Influence of different soil parameters on the transfer factor soil to plant of Cd, Cu and Zn for wheat and rye

M. Puschenreiter and O. Horak

Einfluß verschiedener Bodenparameter auf den Transferfaktor Boden-Pflanze von Cd, Cu und Zn für Weizen und Roggen

1. Introduction

The mobility of the essential micronutrients Zn and Cu varies due to different soil conditions and is influenced by plant species and a number of soil parameters, i.e. the chemical forms in which the metal is present in soil, pH, CEC, content of organic matter and particle size distribution (ADRIANO, 1986). The plant availabiltiy of Zn is influenced by pH and clay content, whereas soil Cu is mainly present in complexed form, therefore the availability of Cu depends most on the molecular weight of the Cu complexes and its amount present in soil. Unlike for Zn the pH is less important for the mobility of Cu (KABATA-PENIDAS and PENDIAS, 1992).

Cd is considered as one of the most toxic elements for living organisms. In contrast to other toxic heavy metals such as Pb or Hg, its mobility in soil and plant is rather high and it can be easily accumulated in edible parts to levels toxic for animal and man (ADRIANO, 1986). Soil Cd is mostly adsorbed at exchange sites and its plant availability is closely related to pH and soil organic matter content.

In previous investigations it could be demonstrated, that element content in plant is correlated with mobile fractions in soil extracted by different procedures (HAQ et al., 1980; HORAK, 1982; BRÜMMER et al., 1986; HORAK and KAMEL, 1990; HORNBURG, 1991; LOMBI et al., 1998). In some reports also the relationship between total metal content in soil and plant levels was analyzed. LÜBBEN (1993) found that for various crop species the transfer factors for Cd, Cr, Cu, Ni, Pb and Zn are lower on contaminated soils compared to uncontaminated control sites. KIEKENS and CAMERLYNCK (1982) reported that after application of heavy metals the accumulation in plant is lower on heavy clay soils than on sandy soils. Mixing a contaminated soil with lime or heavy clay soil can be considered as an effective method to decrease plant metal uptake by increase of

Zusammenfassung

Boden, Stroh und Korn von Weizen und Roggen von 42 verschiedenen landwirtschaftlichen Standorten Österreichs wurden auf den Gehalt von Cd, Cu und Zn untersucht. Aus den gewonnenen Daten wurden die Transferfaktoren vom Boden zur Pflanze errechnet und deren Abhängigkeit von verschiedenen Bodenparametern untersucht. Obwohl die untersuchten Standorte sehr unterschiedliche Eigenschaften aufwiesen, konnten einige signifikante Korrelationen bestimmt werden. Die Transferfaktoren für Cd wurden vom Gehalt organischer Substanz beeinflußt, während jene für Zn und Cu mit dem jeweiligen Totalgehalt und dem Tongehalt im Boden korrelierten. Zn und Cu werden im Korn im Vergleich zu Cd bevorzugt angereichert, weswegen die Transferfaktoren beider Elemente für Boden-Korn höher sind als jene für Boden-Stroh. Weiters weist der Schwermetalltransfer auch charakteristische Unterschiede in Abhängigkeit von der jeweiligen Art oder Sorte auf. Es zeigte sich, daß die Unterschiede zwischen Weizen und Roggen bei Zn und Cu gering sind, jedoch wird Cd von Weizen in größeren Mengen akkumuliert. Somit sind auch die Cd-Transferfaktoren bei Weizen größer als bei Roggen.

Schlagworte: Cadmium, Kupfer, Transferfaktoren, Getreide, Zink.

Abbreviations: CEC = cation exchange capacity; OM = organic matter; TF = transfer factor; TFSG = transfer factor from soil to grain; TFSS = transfer factor from soil to straw

Summary

Wheat, rye and corresponding soil samples from 42 locations in Austria have been analyzed for their Cd, Cu and Zn content in order to determine the transfer factors from soil to plant and their relation to different soil and plant characteristics. The data of this field samples indicate, that in spite of the great variety of investigated soils there are some significant relationships between soil parameters and metal accumulation in plants. The transfer factors for Cd are mainly influenced by the organic matter content. In contrast to that, the Zn and Cu transfer factors show best correlations with both total concentration of element and clay content in soil. Further, the translocation of Cd is restricted to some extent, and its transfer to grain is lower than to straw. However, the essential elements Zn and Cu are mainly transported to generative parts of plant, consequently the transfer factors soil to grain are higher than those for soil to straw. Additionally, the heavy metal translocation is influenced also by plant species and cultivar. There is little difference in the uptake of Cu and Zn for wheat and rye, but wheat accumulates more Cd than rye. Thus transfer factors are generally higher for wheat than for rye.

Key words: cadmium, copper, transfer factors, cereals, zinc.

pH or CEC. FREYTAG (1986) found a relationship between Cu translocation and both pH and cation exchange capacity. KRÄMER and KÖNIG (1982) described a significant negative correlation between Cd contents of wheat grain and organic matter in soil.

