventional tillage produces a total intermixture of the organic wastes with the soil within the plow layer (25 cm). Conservation tillage blends the components to 10 cm. No-tillage omits the mixing of organic wastes with soil. These affects result in distinct distributions of the heavy metals depending on the tillage systems. Theoretical increases of heavy metal concentrations caused by compost or sewage sludge applications were compared to the defacto heavy metal contents determined by aqua regia extraction after the supply of compost (COM) and sewage sludge (SEWSLU) (Table 4). The theoretical increases were calculated on the base of the specific intermixture of the organic wastes depending on the tillage system and the appropriate bulk densities.

The comparison of the data of the application of sewage sludges and composts to the Eutric Luvisol showed wide differences between theoretical and measured increases. The degree of variation for the sewage sludge amendments were 101 and 91% for the elements Zn and Cu, respectively in the non tilled soils. In the RT and CT treatments the values for Zn were 46% and 64%, respectively. The measured increase for Cu was 70% for the RT and CT treatment. For Cd and Ni the differences were 95% and 77% under CT, respectively. Similar to the sewage sludge amendments, the addition of compost resulted in increased heavy metal concentrations. Most of the measured concentrations exceeded the theoretical increase. Especially NT-soils showed higher increases for all elements. Higher increases in Ni and Cr were also seen in the RT and CT soils.

The results are in good agreement with observations of Davis et al. (1988), who found accumulations of seven heavy metals in the upper layer of grassland soils after surface applications of sewage sludge.

The observations for the Eutric Luvisol were partly confirmed for the Eutric Cambisol. The amendments of sewage sludge and compost on the Eutric Cambisol were added in early spring whereas tillage occurred in the winter before. That means the intermixture of the organic wastes was omitted due to the crop rotation of this field site. These conditions contribute to the explanation of the special observations. Both sewage sludge and compost amended plots showed higher actual versus theoretical increases in many cases (Table 4). This might be due to the mentioned tillage conditions but cannot be completely explained by now. Conspicuous are the discrepancies between calculated and measured Zn increases in both the NT soils amended with SEWSLU and COM. This phenomenon cannot be explained at this time.

The Eutric Fluvisol produced different results. In most cases, no increases in the metal concentrations were seen after amending with organic wastes. Only a third of the different treatments showed higher metal contents after the application. Most exceeded the theoretical increase, up to 29 times higher. The measured increases had little relation to the expected theoretical increases. This might be due to groundwater fluctuations because of its location on a flood plain where frequent flooding occurred in the winter months.

The discrepancies between the calculated and actual increases of the heavy metal concentrations in the Eutric Cambisol and Eutric Fluvisol can be explained by the deviations in the soil tilling and the special soil conditions

Table 4: Comparison of theoretical and measured increases of total contents of six heavy metals.

