Effects of compost and digestate on environment and plant production – results of two research projects.

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EXECUTIVE SUMMARY

A yearly amount of $9.3x10^6$t compost and digestate derived from separately collected organic waste is produced in the 25 European Union member states. The improvement of soil properties is a major benefit of compost application. However, little is known about the occurrence of organic pollutants in compost. In order to estimate the potential of Swiss composts and digestates to influence soil fertility and plant health, one hundred products representative for the different composting systems and qualities available on the Swiss market were analyzed in two research projects.

In the first study, polycyclic aromatic hydrocarbons (PAHs), ortho substituted and dioxin-like polychlorinated biphenyls (PCBs, DL PCBs), polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDD/F), polybrominated diphenyl ethers (PBDEs), hexabromocyclododecane (HBCD), tetrabromobisphenol A (TBBPA), perfluorinated alkyl substances (PFAS), pesticides, chlorinated paraffins (CPs), phthalates and nonylphenol (NP) were analyzed. All compound classes were detected except for NP. PFAS, HBCD, TBBPA, some compounds out of PBDEs and pesticides were found in compost and digestate for the first time. Concentrations of most compounds were in the low ppb range. Contents of PAHs were between 600 and 12473 µg/kg dry weight (dw) and contents of HBCD and CPs between 17 and 384 µg/kg dw. Tests with springtails (*Folsomia candida*) have been shown to be a versatile tool for ecotoxicological assessment. Within these tests, inhibiting and stimulating effects due to compost application were observed. Except for high PAHs contents, no major problem with regard to contamination of compost and digestate was identified.

In the second study, the physical, chemical and biological properties of the composts and digestats, and their influence on soil fertility and plant growth, were characterized. The organic substance and the nutrient content of the composts varied largely between the composts with the feedstock materials as major influencing factors. The respiration rate and enzyme activities exhibited large variations as well, particularly in the youngest composts. These differences decreased when the composts became more mature. Maturity, the degradation stage of the organic matter, depended not only on the age of the compost, but also on the management of the process. The N-mineralization potential of compost added to soil showed that a high proportion of young composts immobilized the nitrogen in the soil. Two compost parameters allowed to predict the risk of nitrogen immobilization in soil: the NO3- and the humic acids contents. The phytotoxicity of the composts varied largely even in mature composts, showing that the storage of the compost plays a decisive role. While the majority of composts protected cucumber plants against *Pythium ultimum*, only a few composts suppressed *Rhizoctonia solani* in basil. With respect to disease suppression, the management of the maturation process seems to play a major role. In field experiments, some biologically immature composts immobilized nitrogen in soil and reduced growth of maize. With additional fertilization, however, it was possible to compensate this effect. Digestates and composts increased the pH-value and the biological activity of soil. These effects were observable also one maize season after compost application. In conclusion, the management of the composting process seems to influence the biological quality of the composts and digestats to a higher extent than the feedstock materials or the composting system. More attention should be paid to this biological quality, in order to produce composts with more beneficial effects on crops.

As a conclusion, it is necessary to thoroughly discuss among stakeholders the current state of the art with regard to advantageous properties and contamination of compost and digestate in order to counterbalance potential risks of their application with their positive aspects and to guarantee for beneficial, safe and sustainable recycling of separately collected organic waste.

1 INTRODUCTION

1.1 Background

Composting of organic waste represents an important and well established part of waste management in Europe. In recent years, anaerobic treatment of organic waste materials and production of non-fossil energy have been promoted and thus, production of digestate and presswater (i.e. the products from liquid/solid separation of the fermenters output) has increased. About $9.3*10^6$ t of compost and digestate are produced per year in the 25 European Union member states (Anonymous, 2005a). Composting and digestion of organic residues and application of compost to soils follow the principle of sustainability.

Composts and digestates influence soil fertility and crops growth and health. This influence can be positive or negative, depending on the quality of the products and on their utilization. Inadequate management of the composting process may result in composts which contain plant pathogens, weed seeds or toxic. In contrast, well-managed composts can have the capacity to stimulate plant growth and to protect crops against diseases. While a lot of work has been done with a limited number of composts, little is known on the quality spectrum of the different composts produced and of their different influences on plant growth and plant health. Moreover, organic waste materials might contain pollutants that enter the soil by application of compost and digestate. The problem related to heavy metals has been recognized and investigated thoroughly. However, little is known about organic pollutants. They can enter compost and digestate via atmospheric deposition or accidental (i.e. improper separation of feedstock materials) and deliberate input (e.g. pesticide application) to organic materials. Data on feedstock materials and source-separated organic compost has recently been reviewed (Brändli et al., 2005). It was shown that information is sparse. Results on organic pollutants in digestate and presswater are sparse. In order to evaluate impacts from compost application, analytical studies have to be combined with investigations on effects of compounds (i.e. ecotoxicological tests).

1.2 Research objectives

In order to estimate the potential of Swiss digestates and composts to influence soil fertility and plant health, one hundred composts and digestates representative of the different composting and methanization systems were analyzed in two projects. The first study was carried out with the following aims: determination of (i) the concentrations of organic pollutants in compost and digestate, (ii) the parameters driving concentrations and (iii) impacts of organic pollutants in compost and digestate to soil organisms. Within this investigation, a monitoring study on organic pollutants in compost and digestates and an ecotoxicological assessment on the basis of laboratory tests were performed. A second project investigated the physical, chemical and biological properties of the hundred composts were characterized. In addition to the characterization of quality of the different products, two field experiments were performed to evaluate the short term influence of composts and digestates on soil fertility and plant growth.