The main objectives of this study were to estimate the influence of various soil parameters on the transfer factors of Cd, Cu and Zn and to develop regression models for the relationship of heavy metal translocation and soil properties. To determine the transfer of elements from soil to plant the transfer factor is defined. This term is adopted from radio ecology and is defined by FREYTAG (1986) as TF = (content in plants_{dry})/(content in soil_{dry}).

2. Materials and methods

2.1 Field study 1

40 plant and topsoil samples from different agricultural sites in Austria previously collected by LIEGENFELD (1996) have been analyzed for their Cd, Cu and Zn contents. Investigated plants are wheat and rye, the samples were divided into straw and grain. The soil parameters (Table 1) have been taken from LIEGENFELD (1996).

Table 1: Soil properties of field study 1 (LIEGENFELD, 1996; topsoil 0–20 cm, n = 40)

Tabelle 1: Bodenparameter von Feld-Studie 1 (LIEGENFELD, 1996; Oberboden 0–20 cm, n = 40)

	OM %	carbonate %	CEC mval 100g^{-1}	pH	clay %
mean	3.27	4.92	19.38	6.73	21.85
median	3.24	0.00	17.45	6.90	19.45
standard deviation	0.78	7.77	7.99	0.77	11.06
minimum	2.15	0.00	8.25	5.40	5.50
maximum	5.90	31.74	38.28	7.64	69.60

2.2 Field study 2

Grain samples of 16 different wheat cultivars from two locations (Table 2) east of Vienna have been analyzed for the same elements as above. The soil parameters for Großenzersdorf (G) were taken from AMLINGER (1993), soil characteristics for Raasdorf (R) were kindly provided by H. Wagentriestl (Univ. of Agricultural Sciences, Vienna).

Table 2: Soil parameters for the locations Raasdorf (R) and Großenzersdorf (G) of field study 2

Tabelle 2: Bodenparameter für die Standorte Raasdorf (R) und Großenzersdorf (G) von Feldstudie 2

	Unit	Raasdorf (R)	Großenzersdorf (G)
pH		7.40	7.60
CEC	mval 100 g^{-1}	20.3	22.0
Cd	mg kg^{-1}	0.25	0.27
Cu	mg kg^{-1}	20.0	17.6
Fe	%	2.00	1.80
P	mg kg^{-1}	900	870
Zn	mg kg^{-1}	60.0	70.0
sand	%	24.9	25.0
silt	%	51.6	58.0
clay	%	23.5	17.0
organic matter	%	3.70	3.60

2.3 Chemical analysis

Plant samples were oven-dried at 105 °C and digested by a mixture of nitric and perchloric acid (5:1 v/v; HORAK, 1976). Soil samples were air-dried, passed through a 2 mm sieve and extracted by aqua regia under reflux (BLUM et al., 1996). The Cd concentration was determined by graphite furnace atomic absorption spectrometry (GFAA, Perkin Elmer 5100 ZL), Cu and Zn were measured by inductive coupled plasma emission spectrometry (ICP – AES, Varian Saturn Liberty II).

3. Results

3.1 Field study 1

Table 3 shows the Cd, Cu and Zn contents in soils and plants and the respective transfer factors soil to straw (TFSS) and soil to grain (TFSG). Generally, all TF values are below 1, what has been previously reported by FREYTAG (1986) and LÜBBEN (1993). In all investigated plants the micronutrients Cu and Zn are much higher concentrated in grain than in straw. In contrast to that the Cd content is always higher in straw than in grain. The mean concentration ratio grain:straw is 4.8 for Zn, 2.0 for Cu and 0.6 for Cd. The restricted translocation of Cd to generative parts is also indicated by different transfer factors.

Comparing the TF for the investigated elements, the TFSS is increasing in the order Zn<Cu<Cd. However, the TFSG values are in the reverse order Cd<Cu<Zn. There is a significant correlation between the TFSS and TFSG for Cd (r = 0.81), Cu (r = 0.83) and Zn (r = 0.61). For none of the investigated elements a significant correlation could be found between soil and plant contents. However, if groups of samples of one distinct species and with similar soil properties are evaluated separately, the relationship becomes significant, i.e. wheat grown on soils with a pH above 7 shows for both Cu (Fig. 1A) and Zn (Fig. 1B) a significant correlation resulted between total soil content and levels in straw.

Principal component analysis was performed for all soil and plant characteristics to study the relationship between soil properties and transfer factors. The first two principal components (PC 1 and PC 2) explained 48 % of the variance. The PC loading plot (Fig. 2) shows four distinct clusters. Cluster 1 and 4 contain all measured plant contents and respective TF. A separation of Cd levels and respective TF from those for Zn and Cu indicates that the uptake of Cd is influenced by different factors compared to the other group. This is confirmed by the separation of cluster 2 and 3, which both contain soil characteristics, but cluster 2 includes total Zn and Cu and clay content, whereas cluster 3 contains total Cd and the other soil properties. This indicates, that the uptake of Zn and Cu is mainly influenced by clay content and the translocation of Cd by pH, OM, CEC and carbonate.

