Cadmium in the Environment – An Austrian review

2^{nd} Report: Soil Balances and Risk Characterisation

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Cadmium in der Umwelt – ein Überblick aus Österreich

2. Mitteilung: Boden-Bilanzen und Risikobeschreibung

1. Introduction

In the first communication the Cadmium (Cd) content in Austrian soils and waters was described and the most important inputs into soils (atmospheric deposition, mineral fertiliser, farmyard manure, sewage sludge, organic household waste compost) were reviewed. This second communication also includes Cd outputs through crop uptake and leaching and introduces Austrian soil Cd balances. For some of these balances the Cd behaviour was modelled over a certain time horizon using the initial concentrations and different input/output variables with particular consideration being given to the contribution of mineral phosphate fertiliser. Leaching was computed by using an algorithm for the Cd soil/soil solution distribution. Lastly the risks posed to the environment (soil and water) by Cd were assessed.

One important basis for this work is the Risk Assessment for Cd in Austria (ZETHNER and GOODCHILD, 2001) which

Zusammenfassung

In einem dynamischen Massen-Bilanz-Modell wurden Cadmium (Cd)-Gehalte in österreichischen Böden, im Bodenwasser/Sickerwasser und die Cd-Auswaschung aus österreichischen Böden (mittlere Gehalte und 95 % Perzentilwerte) zu verschiedenen Zeitpunkten (nach 1 und 100 Jahren) und unterschiedlichen Cd-Gehalten im P-Mineraldünger (25 und 90 mg Cd $kg^{-1}P_2O_5$) ermittelt. Simulationsrechnungen zeigen, dass unter Verwendung von P-Mineraldüngern mit dem gegenwärtigen mittleren Cd-Gehalt von 25 mg Cd $kg^{-1}P_2O_5$ die gewichteten mittleren Cd-Gehalte im Bodenwasser/Sickerwasser und die Cd-Auswaschung aus österreichischen Böden in den nächsten 100 Jahren um 21 % und die Cd-Bodengehalte um 46 % steigen werden. Müsste Österreich seinen Grenzwert von 75 mg Cd $kg^{-1}P_2O_5$ aufgeben, so könnten P-Düngemittel mit 90 mg Cd $kg^{-1}P_2O_5$ auf den Markt kommen. Bei diesen Werten könnten die Cd-Gehalte im Sickerwasser und die aus den Böden ausgewaschenen Cd-Mengen um 38 % steigen und die Cd-Gehalte in den österreichischen Böden noch deutlicher (um 81 %) zunehmen.

Bei den meisten angeführten Cd-Bilanzen erwies sich die atmosphärische Deposition als wichtigste Eintragsquelle, gefolgt von Mineraldüngern. Regional und auf Feldebene betrachtet können auch Stalldünger, Klärschlämme und feste organische Abfälle (Bio-Abfall-Kompost) beachtlich zum Cd-Eintrag in Böden beitragen. Pflanzenentzug und Auswaschung aus Böden sind die wichtigsten Ursachen für den Cd-Austrag. Als Algorithmus für die quantitative Verteilung des Cd zwischen der gelösten und der im Boden gebundenen Phase wurde der Ansatz von McBride gewählt und damit auch die Cd-Gehalte im Sickerwasser und die Cd-Auswaschung berechnet.

Die Risikobeschreibung wurde unter besonderer Berücksichtigung von Cd in P-Düngemitteln durchgeführt und zeigte, dass trotz existierender Risiko-Minderungs-Maßnahmen die mittleren PEC (predicted environmental concentration)-Werte – ebenso wie die 95 % Perzentilwerte – die PNEC (predicted no effect concentration)-Werte für Wasser übersteigen. Bei den Böden ist in 5 % der 52 überwiegend ackerbaulich genutzten inkludierten Regionen der Quotient PEC/PNEC größer als 1, wenn eine Bioverfügbarkeit von 60 % berücksichtigt wurde. Das bedeutet, dass gemäß der EU-Richtlinie über die Risikobewertung Cd aus P-Düngemitteln hinsichtlich seiner Umweltauswirkungen bedenklich ist und – vorzugsweise EU-weite – Maßnahmen getroffen werden müssen, um den Cd-Eintrag in landwirtschaftlich genutzte Böden zu reduzieren.

