Tagungsbeitrag zu:
Bodenbiologische Indikatoren für eine nachhaltige Bodennutzung
Kommission III „Bodenbiologie und Bodenökologie“ der Deutschen Bodenkundlichen Gesellschaft, Sitzung 28.-29. Februar 2008 in Osnabrück
Berichte der DBG (nicht begutachtete online Publikation), http://www.dbges.de

Soil Ecological Impact of a Hotspot Copper Contamination

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SUMMARY

In the experimental farm of the Fachhochschule Osnabrück an area (15 m x 20 m) of eutric cambisol over limestone is covered with a 0.3 m layer of very humous sandy substrate with an extremely high copper contamination (> 20 000 mg/kg). In the field the extremely contaminated place was well vegetated but recognisable by its spontaneous vegetation (high dominance of *Urtica dioica*) and a mor / moder like humus form with plant residues and a dense root mat of nettles overlaying the mineral soil. Soil microbial parameters (field respiration, basal respiration, microbial biomass) and decomposition of plant residues in litter bags differed not significantly between the hot spot and an adjacent reference plot with low Cu contamination. Toxicity tests confirmed that the soil contamination is very adverse to earthworms, is depressing plant growth (*Lepidum sativum*), and is inhibiting substrate induced respiration. It is concluded that the contamination disrupted the soil ecological system. A decomposer refuge and shortcut nutrient cycle developed in the litter layer on top of the contamination. Bioturbation is the most affected soil biological process, therefore the spread of the contaminated substrate into the surrounding soil is minimized. Trees are probably able to circumvent the contaminated zone with their root system.

Schlüsselworte: Ökotoxikologie, Kupfer, Humusform, Zersetzerrefugium, Ecotoxicology, copper, humus form, decomposer refuge

INTRODUCTION

Soil contamination may be distributed over large areas (Fründ et al. 2007) or it may occur as small hot spots of toxicity resulting from events like accidental spillage. How does the soil ecological system react to a spot of toxicity? We investigated a hot spot of copper contamination combining field data with laboratory testing.

SITE DESCRIPTION

The contaminated site is a layer of very humous, heavily Cu-contaminated (> 20 000 mg/kg) substrate covering an area of approximately 15 m x 20 m with a depth around 0.3 m on a eutric cambisol over limestone. The situation is most probably caused by the deposition of industrial sewage sludge in the 1970ies. The area containing the contaminated spot was under pasture use for 15 years. In 2000 it was fenced and planted with trees (*Acer, Fagus*) and shrubs (*Rosa, Prunus*). The spontaneous vegetation consists mainly of nettle (*Urtica dioica* L.). At the reference site the spontaneous vegetation is composed of grasses and herbs (*Arrhenaterum elatius, Holcus lanatus, Taraxacum, Rumex*). See tab. 1 for soil properties and heavy metal contents.

Tab. 1: soil properties and concentrations of Zn und Cu in the contaminated (X) and the reference (N) plot

Plot	X	N
soil colour	10YR 2/2	10YR 4/2
loss on ignition	28...30 %	9...10 %
texture (KA4)	Sl2	Sl3
pH (CaCl2)	6.8	6.9
Zn total [mg kg^{-1}]	2‘100	250
Cu total [mg kg^{-1}]		
in soil (0..10 cm)	20‘000...22‘000	65...130
in litter > 2 mm	5‘026	
in litter < 2 mm	8‘777	

METHODS

Field: Litter bags (250 µm mesh) with beech/oak leaves were exposed for 127 days (Oct. 2002 – May 2003). Bait lamina filled with nettle paste were exposed March

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23 - April 01 2005. Soil respiration in situ after Lundegardh (Kleber 1997) for 7 days in autumn (Oct 2002) and spring (April 2003) respectively.

Laboratory: Basal respiration of 2 mm sieved soil at 60 % WHC after 14 day pre-incubation (Isermeyer-method). Microbial biomass with CFE-method (DIN . MPN-estimates of microbial numbers (microtiter plates, 3 % Trypticase soy broth) and Cu-resistant numbers (8 mM L^{-1} $CuSO_4$ added to nutrient broth).

