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Report 483

Dose-response relationships between dietary copper level and growth performance in piglets and growing-finishing pigs and effect of withdrawal of a high copper level on subsequent growth performance

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Abstract

This study showed a clear optimum level at approx. 150 mg added Cu per kg feed on growth performance of pigs from 5 to 25 kg. Reduction of a high to a low Cu dose in the feed may hamper overall growth performance compared with the negative control group.

Keywords

Copper, Pigs, Growth performance, Copper withdrawal

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Title

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Samenvatting

Deze studie toonde een duidelijk optimum van ongeveer 150 mg toegevoegd Cu per kg voer op groeieresultaten bij varkens van 5 tot 25 kg. Vermindering van een hoge naar een lage Cu dosis kan leiden tot een lagere groeieresultaat dan de negatieve controlegroep.

Trefwoorden

Koper, Varken, Groeieresultaten, Weglaten van koper

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Dose-response relationships between dietary copper level and growth performance in piglets and growing-finishing pigs and effect of withdrawal of a high copper level on subsequent growth performance

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June 2011

Preface

This research was initiated and financed as a joint project of the Dutch Product Board Animal Feed (PDV) and the Dutch Ministry of Economic Affairs, Agriculture and Innovation (EL&I). Their financial contribution is gratefully acknowledged. The project was supervised by a working group of representatives of these two sponsors. The persons involved were E.R. Deckers (EL&I) and H. Boelrijk, M.C. Blok, A. Cazemier, M. Hessing, C.A. Makkink, J. Michels, and A. van Wesel (PDV). We highly appreciated the stimulating discussions and valuable suggestions in order to successfully conduct this research project.

Age Jongbloed
Paul Bikker

Summary

Nowadays in the EU growth-promoting levels of Cu (maximum 170 mg/kg of diet) for pigs are allowed to 12 weeks of age, after which a maximum of 25 mg total Cu/kg is permitted (EC, 2003a). In the past, however, a maximum Cu level of 250 mg/kg diet was permitted. The question in this study was whether the level of 170 mg/kg diet results in an optimal growth performance of the pigs.

Two studies were carried out:

1. a meta-analysis in which we quantified the dose-response relationship of supplemental Cu levels in diets on growth performance of pigs in different growth phases, and
2. a review of the effect of withdrawal of a high dietary Cu level on subsequent growth performance of pigs.

A database was compiled with relevant studies published since 1955. We excluded diets with 300 mg added Cu/kg or more. In total 65 publications were used comprising 150 experiments and 214 sub-experiments. The sub-experiments were derived from a subdivision of the experimental period into several growth phases. No overlap in growth phases (sub-experiments) within an experiment was allowed. For example phase 1 comprised 8 to 25 kg, phase 2 25 to 45 kg, and phase 3 45 to 95 kg live weight. In this case no overall performance from 25 to 95 kg was put in the data file, because this would overlap with the other phases. We separated the calculations into the following growing phases:

- the response from approximately 5 kg (> 0) to 25 kg (<25);
- the response from approximately 5 kg (> 0) to 45 kg (<45);
- the response from approximately 20 kg (>20) to 45 kg (<45);
- the response from approximately 45 kg (>45) to 100 kg (>45).

In the live weight range from 5 to < 25 kg both the linear and the quadratic effects of Cu addition levels were highly significant for growth rate and feed intake ($P < 0.01$), while for the other three live weight classes no consistent significant effects of supplementary Cu on performance could be demonstrated. For the live weight range of 5 to < 25 kg there was a clear optimum for body weight gain and feed intake of 146 and 150 mg Cu added/kg diet, respectively, while for feed conversion ratio no effect of Cu dose could be demonstrated. The average optimum of 148 mg Cu added/kg is slightly lower than the level of 160 mg Cu which is applied in practice in the EU. The question can be raised whether lower addition levels of Cu can be used for this pig category with marginal loss of performance, in order to take environmental aspects into consideration.