Schlagworte: Cadmium, Dünger, Modell, Risikobeschreibung, Bilanzen.

Summary

Using a dynamic mass balance model the mean, as well as 95 % percentile concentrations of Cadmium (Cd) in Austrian soils, soil water/leachate and Cd leached from Austrian soils were calculated at different times (1 and 100 years) and with different Cd contents of mineral P-fertilisers (25 and 90 mg Cd $kg^{-1} P_2O_5$). This shows that when P-fertilisers with the current mean concentration of 25 mg Cd $kg^{-1} P_2O_5$ are used, the weighted means of both the Cd concentration in the soil water/leachate and the Cd leached from Austrian soils will increase by 21 % over the next 100 years and the soil Cd content by 46 % over the same time period. Were Austria required to lift its limit value of 75 mg Cd $kg^{-1} P_2O_5$ then P-fertilisers with 90 mg Cd $kg^{-1} P_2O_5$ could come onto the market. At such a value there would be a 38 % increase in both the Cd concentration in the leachate and the Cd leached from Austrian soils. The Cd content of Austrian soils would increase more significantly – by 81 %.

Most of the soil Cd balances quoted assume that atmospheric deposition is the most important input source of Cd, followed by mineral fertilisers. If regional or field level inputs are taken into account farmyard manure, sewage sludge and solid organic wastes (composts) may also contribute significantly to Cd inputs in soils. Crop offtake and leaching from soil were the most important Cd outputs. Cd concentration in the leachate, and thus leaching, was calculated using the McBride algorithm and, in so doing, also the distribution of Cd between soluble and sorbed phase.

The risk characterisation was done placing special emphasis on Cd in P-fertilisers and showed that despite existing risk reduction measures the mean (and 95 % percentiles) PEC values exceed the PNEC for water. For soils in 5 % of the 52 arable regions, the PEC/PNEC ratio is greater than 1 if bioavailable values are used. This means that, according to the EU risk assessment methodology, the substance is "of concern" and further – preferably EU-wide – measures to reduce the Cd input into agricultural soils should be taken.

Key words: cadmium, fertiliser, model, risk characterisation, balances.

was undertaken to contribute to the review process conducted by the European Commission into the justification for a limit value for Cd in inorganic phosphate fertilisers. Preliminary studies were carried out by WENZEL (1999 and 2000), and the underlying detailed procedures for the risk assessment were elaborated by ERM (2000). The Austrian risk assessments, and those of the other EU Member States, will be the basis for a decision on an European level as to whether the Cd content in P-fertilisers will be limited. The European Commission has now evaluated the risk assessments conducted by the EU Member States and a proposal for a regulation was prepared as a working draft, which is currently being discussed within the European institutions.

Presently Austria has a limit value for the Cd concentration in inorganic P-fertilisers of 75 mg Cd $kg^{-1} P_2O_5$ having been reduced in 1995 from 120 mg Cd $kg^{-1} P_2O_5$, where it had been since 1985.

2. Methods

2.1 Model description

ERM (2000) suggested using BFDE's (1999) dynamic mass balance model to estimate the Cd concentration of the plough layer at time (t) years in the future for the risk assessment for Cd to soil and water .

In the following equation (1) the dynamic representation of VISSENBERG and VAN GRINSVEN (1995) and MOOLENAAR et al. (1997), cited in ERM (2000), is used:

$$D(Cd_s)/d_t = k_i - (k_p + k_l)\, Cd_s \qquad (1)$$

Cd_s = Cd concentration in soil (mg kg^{-1} dw)
K_i = input rate of Cd (g $ha^{-1} yr^{-1}$)
K_p = Cd offtake rate by plants (g $ha^{-1} yr^{-1}$)
K_l = Cd leaching rate from the plough layer (g $ha^{-1} yr^{-1}$)

The analytical solution of equation 1 is given by the following equation (2):

$$Cd_s(t) = Cd_s(0) \times e^{-(k_p+k_l)t} + \left(\frac{k_i}{(k_p+k_l)}\right) \times \left(1 - e^{-(k_p+k_l)t}\right) \qquad (2)$$

$Cd_s(t)$ is the estimated concentration of cadmium in soil after *t* years

$Cd_s(0)$ is the initial concentration of cadmium in soil, i.e. present day value.