For further consideration of the correlation between TF and soil properties regression analysis was applied for each element. The most significant correlations were found for polynomal equations (2nd order), if not otherwise stated.

Table 3: Soil and plant contents and respective transfer factors of Cd, Cu and Zn of field study 1
Tabelle 3: Boden- und Pflanzengehalte sowie die entsprechenden Transferfaktoren für Cd, Cu und Zn von Feldstudie 1

		Cd					Cu					Zn				
		soil mg kg^{-1}	straw mg kg^{-1}	grain mg kg^{-1}	TFSS	TFSG	soil mg kg^{-1}	straw mg kg^{-1}	grain mg kg^{-1}	TFSS	TFSG	soil mg kg^{-1}	straw mg kg^{-1}	grain mg kg^{-1}	TFSS	TFSG
wheat and rye	mean	0.25	0.05	0.03	0.20	0.11	19.62	2.48	4.73	0.15	0.28	86.90	6.75	27.08	0.08	0.33
	median	0.25	0.04	0.02	0.16	0.10	19.40	2.45	4.60	0.13	0.23	90.00	5.75	26.38	0.07	0.31
	minimum	0.13	0.01	0.00	0.03	0.00	6.60	1.00	2.50	0.05	0.13	48.00	2.50	17.00	0.03	0.16
	maximum	0.44	0.16	0.09	0.64	0.34	37.00	4.40	11.50	0.38	0.74	128.00	15.50	46.50	0.21	0.68
	st.dev.*	0.07	0.03	0.02	0.15	0.08	7.46	0.62	1.44	0.07	0.15	22.12	3.26	6.08	0.04	0.12
wheat	mean	0.25	0.06	0.04	0.26	0.15	19.18	2.56	4.99	0.16	0.30	85.12	5.78	28.70	0.07	0.36
	median	0.23	0.06	0.03	0.27	0.15	18.00	2.50	4.80	0.15	0.25	82.00	5.00	27.00	0.06	0.36
	minimum	0.13	0.02	0.01	0.06	0.03	8.40	1.00	2.50	0.05	0.15	48.00	2.50	21.25	0.03	0.18
	maximum	0.44	0.16	0.09	0.64	0.34	37.00	4.40	11.50	0.28	0.63	128.00	15.00	46.50	0.16	0.68
	st.dev.*	0.07	0.04	0.02	0.16	0.08	8.14	0.68	1.65	0.07	0.15	24.36	2.78	5.89	0.04	0.11
rye	mean	0.26	0.02	0.01	0.10	0.05	20.36	2.33	4.29	0.13	0.25	89.87	8.37	24.36	0.10	0.29
	median	0.27	0.02	0.01	0.07	0.04	20.40	2.30	4.00	0.11	0.20	94.00	9.00	24.50	0.10	0.27
	minimum	0.16	0.01	0.00	0.03	0.00	6.60	1.70	3.40	0.07	0.13	54.00	3.00	17.00	0.03	0.16
	maximum	0.39	0.05	0.05	0.29	0.16	29.20	3.60	6.10	0.38	0.74	114.00	15.50	34.50	0.21	0.60
	st.dev.*	0.06	0.01	0.01	0.07	0.05	6.35	0.49	0.87	0.07	0.15	18.20	3.45	5.54	0.04	0.11

* standard deviation

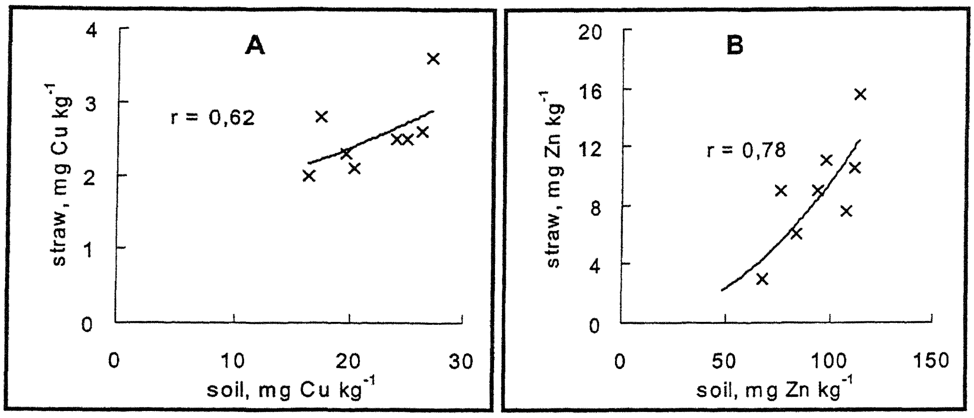

Figure 1: Correlation between Cu (A) and Zn (B) contents in soil and straw for wheat grown on soil with pH > 7
Abbildung 1: Korrelation zwischen Gehalt im Boden und Stroh von Cu (A) und Zn (B) bei Weizen von Böden mit pH > 7

