Zinc and copper in feeds, slurry and soils from Austrian pig fattening farms feeding commercial complete feed or feed mixtures produced on-farm

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Zink und Kupfer in Futter, Gülle und im Boden von Schweinemastbetrieben aus Österreich bei Fütterung von kommerziellem Alleinfutter oder betriebseigenem Mischfutter

1 Introduction

Dung from pig production has been shown repeatedly to contain extraordinary high amounts of Zn and Cu when compared to other agricultural livestock (SEVERIN et al., 1991; DRIESSEN and WESTHOEK, 1997; MÜLLER, 1997; DÖHLER et al., 2002; MCBRIDE and SPEARS, 2001; BONNIER, 2002; KÜHNEN and GOLDBACH, 2002; MÜLLER and

Zusammenfassung

Eine Reihe von Untersuchungen zeigen, dass die Zn-und Cu-Konzentrationen in Wirtschaftsdüngern von Schweinen weit über denen von Rindern und Geflügel liegen, vermutlich aufgrund einer weit verbreiteten Anwendung exzessiver Dosierungen an Zn und Cu im Futter. Es ist deshalb anzunehmen, dass Wirtschaftsdünger von Schweinen wesentlich niedrigere Werte aufweist, wenn auf exzessive Dosierungen im Futter verzichtet wird. Aus diesem Grunde wurden 27 österreichische Schweinemastbetriebe als Modell für die Schweinehaltung herangezogen und die Gehalte an Zn und Cu im Futter sowie in der Gülle untersucht. Darüber hinaus wurde von je 3 Betrieben mit den niedrigsten bzw. höchsten Zn-Gehalten in der Gülle Bodenproben gezogen. Sechs der ausgewählten Betriebe verfütterten ausschließlich kommerzielles Alleinfutter (CCF). Die anderen 21 Betriebe mischten das Mastfutter direkt am Betrieb aus wirtschaftseigenen Futtermitteln und zugekauften Komponenten (z.B. Mineralfutter) (Selbstmischer, FMF). Bei den Alleinfutterbetrieben wurde zusätzlich der Eintrag an Zn und Cu (kg) in die Masteinheit über das Futter und der jeweilige Austrag an Zn und Cu (kg) in das Gülle-Lager erfasst.

Bei den FMF-Betrieben (Selbstmischer) wurden 2 Datensätze zum Zink und 3 zum Kupfer aufgrund unerwartet hoher Konzentrationen im Futter bzw. in der Gülle aus dem Datensatz ausgeschlossen (vermutlich eine Anwendung exzessiver Dosierungen). Das Futter der CCF-Betriebe (Alleinfutter) enthielt 104 ± 26 mg Zn/kg und 20 ± 2 mg Cu/kg (bezogen auf 88 % Trockenmasse (T)) und lag durchwegs im Bereich der zulässigen Grenzen. Die entsprechenden Werte der FMF-Betriebe lagen 25 % höher (129 ± 39 und 25 ± 6) und überschritten teilweise die futtermittelrechtlich zulässigen Grenzen. Die Zn- und Cu-Konzentrationen in der Gülle (mg/kg T) betrugen bei den CCF-Betrieben 522 ± 194 und 105 ± 35, während für FMF-Betriebe höhere Werte beobachtet wurden (695 ± 295 und 154 ± 55). Die Transfer-Rate vom Futter in die Gülle betrug bei den CCF-Betrieben 84 ± 11% (Zn) und 69 ± 6% (Cu). Die Zn- und Cu-Konzentrationen im Boden (mg/kg DM) der Betriebe mit den niedrigsten Zn-Gehalten in der Gülle (nur CCF-Betriebe) betrug 72 ± 11 und 23 ± 6, während Betriebe mit dem höchsten Gülle-Zn (nur CCF-Betriebe) numerisch höhere Werte aufwiesen (78 ± 16 und 25 ± 5). Die Korrelation zwischen Gülle- und Boden-Zn betrug $r = 0{,}70$ ($p < 0{,}11$).

Die Beobachtungen der vorliegenden Studie legen den Schluss nahe, dass die Zn und Cu-Gehalte des Futters die dominierende Einflussgröße der jeweiligen Konzentrationen in Wirtschaftsdünger von Schweinen darstellen. Bei einer Fütterung von Zn und Cu innerhalb der futtermittelrechtlich zulässigen Grenzen und insbesondere bei Verzicht auf exzessive Dosierungen sind wesentlich niedrigere Konzentrationen an Zn und Cu im Wirtschaftsdünger zu erwarten als bisher berichtet wurden. Dies scheint auch einer Akkumulation von Zn und Cu im Boden entgegenzuwirken.