The transformation from g ha^{-1} to mg kg^{-1} is estimated using equation (3).

$$Cd[mg\ kg^{-1}] = \frac{Cd[g\ ha^{-1}]}{10 \times \rho \times d_p} \qquad (3)$$

ρ is soil bulk density (1300 kg m^{-3}),
d_p is the depth of plough layer (0.2 m) as default values

It is important to bear in mind that many uncertainties exist with the model used, the data and the assumptions (EPA, 1999). Models inevitably simplify reality by excluding some variables. They are based on numerous assumptions, simplifications, and often an incomplete understanding of the factors involved. Nevertheless the models, parameters and information used are the best available considering the given restrictions (ZETHNER and GOODCHILD, 2001).

2.2 Input of Cd to agricultural soils

Cd input into agricultural soils consists of:
Atmospheric deposition (k_{dep})
Application of fertilisers (k_{fer})
Application of sewage sludge (k_{sl})
Application of organic waste (k_{ow})
Application of manure (k_{man})

$$k_i = k_{dep} + k_{fer} + k_{sl} + k_{ow} + k_{man} \ [g\ ha^{-1} yr^{-1}] \qquad (4)$$

Detailed information about Cd inputs to soils is given in SPIEGEL et al. (1999). ZETHNER and GOODCHILD (2001) calculated Cd quantities applied to agricultural land using the aforementioned and supplementary information, such as the agricultural area, the quantity and distribution of mineral fertiliser and livestock manure on arable and grassland. Not all fertilisation measures are taken simultaneously. The authors also emphasise that various uncertainties exist when taking into account only one value for each variable or if available the range of values.

2.3 Cd Output

2.3.1 Crop Offtake

HORAK et al. (1995) evaluated the Cd content of different crops (sugar beet, spring barley, winter wheat and maize). Using these values and information on the surface area planted with these crops in Austria (which represents about half of all arable land) ZETHNER and GOODCHILD (2001) calculated the average and range of crop offtake. Further average values for plant uptake were estimated by other authors (see table 3).

2.3.2 Leaching

Leaching of Cd from (agriculturally used) soils depends on the Cd concentration in the soil water and the water flux.

The annual Cd output due to leaching is given by equation 5 (according to BFDE, 1999).

$$L = Cd_l\ 10\ F \ \ (g\ ha^{-1} yr^{-1}) \qquad (5)$$

Cd_l concentration of Cd in the leachate (µg l^{-1})
F annual precipitation excess (m yr^{-1})

According to ERM (2000) the annual precipitation excess (F) is given by the product of the rate of precipitation P (m yr^{-1}) and the fraction of rainwater that infiltrates the soil:

$$F = P * f_{inf}\ (m\ yr^{-1}) \qquad (6)$$

A default value of f_{inf} (0.25) was also suggested and this was used in the Austrian calculation by ZETHNER and GOODCHILD (2001).

In his model WENZEL (1999 and 2000) used the relationship between the annual leaching rate of water (L, l m^{-2}), the annual rates of precipitation (P, l m^{-2}) and evapotranspiration (ET, l m^{-2}):

$$L = P - ET \qquad (7)$$

with ET being fixed at 480 l m^{-2}, based on data presented in SCHEFFER and SCHACHTSCHABEL (1998).

Cd_l is calculated from the solid/liquid partition coefficient K_D given by

$$K_D = Cd_s/Cd_l \ \ l\ kg^{-1} \qquad (8)$$

Where Cd_s is the total amount of Cd in the solid phase (µg kg^{-1}) and Cd_l the concentration of Cd in the leachate (µg l^{-1}).

The partition of total soil Cd between the soil particles and the soil solution is of great importance and is largely determined by pH. Organic matter content and the presence of ligands e.g. chloride and, if present at large concentrations, dissolved organic matter (ADRIANO, 1986;, KOOKANA et al., 1999) are less important. Different algorithms to describe the distribution of Cd between the soluble and sorbed phase have been developed under various experimental conditions and some of them are cited in ERM (2000). WENZEL (1999) evaluated several pedotransfer functions for the prediction of Cd in the soil water (leachate) and considered the equation of MCBRIDE et al., (1997) the most appropriate predictor of Cd solubility in Austria. Cd concentration in soil solution (Cd_l in µg l^{-1}) was calculated as a function of total soil Cd concentration (Cd_s in mg kg^{-1} dw, soil pH and soil organic matter (OM in g kg^{-1})):