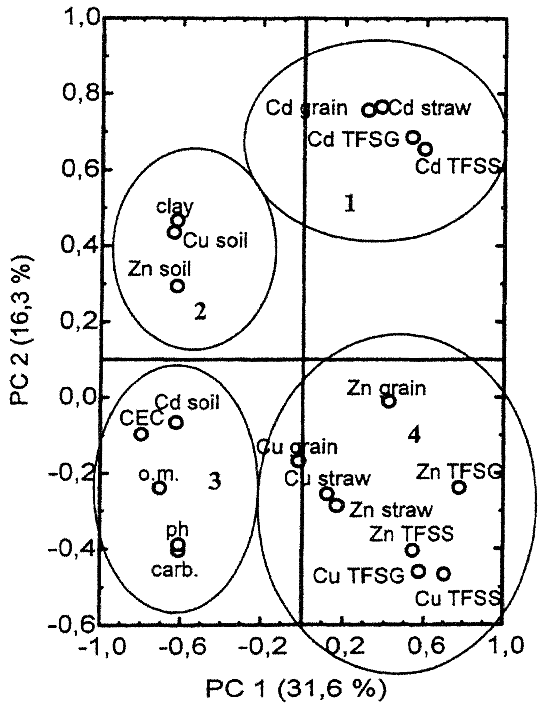

Figure 2: Principal component analysis of soil parameters, plant levels and respective TF of field study 1
Abbildung 2: Hauptkomponenten-Analyse der Bodenparameter, Pflanzen-Gehalte sowie der TF von Feldstudie 1

Cadmium

The mean TFSS is 0.20 with a range between 0.03 and 0.64, while the mean TFSG is 0.11 and ranges between <0.01 and 0.34. Fig. 3A and 3B show the correlation between the TF and organic matter content and pH, which are the soil parameters having most influence on the TF. These results indicate, that the highest TF will be found on soils with low pH and low organic matter content. In contrast to Cu and Zn no correlation was found between TF and clay content. The regression values for the relationship between TFSG and soil parameters are lower than for TFSS, respectively. Generally, the TF are higher for wheat than for rye (Table 3).

Copper

The mean TFSS for all samples is 0.15 with a range of 0.05–0.38, the TFSG ranges between 0.13–0.74 with a mean of 0.28. The dominant parameter is the total Cu content in soil, the correlation with TFSS gives a regression value of – 0.88 and with TFSG – 0.83, respectively (Fig. 3C). Due to the negative correlation between soil content of Cu and its plant uptake higher TF were found for soils with low Cu levels. Significant negative correlations were also estimated between TF and clay content (Fig. 3D), indicating higher Cu TF on soils with low clay content.

There is almost no difference between the TF for wheat and rye and also the r values are similar. Only for the relationship of clay content with TF better correlations were found for wheat (Table 4). The correlations of TF with both soil Cu and clay content are of higher significance if only soils with a pH above 7 are considered (Table 5).

Zinc

The mean TFSS is 0.08 with a range of 0.03 – 0.21, while the TFSG was found in a higher range between 0.16 and 0.68 with a mean of 0.33. As for Cu the transfer factors of Zn are mostly influenced by total Zn in soil (TFSS: r = – 0.38; TFSG: r = – 0.78) and by the clay content (r = – 0,46 for TFSS and r = – 0.50 for TFSG, Fig. 3E and 3F). These correlations indicate that high TF will be found for soils having low contents of Zn and of clay.

