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Contribution of additives Cu to its accumulation in pig feces: study in Beijing and Fuxin of China

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Abstract

Massive amounts of pig manure are produced by intensive pig farm in China, and the composition of pig manure has changed much due to the use of feed additives. However, little is known about the exact Cu (copper) feed as additives or present as contaminants in pig feed and the residues in feces. One hundred and thirty-seven feeds and one hundred and forty-two fecal samples from 48 pig farms were collected in Beijing and Fuxin cities in 1999 and 2005, respectively. The concentrations of Cu were in the range of 6.86–395.19 mg/kg in the feed samples, and the mean values were in the order of weaner>grower-finisher>sow's feeds. The high concentrations over EU recommendations implied that excessive levels of Cu are fed on many pig farms in Beijing and Fuxin. Cu was also present in high concentrations in feces, and concentrations were highly variable. Cu concentrations in the feces from grower-finisher and weaner pigs were significantly greater than feces of sows. The super-intensive and small-scale farms had higher levels of Cu in feces than the middle farms. Cu concentrations in pig feces were approximately 5-times greater than in pig feeds. Feed management in grower-finisher pigs on super-intensive and small-scale pig farms is needed to reduce high Cu concentrations in feces and risks to soil contamination while feces are land-applied.

Key words: copper (Cu); pig feed; pig feces; intensive pig production

Introduction

Intensive pig production systems are on the increase in many regions of the world, although the growth rates differ substantially. China has perhaps one of the highest growth rates in the world (Simpson *et al*., 1994). In the last two decades alone, pork production in China has increased from 10 million tons in 1979 to 47.3 million tons in 2004 (Chinese Animal Husbandry Yearbook, 2005), and China is currently the largest pork producer in the world, accounting for nearly 42% of all global pork production (Best, 2001).

Copper (Cu) is widely used in pig diets not only as an essential micro-nutrient, but also its stimulating effect on animal growth performance (Živković and Zlatić , 1979; Dréau and Lallès, 1999). In general, Cu levels in various feeds are high enough to meet the animals' Cu requirements. Nevertheless, it is a common practice to add Cu to feed rations via mineral additives in modern pig industry (Lillie *et al*., 1977; Underwood and Suttle, 1999), this additional Cu generally results in excessive Cu levels in feed (Jongbloed *et al*., 1985).

Previous studies have shown that excessive dosages of feed additives may almost completely be excreted into feces or urine, and may subsequently lead to environmental contamination (Zervas *et al*., 1990; Kirchgessner, 1993; Livesey, 1994; Craigmill, 1994; Bolan *et al*., 2003; Nicholson *et al*., 2003). It is well known that most animal manure is directly spread on the agricultural land, the contaminants like Cu will enter the soils with manure (Zhang *et al*., 1994; Han *et al*., 2000). Since the mobility of Cu in the soil is extremely low, the metal can be progressively accumulated in soils fertilized with pig manure (Livesey, 1994; Alloway, 1995). The impacts of the Cu accumulation in agricultural soils are numerous, may include a reduction in soil fertility and water quality. Moreover, Kong *et al*. (2006) reported the significant negative effects on microbial community function owing to the excess Cu concentrations in soil. It has been shown that the extent of Cu accumulation in German soil amended with pig manure was comparable to that in agricultural areas fertilized with sewage sludge (Wong *et al*., 1982; Atteia and Dubois, 1994). Kerr and Mcgavin (1991) observed that excessive accumulation of

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Cu in pasture received Cu-enriched swine manure caused chronic Cu poisoning in sheep.