2 METHODOLOGY

2.1 Collection of composts and digestats samples

Hundred samples of compost or digestate derived from source-separated organic waste were collected from 32 commercial composting and 7 digestion plants in Switzerland, according to the guidelines and recommendations with respect to waste fertilizers (FAC 1995). The process technology used by the plants was open windrow composting (triangle windrows: n= 19; table windrows: n=3), thermophilic digestion (n=6), combined digestion and composting (n=5), aerated boxes (n=3), aerated trenches (n=2), mesophilic digestion and vermicomposting (n=1 each). The experimental design accounted for the factors hypothesized to drive the level of pollutants in compost and digestate (Brändli et al., 2005): (i) treatment process: aerobic and anaerobic treatment with compost and digestate/presswater as resulting products. Note that most of the digestates underwent subsequent aerobic treatment. (ii) feedstock materials: The quantitatively most important materials are kitchen waste (crude organic waste originating from private kitchens) and green waste (organic waste from private gardens and public green areas) (Hügi and Kettler, 2004). Note that compost containing kitchen waste was always derived from a mixture of kitchen waste and green waste. All digestates contained kitchen waste. Other residues originating from industry, agriculture or from maintenance of roadsides were included in some of the composts and digestates. Paper and cardboard were not allowed as feedstock materials. (iii) origin of the feedstock materials: urban, rural. (iv) season of input material collection: spring/summer, autumn, winter.

2.2 Analyses of organic pollutants

The compounds analyzed within the monitoring study and the number of samples analyzed are given in tab 1. The analytical methods are described in Brändli et al. (2006, 2007a,b).

2.3 Ecotoxicological assessment

An ecotoxicological assessment was carried out on the basis of tests using collembola, commonly known as springtails (*Folsomia candida*). Within the test, the survival and reproduction rates of springtails were evaluated after 28 days of exposure to compost mixed with an arable soil at a ratio of 1:7.5 (corresponding to an application rate of 100 t dw (dry weight)/ha incorporated in the top 5cm of the soil layer). The observed effects were compared to the control (i.e. arable soil used for the soil-compost mixture). A subset of 18 samples analyzed within the monitoring study was investigated.

2.4 Physical, chemical and biological quality of composts and digestates

Nutrients and heavy metals were analyzed with ICP-AAS according to the official Swiss methods (Schweizerische Referenzmethoden, 2005).
Humic acids were determined according to Gerzabek et al. (1993) by alkaline extraction using 0.1 molar Na-pyrophosphate solution.
The influence of compost on nitrogen mineralization in soil was determined with the incubation experiment according to the official Swiss methods (Schweizerische Referenzmethoden, 2005). Five to 10 percent of compost was added to a reference soil, placed in PVC boxes (12 x 10 x 5 cm, with aeration holes), wetted and incubated at 25°C. The mineralized nitrogen (NH4 and NO3) in the soil was determined after 0, 2, 4, 6 and 8 weeks.
The activity of four enzymes was determined: fluorescein diacetate according to Inbar et al. (1991), dehydrogenase, protease and cellulase according to Alef and Nannipieri (1995).
The phytotoxicity tests were performed according to Fuchs and Bieri (2000). In the open phytotoxicity tests, the growth of cress (Lepidium sativum L.), salad (Lactuca sativa L.) and bean (Phaseolus vulgaris L. var. nanus L) in pots (Ø 10 cm) filled with compost was compared with the growth in reference substrate BRS-200 (Biophyt Ltd, CH-Mellikon). In the closed phytotoxicity test, PVC boxes (1 liter) were half-filled with compost or reference substrate BRS-200, cress sown onto it, then the boxes were closed hermetically. The growth of the plants in the boxes was then observed.
Two disease suppressivity tests were performed: cucumber (Cucumis sativus)-Pythium ultimum and basil (Ocymum basilicum)-Rhizoctonia solani. Both tests were performed in 200-ml plastic pots. Compost (20 % v/v) was added to the soil. In the cucumber-Pythium test, the pathogen was grown for 7 days on autoclaved millet, and then added to the soil. In the basil-Rhizoctonia test, the pathogen was also grown on millet which was placed on the bottom of the pots before the plants were sown. Damping-off of the cucumbers was evaluated 10 to 15 days after sowing. In the basil-Rhizoctonia test, the living plants were counted after one, two and three weeks.

Compounds analyzed within the monitoring study (abbreviations used throughout the text in bold letters), their main applications and the number of analyzed samples [i)]

	n(s)*	n(p)*
Polycyclic aromatic hydrocarbons, **PAHs** (sum of 15 PAHs), Ortho substituted polychlorinated biphenyls, **PCBs** (sum of 7 congeners)	85	39
Dioxin-like polychlorinated biphenyls, **DL PCBs** (sum of 12), Polychlorinated dibenzo-p-dioxins and -furans, **PCDD/Fs,** Polybrominated diphenyl ethers, **PBDEs**, **pentaBDE**, **octaBDE**, **DecaBDE**, Hexabromocyclododecane, **HBCD,** Tetrabromobisphenol A, **TBBPA**	20	12
Perfluorinated alkyl substances, **PFAS**: sum of 6:2 fluorotelomer sulfonate and saturated/unsaturated fluorotelomer carboxylates, **6:2 FTS/FT(U)CA**; sum of perfluorinated sulfonates, **PFS**; sum of perfluorinated carboxylates, **PFCA**; sum of fluorooctane sulfonamides and –sulfonamidoethanols, **FOSA/FOSE,** Pesticides: sum of 271 compounds	18	11
Chlorinated paraffins, **CPs**	3	3
Phthalates: di-2-ethylhexyl phthalate, **DEHP**; dibutylphthalate, **DBP,** Nonylphenol, **NP**	6	6

[i)] An exhaustive characterization of the compounds analyzed and their sources is given in Brändli et al. (2007a,b)
[*] n(s): number of samples analyzed, n(p): number of composting or digestion plants investigated

2.5 Field experiments

Two field experiments were performed in maize: in 2004, the experiment was made in a loamy soil and 2005 in a sandy soil. Digestates and composts were applied in the spring before the maize was sown (100 m3 per ha). Eight weeks after sowing, Nmin and plant height were measured. At harvest, total yield was determined. After harvest, soil samples were taken and analyzed chemically and biologically.