There is hardly any literature available in which the effect of withdrawal of a high dosage of Cu in the diet on subsequent growth performance is studied. The effect of withdrawal on growth performance over the whole growing period is variable and may depend on the weight of the pig. In the majority of the experiments studying the effect of withdrawal of high Cu levels it was shown that the overall performance of the withdrawal group was similar to or lower than of the negative control group.

Important information is lacking e.g. regarding the levels of Cu before experiments started, so that no firm conclusions can be drawn. Studies are recommended to determine the effect of withdrawal of high dietary Cu levels between 25 and 35 kg live weight on subsequent growth performance.

Based on the results of these two studies it would be relevant to determine whether reducing the supplementary Cu level in diets for piglets in the nursery phase from 160 to 100 mg Cu/kg would be adequate for a growth promoting effect and might have less negative effect on performance of pigs until slaughter weight after withdrawal.

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1 Introduction

According to EU legislation it is allowed to supply diets for pigs until 12 weeks of age with a maximum of 170 mg copper (Cu) per kg of diet, after which a maximum of 25 mg Cu/kg of diet is allowed (EC, 2003a). A high level of Cu is supplied because of its beneficial effect on pig health and growth performance (Barber et al., 1955). In the past an addition of 250 mg/kg to diets of piglets and growing-finishing pigs was generally applied, but for environmental reasons the maximal allowed amount of Cu in diets for pigs has been decreased during the last decades. It should be realized that in the early seventies pigs from birth to 110 kg body weight consumed approximately 80 g Cu, of which less than 1% was retained in the body. Furthermore, a good crop retains on average 50 g Cu/ha of land. Thus, application of pig manure resulted in substantial accumulation of Cu in the soil.

Several reviews on the growth-promoting effect of Cu have been presented (Meyer and Kröger, 1973; Borggreve, 1977; EC, 2003b). The conclusion of the latter is that high levels of Cu (170 mg/kg) as authorized for piglets are efficient in promoting growth, but efficacy for growing-finishing pigs could not be demonstrated. EC (2003b) recommended that as long as 170 mg/kg remains authorized, comparably high dietary levels of Zn and Fe should be used to prevent adverse effects of Cu on the absorption of these minerals.

It is common practice now to supplement diets for piglets with 160 mg Cu/kg up to 25 or 30 kg live weight, after which abruptly or in a few days the pigs receive diets with a maximum of 25 mg Cu/kg of diet. In some cases a transition diet is offered from 25 to 35 kg with reduced concentrations of Cu (approx. 100 mg/kg). However, the effect of changing the dietary Cu concentration for growth performance over the whole fattening phase is not clear.

This study aims at:

- 1) quantifying the dose-response relationships between dietary Cu level and growth performance of pigs in different growth phases;
- 2) studying the effect of withdrawal of a high dietary Cu level on subsequent growth performance of pigs.

First the quantification of the dose-response relationships is described and discussed after which the effect of withdrawal of high Cu levels on subsequent growth performance is addressed.

2 Quantifying the dose-response relationships of dietary Cu levels and growth performance of pigs in different growth phases

2.1 Material and methods

2.1.1 Data collection

We searched literature dealing with the effect of dietary Cu level on growth performance, and on mineral levels in serum as well as in several organs of pigs. A database was compiled with studies published since 1955. Keywords were “copper”, “growth-promoting”, “pigs”, “swine”, “growth” and “liver”. Publications reporting several experiments were dealt with by assigning a specific code to each experiment. A survey of the collected data is presented in Appendix 1. Each observation corresponded to the mean of one treatment group. Within each (sub)-experiment the only difference was the dietary Cu concentration. The sub-experiments were derived from a subdivision of the experimental period into several growth phases. We also judged whether the diets contained sufficient minerals and vitamins, and were formulated according to the recommendations of today (NRC, 1998). Therefore, several old experiments were excluded from the calculations because no information was given on addition of vitamins or minerals (Barber et al., 1955; Dammers et al., 1959; Barber et al., 1961; Braude et al., 1973). Furthermore, one experiment by Pond et al. (1978) was discarded because no additional Zn was used, while no information was presented on diet composition by Lüdke and Schöne (1991). The results of the experiment by Radecki et al. (1994) were not used because the experiment lasted only 14 days and the results showed negative growth rates. Also, an experiment by Schiavon et al. (2000) could not be used because apart from enhanced Cu concentrations also those of other minerals were enhanced. In the experiment by Rothe et al. (1994) no information was given on animal growth performance and it was therefore excluded from the datafile.