Schlagworte: Zn, Cu, Futter, Gülle, Boden, Schwein, Mast.

Summary

Dung from pig production (breeding as well as fattening) has been repeatedly reported to contain high amounts of Zn and Cu compared to dung from cattle and poultry, presumably due to abundant application of excessive Zn and Cu in feeds. This gives raise to the assumption that Zn and Cu in pig dung is significantly lower if such practices are not applied. Therefore, the present model study assessed 27 Austrian pig fattening farms as a model to pig production. Zn and Cu in feeds and slurry were monitored, as well as in soils from each 3 farms with lowest and highest slurry Zn, respectively. Six of selected farms used commercial compound feed (CCF) as only feed source, while 21 farms fed feed mixtures produced on-farm (FMF) In CCF-type farms, the amounts of Zn and Cu entering the fattening units via feeds and the corresponding efflux into the slurry stores were quantitatively recorded.

Within FMF-type farms, 2 datasets for Zn and 3 for Cu were withdrawn from further evaluation due to unusually high contents in feeds and slurry (probablyreflecting dietary Zn and/or Cu excess). Feed from CCF-type farms contained 104 ± 26 mg Zn/kg and 20 ± 2 mg Cu/kg (based on 88 % dry matter (DM)) and matched the limits given by feed law. Respective values for FMF-type farms were 25 % higher (129 ± 39 and 25 ± 6) and partially exceeded legal limits. Corresponding mean concentrations on Zn and Cu in slurry (mg/kg DM) were 522 ± 194 and 105 ± 35 for CCF-type farms, but higher in FMF-type farms (695 ± 295 and 154 ± 55). For CCF-type farms, transfer rate from feed into slurry accounted for 84 ± 11 % (Zn) and 69 ± 6 % (Cu). Soil Zn and Cu (mg/kg DM) from farms with lowest slurry Zn (only CCF-type farms) averaged 72 ± 11 and 23 ± 6, while farms with highest slurry Zn (FMF-type farms only) exhibited numerically higher levels (78 ± 16 and 25 ± 5). The correlation between slurry and soil Zn was $r = 0.70$ ($p < 0.11$).

The observations of this study suggest that Zn and Cu in feeds are the dominant factors affecting respective concentrations in pig dung. If Zn and Cu is fed according to limits set by feed law without using dietary excess (e.g. Cu to piglets), Zn and Cu concentrations in pig dung may be expected to be significantly lower than previously reported. This would counteract accumulation of Zn and Cu in soils.

Key words: Zn, Cu, feed, slurry, soil.

Ebert, 2002; Roth et al., 2002; Schenkel, 2002; Schultheiss et al., 2002; UBA, 2004; Nicholson et al., 2005; Kickinger et al., 2008). It was hypothesized that this originates mainly from use of excessive dietary doses for purpose of health and growth promotion. Indeed, feed law allows excessive dietary Cu to piglets, but high contents of Cu as well as of Zn in dung from all categories of pig production suggest abundant application of excessive dietary Zn and Cu (e.g. Kickinger et al., 2008). This gives raise to the assumption that Zn and Cu in pig dung produced without such practices shows considerably lower values than reported previously. Furthermore, the maximum permitted limits set by the feed law were reduced in year 2004 following Regulation (EC) No. 1334/2003, which might have entailed a further decrease of Zn and Cu contents in regular pig dung. In this context, the aim of the present study was to estimate of Zn and Cu in pig dung generated under condition of feeding Zn and Cu according to current limits set by the feed law. It was focused in particular on pig fattening because for this category the feed law prohibits also the application of excessive dietary Cu. In order to improve reliability, the study differentiated between pig fattening farms using commercial complete feed as only feed source and those who produced their feed on-farm by mixing commercial components (e.g. mineral premix) with home-grown feed. feedFarms using commercial complete feed were assumed to exhibit the lowest levels of slurry Zn and Cu due to higher precision of feed mixture and reduced possibility for entry of extra Zn and Cu into slurry (e.g. via application of excessive dietary doses). Furthermore, soil samples were derived from farms showing extreme levels on slurry Zn (high – low) in order to assess possible impacts on accumulation of Zn and Cu.