Toxicity tests with dilution series of X-soil with uncontaminated soil: Plant growth *Lepidum sativum* 11 days (DIN ISO 11269-2 1997). Earthworm avoidance (*Eisenia fetida*) (DIN ISO 17512-1, 2005). Substrate-Induced-Respiration method DIN ISO 17155 (2003).

RESULTS AND DISCUSSION

Humus form

The contaminated plot is characterized by a moder-like humus form (fig. 1). A thick litter layer of beech and oak leaves is covering the ground. The Oh/Ai horizon is densely rooted by nettles and separates easily from the yyAh below. At the reference plot (N) the humus from is mull without a continuous litter layer.

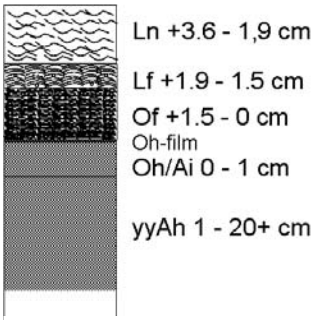

Fig1 Humus profile at contaminated plot X

Soil fauna feeding activity

In contrast to the reference plot (N) there was virtually no feeding activity in the mineral soil of the contaminated plot (X) (fig. 2). There was feeding activity in the humus layer of plot X but it was less than half the activity in plot N.

Litter decomposition, respiration, and microbial biomass

There were no significant differences between plot X and plot N in field respiration, basal respiration, microbial biomass (CFE) and medium term (127 days) degradation of beech and oak leaves in litter bags (tab. 2).

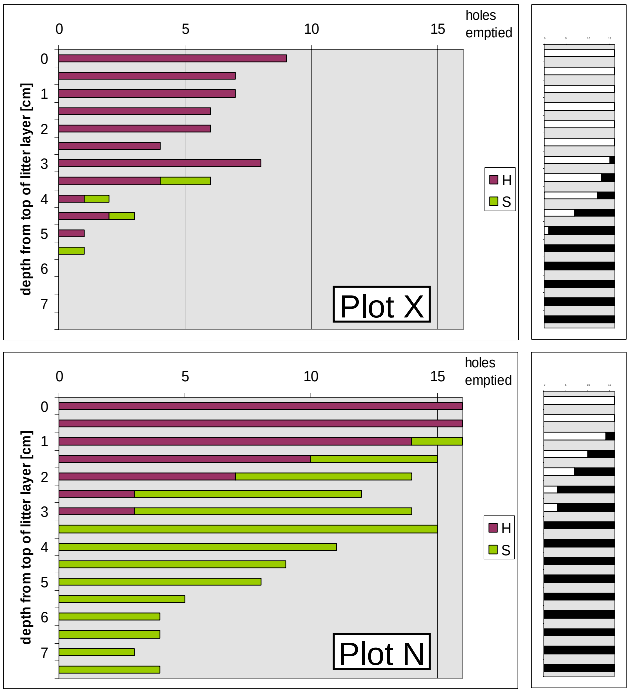

Fig. 2 Number and depth distribution of emptied holes in 16 bait lamina. Above: contaminated plot X, below: reference plot N. The columns to the right indicate the proportion of bait lamina in humus layer (H) or in mineral soil (S)

Tab. 2 Soil biology at plot X (contaminated) and plot N (reference)

Parameter	Plot X	Plot N	remarks
CO_2-release in situ [g m^{-2} h^{-1}]	0.16 0.10	0.15 0.13	autumn, 7 d, 8.8 °C spring, 7 d, 5.4 °C
basal respiration [µg CO_2-C g^{-1} h^{-1}]	2.67 ± .41	2.11 ± .44	
microbial biomass (CFE) [µg C_{mic} g^{-1}]	500 ± 79	550 ± 48	
decomposition $t_{1/2}$ [days]	378 ± 91	432 ± 75	mesh 250 µm; 127 d beech/oak leaves
MPN CFU [g^{-1} soil] after 72 hours at 20°C	7.7E05	1.4E06	3% Trypticase soy broth (TSB)
MPN CFU (Cu resistant) [g^{-1} soil]; 72 h at 20°C	3.5E05	1.4E04	3% TSB + 8 mM L^{-1} $CuSO_4$

The ratio of basal respiration to microbial biomass reveals a distinctly higher metabolic quotient in plot X (qCO_2 = 5.3) compared to the reference plot (qCO_2 = 3.8). This indicates higher physiological stress of the soil microflora in the contaminated soil. The microbial biomass is much reduced in plot X if seen in relation to the soil organic matter (loss on ignition) which is about three times higher in plot X than in plot N (tab. 1).