Most intensive animal farms in China are located in the developed or the coastal cities. The environmental problems in these regions associated with land application of animal manure have centered on the contamination of groundwater and surface water with two major nutrients, N and P (Wang *et al*., 2001; Gan *et al*., 2003; Li and Li, 2004.). Recently, however, heavy metal and veterinary antibiotic contaminants in animal manure have attracted the attention of scientists in China (Cang *et al*., 2004; Li and Chen, 2005; Zhang *et al*., 2005; Kong *et al*., 2006). The extremely high concentrations of heavy metals including Cu, As and some organic contaminants were reported in Beijing, Jiangsu and Shandong provinces (Cang *et al*., 2004; Li and Chen, 2005; Zhang *et al*., 2005).

The objective of this study is to quantify Cu concentrations in pig feeds and feces on Beijing and Fuxin pig farms. A comparison of differences in Cu concentrations in feeds and feces across these two major pig producing area over a five-year period provides an assessment of the potential risk of excessive feeds Cu on fecal Cu concentrations.

1 Materials and methods

1.1 Study areas

Beijing, as the capital of China, has approximately 3000 large-scale pig and chicken farms (Shaoqi, 1994; Li and Chen, 2005). In the last 20 years, the total pig manure produced from these facilities amounted to 2.63×10^6 t, reflecting an increase of over 40% (Statistic Yearbook of Beijing, 1985–2003). Fuxin City, a typical industrialized city located in Liaoning Province, has more than one hundred years of mining history. However, the coal resource has been getting exhausted. Livestock and poultry production has been selected as the premier industry to improve the local economy. Animal production has increased more than 2–3 times in the last 5 years. The need for scientific knowledge and public awareness of the environmental risks from this great increase in animal production has become more and more pressing.

Six of ten counties in Beijing and four of seven counties in Fuxin were selected for collecting the pig feed and fecal samples.

1.2 Sampling and analysis

Eight pig farms ranging in size from 3000 to 10000 pigs and 30 pig farms ranging in size from 140 to 12000 pigs were chosen in Beijing in 1999 and 2005, respectively. In 2005, 10 pig farms from Fuxin City were selected ranging between 200 and 6000 pigs. At each farm, the feed samples along with the corresponding fecal samples (paired of feed and feces) were taken individually from 3 groups of pigs. Pig groups were stratified by stage of growth and are described in Table 1.

All feed samples were commercial or home mixes being fed to pigs the day of each visit. Samples were collected by taking a minimum of 20 sub-samples from different areas within the feed bunker. Sub-samples were then bulked together and thoroughly mixed to provide one representative sample of approximately 2 kg for analysis.

Table 1 Description of sample collection for feed and fecal materials

Pig type	Beijing 1999		Beijing 2005		Fuxin 2005	
	Feeds	Feces	Feeds	Feces	Feeds	Feces
Weaner	7	8	28	29	9	9
Grower-finisher	7	8	29	29	10	10
Sow	10	12	28	28	9	9
Total	24	28	85	86	28	28

Fecal samples were taken directly from the floor of each barn. A minimum of 30 fecal sub-samples were taken from different areas of the unit floor. Sub-samples were then bulked and thoroughly mixed to provide one representative sample of approximately 2 kg for analysis.

The fresh feed and fecal samples were air dried in the shade, then ground and passed through a 0.25-mm mesh PVC sieve. A 0.5-g sub-sample of the dry powder was weighed and digested in heated, concentrated HNO_3 and H_2O_2 (USEPA, 1996). Cu concentration was determined by atomic absorption spectrometry (AAS, Vario 6, Jena Co. Ltd., Germany). Repeated and spiked samples (GSS-1) were added for QA/QC.

1.3 Statistical analysis

SPSS 11.0 statistical package was employed for statistical analysis.