2 Material and Methods

The present paper comprises assessment of Zn and Cu contents in feeds and dung from 27 registered pig fattening farms as well as in selected cases corresponding contents in soils collected mainly in year 2008. The farms were located in the Austrian federal states of Lower Austria and Styria.

Pre-selection of farms were done by the AGES (Austrian Agency for Health and Food Safety) on base of the following criteria: the only type of livestock production should have been pig fattening (growing-finishing from about 30 to 105 kg of body weight); housing and feeding should have reflecting common local practice; dung should have been collected only as slurry without any entry of other organic material (e.g. no straw beddings, slatted floor only); the way of livestock production should have been exerted at least for one year before sampling; for farms where soil samples were derived, slurry from fattening pigs should have been completely spread on the agricultural area of the respective farm as the only source of organic dung. Farms were visited along with official control in cooperation with the AGES. Derivation of feed and slurry samples were executed according to Directive 76/371/EC (1976).

The assessed farms were split into two subgroups: The first subgroup consisted in farms which fed only commercial complete feed (*CCF).* These farms were visited 2 times in order to estimate the amounts of Zn and Cu entering the fattening unit via feeds and the corresponding efflux into the slurry stores. During the first visit, feed samples of 1kg were derived directly from the barn for proximate analysis of Zn and Cu concentration, current slurry volume was assessed, and the farmer was asked not to change feeding methods. At the second visit (1 to 6 months later), feed consumption by the entire fatting unit was recorded for the time period between the 1st and 2nd visit, and the current volume of slurry was measured (spreading of slurry was not allowed between the two visits). Slurry was stirred in the slurry store, at least 3 sub-samples of 1kg were derived and pooled, of which 1 kg was retrieved for proximate analysis of Zn and Cu concentration. The amounts of Zn and Cu entering the fattening units via feeds and the corresponding efflux into the slurry stores during the period of observation were calculated from respective Zn and Cu concentrations in feeds and slurry, total consumption of feed, and increase in slurry volume, respectively.

The second subgroup comprised farms which produced their feed on-farm using home-grown components (e.g. cereals, maize) and other commercial feedstuffs (e.g. soybean meal and mineral premix) *(FMF, feed mixtures produced on-farm).* FMF-type farms were visited only once. Samples (1 kg) of final feed mixtures were derived directly from the barn. Slurry samples were derived as described above for CCF-type farms. Table 1 presents further details on farms included into this study.

Table 1: List of assessed farms
Tabelle 1: Liste der der untersuchten Betriebe

Farm No.	Location 1)	No. of Fattening places	Farm type2)	Feeding type3)	Year of assess-ment	Months of assess-ment4)
1	STM	62	CCF	Dry	2008	4
2	STM	35	CCF	dry	2008	6
3	LA	740	CCF	liquid	2008	1
4	STM	280	FMF	dry	2008	
5	STM	420	FMF	dry	2008	
6	STM	165	FMF	liquid	2008	
7	STM	420	FMF	liquid	2008	
8	STM	360	FMF	liquid	2008	
9	STM	450	FMF	dry	2008	
10	STM	190	FMF	dry	2008	
11	STM	200	FMF	dry	2008	
12	STM	225	FMF	dry	2008	
13	STM	160	FMF	dry	2008	
14	LA	19	CCF	dry	2008	2
15	LA	90	CCF	dry	2008	1
16	LA	10	FMF	dry	2008	
17	LA	50	FMF	dry	2008	
18	LA	3000	FMF	liquid	2008	
19	LA	700	FMF	dry	2008	
20	LA	500	FMF	dry	2008	
21	LA	150	FMF	dry	2008	
22	LA	55	FMF	dry	2008	
23	LA	650	FMF	liquid	2008	
24	LA	900	FMF	liquid	2008	
25	LA	90	FMF	dry	2008	
26	LA	500	FMF	dry	2007	
27	LA	150	CCF	dry	2007	2

1) STM = Austrian federal state of Styria, LA = Austrian federal state of Lower Austria
2) CCF = farms using commercial complete feed, FMF = farms producing feed mixtures on-farm
3) dry = dry feeding, liquid = liquid feeding
4) Time distance (months) between first and second visit (CCF-type farms only)

Homogenized samples of feed and slurry were submitted to dry matter analysis and then mineralized in a muffle furnace at 550 °C (Naumann and Bassler, 1997). The ash was dissolved with hydrochloric acid (32 %) and transferred into HCl solution (1.5 %). Concentrations of Zn and Cu in mineralized samples of feed and slurry were analyzed with ICP-AES on base of calibrated Zn and Cu solutions. All analyses were done in triplicate.