3 RESULTS AND DISCUSSION

3.1 Organic pollutants: monitoring study

All compound classes investigated were detected except for nonylphenol (NP). Concentrations were in the range of µg/kg dw for most of the substances (Tab. 2). Polycyclic aromatic hydrocarbons (PAHs) showed contents between 600 and 12473 µg/kg dw. Approximately 25 % of the samples exceeded the guide value defined in the Swiss ordinance on the reductions of risks linked to chemical products (Anonymous, 2005b). The contamination level for PAHs was higher as compared to values available from the literature (Brändli et al., 2005). Concentrations of ortho substituted polychlorinated biphenyls (PCBs) and polychlorinated dibenzo-p-dioxins and -furans (PCDD/Fs) were lower compared to former analytical results (Brändli et al., 2005). This might reflect declining environmental concentrations for PCBs due to their ban in the 1970ies. The decrease of PCDD/Fs has been observed for other matrices such as sewage sludge as well (Rappe et al., 1997) and is mainly due to measures taken in waste incineration and industrial activities. Concentrations of phthalates were in the same range as levels observed in other studies (Brändli et al., 2005). Hexabromocyclododecane (HBCD), tetrabromobisphenol A (TBBPA), perfluorinated alkyl substances (PFAS), decaBDE among polybrominated diphenyl ethers (PBDEs) and several emerging pesticides (e.g. triazoles) were detected in compost and digestate for the first time. The concentrations were in the low ppb range except for HBCD and chlorinated paraffins (CPs) which showed contents between 17 and 384 µg/kg dw. It is not surprising that these compounds were found in compost and digestate since they belong to high production chemicals and are incorporated in a vast number of products for daily use or, as for pesticides, they are directly applied onto agricultural products that end up in organic waste. For PAHs, PCBs, PCDD/Fs and PBDEs, concentrations determined in compost and digestate were above levels found in arable soils or grassland (Bucheli et al., 2004; Schmid et al., 2005; Sellström et al., 2006). In urban areas or at contaminated sites, levels of organic pollutants in soil can be in the same range or considerably higher compared to contents in compost.

Digestate tended to exhibit higher concentrations as compared to compost except for PCDD/Fs, PCBs and PFAS. Except for PAHs, the differences were not statistically significant however. Presswater showed contents in the same range as digestate except for HBCD. Compost from urban areas exhibited higher concentrations of PCBs (statistically significant difference). For PAHs, no corresponding difference was observed. In urban areas, composts are preferentially susceptible for contamination due to higher burdens of pollutants as compared to rural sites. A major input pathway to organic feedstock materials is likely to be atmospheric deposition. For PAHs, motorized road traffic might be another important source. However, this point was not thoroughly investigated within this study.

Compost containing kitchen waste showed slightly lower contents of PCBs compared to green waste compost (statistically significant difference for 3 congeners). For PAHs, no significant difference was observed. It can be hypothesized that organic waste collected in private households exhibits higher concentrations of organic pollutants than green waste due to higher contents of impurities resulting in elevated contamination levels (Brändli et al., 2005). This was not confirmed by the results of this study. Statistical analysis of the dataset as well as determination of impurities contents did not correlate with the concentrations of pollutants.

In general, PAH concentrations were highest in compost derived from feedstock material collected in spring/summer, decreased in winter and were lowest in autumn. This is not in line with emission data which was higher in winter than in summer (Schauer et al., 2003), but it was found before that contents in compost were highest in seasons with low emissions (Brändli et al., 2005) indicating a certain lag phase between imission and feedstock material collection. Additionally, the composition of feedstock materials varies over the year which might play a certain role for contamination of the resulting composts as well.

Among the pesticides, 20 % of the compounds analyzed were detected with fungicides as dominating compounds. Highest median concentrations were found for imazalil (9.0 µg/kg dw; detected in 14 out of 18 samples) and thiabendazole (5.3 µg/kg; detected in 13 out of 18 samples). They are used for post-harvest treatment of citrus fruit where residues are frequently detected (Taube et al., 2002). Among the fungicides, triazoles (e.g. difenoconazole, fenbuconazole, propiconazole, tebuconazole) were dominating in terms of frequency of occurrence with contents in the low ppb range.

3.2 Ecotoxicological assessment

Within the ecotoxicological assessment, 16 samples showed inhibiting and 13 samples stimulating effects with regard to the reproduction of springtails Folsomia candida (Pohl et al., in preparation). The effects were statistically significant for 4 and 5 samples, respectively. Mortality of adult springtails higher than 20 % was found for 14 samples (for 3 statistically significant). Reproduction was not related to adult survival. It was not possible to identify substances responsible for the observed impacts of compost on reproduction and mortality since the effects were not correlated with the concentration of pollutants. The classification scheme for the evaluation of toxicity defined for soil according to Achazi et al. (2000) was applied to compost. Four samples were considered as low toxic, the others were not toxic or even stimulating. These findings are in accordance with a risk assessment on compost application carried out previously within the present study (Aldrich and Daniel, 2003) and field or laboratory investigations which found positive effects for springtails (Petersen et al., 2003) and other soil organisms (Hund et al., 1999) due to organic matter originating from compost or sewage sludge application.