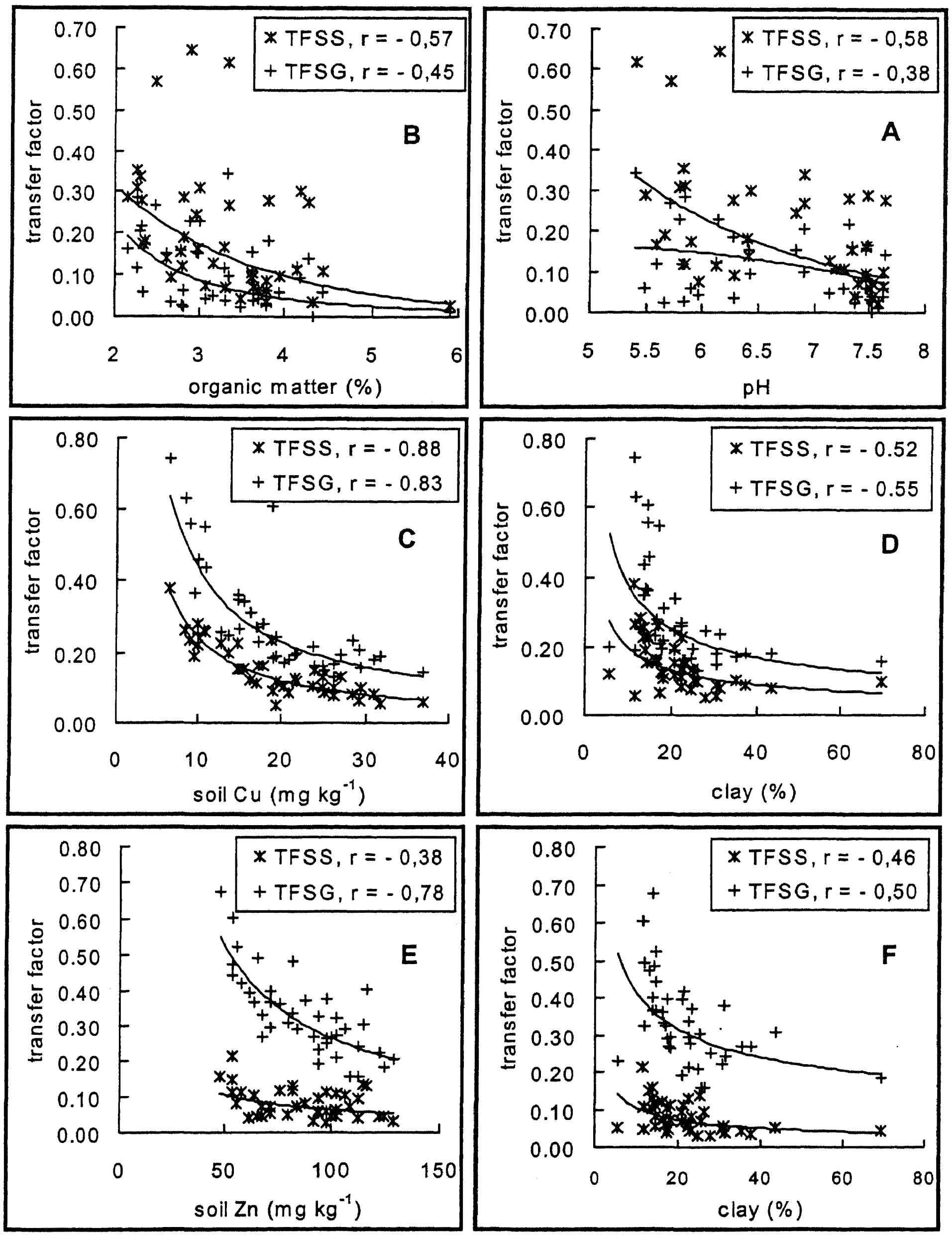

Figure 3: Correlation between soil parameters and TF for Cd (A, B), Cu (C, D) and Zn (E, F) for all samples of field study 1

Abbildung 3: Korrelation zwischen Bodenparametern und den Transferfaktoren für Cd (A,B), Cu (C,D) und Zn (E,F) für alle Proben von Feldstudie 1

Considering the difference between wheat and rye, it can be seen that the TFSS is higher for rye, while the TFSG is higher for wheat. As for Cu the correlations for soils with a pH above 7 are highly significant (Table 5).

3.2 Field study 2

Table 6 shows the contents of Cd, Cu and Zn in grain samples of 16 different wheat cultivars from two locations and the respective TF. For all three elements the TFSG values are significantly higher at the 5 % level for plants grown on location G. The greatest difference was obtained for Cd: For the samples from G a mean of 19 ± 4 µg Cd kg^{-1} and a corresponding TFSG of 0.070 ± 0.014 were found, whereas the samples from R had only 11 ± 2 µg Cd kg^{-1} with a respective TFSG of 0.045 ± 0.008. The differences between the mean Cu and Zn values and the respective TFSG are lower.

The soil parameters determined (Table 2) are similar for both locations. The lower clay content on location G may

Table 4: Regression values for the correlation of TF of wheat and rye with soil parameters
Tabelle 4: Regressionswerte für die Korrelation von TF von Weizen und Roggen mit Bodenparametern

		wheat	rye
Cd	TFSS vs. Organic matter in soil	-0.42	-0.42
	TFSS vs. pH	-0.68	-0.78
	TFSG vs. Organic matter in soil	-0.46	-0.78
	TFSG vs. pH	-0.52	-0.35
Cu	TFSS vs. Total Cu in soil	-0.85	-0.90
	TFSS vs. Clay content	-0.58	-0.42
	TFSG vs. Total Cu in soil	-0.80	-0.88
	TFSG vs. Clay content	-0.65	-0.46
Zn	TFSS vs. Total Zn in soil	-0.54	-0.23
	TFSS vs. Clay content	-0.56	-0.30
	TFSG vs. Total Zn in soil	-0.81	-0.77
	TFSG vs. Clay content	-0.72	-0.31

be the reason for the higher TF of Zn and Cu. However, no soil characteristic was found which could explain the higher Cd-TF. Probably there are other influencing factors which have not been identified, i.e. soil hydrology, climate and agricultural management.