After analysis of Zn and Cu in feed mixtures and in slurry, some farms stood out with unusually high values. The following limits were set in order to decide whether or not a dataset on either Zn or Cu in feeds and slurry was accepted for further use within the regular dataset:

a) Feeds: max. 225 mg Zn/kg or 37.5 mg Cu/kg (based on 88 % dry matter). These values reflect the current maximum permitted Zn and Cu contents in feeds (Regulation (EC) No. 1334/2003) multiplied with a tolerance factor of 1.5.
b) Slurry: 1800 mg Zn/kg or 300 mg Cu/kg (based on 100 % dry matter). These limits were calculated according to the thresholds given for feeds by the feed law, a factor for concentration from feed to slurry of 4 (e.g. KICKINGER et al., 2008) and a tolerance factor of 2.

According to these limits, two datasets on Zn in feed and slurry (farm No. 23, and 26) and 3 datasets for Cu (farm No. 8, 25, and 26) were excluded from regular dataset (the respective data are described separately). Furthermore, feed analysis for Zn and Cu from farm No 6, 9 and 18 failed due to lack of sufficient homogeneity after triplicate analysis. In total, 22 complete data sets on feeds and slurry were available for Zn and 21 for Cu.

From farms presented in table 1, each 3 farms with either the highest or the lowest analyzed slurry Zn contents were selected for derivation of soil samples (farm No, 14, 15, 27, and 22, 23, 26, respectively). Two agricultural areas were selected per farm, one located most close to the farm buildings and one most apart. Within each area, 25 individual soil sub-samples (0–25 cm depth, at least 1kg) distributed homogenously over a total space of 1 hectare were derived and pooled into one sample per area (1 kg). These two samples per farm were submitted to dry matter analysis, mineralized with concentrated nitric acid and concentrated hydrochloric acid (volumetric ratio of 1:3), and analyzed for Zn and Cu concentration by ICP-OES. All soils analyses were done in triplicate.

Table 2: Records showing high contents of Zn or Cu in feeds or slurry (data excluded from further evaluation)

Tabelle 2: Datensätze mit hohen Gehalten an Zn oder Cu im Futter oder in der Gülle (Daten für die weitere Auswertung ausgeschlossen)

Farm No.	Type of farm	Zn in feeds (mg/kg) (88 % DM)	Zn in manure (mg/kg DM)	Cu in feeds (mg/kg) (88 % DM)	Cu in manure (mg/kg DM)
8	FMF1)	–	–	41	150
23	FMF	153	2882	–	–
25	FMF	–	–	90	223
26	FMF	2138	6210	45	290

FMF = farms producing feed mixtures on-farm

The following tables present descriptive statistics (e.g. number of observations (n), arithmetic mean, standard deviation (±), median, minimum, maximum) with respect to the type of element (Zn, Cu) and matrix (feed, slurry, soil). Furthermore, linear regression and Pearson correlation analysis was done to describe the interrelationship between Zn and Cu in feed, slurry and soil. Statistical significance was considered to be given at $p < 0.05$.

3 Results

Table 2 lists records showing high Zn or Cu contents in feeds or slurry that were excluded from the regular dataset. Farm No 8, 23 and 25 stood out with high concentrations of Zn in slurry and Cu in feeds, respectively. Farm No 26 showed high values for Zn as well as for Cu in feeds and slurry. All farms showing unusual observations were FMF-type (feed mixtures produced on-farm).

As shown in table 3, pig fattening farms using commercial complete feed (CCF) exhibited Zn and Cu concentrations in feeds of 104 mg/kg and 20 mg/kg on average. In no case, legal limits (max. 150 mg Zn/kg, 25 mg Cu/kg) were exceeded. Corresponding Zn and Cu concentration in slurry averaged 522 and 105 mg/kg, respectively. In contrast, Zn and Cu in feeds produced on-farm (FMF) were about 25 % higher than those from CCF-type farms (129 and 25 mg/kg on average) and partially exceeded legal limits. Also corresponding Zn and Cu concentrations of slurry dry mater were higher by about one third compared to CCF-type farms (695 and 154 mg/kg on average). In case of Cu, means of feeds and slurry were statistically different between CCF-type and FMF-type farms (t-test: $p < 0.02$ and $p < 0.03$).