	Eutric Cambisol											
	sewage sludge						**compost**					
	Zn	**Pb**	**Cd**	**Ni**	**Cr**	**Cu**	**Zn**	**Pb**	**Cd**	**Ni**	**Cr**	**Cu**
	theoretical increase [mg kg^{-1}]											
NT	15.51	0.87	0.038	0.58	2.43	2.98	7.98	0.87	0.018	0.72	1.18	5.25
RT	4.68	0.26	0.011	0.18	0.73	0.90	2.41	0.26	0.005	0.22	0.36	1.58
CT	1.83	0.10	0.004	0.07	0.29	0.35	0.94	0.10	0.002	0.08	0.14	0.62
	measured increase [mg kg^{-1}]†											
NT	7.01	2.13	0.060	*-0.11*	0.43	*-0.04*	1.97	1.95	0.031	*-0.40*	0.33	0.27
RT	5.70	1.29	*-0.070*	0.03	0.83	1.10	1.23	*-3.12*	*-0.099*	*-0.38*	0.37	0.59
CT	3.66	0.32	*-0.127*	*-0.09*	0.11	0.44	1.38	*-2.55*	*-0.149*	8.71	2.47	0.43
	Eutric Fluvisol											
	sewage sludge						compost					
	Zn	Pb	Cd	Ni	Cr	Cu	Zn	Pb	Cd	Ni	Cr	Cu
	theoretical increase [mg kg^{-1}]											
NT	14.18	1.30	0.031	0.91	1.13	3.16	5.18	1.12	0.016	1.06	1.24	0.80
RT	4.51	0.41	0.010	0.29	0.36	1.00	1.65	0.36	0.005	0.34	0.39	0.25
CT	1.92	0.18	0.004	0.12	0.15	0.43	0.70	0.15	0.002	0.14	0.17	0.11
	measured increase [mg kg^{-1}] †											
NT	*-9.70*	*-3.13*	0.037	*-1.78*	0.01	*-1.15*	*-8.08*	*-2.99*	0.033	*-0.02*	0.21	1.45
RT	*-11.82*	*-8.80*	*-0.020*	0.14	0.41	*-6.12*	*-9.68*	*-0.40*	*-0.040*	*-1.61*	*-0.53*	0.41
CT	*-4.52*	*-22.63*	*-0.018*	1.55	2.34	*-7.35*	1.75	*-14.24*	*-0.001*	4.09	3.29	6.49
	Eutric Luvisol											
	sewage sludge						compost					
	Zn	Pb	Cd	Ni	Cr	Cu	Zn	Pb	Cd	Ni	Cr	Cu
	theoretical increase [mg kg^{-1}]											
NT	14.85	1.17	0.032	0.78	1.04	3.22	5.57	1.29	0.014	1.19	1.36	0.96
RT	5.43	0.43	0.012	0.28	0.38	1.18	2.04	0.47	0.005	0.43	0.50	0.35
CT	1.95	0.15	0.004	0.10	0.14	0.42	0.73	0.17	0.002	0.16	0.18	0.13
	measured increase [mg kg^{-1}] †											
NT	15.07	3.84	0.006	*-1.53*	*-1.46*	2.95	14.02	2.77	0.000	3.89	4.71	2.61
RT	2.93	0.12	0.004	0.57	0.57	0.83	0.62	*-0.60*	*-0.029*	2.01	1.27	0.34
CT	0.70	*-0.50*	0.004	0.08	*-0.01*	0.29	0.92	*-0.22*	*-0.011*	1.76	0.95	0.10

†: Values in *italic* represent measured increases with lower heavy metal concentrations after sewage sludge and compost amendment, respectively, compared to the control plots.

due to the flooding, respectively. The results of the Eutric Luvisol show close similarities between the theoretical and the actual conditions.

Bioavailable Heavy Metal Portions

Extraction with NH_4NO_3 showed decreases in Cd concentrations in SEWSLU and COM amended treatments of the Eutric Cambisol compared to the control (Table 5). A single exception, in the RT/SEWSLU treatment, showed increased amounts. The tillage treatments showed stratifications of the Cd concentrations. In NT soils, a decrease was observed from the upper to the lowest sampling depth, whereas the CT treatment showed an opposite trend. The RT treatment contained the highest amounts in the 3 – 10 cm sampling depth .

Slight increases were seen after the SEWSLU amendment to the Eutric Luvisol. The NT variant showed an increase through the soil profile down to 25 cm. In the RT treatment, small increases for the SEWSLU and a decrease in the upper layer after COM was observed. Conventional tillage produced no shift in the concentrations for any amendment.

In the Eutric Fluvisol, the Cd concentrations for the NT and the RT treatment increased slightly. In the upper layer of the CT soil, Cd contentrations increased after the SEWSLU amendment. Cd concentrations of all tillage treatments were decreased after COM amendment.

The NH_4NO_3 – extractable copper (Table 5) showed decreasing concentrations down to 25 cm for all NT and RT soils. In the Eutric Cambisol control plots, the copper was evenly distributed between all sampling depths, whereas the Eutric Luvisol and the Eutric Fluvisol controls showed decreasing concentrations to the lowest depth. The SEWSLU and COM amendments produced different results. Cu concentrations in the Eutric Cambisol were higher in the upper layers of NT, RT, and CT (0 – 3 and 3 – 10 cm) after SEWSLU and COM application. In the Eutric Luvisol these increases were observable for the NT and the RT treatment after SEWSLU amendment, however concentrations in the CT treatment decreased. Application of COM raised the concentrations in the NT soil, whereas RT and CT showed no alterations.