Stimulatory effects of low-doses of pollutants have been reported in the literature (e.g. Erstfeld and Snow-Ashbrook, 1999). It is not yet clear, whether this might be an indication of stress. Moreover, adverse effects of mixtures of pollutants and their metabolites present at low concentrations were observed in aquatic organisms. However, little is known on these topics for terrestrial ecosystems.

Concentrations in Swiss compost, digestate and presswater in µg/kg dw except for dl-PCBs given as ng WHO-TEQ/kg dw and PCDD/Fs given as ng I-TEQ (TEQ: toxicological equivalents); n: number of samples analyzed

	Compost*				Digestate**				Presswater			
	Mean	Med	Range	n	Mean	Med	Range	n	Mean	Med	Range	n
PAHs	3098	2750	600-10047	56	5925	4202	2337-12473	13	6565	5780	5445-9310	5
PCBs	30	25	9-102	55	32	31	20-52	13	26	25	21-35	5
DL PCBs	3.1	2.7	0.4-6.3	13	4.1	3.7	2.4-6.8	5	4.2	4.2	3.1-5.3	2
PCDD/Fs	5.6	4.0	0.5-21.0	13	3.2	2.7	1.3-6.6	5	6.1	6.1	3.8-8.5	2
pentaBDE	2.1	1.9	0.2-3.6	13	2.7	1.9	1.2-4.9	5	2.0	2.0	1.5-2.5	2
octaBDE	0.4	0.2	0.1-3.6	13	0.3	0.3	0.2-0.5	5	0.3	0.3	0.2-0.4	2
decaBDE	7.0	6.9	0.6-13.9	13	13.8	10.0	1.7-30.8	5	12.8	12.8	7.0-18.5	2
HBCD	83	47	17-234	13	187	174	98-372	5	43	43	30-56	2
TBBPA	0.6	0.5	0.1-2.3	13	0.9	1.0	0.4-1.5	5	1.6	1.6	1.0-2.3	2
6:2FTS/ FT(U)CA	1.2	1.4	0.4-1.5[i)]	13	0.2	0.0	nd-0.9[ii)]	5	-	-	-	-
PFS	4.3	2.2	1.0-23.6	13	3.9	2.3	2.0-8.6	5	-	-	-	-
PFCA	3.5	2.2	1.3-9.9	13	4.1	3.1	2.4-6.6	5	-	-	-	-
FOSA/FOSE	0.1	0.2	0.0-0.3[iii)]	13	0.3	0.3	0.2-0.4[iv)]	5	-	-	-	-
Pesticides	54	39	17-160	13	114	78	28-251	5	-	-	-	-
CPs	242	194	142-384	3	-	-	-	-	-	-	-	-
DEHP	240	212	145-395	4	1140	1140	295-1985	2	-	-	-	-
DBP	nd[v)]	nd	nd	4	nd	nd	nd-105	2	-	-	-	-
NP	nd	nd	nd	4	nd	nd	nd	2	-	-	-	-

* Composts containing important amounts of feedstock materials other than kitchen or green waste (e.g. farmyard manure) were excluded from statistical evaluation. Results of these samples:
PAHs (n=8): median: 978 µg/dw (range: 625-2954 µg/dw); PCBs (n=9): median: 16 µg/dw (range: 6-536 µg/dw)
** Products from thermophilic digestion. Results for products from mesophilic digestion (n=3):
PAHs: median: 2314 µg/dw (range: 947-3784 µg/dw); PCBs: median: 10 µg/dw (range: 6-74 µg/dw)
[i)] detected in 7 samples; [ii)] detected in 2 samples; [iii)] detected in 7 samples; [iv)] detected in 4 samples, [v)] nd: not detected

3.3 Chemical characteristics of the Swiss composts

The chemical characteristics of the different products are presented in tab. 3. The values for the different composts varied greatly. The contents of salts, nitrogen, phosphorus, potassium, magnesium and calcium depend predominantly on the feedstock materials. The organic matter and the density are mainly influenced by the maturity of the products. However, high variability was observed for all parameters within a product category. For example, the salt content, which should be low in the composts for covered cultures and private gardening, varied between 328 and 1539 [g KCL equivalent / 100 g fresh matter]. Through a more consistent choice of the feedstock materials, the compost producers could obtain a more constant salt content in the final product.

Chemical characteristics of Swiss composts[1]