Figure 1 presents the efflux of Zn and Cu into slurry stores of CCF-type farms as affected by respective consumption of Zn and Cu of the fattening units via feeds during the period of observation. There was a linear relationship (R^2 = 94 % and 97 %). Intercepts of the regression equations were virtually zero indicating that there was no other relevant entry of Zn and Cu into slurry except for feed. According to the slopes of the regression equations, 84 ± 9 % and 67 ± 3 % of Zn and Cu consumed by the animals was excreted into the slurry, irrespective of the quantitative amounts actually fed to the animals.

Table 4 presents Pearson correlation coefficients between feeds and slurry regarding Zn or Cu concentrations (excluding unexpected observations listed in table 2). In CCF-

Table 3: Zn and Cu concentrations in feeds (mg/kg, 88 % DM) and slurry (mg/kg DM) (without data listed in table 2)
Tabelle 3: Konzentrationen an Zn und Cu im Futter (mg/kg, 88 % TM) und in der Gülle (mg/kg TM) (ohne Daten aus Tabelle 2)

	Descriptive statistics					
	n	Mean	±	Median	Min.	Max.
*CCF type farms*1)						
Zn in feeds (mg/kg, 88 % DM)	6	104	26	96	80	150
Zn in manure (mg/kg DM)	6	522	194	502	277	793
*FMF type farms*1)						
Zn in feeds (mg/kg, 88 % DM)	16	129	39	128	62	183
Zn in manure (mg/kg DM)	19	695	295	616	171	1523
All farms						
Zn in feeds (mg/kg, 88 % DM)	22	122	37	118	62	183
Zn in manure (mg/kg DM)	25	653	281	601	171	1523
CCF type farms						
Cu in feeds (mg/kg, 88 % DM)	6	20	2	20	18	25
Cu in manure (mg/kg DM)	6	105	35	119	52	136
FMF type farms						
Cu in feeds (mg/kg, 88 % DM)	15	25	6	24	10	34
Cu in manure (mg/kg DM)	18	154	55	142	64	291
All farms						
Cu in feeds (mg/kg, 88 % DM)	21	24	6	24	10	34
Cu in manure (mg/kg DM)	24	142	55	136	52	291

1) CCF = farms using commercial complete feed, FMF = farms producing feed mixtures on-farm

Table 4: Pearson correlation coefficients between Zn or Cu concentrations in feeds and slurry (without data listed in table 2)
Tabelle 4: Pearson Korrelationskoeffizient zwischen den Zn und Cu Gehalten in Futter und in der Gülle (ohne Daten aus Tabelle 2)

	CCF-type farms1)	MFM-type farms1)	All farms
Zn, feed vs. manure	$r = 0.86$, $p < 0.01$ 2)	$r = 0.16$, n.s.2)	$r = 0.31$, n.s.
Cu, feed vs. manure	$r = 0.55$, $p < 0.02$	$r = 0.41$, n.s.	$r = 0.51$, $p < 0.02$

1) CCF = farms using commercial complete feed, FMF = farms producing feed mixtures on-farm
2) $p < 0.xx$ statistical significance of correlation coefficient r, n.s. = statistically not significant

Table 5: Concentrations of Zn and Cu in soils from farms with lowest and highest slurry Zn (including data listed in table 2)
Tabelle 5: Gehalte an Zn und Cu in Böden von Betrieben mit den niedrigsten und höchsten Gehalten an Zn in der Gülle (inklusive Betriebe aus Tabelle 2)

Selection criterion for derivation of soil samples	N	Zn in manure (mg/kg DM)	Zn in soil (mg/kg DM)	Cu in manure (mg/kg DM)	Cu in soil (mg/kg DM)
Lowest manure Zn1)	3	486 ±151	72 ± 11	128 ± 13	23 ± 6
Highest manure Zn2)	3	3538 ± 2411	78 ± 16	275 ± 26	25 ± 5
All tested farms	6	2012 ± 2265	75 ± 13	202 ± 83	24 ± 5
Pearson correlation coefficient manure vs. soil	6	$r = 0.70$ $p < 0.10$ 3)		$r = 0.05$ n.s.3)	

1) Lowest manure Zn was found exclusively in CCF-type farms (commercial compound feed) (farms No. 14, 15, 27)
2) Highest manure Zn was found exclusively in FMF-type farms (feed mixtures produced on-farm) (farms No. 22, 23, and 26, see also table 2).
3) $p < 0.xx$ statistical significance of correlation coefficient r, n.s. = statistically not significant

type farms, there was a positive correlation between Zn or Cu contents of slurry and feeds (r = 0.86 and 0.55) indicating raising slurry Zn and Cu with increasing concentrations of the feeds. Also for FMF-type farms, correlation coefficients were numerically positive but without statistical significance.