The increase of copper concentrations in the Eutric Fluvisol was pronounced due to SEWSLU and COM treatments in the NT soil (0 – 3 cm). Except for the RT/SEWSLU treatment which was not altered, all other tillage and manuring treatments showed decreased concentrations.

Table 5: NH_4NO_3-extractable amounts of Cd and Cu

Tillage variants	Eutric Cambisol			Eutric Luvisol			Eutric Fluvisol		
				soil sampling depth (cm)					
	0-3	3-10	10-25	0-3	3-10	10-25	0-3	3-10	10-25
Cd [µg kg^{-1}]									
Control									
NT	9.6	9.4	3.3	4.7	4.1	5.3	5.8	6.7	8.0
RT	7.5	9.5	6.9	6.6	4.0	5.7	5.7	5.7	4.6
CT	9.0	13.5	15.5	8.0	0.0	7.3	3.6	3.9	3.8
Sewage Sludge									
NT	7.1	6.1	3.5	5.6	6.0	7.6	6.1	9.1	11.9
RT	8.4	11.8	9.4	7.0	6.9	5.7	8.7	8.2	8.6
CT	6.3	12.3	11.2	8.0	8.6	7.7	10.3	9.1	9.6
Compost									
NT	6.6	6.7	3.9	2.8	3.0	6.4	4.2	5.6	6.7
RT	5.1	7.0	6.8	4.8	5.3	5.7	5.2	4.9	5.9
CT	6.9	10.5	12.7	7.3	7.6	6.7	4.7	4.3	3.6
Cu [µg kg^{-1}]									
Control									
NT	67.5	48.3	79.9	171.0	110.0	39.4	131.8	127.5	56.0
RT	65.7	50.5	51.3	101.0	90.6	53.5	167.2	111.5	141.8
CT	42.8	39.8	35.9	39.1	59.1	52.0	83.1	93.4	165.8
Sewage Sludge									
NT	119.4	84.9	80.1	333.8	105.1	35.7	237.9	85.6	61.5
RT	86.4	65.7	53.9	105.8	111.9	52.0	80.4	104.6	64.7
CT	77.8	63.2	47.5	30.3	37.2	40.8	62.7	64.6	86.3
Compost									
NT	91.9	74.4	98.6	199.3	121.0	40.0	229.8	125.6	76.4
RT	69.6	66.0	58.3	80.6	76.2	44.6	151.1	142.0	130.1
CT	80.8	53.8	46.8	53.4	54.0	54.2	93.6	94.6	96.8

Table 6: EDTA-extractable amounts of Cu and Zn

Tillage treatments	Eutric Cambisol			Eutric Luvisol			Eutric Fluvisol		
				Soil Sampling Depth (cm)					
	0-3	3-10	10-25	0-3	3-10	10-25	0-3	3-10	10-25
Cu [mg kg^{-1}]									
Control									
NT	3.93	4.03	4.90	8.35	8.05	6.75	12.78	13.70	14.08
RT	5.93	5.90	5.33	6.05	5.85	5.10	16.03	13.35	17.55
CT	4.20	4.28	4.15	3.23	5.35	4.53	13.08	15.33	11.60
Sewage sludge									
NT	5.06	4.49	5.09	8.03	5.34	4.54	11.32	11.53	10.44
RT	4.77	4.65	4.81	6.45	6.55	5.09	11.40	11.26	11.20
CT	5.84	5.66	5.50	4.73	5.04	5.06	11.29	11.79	11.88
Compost									
NT	4.49	4.86	5.09	10.23	10.45	5.65	14.89	16.13	16.21
RT	5.00	4.76	5.20	5.08	5.98	4.58	15.02	14.60	14.73
CT	5.23	4.48	4.48	5.13	5.20	4.78	12.10	14.95	14.15
Zn [mg kg^{-1}]									
Control									
NT	0.84	0.72	0.81	1.22	1.00	0.68	1.85	1.95	1.91
RT	0.74	0.77	0.69	1.13	1.10	0.74	2.46	2.14	2.59
CT	0.56	0.59	0.53	0.58	0.58	0.79	2.25	2.59	1.95
Sewage Sludge									
NT	1.61	1.02	1.08	2.47	0.77	0.50	2.42	1.61	1.51
RT	1.07	1.30	0.84	1.45	1.35	0.93	2.02	1.86	1.78
CT	1.10	2.01	0.79	0.59	0.68	0.77	1.89	2.08	2.09
Compost									
NT	0.85	0.80	1.37	1.95	1.39	0.65	2.72	2.34	2.32
RT	0.78	1.02	1.06	0.89	1.05	0.57	2.50	2.28	2.22
CT	0.70	0.55	0.84	0.82	0.84	0.77	1.86	2.21	2.11