The McBride algorithm is:

$$\log Cd\ [Cd^{2+}] = 3.62 - 0.5\ pH + 0.96 \log Cd_S - 0.45 \log (OM)\ [\mu g\ l^{-1}] \qquad (9)$$

where

Cd_S = total cadmium content of soil (mg kg^{-1} dw)

OM = organic matter (g kg^{-1} dw)

Cadmium is subjected to a conversion factor of 0.85 to take account of the transition from Cd^{2+} in order to achieve Cd_l by assuming that Cd^{2+} constitutes on average 85 % of Cd_l (WENZEL, 1999).

In the balances of WENZEL (2000) and ZETHNER and GOODCHILD (2001) Cd leaching was thus calculated according to the McBride algorithm. For the purpose of predicting Cd balances in soils WENZEL (2000) divided Austria into more than 80 growing regions, 52 of which were defined as predominantly arable. Information on the soil pH, the total cadmium concentration and the organic matter content were mostly taken from different Austrian soil inventories (most of which are included in the BORIS database, described in SCHWARZ et al., 2001). Using an (adapted) version of WENZEL (2000) with Modelmaker 3®[1] the changes over a 100 and 200 year period were calculated with different Cadmium contents of phosphate fertiliser.

3. Results and Discussion

3.1 Modelled concentration of Cd in the leachate, in the soil and leaching rate

ZETHNER and GOODCHILD (2001) calculated the mean concentration of Cd in the soil water (leachate), in Austrian soils and the mean quantities of Cd leaching from these soils. The Cd input from fertiliser was estimated at 25 mg kg^{-1} P_2O_5, which is the current average concentration of Cd in fertilisers in Austria. If Austria were required to lift its limit value of 75 mg Cd $kg^{-1} P_2O_5$ a value of 90 mg Cd $kg^{-1} P_2O_5$ within Europe would appear realistic when using the timeframe of the next hundred years (see Table 1). This was an assumption after the evaluation of Cd contents in European P-fertilisers. The method for calculating the values is described in paragraph 2.

ZETHNER and GOODCHILD (2001) estimated a weighted mean Cd content in the soil water of 0.10 µg l^{-1}. Given that

Table 1: Mean Concentration of Cadmium in the Leachate (µg l^{-1}), in Austrian Soils (mg kg^{-1} DM) and Mean Quantities of Cd Leaching from Austrian Soils (g ha^{-1}) at Different Times and Different Fertiliser Cadmium Contents (ZETHNER and GOODCHILD, 2001)

Tabelle 1: Mittlere Cd-Gehalte im Sickerwasser (µg l^{-1}), in Österreichischen Böden (mg kg^{-1} DM) und mittlere Cd-Auswaschung aus Österreichischen Böden (g ha^{-1}) zu verschiedenen Zeitpunkten (nach 1 und 100 Jahren) und unterschiedlichen Cd-Gehalten im P-Mineraldünger (ZETHNER and GOODCHILD, 2001)

	Cd Concentration in the Leachate (µg l^{-1})			Cd Concentration in Soil (mg kg^{-1} DM)			*Cd leached in (g ha^{-1})*		
	25 mg Cd $kg^{-1}P_2O_5$		90 mg Cd $kg^{-1} P_2O_5$	25 mg Cd $kg^{-1} P_2O_5$		90 mg Cd $kg^{-1} P_2O_5$	25 mg Cd $kg^{-1} P_2O_5$		90 mg Cd $kg^{-1} P_2O_5$
Time Elapsed (years)	1	100	100	1	100	100	1	100	100
Max	0.328	0.375	0.416	0.5	0.579	0.657	0.908	0.977	1.046
Min	0.006	0.007	0.007	0.15	0.250	0.327	0.007	0.009	0.01
Mean	0.115	0.138	0.157	0.242	0.345	0.423	0.261	0.312	0.353
SD	0.089	0.105	0.120	0.072	0.070	0.070	0.226	0.261	0.293
Weighted mean*	0.099	0.120	0.137	0.228	0.333	0.412	0.209	0.253	0.289
95% Percentile	0.275	0.326	0.371	0.402	0.509	0.589	0.647	0.780	0.898