Results on Zn and Cu concentrations of soils are shown in table 5. Farms with lowest slurry Zn were CCF-type (commercial complete feed) only, while those with highest slurry Zn were exclusively FMF-type (feed mixtures produced on-farm). The latter included also farms No. 23 and 26 (see table 2). Soil Zn and Cu concentrations were numerically higher by 10 % and 7 % in case of highest slurry Zn (FMF-type farms) compared to low slurry Zn (CCF-type farms), but without statistical significance (t-test, $p > 0.1$). Nevertheless, Pearson correlation coefficient between slurry and soil Zn accounted for r = 0.7 ($p < 0.11$) indicating a trend for increasing soil Zn with rising slurry Zn. In case of Cu, however, no trend was visible, which partially reflects the fact that selection criterion for derivation of soil samples was slurry Zn and not slurry Cu.

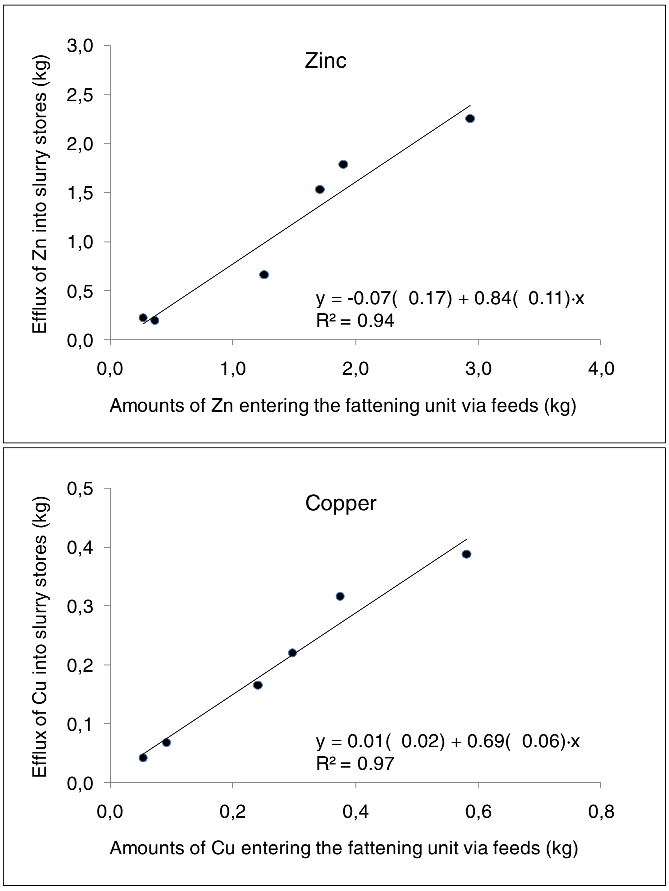

Figure 1: Efflux of Zn and Cu (kg) into slurry stores of CCF-type farms as affected by respective amounts of Zn and Cu (kg) entering the fattening units via feeds

Abbildung 1: Austrag an Zn und Cu (kg) in das Gülle-Lager in Abhängigkeit vom jeweiligen Eintrag an Zn und Cu (kg) in die Masteinheit über das Futter

4 Discussion

The data presented in this study originated from samples of feeds to fattening pigs and respective slurry derived mainly in year 2008. During this period of time, the current limits of Zn and Cu contents to feeds have been valid since 5 years and hence have been well established in current practice (150 mg Zn/kg and 25 mg Cu/kg of feed to fattening pigs (88 % DM); Regulation (EC) No. 1334/2003). As shown in table 3, all samples of commercial complete feed tested in the present study matched these limits. Also most of feed produced on-farm by mixing home-grown feedstuffs (e.g. grain, maize) with other commercial components (e.g. soybean meal, mineral premix) ranged within permitted limits. But Zn and Cu concentrations were systematically higher than in commercial complete feed and in some cases above legal limits. This obviously reflects the widespread habit of farms producing their own feed-mixtures (FMF-type farms) to adjust additions of mineral premixes by other criteria than maximum limits to trace minerals and to ignore additional entry of Zn and Cu into feed from native contents in major feed components.