Cu-resistance of microorganisms

The population of responsive microorganisms in MPN assessments was higher in the reference soil (plot N), but the Cu-resistant percentage growing in nutrient broth with 8 mM L^{-1} Cu was much higher in the soil from plot X (45 % compared to 0.9 % in plot N) (tab. 2).

Toxicity tests

For quantitative toxicity testing a series of dilutions of soil from plot X with an uncontaminated loamy sand (soil R) was set up. The dilution steps and the resulting concentrations (measured) of total Cu and AN-extractable Cu are shown in tab. 3.

Tab. 3 Soil dilutions for toxicity testing, total and AN-extractable Cu-concentrations, and test results

Dilution (soil X:soil R)	X only	25% X 75% R	6% X 94% R	1.5% X 98.5% R	R only
mg Cu kg^{-1} (aqua regia)	22000	5000	1400	381	47
mg Cu kg^{-1} (NH_4NO_3)	71.6	39.3	11.2	2.3	0.1
plant growth[a]	47 %	76 %	92 %	90 %	control 100 %
earthworm avoidance[b]	96 %	100 %	99 %	80 %	[34%][c]
lag SIR (h)[d]	23	21	20	14	18

[a] DIN ISO 11269-2 (1997): *Lepidum sativum*; biomass of 20 seedlings after 11 days

[b] Percentage of worms in soil R (reference)

[c] Soil R was tested against artificial OECD-soil.

[d] DIN ISO 17155 (2003): lag time between addition of growth substrate (Glucose-NPK) and start of exponential growth.

Plants, earthworms and microbial growth were clearly affected by soil X (tab. 3). The impact of the copper contamination is surprisingly low on the plant *Lepidum sativum*. The seedlings were surviving even at the extreme concentration of 2 % Cu kg^{-1} soil. The reduction of plant growth became significant between 1400 and 5000 mg total Cu kg^{-1} soil corresponding to 11…40 mg AN-extractable Cu kg^{-1} soil.

In the SIR-test (DIN ISO 17155) a soil is considered toxic if the lag-time between substrate addition and the beginning of exponential growth is exceeding 20 hours (DIN ISO 17155). This threshold was reached in our tests at the same soil-X dilution where growth effects on Lepidum sativum became obvious (1400 mg total Cu kg^{-1} soil).

A higher sensitivity against the contaminated soil from plot X was observed in the earthworm test. *Eisenia fetida* showed a significant avoidance already if the reference soil contained 1.5 % soil from plot X corresponding to 381 mg total Cu kg^{-1} soil. This is similar to the earthworm toxicity of Cu contaminated floodplain soils (Fründ et al. 2005).

CONCLUSION

Although the toxicity tests confirmed that the soil contamination at plot X is highly toxic, the situation in the field looked quite alive. Most of the planted trees were growing well and the nettles were green and flourishing. Obviously the system adapted to the situation by circumventing the toxic hot spot.

The low effect concentration in the earthworm avoidance test suggests that bioturbation is the most affected soil biological process. Consequently a litter layer with humus form moder developed serving as a decomposer refuge. The root mat in this humus layer and the growing nettles indicate that there is a shortcut nutrient cycle on top of the contamination.

The lack of earthworm activity also minimizes the spread of contaminated substrate into the surrounding soil.

So the hot spot of contamination stays localized because it is a cold spot of biological activity, and even an extreme contamination can be tolerated by the ecosystem. This illustrates an important difference between terrestrial and aquatic ecosystems with respect to ecotoxicological effects.

Most of the data were collected during projects in the study course “Bodenwissenschaften”. The contribution of the students is gratefully acknowledged.

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