*weighted according to the area of arable land

Table 2: Modelled Cd Balances of Agricultural Soils ($g\ ha^{-1}yr^{-1}$)
Tabelle 2: Cd-Bilanzen landwirtschaftlich genutzter Böden ($g\ ha^{-1}a^{-1}$) anhand von Modellrechnungen

	Wenzel 2000 (modified)		Zethner and Goodchild 2001 (modified)	
	Arable land	Grassland	Scenario now with 25 mg Cd kg^{-1} P_2O_5 Arable land	Scenario in 100 years with 90 mg Cd kg^{-1} P_2O_5 Arable land
Input				
Deposition	2		2.1	2.1
Mineral fertiliser	0.95	0.4	0.79	2.83
Livestock manure	0.25	1.5	0.46 (0.122-1.54)	0.46 (0.122-1.54)
Compost	0.02		0.04	0.04
Sewage Sludge	0.04		0.04	0.04
Crop residues	1.25			
Σ Input	4.51	3.96	3.43	5.47
Output				
Harvest	1.55		0.40 (0.287-0.503)	0.40 (0.287-0.503)
Leaching rate	0.45* (0.003-1.95)	3.3* (0.09-15)	0.21 (0.007-0.908)	0.29 (0.01-1.046)
Σ Output	2.0	4.85	0.61	0.69
	+2.51	-0.89	+2.82	+4.78

*model prediction for Cd average leaching rate 2000 to 2200

the average current concentration of Cd in fertilisers will remain at around 25 mg kg^{-1} P_2O_5 the Cd concentration in the soil water will increase 21 % over the next 100 years. At the Cd concentration of 90 mg Cd $kg^{-1}P_2O_5$ the increase of the weighted mean would be 38 %. Zethner and Goodchild (2001) estimated that the weighted mean quantity of Cd presently leached is 0.21g ha^{-1}, which will increase to 0.25 g ha^{-1} with the existing limit value or 0.29 g ha^{-1} without. The weighted mean Cd concentration in soils is 0.23 mg kg^{-1} now and would rise 46 % with the existing limit value and 81 % without.

3.2 Cd Balances

The following balances (Table 2) summarise the data of Wenzel (2000) and Zethner and Goodchild (2001). The computations were done according to the described model (see paragraph 2) for the prediction of Cd behaviour in soils for different timeframes.

In his calculations Wenzel (2000) differentiated between arable and grassland soils by assuming different inputs of Cd via mineral fertilisers and farmyard manure (see Table 2). Arable soils are predominantely located in the dryer parts of eastern Austria with pH neutral to alkaline. Grassland soils tend to be primarily located in the alpine western regions with higher precipitation, where pH values are often acid. Wenzel (2000) predicted average Cd leaching rates between < 0,1 and 15 g ha^{-1} yr^{-1} within 200 years according to the different precipitation rates of the regions. The balance sheet shows that Cd typically accumulates in arable soils and is leached or less accumulated in grassland soils.

Therefore Wenzel (1999) stated that Cd balances should be computed for smaller regions with similar conditions (soils, climate, land-use, deposition rates) than for whole countries.

Zethner and Goodchild (2001) calculated different scenarios for arable land (see Table 2), Cd inputs were also calculated for grassland. Data for atmospheric deposition was taken from Böhm and Roth (2001). The Cd input on arable land due to mineral fertilisation was computed at 0.79 g $ha^{-1}yr^{-1}$ (situation with limit value) and 2.83 g $ha^{-1}yr^{-1}$ (without limit value). Input due to livestock manure was on average 0.46 g $ha^{-1}yr^{-1}$. The corresponding values for grassland (not included in the table) were calculated with 0.35 and 1.26 g $ha^{-1}yr^{-1}$ (inputs due to mineral fertiliser with and without the limit value) and 0.82 g $ha^{-1}yr^{-1}$ (input from livestock manure). The situation today, with the current mean Cd concentration in P-fertilisers of 25 mg Cd kg^{-1} P_2O_5, resulted in a Cd surplus of 2.82 g $ha^{-1}yr^{-1}$ on arable land. In the second scenario, without the limit value, the mean average accumulation in 100 years will rise to +4.78 g $ha^{-1}yr^{-1}$, an increase of 70 %.