Nevertheless, 3 FMF-type farms stood out with exceptionally high levels of Zn and Cu in feeds (table 2). In one case, dietary Zn contents of more than 2000 mg/kg probably reflected overdose of Zn for purpose of health and growth promotion e.g. (HAHN and BAKER, 1993; POULSEN, 1995; WINDISCH et al., 1999). Corresponding Zn content of slurry was also quite high and ranged at levels to be expected at such excessive dietary doses (KICKINGER et al., 2008). Another farm showed rather high slurry Zn, while Zn in feed was normal. Probably, excessive use of dietary Zn was applied transiently before the farm visit. Three cases of detected Cu overdose seem to reflect the preparation of feed according to permitted levels to piglets (170 mg/kg), e.g. by admixing mineral premix to piglets into feed for fattening pigs. Similar to Zn, the purpose of such feeding practice is to induce health and growth promoting effects (e.g. CROMWELL et al., 1998; COFFEY et al., 1994; APGAR et al., 1995, APGAR and KORNEGAY, 1996; WINDISCH et al., 2001). It leads to comparably high Cu contents in slurry as well (cf. table 3; see also KICKINGER et al., 2008).

In pig fattening farms using commercial complete feed as only feed source (CCF-type farms), fluxes of Zn and Cu via feed into slurry can be easily monitored. Such farms may therefore serve as a robust model to describe regular Zn and Cu in pig slurry. According to table 3, Zn and Cu concentrations in slurry of CCF-type farms were only about half of levels reported previously for pig dung (for list or references see introduction). One reason might be fact that permitted Zn and Cu concentrations in feeds to pigs were reduced about 5 years ago (from 250 to 150 mg Zn/kg; from 35 to 25 mg Cu/kg; DIRECTIVE (EC) No. 524/1970, Regulation (EC) No. 1334/2003). However, these changes in feed law were too small to explain the full difference (cf. KICKINGER et al., 2008). The major reason may be seen in the sole use of commercial complete feed in CCF-type farms which did not offer the possibility to apply excessive doses of Zn and Cu for purpose of health and growth promotion. Interestingly, the concentrations of Zn and Cu in slurry actually observed in CCF-type farms matched quit well to expected maximum levels derived from physiological considerations: as dry matter quantity released via feces and urine after completion of digestion accounts for about 25 % of ingested feed dry matter quantity, Zn and Cu concentration in slurry should range at about 4-times higher levels than in feeds, provided that only a minor proportion of dietary Zn and Cu is absorbed (KICKINGER et al., 2008). Accordingly, full utilization of currently permitted Zn and Cu levels in feeds would result in slurry Zn and Cu concentrations of around 600 and 100 mg/kg DM, respectively.

As shown in figure 1, the transfer rate of Zn and Cu from feed into slurry averaged 84 % and 67 %. Consequently, most of ingested Zn and Cu was not retained in the animals' bodies. This is a typical reaction of homeostatic regulation to dietary supplies exceeding the metabolic requirement for these trace minerals. In general, the transfer rates observed in this study confirm quite well estimates on concentration factors of Zn and Cu from feed to dung derived from physiological considerations (see above). Furthermore, the transfer rates were independent from the absolute amounts of Zn and Cu fed to the animals. These results suggest that there is no other quantitatively relevant entry of Zn and Cu into slurry than from feeds. Vice versa, exceptionally high Zn and Cu concentrations in pig slurry are most likely caused by dietary overdose (e.g. for purpose of health and growth promotion). Regarding the transfer rate of Zn and Cu from feeds into slurry, it has to be considered that excretion of Zn and Cu via feces and urine is submitted to homeostatic regulation and may change with dietary supply in relation to metabolic requirement. Therefore, the transfer rates observed in this study reflect current feeding practice rather than a biologically determined threshold. Nevertheless, it is obvious that under practical conditions the dominant part of Zn and Cu fed to pigs will be transferred into slurry and that restrictions of dietary Zn and Cu are very effective means to control fluxes of Zn and Cu via dung onto the agricultural area.