	Digestate for agricultural use[2]	Compost for agricultural use[2]	Compost for horticultural use[2]	Compost for covered cultures and private gardening[2]
salt content[3] [mg KCl/100g FM] median (minimum; maximum)	970 (704; 1384)	862 (361; 1580)	787 (173; 2657)	660 (328; 1539)
pH[3] median (minimum; maximum)	8.5 (8.0; 8.8)	8.2 (7.5; 8.7)	8.1 (7.6; 8.7)	7.9 (7.2; 8.5)
density [g/l] median (minimum; maximum)	468 (321; 631)	556 (412; 851)	609 (434; 836)	715 (631; 904)
dry matter [% FM] median (minimum; maximum)	53.1 (45.4; 75.2)	50.8 (28.2; 73.4)	56.7 (40.8; 71.1)	56.3 (32.2; 64.5)
organic matter [% DM] median (minimum; maximum)	50.3 (28.9; 73.4)	47.7 (17.0; 80.1)	38.1 (23.9; 54.7)	30.6 (20.9; 52.8)
total N [g/kg DM] median (minimum; maximum)	15.3 (9.4; 20.3)	16.6 (8.7; 26.0)	14.6 (9.2; 27.6)	15.1 (8.6; 25.2)
total P [g/kg DM] median (minimum; maximum)	3. 6 (2.0; 8.0)	3.0 (1.7; 6.1)	3.0 (1.3; 12.7)	3.3 (2.1; 8.8)
total K [g/kg DM] median (minimum; maximum)	12.5 (6.4; 20.8)	12.0 (5.7; 25.2)	11.6 (2.2; 20.7)	10.7 (5.5; 27.8)
total Mg [g/kg DM] median (minimum; maximum)	6.8 (3.7; 9.7)	4.8 (3.6; 10.3)	6.5 (4.4; 10.7)	6.5 (4.4; 13.3)
total Ca [g/kg DM] median (minimum; maximum)	46.6 (23.0; 57.8)	53.1 (24.0; 83.7)	64.0 (35.0; 91.5)	44.5 (69.4; 29.5)
Fe [mg/kg DM] median (minimum; maximum)	8.9 (3.7; 12.3)	8.8 (2.9; 16.7)	10.1 (5.4; 14.7)	12.0 (6.1; 15.8)

[1] according to the "Guidelines and Recommendations of the Research Centre for Agricultural Chemistry and Environmental Science with respect to waste fertilisers" (FAC 1995).
[2] product description according to ASCP Guidelines 2001 (Fuchs et al., 2001)
[3] value determined in 1:2 water extract

3.4 Characterisation of the biological activities of the Swiss digestates and composts

Respiration rate decreased with compost maturation, as already shown by different authors (Paletski and Young, 1995; Lasaridi and Stentiford, 1998; Popp et al., 1998). Interesting to notice is the reactivity of digestates, which show a very intensive biological activity as soon as they are coming in contact with oxygen. This reactivity of digestates can also be observed by the enzymatic ativities of the products (fig 1). However, the evolution of the activity of four enzymes during composting differed greatly (fig. 1). The FDA (fluorescin diacetate activity) and the protease activity differed significantly between the different product classes (fig. 1). Their activities are decreasing with the advancement of product maturity. A similar evolution, but less evident, is observable in the cellulase activity. By contrast, the dehydrogenase activity was less influenced by the maturity of the products.

3.5 Influence of composts and digestates on plant growth

Plants react on compost or digestate quality as a whole. Sometimes, all of the above-mentioned chemical parameters of a compost are good, but plants do not develop well in it for unknown reasons. To assess this risk, the phytotoxicity tests are used. The four phytotoxicity tests used react differently to compost quality. The open cress test is the least sensitive, and the plants showed growth depression only in the digestates (fig. 2Co). The open lettuce test is more sensitive, and only the more mature products allowed a good growth of the plants. In the closed cress test, the plants are not only in contact with the compost, but are also strongly influenced by the gases which evaporate from the compost. This test is therefore very sensitive, and only composts with high plant compatibility allowed a good growth of the cress (fig. 2Ccl). Digestates are generally less compatible with plant growth than composts. In all test systems, an evolution in the plant compatibility was obvious, with the plants growing better in more mature composts. Nevertheless, there was considerable variation within a product class. This fact shows that the management of the composting is at least as important for the biological quality as the maturation advancement.