The data of the wheat cultivars indicate, that there are some differences in Cd accumulation characteristics, i.e. cv. "Tambor" and "Brutus" and "Perlo" have the highest transfer factors on both locations, while for "Compass" and "Agron" lower Cd levels were determined. However, this cannot be generalised, because only two locations were investigated.

Table 5: Regression values for the correlation of TF with total soil element content and texture calculated for soils with pH > 7
Tabelle 5: Regressionswerte für die Korrelation von TF mit dem Elementgehalt im Boden und der Textur bei Böden mit pH > 7

		wheat	rye
Cu	TFSS vs. Total Cu in soil	-0.77	-0.86
	TFSS vs. Clay content	-0.87	-0.86
	TFSG vs. Total Cu in soil	-0.77	-0.94
	TFSG vs. Clay content	-0.81	-0.80
Zn	TFSS vs. Total Zn in soil	-0.69	-0.23
	TFSS vs. Clay content	-0.47	-0.30
	TFSG vs. Total Zn in soil	-0.72	-0.77
	TFSG vs. Clay content	-0.72	-0.31

4. Discussion

From the results of the field studies it can be concluded, that there are some important differences between the transfer of the essential micronutrients Cu and Zn and the toxic heavy metal Cd. Zn and Cu are accumulated at a much higher extent in edible parts compared to Cd. There are

Table 6: Plant contents of Cd, Cu and Zn in wheat grain and respective transfer factors for field study 2
Tabelle 6: Pflanzengehalte von Cd, Cu und Zn im Weizenkorn und entsprechende Transferfaktoren von Feldstudie 2

Cultivar	Raasdorf						Großenzersdorf					
	Cd mg kg^{-1}	TFSG	Cu mg kg^{-1}	TFSG	Zn mg kg^{-1}	TFSG	Cd mg kg^{-1}	TFSG	Cu mg kg^{-1}	TFSG	Zn mg kg^{-1}	TFSG
Agron	0.011	0.043	1.75	0.09	17.50	0.29	0.014	0.053	2.50	0.14	21.50	0.31
Alidos	0.011	0.043	1.76	0.09	17.59	0.29	0.022	0.083	3.00	0.17	29.50	0.42
Brutus	0.013	0.051	2.00	0.10	18.75	0.31	0.023	0.086	3.25	0.18	22.50	0.32
Capo	0.010	0.040	1.76	0.09	18.84	0.31	0.022	0.083	2.25	0.13	26.25	0.38
Compass	0.010	0.040	2.00	0.10	18.75	0.31	0.012	0.045	2.25	0.13	23.00	0.33
Exquisit	0.012	0.047	2.00	0.10	18.25	0.30	0.021	0.079	3.00	0.17	27.50	0.39
Extrem	0.009	0.036	2.22	0.11	19.70	0.33	0.016	0.060	2.81	0.16	26.01	0.37
Georg	0.009	0.036	1.75	0.09	16.75	0.28	0.021	0.079	2.24	0.13	24.38	0.35
Josef	0.009	0.036	2.22	0.11	19.70	0.33	0.019	0.071	2.30	0.13	25.50	0.36
L-DBK-95	0.012	0.047	2.32	0.12	20.59	0.34	0.015	0.056	2.25	0.13	23.25	0.33
Pegassos	0.009	0.036	2.00	0.10	15.50	0.26	0.016	0.060	2.25	0.13	23.25	0.33
Perlo	0.015	0.059	2.50	0.13	19.75	0.33	0.023	0.086	2.71	0.15	28.08	0.40
Renan	0.015	0.059	1.97	0.10	20.44	0.34	0.016	0.060	2.00	0.11	22.00	0.31
Spartakus	0.012	0.047	2.00	0.10	19.00	0.32	0.015	0.056	2.25	0.13	23.75	0.34
Tambor	0.014	0.055	2.00	0.10	20.00	0.33	0.024	0.090	2.55	0.14	31.37	0.45
Victo	0.010	0.040	2.50	0.13	18.00	0.30	0.018	0.068	1.75	0.10	20.75	0.30
mean	0.011	0.045	2.05	0.10	18.70	0.31	0.019	0.070	2.46	0.14	24.91	0.36
median	0.011	0.043	2.00	0.10	18.80	0.31	0.019	0.070	2.27	0.13	24.06	0.34
minimum	0.009	0.036	1.75	0.09	15.50	0.26	0.012	0.045	1.75	0.10	20.75	0.30
maximum	0.015	0.059	2.50	0.13	20.59	0.34	0.024	0.090	3.25	0.18	31.37	0.45
standard	0.002	0.008	0.245	0.012	1.390	0.023	0.004	0.014	0.401	0.023	3.020	0.043

reports on other crops with restricted Cd translocation to seed, fruit or even potato tubers and carrot roots (MacLean, 1976). It has been shown previously, that Cd movement into generative parts is considered to be not correlated with root to shoot translocation, but may be related to phloem-mediated transport to the grain (Hart et al., 1998; Popelka et al., 1996). The data of field study 1, where Cd levels in straw were found to be higher than in grain, may be due to decreased phloem loading of Cd.