The results indicated in the concentration increases of copper in the upper soil layer in all soils. A decrease in NH_4NO_3–extractable Cu concentrations due to COM addition could not be seen for cadmium. The increases in concentrations of both elements after SEWSLU amendment exceeded those after COM amendment due to the higher loads of copper supplied with sewage sludge.

EDTA–extractions, determining the potentially available fractions (Alloway, 1995; Zeien, 1995), indicated increasing copper amounts in the three soils (Eutric Cambisol < Eutric Luvisol < Eutric Fluvisol) due to increasing total carbon (Table 6). The Eutric Cambisol showed no differences between soil layers in the different tillage systems. The concentration of copper in the control NT, and CT were the same, with slightly higher contents in the RT. The organic amendment raised the Cu content in the NT and CT treatments, whereas it decreased in the RT. Contrary to the CT, RT, and NT in the Eutric Luvisol, the Control showed a stratification of Cu concentrations with the upper soil layer of NT treatment being about twofold greater than the CT. The SEWSLU amendment increased the Cu concentration in the upper layer of RT and CT and decreased it in the layers 0 – 3 cm and 3 – 10 cm of NT. Whereas COM raised the copper concentration in NT (0 – 3 cm, 3 – 10 cm), CT, and RT (0 – 3 cm). In the Eutric Fluvisol, no stratification was seen in the control with any tillage system. Similar observations were made for the SEWSLU treatments, although the contents were less than the control. After the COM amendment, no stratification within the soil profile was seen. The Cu concentrations were slightly raised in the NT while the other treatments showed small alterations.

The EDTA–extraction of zinc showed the same series of increasing concentrations as was seen for Cu. The Eutric Cambisol showed stratification of the zinc within the control (Table 6). The Zn content decreased with tillage from NT > RT > CT. With the exception of COM amendment to the CT, Zn concentrations increased after COM and SEWSLU treatments. The SEWSLU increases were greater than the COM due to the higher loads of the amendment. Eutric Luvisol showed stratifications in the zinc contents in the NT and RT, although they were not seen for the CT variant. The control followed the same pattern as for the Eutric Cambisol, while the NT and RT were slightly higher. SEWSLU applications produced increases in the NT (0–3 cm) and the RT (down to 25 cm). In CT, no increases were observable. These observations were true for the COM, with the exception of the RT upper layer, which was slightly less. The CT/COM variant showed small increases in the layers 0–3 cm and 3–10 cm. Stratifications of EDTA–extractable zinc did not occur in the control plots of the Eutric Fluvisol. The CT and RT showed equal levels, whereas the NT contained the lowest Zn concentrations. The SEWSLU treatment raised the zinc concentration in the NT upper layer, similar to the COM amendment.

Sorption Capacities for Heavy Metals

The sorption patterns of Cd were influenced by the soil tillage. Each of the three soils showed the highest sorption capacities in the NT (Fig. 1). Sorption capacities of the RT soils fell between CT and NT. Due to regular lime additions to all soils, the pH was such as to prevent mobilization of cadmium. It is likely that varying pH played a role in the different sorption capacities of NT and CT of the Eutric Cambisol.

Tillage system influence on the As sorption capacities were not apparent. The three soils showed differences that were related to clay content and to the amount of ammonium oxalate- extractable Al (Livesey and Huang, 1981). Basically the sorption behavior was highly influenced by the redox potential of the soils, impacting As speciation (Masscheleyn et al., 1991).