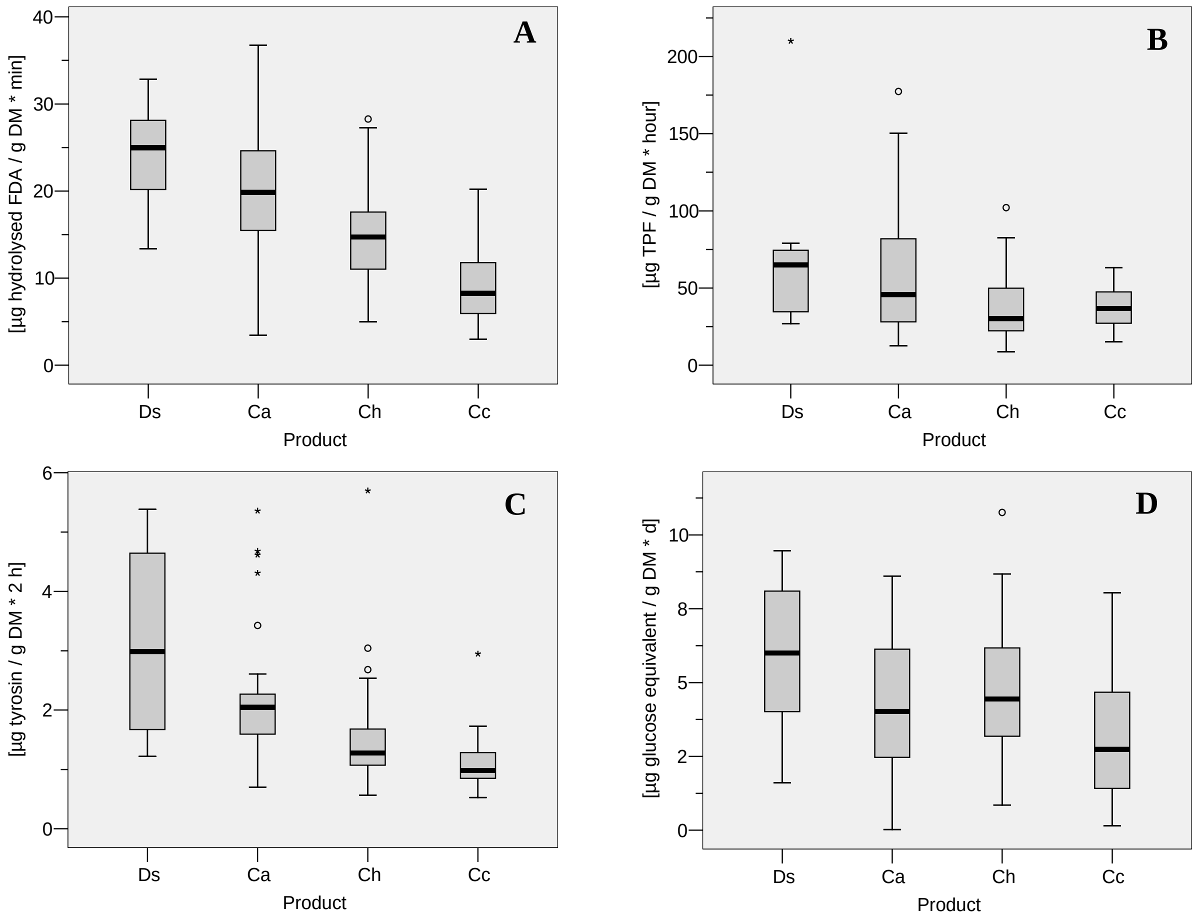

Figure 1 Enzymatic activities of Swiss composts. A: FDA activity; B: dehydrogenase activity; C: protease activity; D: cellulase activity.
Products according to ASCP Guidelines 2001 (Fuchs et al., 2001): Ds=digestate solid, Ca=compost for agriculture, Ch=compost for horticultural used, Cc=compost for covered cultures and private gardening.

3.6 Capacity of Swiss composts and digestates to protect plants against soil borne diseases

The suppressive potential of the composts against two pathogens was tested: Pythium ultimum and Rhizoctonia solani. P. ultimum causes damage mainly during germination. R. solani can attack the plant later and cause important damage also to larger plants.

The great majority of the composts significantly reduced the incidence of P. ultimum on cucumber. No differences were observed between the products of the different classes (fig. 3P). The protection of basil against R. solani was clearly less efficient (fig. 3R). It seems that the capacity of the composts to protect basil against R. solani reached a maximum at the stage Ch (fig. 3R). In agreement with other authors, we assume a general protection mechanism for P. ultimum and a specific mechanism in the case of R. solani (Hoitink et al., 1997; Fuchs, 2002, Fuchs and Larbi, 2005).

In both cases, there was large variability within the product classes. This indicates that the management of the composting process is a major factor influencing the suppressive capacity of the composts.

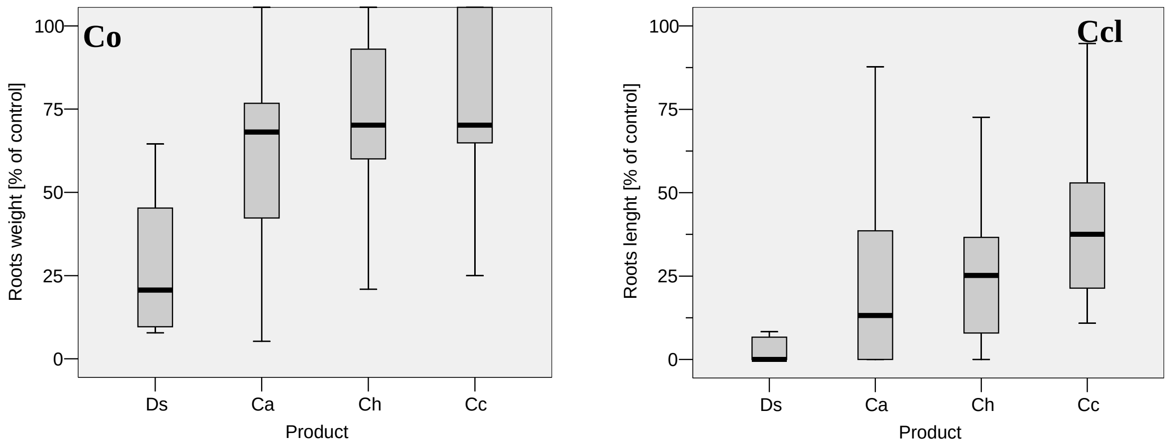

Figure 2 Phytotoxicity of Swiss composts, determined with the open (Co) and closed (Ccl) cress biotest.
The growth of plants in pots filled with compost was compared with the growth of plants in reference substrate (Co, S and B). Products were sampled according to ASCP Guidelines 2001 (Fuchs et al., 2001): Ds=digestate solid, Ca=compost for agriculture, Ch=compost for horticultural used, Cc=compost for covered cultures and private gardening.

3.7 Influence of digestates and composts on the mineralized nitrogen content of soils

The mineralized nitrogen in soil greatly influences plant growth. The influence of compost on the mineralized nitrogen content in soil depends, beyond the quantity of available nitrogen, also on the microbiological activity of the compost. Normally, digestates contain a high amount of mineralized nitrogen, mainly as ammonia, and they contain relatively low quantities in the form of lignin rich materials. Therefore, nitrogen immobilization is not expected after the utilization of such products. In our experiments, this was not always the case (fig. 4Ds). The reason for the immobilization of nitrogen in soil by some digestates is that these products are not used fresh, but after an inadequate subsequent treatment, during which the digestate has been dry and has lost all the ammonia.

In the other products, the evolution of the nitrogen immobilization risks can be clearly observed (Fig. 4). The composts for agricultural use are mainly young composts rich in undegraded lignin. The degradation of these woody substances in soil leads to a momentary immobilization of the available nitrogen (Fig 4Ca). When the composts were more mature, this risk decreased (fig. 4Ch and 4Cc).