Table 3: Cd Balances of Agricultural Soils (g $ha^{-1}yr^{-1}$)
Tabelle 3: Cd-Bilanzen landwirtschaftlich genutzter Böden (g $ha^{-1}a^{-1}$))

	HORAK et al., 1995	BLUM and WENZEL, 1989	REINER et al., 1996			
	1)	2)	3)	4)	5)	6)
Input						
Deposition	1.5	3	4	4	4	4
Mineral fertiliser	2.1	1.5	2.39	1.55	1.03	0.27
Farmyard manure		1.3		1.13	1.57	0.77
Compost	3.0					4.44
Sewage Sludge		0.08			0.95	
Pesticides		0.05				
Crop residues			3.75	1.33	0.95	0.68
Σ Input	**6.6**	**5.93**	**10.14**	**8.01**	**8.50**	**10.16**
Output						
Harvest	1.6	1.25	4.56	1.79	1.16	0.86
Leaching and erosion	1.0	0.5	1.05	1.05	1.03	1.00
Σ Output	**2.6**	**1.75**	**5.61**	**2.84**	**2.19**	**1.86**
	+4.0	***+4.18***	***+4.53***	***+5.17***	***+6.31***	***+8.30***

1) typical data for Upper Austria if P-fertilisers are applied
2) referring to intensively used agricultural areas
3) referring to soils of agricultural enterprises which apply mineral fertilisers
4) referring to soils of agricultural enterprises which apply farmyard manure and mineral fertilisers
5) referring to soils of agricultural enterprises which apply sewage sludge
6) referring to soils of agricultural enterprises which apply compost

In Austria several other authors have compiled soil balances for Cd (Table 3) for different purposes based on measurements and estimations. These balances compare mean Cd inputs (due to bulk deposition, fertilisation, liming, manure and sewage sludge) with mean Cd outputs (via crop uptake, leaching and partly eroded soils) estimating a net accumulation rate in Austrian soils.

If in these balances (see Table 3) the value for the Cd deposition was uniformly 4 g ha^{-1} yr^{-1} (as cited in REINER et al. 1996, which is quite high) the surplus of the balances (without use of sewage sludge and compost) would range between 3.5 and 5.2 g ha^{-1} yr^{-1}. From these balances it is also evident that especially in case of low harvest uptake applications of sewage sludge and compost may contribute heavily to Cd balance. AICHBERGER and PERFAHL (1997) also stress that using sewage sludge and compost may cause the highest surpluses of Cd in agricultural soils on field level.

4. Risk Characterisation

According to Commission Regulation No 1488/94 the assessment of risks should be based on a comparison of the potential adverse effects of a substance with the known or reasonably foreseeable exposure of the environment (e.g. soil and water) to that substance. The first objective shall be to predict the concentration of the substance below which adverse effects in the environmental sphere of concern are not expected to occur (PNEC: predicted no effect concentration). This will be compared with the concentration of the substance that is likely to be found in the environment (PEC: predicted environmental concentration). For any given environmental sphere, the risk characterisation shall, as far as possible, entail comparison of the PEC with the PNEC so that a PEC/PNEC ratio may be derived. Only if the PEC/PNEC ratio is equal to or less than one, no risk reduction measures beyond those which are being applied already are necessary. That is the reason why the level of the PNEC is of great importance. The PNEC was derived from a scientific literature review, different values for PNEC (water and soil) are compiled in ERM (2000).

The PEC values calculations of ZETHNER and GOODCHILD (2001), with the emphasis on the different Cd concentrations in mineral P-fertilisers and two different timeframes (Table 4), are used. Analytic results of river water monitoring points as well as data from Austrian soil surveys (summarised in SPIEGEL et al., 1999) are taken into consideration.