FMF-type farms showed higher Zn and Cu concentrations in slurry than CCF-type farms (table 3). This was to be expected because of systematically higher concentrations of these elements in the feeds. The relative differences in feed and slurry samples between FMF-type and CCF-type farms were rather similar. Obviously, the transfer rate of Zn and Cu from feed into slurry is virtually the same as in FMF-type farms and entries of Zn and Cu into slurry other than feeds do not play a quantitatively relevant role in FMF-type farms as well. In comparison to previous reports on Zn and Cu concentrations in slurry, also FMF-type farms revealed significantly lower values, which is to be explained by the same reasons as described above for CCF-type farms. In total, it may be assumed that Zn and Cu in slurry of FMF-type farms will be equal to CCF-type farms once the concentrations of Zn and Cu in the feeds are controlled at the same level. Under condition of respecting the limits set by feed law, concentrations of Zn and Cu in slurry DM from fattening pigs may therefore be expected to range between about 500 to 750 mg Zn/kg, and 60 to 140 mg Cu/kg, respectively. These values should roughly apply to pig production in general (including sows and piglets) provided that piglet feed does not contain excessive Cu. Additionally, organic material other than feces and urine (e.g. bedding material such as straw) may enter the slurry and further reduce respective Zn and Cu concentrations.

Zn and Cu are essential trace elements, but also heavy metals with high potential for environmental pollution as they may effectively accumulate in soils. When spread in excess on agricultural areas on a long term base, Zn and Cu may significantly harm the vital role of soil to act as buffer, filter and cleaning media at the interface to groundwater, as well as its suitability for providing a habitat to plants for generation of foods and feeds. For these reasons, Zn and Cu loads of soils have been submitted to soil protection regulations e.g. by setting limits to Zn and Cu concentrations in biomass from municipal sources (400 mg Zn/kg DM and 100 mg Cu/kg DM, BIOABFV, 1998) or to sewage sludge (2000 mg Zn/kg DM and 500 mg Cu/kg DM; KSVO, 1994; MKVO, 1989). Dung from agricultural livestock production, however, is controlled only indirectly by feed legislation through setting upper limits of Zn and Cu to livestock feeds. But dung covers about three fourth of total Zn and Cu loads on agricultural areas and is considered to be the dominant source of accumulations in the soils (Aichberger et al., 1995; Müller, 1997; Danneberg, 1997; Kilian, 1999; Bonnier, 2002; Roth et al., 2002; Dersch and Hösch, 2003; UBA, 2004; Nicholson et al., 2005). For these reasons there are ongoing debates to limit Zn and Cu contents in dung dry matter in the range of 200 to 450 mg/kg, and 60 to 90 mg/kg (UBA, 2001; Döhler et al., 2002; Schwarz et al. 2004).

In view of the wide gap between high levels of dung Zn and Cu reported previously and the limits suggested by soil protection bodies, the observations of the present study demonstrate that the situation has been significantly improved. Nevertheless, the majority of slurry Zn and Cu observed in this study exceeded the limits under discussion by about 80 % and would require further reduction, e.g. by improving the precision of feed mixtures produced on-farm. Furthermore, there is no physiological need to fully utilize the range of dietary Zn and Cu concentrations set by the feed law. A feeding strategy considering the animals' requirement for Zn and Cu (GFE, 2006) rather than the maximum permitted levels, e.g. in combination with use of phytase and highly bioavailable Zn and Cu supplements, should provide an additional space to reduce Zn and Cu concentrations in dung.

Zn and Cu concentrations in soil samples derived from 3 farms with highest slurry Zn suggested a numerical trend for somewhat higher levels compared to those from 3 farms with lowest slurry Zn (table 5). Indeed, the correlation coefficient between slurry Zn and soil Zn was numerically strong (r = 0.70), and the highest soil Zn (91.7 mg/kg) was found in farm No. 26, which stood out for highest levels of Zn in feeds and in slurry (see table 2). This gives raise to the suspicion that (repeated) excess of Zn in pig feeds might in the long run cause a detectable increment of Zn in agricultural soils. But the dataset available in the present study is too small to derive firm conclusions. The same applies for the interrelationship of Cu in slurry and soils.

In conclusion, the present study revealed that Zn and Cu concentration of pig slurry may be significantly lower than previously reported. Vice versa, it may be assumed that the high concentrations of Zn and Cu in pig dung shown by former reports were mainly due to high levels of Zn and Cu in the feeds (especially when applied excessively for purpose of health and growth promotion). Such practices should be stopped in order to reach the low levels of Zn and Cu in pig dung observed in the present study. A more accurate control of concentrations of Zn and Cu in pig feeds produced on-farm (especially dietary inclusion of mineral premixes) as well as feeding animals according to nutritional recommendations could further reduce Zn and Cu in pig dung. In total, pig production may achieve the same ecological compatibility in view of Zn and Cu emissions via dung as other livestock.

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