2 Results and discussion

2.1 Cu concentrations in pig feeds

Cu concentrations showed large variation among the feed samples (Table 2). The maximum value of 395.19 mg Cu/kg is 180 times higher than the minimum of 2.16 mg Cu/kg, which implied that the additives Cu applied by each pig farmer differ remarkably. Weaner feeds were found to have the highest Cu concentration in Beijing 2005 samples, but the highest Cu concentrations in Beijing 1999 samples and Fuxin 2005 samples were found for grower-finisher. The mean values of Cu concentrations are in the order of weaner>grower-finisher>sow, significant differences ($P<0.05$) were observed between weaner,

Table 2 Concentration of Cu in pig feeds (mg/kg dm)

	Min	Max	Mean	SD
Beijing 2005				
Weaner	9.50	395.19	207.96a*	83.73
Growe-finisher	11.81	283.88	159.24b	80.92
Sow	6.86	149.23	43.31c	35.55
Beijing 1999				
Weaner	18.20	232.60	160.79a	90.14
Growe-finisher	12.70	287.70	130.01a	118.05
Sow	17.60	32.70	23.75b	6.70
Fuxin 2005				
Weaner	108.80	256.01	191.90a	52.38
Growe-finisher	10.52	256.73	148.29a	66.12
Sow	2.16	115.44	41.05 b	35.39

*Values followed by different small letter were significantly different between pig groups at 0.05 levels.

grower-finisher feed samples and sow feeds, indicating that sows might get less Cu additives in their diets than the other two groups. 30 mg Cu/kg feed for sow but 84.8–217 mg Cu/kg feed for weaner and grower observed by Nicholson *et al*. (1999) radically proved that additives Cu were generally used as growth promoter for growing animals during pig production (Bolan *et al*., 2003). The average Cu concentration of 105 mg/kg, in Cang's survey (2004), was comparable to 128 mg/kg of the present study. Hence, the general conclusion could be drawn that, the Cu additives were widely used for pig production in Chinese pig farm.

European Commission announced the recommendation dosages for the use of copper in animal feeds (EC, 2003), 175 mg Cu/kg for weaner and 25 mg Cu/kg for grower-finisher and sow were suggested. The features of the feeds Cu concentration in each type of the pig feeds as compared with 25 mg Cu/kg and 175 mg Cu/kg are shown in Fig.1.

More than 60% of the weaner feeds tested in the present study, across locations and time periods, exceeded the recommendation of 175 mg Cu/kg. Few feeds of grower-finisher contained Cu above 175 mg Cu/kg, however, on the basis of recommendation value of 25 mg Cu/kg for adult pigs, at least 70% of feeds were found over the EU recommendation. Feed samples taken from Beijing farms in 2005 displayed the most serious excessive levels of Cu, with 74% of samples having excessive Cu levels compared to 57% from Beijing 1999. Among the three pig types, feeds for the grower-finisher were the largest group containing excessive Cu, followed by weaner, and sows, which testified that sow is not the major additives Cu consumer in Chinese pig farms. The high ratios over EU recommendations in grower-finisher feeds implied that the rich-Cu diets generally applied to growing pig both in Beijing and Fuxin.

2.2 Cu concentrations in pig feces

Consistent with the results of feeds, the highest mean value of Cu was found in weaner fecal samples, the order of the mean values was weaner>grower-finisher>sow (Table 3). Certainly, the significant difference of fecal Cu displayed the same tendency as feeds Cu between the growing pigs (weaner and grower-finisher) and reproductive pig (sow). Similar to the report from Cang *et al.* (2004), the fecal Cu concentrations in this survey (50–2017 mg Cu/kg) were much higher than those in Nicholson's study in England and Wales (1999).

Table 3 Concentration of Cu in pig feces (mg/kg dm)

	Min	Max	Mean	SD
Beijing 2005				
Weaner	289.63	1918.17	1112.3a	424.92
Grower-finisher	138.14	2016.74	887.68b	427.89
Sow	70.13	993.74	254.74c	220.48
Beijing 1999				
Weaner	57.70	1390.40	1095.75a	261.39
Grower-finisher	73.20	1218.00	505.99b	477.30
Sow	133.90	252.58	187.84bc	47.01
Fuxin 2005				
Weaner	496.81	1318.33	849.09a	253.31
Grower-finisher	90.41	942.57	692.24a	347.14
Sow	49.96	705.37	266.52b	204.78

*Values followed by different small letter were significantly different between pig groups at 0.05 levels.