The sorption studies were conducted to assess filtering potentials of soils for heavy metals without exceeding their specific sorption capacities. This was obtained by developing Freundlich sorption isotherms (Fig. 1). The calculated coefficients from the Freundlich equations were implemented in a leaching model to estimate the downward movement of heavy metals in the soil depending on the heavy metal load supplied by sewage sludge and compost, respectively.

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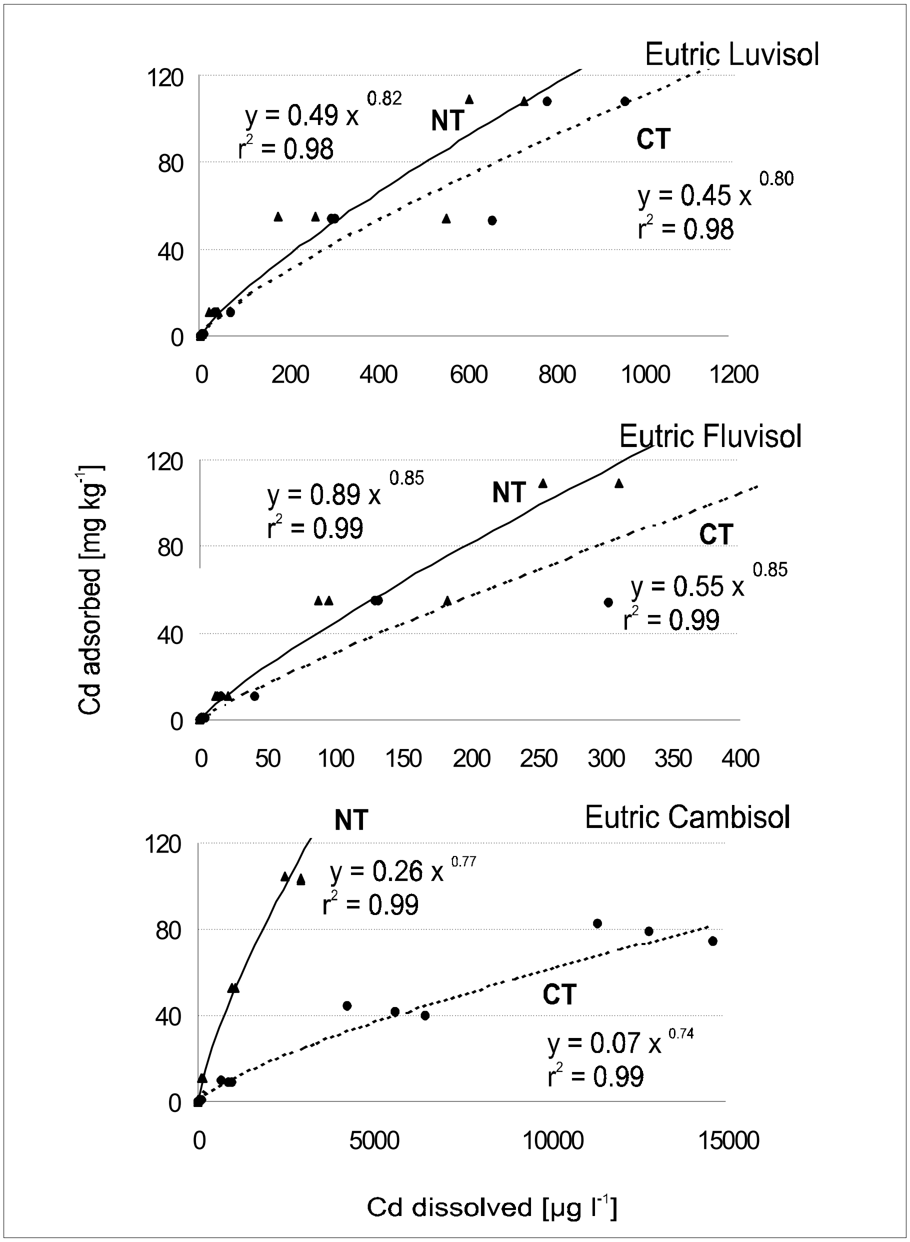

Figure 1: Freundlich sorption isotherms for the three soils, representing each single data point (n=3): Eutric Luvisol, Eutric Fluvisol, and Eutric Cambisol (from top to bottom).