In most cases CuSO₄ was used as Cu source, but in 9 experiments Cu-lysine was used, and in one experiment Cu-proteinate. Two experiments were carried out with Cu-citrate and three experiments with CuCl₂. In these experiments it was shown that there were no differences in effects compared with CuSO₄. Moreover, in our own review on availability of Cu sources (Jongbloed, 2010) no differences in their effect on growth performance could be demonstrated. Therefore, also the studies with these Cu sources were included in our meta-analysis. Data obtained with addition of CuO were not included in the data file.

We made a distinction between type of diets: maize-soybean meal diets (132 experiments) and other type of diets (61 experiments). Furthermore, there were 112 experiments without added antibiotics and 80 experiments with antibiotics included in the diet. Since from an abundance of literature is shown that the effects of added Cu and antibiotics are additive (no interaction), no distinction between diets with and without antibiotics was made in further calculations. Furthermore, we did not take the effect of sex into account; most of the studies were with castrates and gilts in a pen.

Most of the diets did not contain organic acids. In two publications, however, organic acids had been added to all diets (Van der Aar et al., 1986; Burnell et al., 1988). In only one experiment by Burnell et al. (1988) a direct comparison was made between the effect of an organic acid (0 and 1% citric acid) and supplementary Cu (0 and 250 mg Cu/kg) on growth performance of piglets weaned at 4 weeks during a 4-week experimental period. The diets contained an antimicrobial growth promoter. They concluded from their experiment that there was no interaction between the dietary factors. Therefore we did not discriminate between diets with or without organic acids in our calculations. With regard to the dietary Cu content, we choose for the amount of added Cu and not for the estimated or analyzed values. This was done because only 321 out of 712 diets had been analyzed for their Cu content.

Moreover, it is known that analysis on Cu content in diets is rather difficult due to inhomogeneity. In quite a number of studies only two levels of Cu were present in the diets, mostly a low level of supplementation and a high level, such as 175 to 250 mg/kg. We decided to exclude diets with 300 mg added Cu/kg or more, because it has been shown that levels above 300 mg Cu/kg diet may have negative effects on growth performance of pigs. This was found in studies by Cromwell et al. (1989) (+568 mg Cu/kg), Kline et al. (1971; 1972; 1973) (+500 mg Cu/kg; in six subexperiments), Kornegay et al. (1989) (+400 mg Cu/kg; in four subexperiments), Lillie et al. (1977) (510 mg Cu/kg; in two subexperiments), Roof and Mahan (1982) (375 and 500 mg Cu/kg), Edmonds and Baker (1986) (+658 mg Cu/kg; in three subexperiments).

In total 65 publications were used, comprising 150 experiments and 214 sub-experiments. If possible the sub-experiments were separated into relevant growth phases. No overlap in growth phases within a sub-experiment was allowed so that phase 1 comprised (part of the phase from 5 to 25 kg, phase 2

25 to 45 kg, and phase 3 45 to 95 kg live weight. In this case no overall performance from 25 to 95 kg was put in the data file.

Descriptive statistics for each variable in the dataset that was used for further calculations were generated (Table 2.1).