Fig.2 demonstrates the features of Cu concentrations in each group of pig feces. Beijing 2005 fecal samples showed the largest variation, especially among feces of weaner and grower-finisher pigs. Most of weaner samples of Beijing 2005 contained high Cu concentration, 20% exceeded 1500 mg/kg, at least 40% were in the range of 1000–1500 mg Cu/kg, therefore, more than 60% of total exceeded 1000 mg Cu/kg. The weaner feces of Beijing 1999 illustrated the same feature as Beijing 2005, despite that none of fecal samples contained Cu beyond 1500 mg/kg. In contrast to weaner and grower-finisher's feces, the sow feces mainly contained Cu below 500 mg/kg, except 10% of Beijing 2005 ranged from 500–1000 mg Cu/kg. The sow's feces can be regarded as having the lowest Cu concentrations compared to the other two pig groups, and the weaner's feces appear to have the highest fecal Cu concentrations. However, weaners excrete less waste than grower-finisher, so weaner's excretion is always diluted on a whole-farm basis (LBP 1997). Accordingly, the grower-finisher group may need particular attention, because this group is the largest one among the pig farms, and will excrete the main portion of the wastes. At the same time, the rising tendency of Cu concentrations in pig feeds and feces were found between Beijing 1999 and Beijing

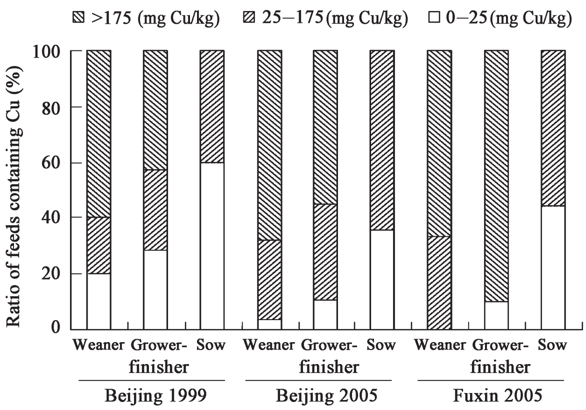

Fig. 1 Ratios of feeds containing Cu beyond the EU recommendation values.

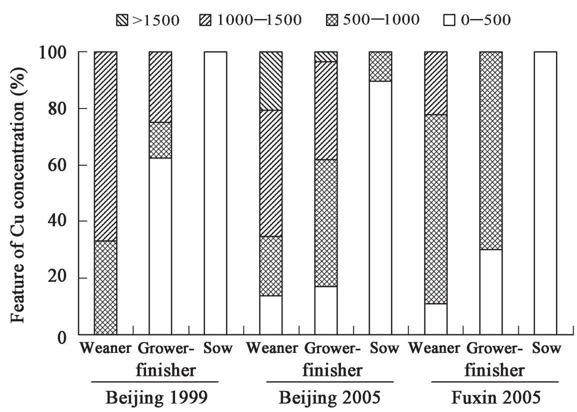

Fig. 2 Features of Cu concentrations (mg Cu/kg) in each group of pig feces.

2005, which implied that the use of additives Cu has been enhanced in Beijing.

There are no guidelines on animal manure land application concerning Cu contaminant in China so far. Compared to the Biosolids criteria (USEPA, 40 CFR, Part 503), the concentrations of Cu in pig feces are far lower than the up limits of 4300 mg Cu/kg, but six of weaner's feces and one grower-finisher's feces exceeded 1500 mg Cu/kg (the criteria for the high quality Biosolid), and two grower-finisher's feces contained closely to 1500 mg Cu/kg. Although the fecal Cu was hardly comparable with EPA standard for Biosolids, scientists still suggested the more attention should be paid for animal feces rather than Biosolids (Spicer, 2002; Chen *et al*., 2003). Because people used pig manure as land amendment instead of Biosolids, and they do not think about comparing the risks and benefits of its use, and are not aware about the risks from manure application. Furthermore, land use of pig manure can be 40 times more than Biosolids (Spicer, 2002). Hsieh and Hsieh (1990) proved that long-term application of pure pig and poultry manures is discouraged in Taiwan because of the high Cu and Zn contents.