Moreover, the transfer characteristics for Zn and Cu on the one hand and Cd on the other hand are also affected by different soil properties (Fig. 2, Table 4 and 5). The accumulation of Zn and Cu was found to depend on soil element content and texture while the pH, at least in the range of the investigated soils here, had less influence. In contrast to that, Freytag (1986) described a significant relationship between Cu transfer and pH and CEC. Gupta and Aten (1993) observed an increasing bioavailability of Cu as the soil pH decreases or when the cation exchange capacity and the level of soil organic matter increases. Also for Zn a relationship between pH and availability was described: Wu and Aasen (1994) obtained a significant effect of pH changes on Zn mobility at pH values above 6.5. Below this point the pH effect was found to become gradually less important. Although soil acidity has been recognized as one of the most important factors affecting the availability of Zn in soils (Lindsay, 1972; Jahiruddin and Hoque, 1983), the results of this study indicate, that other soil properties like texture may also be significant. The soil characteristics dominating Cd transfer are pH and organic matter content, unlike for Cu and Zn the amount of clay is not relevant. This is in agreement with previously published data (Haghiri, 1974; MacLean, 1976; Krämer and König, 1982; Naidu et al., 1994, Wenzel et al., 1996). Poelstra (1979) stated that the estimation of plant Cd-uptake from soils of variable properties is difficult and uncertain. However, Hornburg and Brümmer (1990) and Hornburg (1991) found that the Cd content in wheat grain increased linearly with total soil-Cd. In contrast to that, no significant linear relationship was found between soil and plant contents of field study 1.

Some studies were conducted in the past to investigate the amount of Cd accumulated by different plant species or cultivars. Horak (1976) reported, that wheat accumulates about twice as much as rye, oat or barley. Similar results were obtained in field study 1, where the mean Cd contents were 36 µg kg^{-1} in wheat grain and only 13 µg kg^{-1} in rye grain.

Moreover, also plant varieties show differences in their Cd accumulation characteristics. Wenzel et al. (1996) reported that Cd accumulation in grain of spring durum wheat varies by a factor of about 2.5. Kloke (1994) found great differences in Cd accumulation for a number of wheat cultivars (0.15 – 2.05 mg kg^{-1}). The Cd-range for wheat cultivars of field study 2 was lower (Table 6). Considering that crops like rye or oat or some wheat cultivars like "Agron" or "Compass" have lower Cd TF, it may be possible to prevent higher Cd levels in grain by using such plants for cultivation on sites with higher Cd levels.

Although the transfer factors of heavy metals from soil to plant are influenced by a great variety of soil parameters, it is possible to detect some regressions between soil properties and heavy metal uptake, even when the mobile or plant available fraction is unknown. Such relationships could possibly help to predict the extent of heavy metal accumulation in plants if a higher number of samples is included.

References

Adriano, D. C. (1986): Trace Elements in the Terrestrial Environment. Springer, New York.

Amlinger, F. (1993): Biotonne Wien. Magistratsabteilung 48 – Stadtreinigung und Fuhrpark, Wien.

Blum, W. E. H., H. Spiegel and W. W. Wenzel (1996): Bodenzustandsinventur. Konzeption, Durchführung, Bewertung. Institut für Bodenforschung, Universität für Bodenkultur, Wien.

Brümmer, G. W., J. Gerth and U. Herms (1986): Heavy metal species, mobility and availability in soils. Z. Pflanzenernähr. Bodenk. 149, 382–398.

Freytag, J. (1986): Bestimmung von Transferfaktoren Boden/Pflanze einiger Elemente und Untersuchungen über deren Abhängigkeit von ausgewählten Bodeneigenschaften. Hamburger Bodenkundliche Arbeiten 1, 43–51.

Gupta, S. K. and C. Aten (1993): Comparison and evaluation of extraction media and their suitability in a simple model to predict the biological relevance of heavy metal concentrations in contaminated soils. Intern. J. Environ. Anal. Chem. 51, 25–46.

Haghiri, F. (1974): Plant uptake of cadmium as influenced by cation exchange capacity, organic matter, zinc and soil temperature. J. Environ. Qual. 3, 180–183.

Haq, A. U., T. E. Bates and Y. K. Soon (1980): Comparison of extractants for plant-available zinc, cadmium, nickel, and copper in contaminated soils. Soil Sci. Am. J. 44, 772–777.