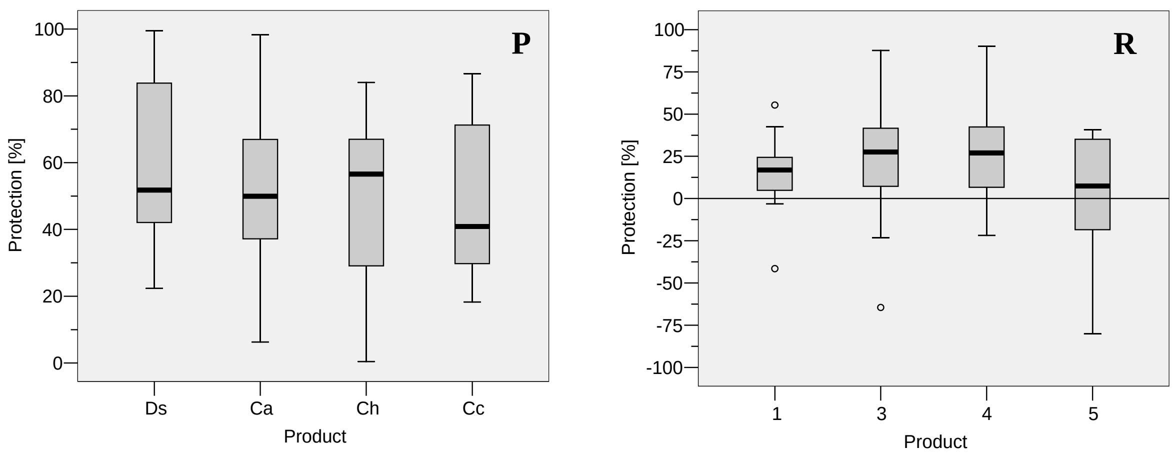

Figure 3 Capacity of Swiss composts to protect plants against soilborne diseases.
P: protection from cucumber against Pythium ultimum; R: protection of basil against Rhizoctonia solani. Products sampled according to ASCP Guidelines 2001 (Fuchs et al., 2001): Ds=digestate solid, Ca=compost for agriculture, Ch=compost for horticultural used, Cc=compost for covered cultures and private gardening.

Two compost parameters allowed to predict the risk of nitrogen immobilization with compost: the nitrate and the humic acids contents. As soon as the nitrification process began and nitrate was present, the composts did not immobilize nitrogen in the soil. Further, no relevant nitrogen immobilisation was observed with composts with a content of humic acids higher than 130 [mg / g oDM].

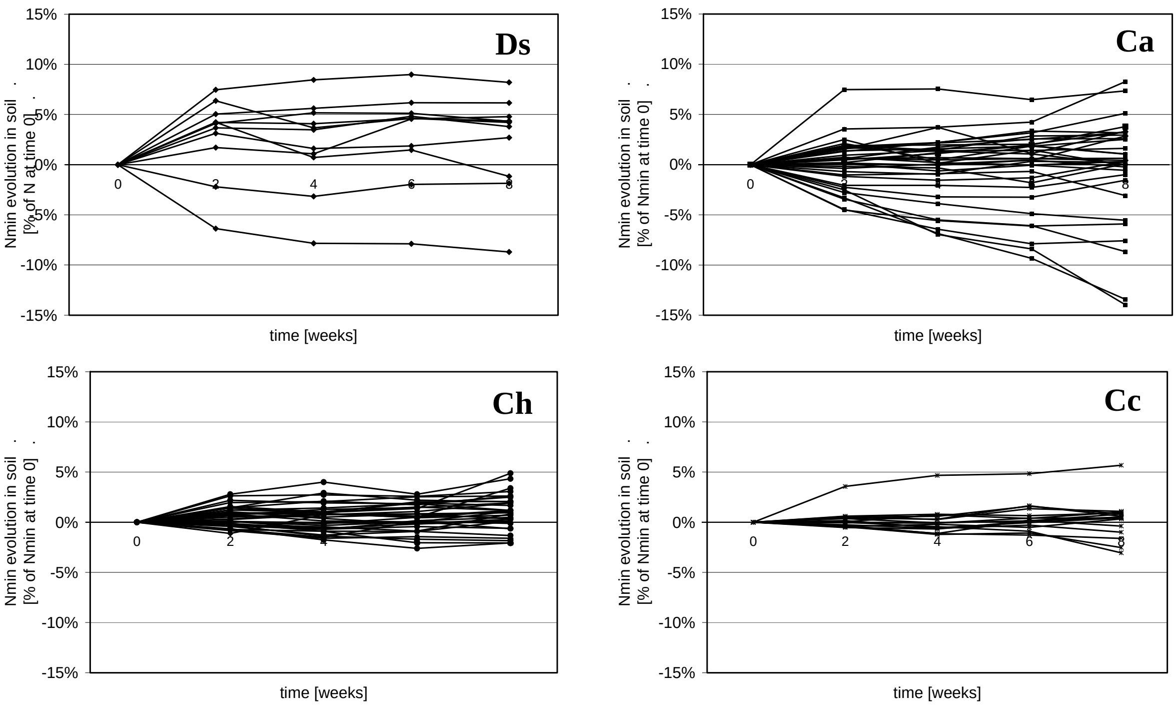

Figure 4 **Influence of the addition of different composts to soil on the evolution of its mineralized nitrogen content.**
For each compost, the mineralized nitrogen after 2, 4, 6 and 8 weeks are compared to the mineralized nitrogen present in the soil immediately after compost addition. Products according to ASCP Guidelines 2001 (Fuchs et al., 2001): Ds=digestate solid, Ca=compost for agriculture, Ch=compost for horticultural used, Cc=compost for covered cultures and private gardening.