2.3 Comparison of Cu concentrations in feeds and feces with farm sizes

As described above, there was large variation among Cu concentrations in feed and fecal samples, indicating the differences in the use of feed additives Cu among farms. Thirty pig farms of Beijing 2005 were selected to investigate the difference of Cu application and excretion in different sizes of pig farms. The farm sizes were between 140 to 12000 pigs, 25% of the 30 farms were small-scale operations having between 140 to 2000 pigs, and 25% were defined as the super-intensive scale, having between 6000 to 12000 pigs, and the rest 50% were in the middle.

The super-intensive farms displayed the highest Cu concentration in pig feeds (Fig.3). On small-scale farms, especially for grower-finisher, the Cu concentrations in feeds were equal to concentrations found in feeds on the super-intensive farms. The middle sized farms can be considered as having the lowest Cu concentrations in feeds. The large intensive pig farms demonstrated the high dosage of additives Cu in the feeds can be explained that, the financial capacity may let the farmers to easily afford feed additives. This possibility was also mentioned by Zhang *et al*. (2001). As a whole, sub-optimal management levels of farmers and short of governmental regulation will be the keys of excessive additives Cu applying in China now.

The Cu concentrations in pig feces showed the same tendency as those of feeds. Super-intensive farms distinctly illustrated the highest fecal Cu excretion compared to the middle and the small farms. It is roughly estimated that, 1080 kg Cu pollutants in the feces might be discharged each year through a swine farm raising 10000 grower-finisher, therefore, the super-intensive pig farms will cause potential Cu pollution hazard due not only to the massive amounts of manure produced, but also to the high concentrations of fecal Cu. On the other hand, small farms widely distribute in the rural areas, less supervision from the government and professional knowledge might cause the farmers oversupplying additives and abusing the manure to the farmland. For these reasons, the small and the super-intensive pig farms should be paid more attention concerning the high levels of Cu in feeds and therefore residues in feces.

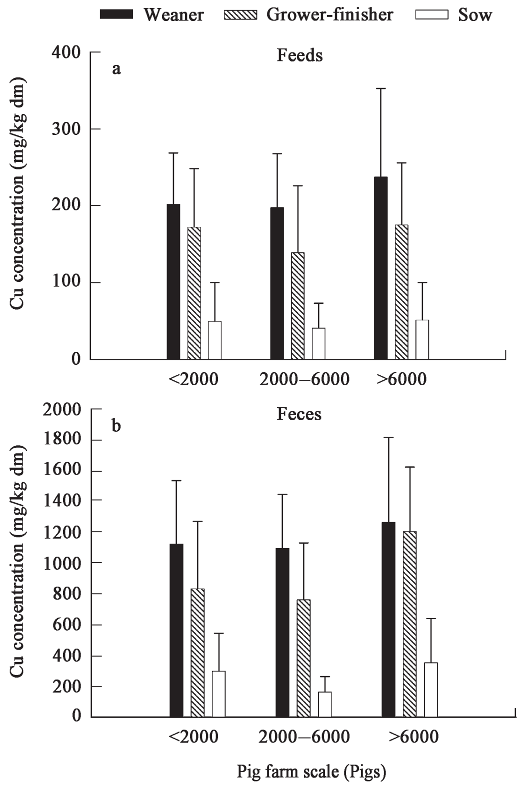

Fig. 3 Comparison of Cu concentrations in pig feeds and feces within three scales of pig farms.