HART, J. J., R. M WELCH, W. A. NORVELL, L. A. SULLIVAN and L. V. KOCHIAN (1998): Characterization of cadmium binding, uptake, and translocation in intact seedlings of bread and durum wheat cultivars. Plant Physiol. 116, 1413–1420.

HORAK, O. (1976): Bestimmung von Blei und Cadmium in Getreide- und Grasproben aus verschiedenen Entfernungen von Autostraßen mit Hilfe der flammenlosen Atomabsorptions-Spektroskopie. Landwirtsch. Forsch. 29, 1–10.

HORAK, O. (1982): Die Beziehung zwischen der pflanzlichen Aufnahme einiger Mikroelemente und deren wasserlöslichem Anteil im Boden. Landwirtsch. Forsch., Sonderh. 39, Kongressband, 404–414.

HORAK, O. and A. A. KAMEL (1990): Ein Langzeitversuch der Pflanzenverfügbarkeit von Schwermetallen. VDLUFA-Schriftenreihe 32, Kongressband, 803–808.

HORNBURG, V. and G. W. BRÜMMER (1990): Schwermetall-Verfügbarkeit in Böden und Gehalte im Weizenkorn und anderen Pflanzen. VDLUFA-Schriftenreihe 32, Kongressband, 821–826.

HORNBURG, V. (1991): Untersuchungen zur Mobilität und Verfügbarkeit von Cadmium, Zink, Mangan, Blei und Kupfer in Böden. Bonner Bodenkundl. Abh. 2.

JAHIRUDDIN, M. and M. S. HOQUE (1983): Factors affecting zinc availability to crops. A review. Bangladesh J. Agric. Sci. 10, 1–12.

KABATA-PENDIAS A. and H. PENDIAS (1992): Trace Elements in Soils and Plants. 2nd ed., CRC Press, Boca Raton.

KIEKENS, L. and R. CAMERLYNCK (1982): Transfer characteristics for uptake of heavy metals by plants. Landwirtsch. Forsch., Sonderh. 39, Kongressband 1982, 255–261.

KLOKE, A. (1994): Schwermetalle in Pflanzensorten. Gartenbau-Mitteilungen 4/94, 18–19.

KRÄMER, K. and W. KÖNIG (1982): Cadmium-Gehalte in Böden und Pflanzen auf klärschlammgedüngten landwirtschaftlichen Nutzflächen. Landwirtsch. Forsch., Sonderh. 39, Kongressband 1982, 434–447.

LIEGENFELD, R. (1996): Untersuchungen zum Selen-Transfer aus dem Boden in Getreidepflanzen. Diplomarbeit, Universität Wien.

LINDSAY, W. L. (1972): Zinc in soils and plant nutrition. Adv. Agron. 24, 147–186.

LOMBI, E., M. H. GERZABEK and O. HORAK (1998): Mobility of heavy metals in soil and their uptake by sunflowers grown at different contamination levels. Agronomie 18, 361–371.

LÜBBEN, S. (1993): Abhängigkeit der Schwermetall-Transferfaktoren Boden/Pflanze vom Kontaminationsgrad des Bodens. VDLUFA-Schriftenreihe, Kongressband, 605–608.

MACLEAN, A. J. (1976): Cadmium in different plant species and its availability in soils as influenced by organic matter and additions of lime, P, Cd and Zn. Can. J. Soil Sci. 56, 129–138.

NAIDU, R., N. S. BOLAN, R. S. KOOKANA, and K. G. TILLER (1994): Ionic-strength and pH effects on the sorption of cadmium and the surface charge of soils. Eur. J. Soil Sci. 45, 419–429.

POELSTRA, P., M. J. FRISSEL and N. EL-BASSAM (1979): Transport and accumulation of Cd ions in soils and plants. Z. Pflanzenernähr. Bodenk. 142, 848–864.

POPELKA, J. C., S. SCHUBERT, R. SCHULZ and A. P. HANSEN (1996): Cadmium uptake and translocation during reproductive development of peanut (Arachis hypogaea L.). Angew. Bot. 70, 140–143.

WENZEL, W. W., W. E. H. BLUM, A. BRANDSTETTER, F. JOCKWER, A. KÖCHL, M. OBERFORSTER, H. E. OBERLÄNDER, C. RIEDLER, K. ROTH and I. VLADEVA (1996): Effects of soil properties and cultivar on cadmium accumulation in wheat grain. Z. Pflanzenernähr. Bodenk. 159, 609–614.

WU, X. and I. AASEN (1994): Models for predicting soil zinc availabiltiy for barley. Plant Soil 163, 279–285.

Address of authors

Dr. Markus Puschenreiter and Ao. Univ.-Prof. Dr. Othmar Horak, Austrian Research Centers, Division of Life Sciences, A-2444 Seibersdorf, Austria;
e-mail: othmar. horak@arcs.ac.at

Eingelangt am 12. April 1999
Angenommen am 5. August 1999