Table 4: Comparison of PNEC and PEC for Cadmium in Soil and Water (ZETHNER and GOODCHILD, 2001)
Tabelle 4: Vergleich von PNEC- und PEC-Werten für Cadmium in Böden und Wasser (ZETHNER und GOODCHILD, 2001)

	$PNEC_{soil}$ 0.18µg g^{-1}			**$PNEC_{water}$ 0.047µg l^{-1}**		
	Values with 25 mg Cd kg^{-1} P_2O_5 (µg g^{-1})		Values with 90 mg Cd kg^{-1} P_2O_5 (µg g^{-1})	Values with 25 mg Cd kg^{-1} P_2O_5 (µg l^{-1})		Values with 90 mg Cd kg^{-1} P_2O_5 (µg l^{-1})
Time Elapsed (years)	1	100	100	1	100	100
“Total” Cd Weighted Mean*	0.228	0.333	0.412	0.099	0.120	0.137
Estimated bioavailable (60%) Mean	0.137	0.2	0.247			
PEC/PNEC	0.76	1.1	1.4	2.1	2.6	2.9
95% Percentile	0.401	0.509	0.589	0.275	0.326	0.371
Estimated bioavailable (60%)of 95%Perc.	0.241	0.305	0.353			
PEC/PNEC	1.34	1.7	2.0	5.8	6.9	7.9

* weighted according to the area of arable land

4.1 Risk to Soil

Austria decided to use a $PNEC_{soil}$ of 0.18 µg g^{-1} , which was calculated by applying the lowest assessment factor 10 to the lowest NOEC value of 1.8 µg g^{-1} (BFDE, 1999). ZETHNER and GOODCHILD (2001) took into consideration that this PNEC was calculated for spruce, which is mostly grown on soils with low pH values and a high cadmium mobility, and estimated a bioavailability of 60 %. Thus PEC values were calculated multiplying the total content by the factor 0.6 (see Table 4). From this it follows that PEC/PNEC is only ≤ 1 if total Cd content in soils does not exceed 0.3 µg g^{-1} . This is only the case with the weighted mean values of ZETHNER and GOODCHILD (2001) considering the present Cd concentration of P-fertiliser. In 100 years there will be a risk to soils with continuing P-fertilisation both with the present Cd concentration and the higher one. But following the guidelines of the TGD (Technical Guidance Document), 1996, risk should be based on the 95 % percentile of the data set. The 95 % percentile figures represent the mean values of about 5 % of the 52 arable regions. Including these 95 % percentiles the ratio PEC/PNEC is also > 1. When the results of the Austrian soil surveys (summarised in SPIEGEL et al., 1999) are used all 95 % percentile figures exceed the aforementioned PNEC. In addition the weighted mean of the Cd content in agricultural soils (arable and grassland soils, 0–20 cm soil depth) is with 0.33 µg g^{-1} slightly above this value. It is therefore possible to conclude that the current soil applications, even with the existing limit values, are problematic for sensitive plants and soil organisms.

4.2 Risk to Water

As recommended in the TGD (1996) the $PNEC_{water}$ was calculated using the lowest NOEC value identified (with a reliability index ≤ 3) and the lowest assessment factor 10, which equals 0.047 µg l^{-1}. This is the PNEC value with which the comparison in Austria was made. ZETHNER and GOODCHILD (2001) stated that when fertiliser is applied with an average concentration of 25 mg Cd kg^{-1} P_2O_5 the PNEC value is exceeded by the weighted means both now and in 100 years. When the same calculations are made but with 90 mg Cd kg^{-1} P_2O_5 it is clear that the PEC values are also clearly above those of the PNEC and the margin of safety (MOS) three to four times so. If the guidelines of the TGD risk are used this should be based on the 95 % percentile of the data set. Taking into account the PNEC risk assessment factor of 10 it is still of great concern that the soil water concentration is far from the margin of safety and that such leaching or erosion water impacts upon the environment.

This last statement is also true if mean Cd values of the river water analysis (summarised in SPIEGEL et al., 1999) are taken into consideration. The mean values of all Austrian provinces (but only the median of Lower Austria) exceed the derived PNEC. This shows that Cd is of concern for Austrian river waters now and all additional inputs of Cd should be avoided.

5. Conclusions

The risk assessment conducted in Austria by Zethner and Goodchild (2001) showed that, even with existing Cd limits in P-fertilisers, a risk to water and, to some extent, soils exists. In such a situation the two options available are that "further information shall be requested immediately" or "the competent authority shall immediately make recommendations for risk reduction". It is clear that the collection of further information would be of great use in better defining both the PNEC and the PEC and should be coordinated at the European level. The authors also state that it is necessary for the existing measures (i.e. the limit value for P-fertilisers of 75 mg Cd kg^{-1}P_2O_5) to be reconsidered in the light of their study.

Anmerkung

[1] Cherwell Scientific, Oxford

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