2.4 The concentrated factor of Cu in pig feces

Fig.4 shows the relationship between feed Cu and fecal Cu. The linear regression equations were derived from the data. The regression slopes could be considered as ratios of Cu concentrations in feces to those in feeds. The three groups of pigs exhibit different concentrated factors (4.69–5.01), in the order of weaner>grower-finisher>sow. The finding suggested that different group of pigs might absorb or excrete the additives Cu at different levels. In other words, the more additives Cu fed to the pigs will be excreted the more by weaner than by grower-finisher or sow, which might imply the availability of additives Cu to weaner is the lowest among the three types of pigs.

Many researches had been conducted to observe the Cu excretion associated with the dietary Cu supplements. Krishnamachari and Fluorine (1987) and Miller *et al*. (1991) stated that the concentrations of metal in manure depended primarily on the concentration in diets. Kornegay *et al*. (1976) found more than 90% of Cu in pig feeds excreted in feces, and increasing the Cu concentration in pig diet from 7–10 mg/kg to 250–370 mg/kg proportionately increased the Cu concentrations from 59–88 mg/kg to 1330–2367 mg/kg in the manure. Similarly, Kunkle *et al*. (1981)

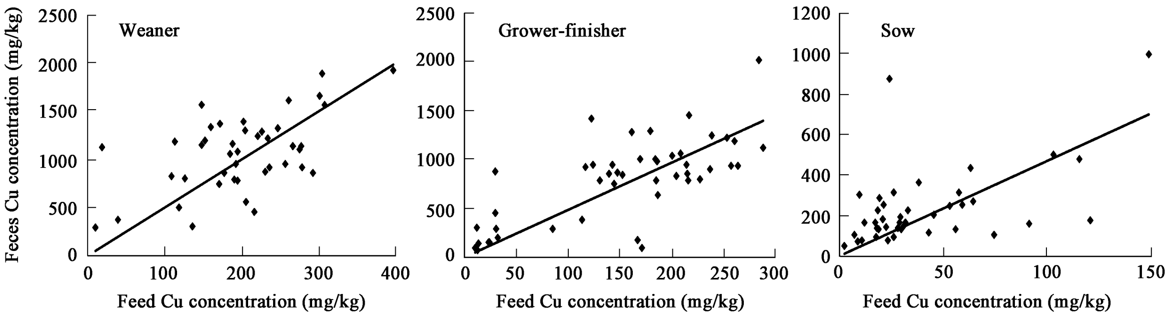

Fig. 4 Scatter plots of Cu concentration in pig feeds and feces. Weaner: Y=5.01X, R^2=0.894**, p<0.05; grower-finisher: Y=4.85X, R^2=0.878**, p<0.05; sow: Y=4.69X, R^2=0.662**, p<0.05; where Y is the concentration of Cu in pig feces; X is the concentration of Cu in pig feed.

noticed that Cu concentrations in poultry manure were linearly related to Cu added in the diet and were typically concentrated 3.25 times. The significantly positive linear relationships of Cu concentrations between pig feeds and pig feces found in this study demonstrated that fecal Cu will linearly rise with feed Cu at the ratios of 4.69–5.01. The good relationships of Cu concentrations between pig feeds and feces can be used as a predictor of the likely Cu concentrations of pig feeds from the fecal Cu contents, where the real feed samples are not available for inspecting.

3 Conclusions

The investigation of 48 pig farms in Beijing and Fuxin revealed excessive Cu use in pig production. The oversupplying of Cu in feed additives caused Cu accumulation in feces. Pig production in China will keep growing in the future, the huge amounts of pig manure may represent an important source of increasing heavy metal concentrations in agricultural land. The soil is a sink for pollutants but it is more difficult than water and air to clean up. Therefore, to regulate Cu limitations in pig feeds and feces will be necessary not only for improving the pig feeds quality but also for guaranteeing the environmental safety.

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