3.8 Application of Swiss digestates and composts in the field

Two field experiments were performed in 2004 (loamy soil) and 2005 (sandy soil). Digestates and composts were applied in the spring before a maize crop. After harvest, soil samples were taken and analyzed.

The four composts for agriculture tested immobilized nitrogen in soil and had a negative influence on maize growth at the beginning of the culture. These results confirm the results obtained in the laboratory: compost with almost no NO3-N Nmin and with humic acids contents lower than 130 [mg / g oDM] immobilized nitrogen also in the field. Notice that this point is relevant only for compost, and not for digestates. Nitrogen fertilization after 8 weeks allows correcting the nitrogen deficiency, so that at harvest no significant differences in the yield of the different treatments were observed (data not shown).

The digestates and the composts enhanced the soil pH for about 0.5 units. This effect is still observable after the harvest of maize. All the products enhanced also the biological activity in the soil. However, no influence could be observed on the disease receptivity of the soil. The enhancement of the pH did not correspond exactly with the Ca content of the composts, although in 2004 the two composts with the greatest quantity of calcium caused the highest rise of the soil pH.

To characterize the biological activity of the soil, its enzymatic FDA activity was investigated after the maize harvest. Almost all digestates and composts increased the FDA activity between 10 and 30%. This shows that compost and digestate have a prolonged effect on the biology of the soil. The biological activity of the soil was not correlated with the biological activity of the compost or digestate applied. So it is probable that activity the soil microorganisms is enhanced by compost amendement, and that the activity of the compost microorganisms are not responsible for the observed enhanced enzymatic activities in the soil after the maize harvest.

The influence of digestates and composts on the receptivity of soil to diseases was investigate with the two pathosystems cucumber / Pythium ultimum and basil / Rhizoctonia solani. No influence of digestates or composts could be observed on the disease receptivity of the soil after one maize season (data not shown)..

4 CONCLUSIONS

The first study provides a comprehensive overview on organic pollutants in source-separated compost and digestate. To our knowledge, it is the first time that compounds such as PFAS, HBCD, TBBPA, decaBDEs and some emerging pesticides were analysed in compost. Moreover, digestate and presswater have not been included in a monitoring study on organic pollutants before. Most of the compounds could be quantified in the range of µg/kg dw. The concentrations were equal or above concentrations found in arable soil, the main recipient of these organic waste products.

Highly toxic effects were not found among the 18 samples tested within ecotoxiological tests. This is in line with the literature based ecotoxicological risk assessment carried out by Aldrich and Daniel (2003). Within field studies, adverse effects due to application of compost or sewage sludge were not observed or to a minor degree only (Bartl et al., 2002; Traulsen et al., 1997). Even if considering results from a recent risk assessment which included organic pollutants, it seems that there is no need to exclude recycling fertilizers from land application. However, large gaps of knowledge with regard to analytical and ecotoxicological aspects were pointed out (Aldrich and Daniel, 2003). Such gaps were filled within the present study to a certain extent. Therefore, it is suggested to launch the discussion on the sustainability of organic waste recycling and application of the resulting products to soils among stakeholders (e.g. environmental and soil scientists, producers of compost, decision makers from authorities and associations, consultants, non-profit organisations etc.) considering the actual state of the art. This process aims at identifying future topics within this domain such as:

- Determination of sources of organic pollutants in compost and digestate. New issues might arise from co-digestion of organic wastes with farmyard manure in mesophilic digestion plants since new waste products are expected to be introduced in these facilities,
- Monitoring the trends of pollutants concentrations in compost and digestate (e.g. once in five or ten years) on a selected number of facilities,
- Investigation of the spatial distribution of compost on agricultural surfaces,
- Monitoring of concentration trends, investigation of availability and long-term fate of organic pollutants in soils fertilized with compost, digestate or presswater,
- Investigation of effects induced by mixtures of pollutants and their metabolites to soil organisms.

Further investigations on these topics might contribute to improve the environmental safety with respect to recycling of source-separated organic waste and thus, to better establish the products derived thereof within sustainable land use systems.

The second study shows that in general the quality of the Swiss composts is good. No major problems were observed in any sample. One important reason for this is that only source separated organic materials are composted. Nevertheless, the characteristics of the different digestates and composts vary considerably. Some parameters like the nutrient contents, the heavy metal contents and the salinity are influenced principally by the feedstock materials. Other parameters like density, organic matter, enzymatic and respirometric activity and phytotoxicity are principally influenced by the maturity of the products. The potential for nitrogen immobilization is affected by maturity, by the composition of the composted materials and by the management of the composting process. The major influence of the biological quality of the composts (phytotoxicity and suppressive potential) seems to be due to the management of the composting process.

The differences observed between the different composts clearly indicate that the choice of the right compost for the envisaged utilization is very important. The results confirm that the four product classes proposed in Switzerland are useful for practice (solid digestate (Ds), compost for agricultural use (Ca), compost for horticultural use (Ch), compost for covered cultures and gardening (Cc)). They should be refined for some parameters, for example for the nitrogen immobilization potential. This is a very important parameter for the compost users, and this characteristic can show large variation especially in digestate and young composts. Field experiments carried out in the last two years show that the incubation tests presented here correlate very well with the performance of maize in the field (data not shown). More attention should be given to nitrogen immobilization, particularly when compost is used in spring.

In the field experiment, the digestates and composts showed very interesting effects on the soil pH and on the microbiological soil activity after one season of maize. These effects were observed in fields managed with good agricultural practise and with good fertility potential. Bigger effects are likely in fields with structural or fertility problems.

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