Table 2.1 Descriptive statistics of the main variables, means of treatment group

	n	Mean	Minimum	Maximum	SD	Median
Length of exp. period, d	622	47	14	135	24	41
Initial weight, kg	622	21	4	69	17	15
Final weight, kg	622	49	10	109	32	46
Cu added, mg/kg	622	118	0	270	104	125
Zn added, mg/kg	616	113	26	440	48	100
Fe added, mg/kg	566	94	0	300	49	86
Mn added, mg/kg	541	37	0	160	23	30
Growth rate, g/d	622	561	143	1059	197	578
Feed intake, g/d	557	1465	286	4020	873	1420
FCR	557	2.45	1.09	4.49	0.75	2.42
Survival rate, %	41	97.8	91.6	100.0	3.1	100
Dressing percentage	45	75.7	67.4	81.0	24.1	75.6
Cu in liver, mg/kg DM	171	125	4	1628	180	49
Zn in liver, mg/kg DM	54	168	33	288	74	187
Fe in liver, mg/kg DM	55	485	37	1394	323	360
Cu in kidney, mg/kg DM	33	31	6	62	14	32
Zn in kidney, mg/kg DM	24	100	24	154	40	115
Fe in kidney, mg/kg DM	20	143	37	258	59	160
Haemoglobin (Hb), g/dl	66	12.7	8.8	17.0	2.1	12.6
Haematocrit (Hct), %	42	40.0	30.3	50.0	4.0	40.2
Serum Cu, mg/l	78	1.7	0.92	2.9	0.4	1.60
Serum Zn, mg/l	25	1.0	0.64	1.29	0.2	1.05
Serum Fe, mg/l	26	2.0	1.3	2.5	0.4	2.08

In addition to growth performance, we also included other response parameters, e.g. blood and tissue mineral levels in the data file but we did not evaluate these response parameters because this was beyond the scope of the study. It should be noted that in only eight experiments survival rate of the pigs was recorded.

2.2 Statistical calculations

Several models were used to obtain the best estimates for the effect of dietary Cu content on growth performance. We found an interaction between Cu level and the growth phase of the pigs. We chose a model in which the effect of Cu dose was estimated in different growth phases, which are regarded as interesting for the aim of the study. We therefore separated the calculations into the following phases or body weight ranges:

- the response from approximately 5 kg (> 0) to 25 kg (<25);
- the response from approximately 5 kg (> 0) to 25-45 kg (<45);
- the response from approximately 20 kg (>20) to 45 kg (<45);
- the response from approximately 45 kg (>45) to 100 kg (>45).

The following model was used for each of the above mentioned phases:

$Y = b_0 + b_1 \cdot \text{Cu_added} + b_2 \cdot (\text{Cu_added})^2 + e$, in which

Y =	Response variable (growth rate, feed intake and FCR)
b0=	Constant, intercept
b1=	Regression coefficient for linear effect of Cu added
b2=	Regression coefficient for quadratic effect of Cu added
e	Error term

2.3 Results

The major results of the statistical analyses are presented in table 2.2. Based on these analyses predictions are made for daily gain, feed intake and FCR at graded levels of Cu (Table 2.3). In the phase from 5 to <25 kg live weight (LW), there were between 235 and 252 observations. In this LW range significant effects of the Cu dose were observed for daily gain and feed intake ($P < 0.01$) but not for FCR ($P = 0.74$). In the LW phase from 5 to < 25 kg as initial weight and 25-45 kg as final weight there were only 50 observations and no significant effects ($P > 0.10$) of the Cu dose on growth performance were noted. For the growing phase from 20 to >45 kg, no significant effect was noted for daily gain. However, the quadratic effect of Cu dose on feed intake and FCR was significant ($P = 0.035$ and 0.036 , respectively). In the growing phase from 45 to >45 kg, no significant linear effect ($P = 0.54$) or quadratic effect ($P = 0.82$) of the Cu level on daily gain was observed. For feed intake and FCR both the linear and the quadratic effect of Cu dose were significant ($P = 0.02$ and 0.03 for feed intake and 0.24 and 0.02 for FCR, respectively).

A graphic representation of the linear and quadratic effects of Cu level on growth performance is given in Figure 2.1a-2.1c.

Table 2.2 Effect of added Cu (mg/kg diet) on growth performance (ADG= average daily gain, g/d; FI= average feed intake, g/d; FCR = feed conversion ratio) in different growth phases.

Phase	Variable	N	b0	b1	Sign.	b2	Sign.
5 - <25 kg	ADG	252	354±4.1	0.850±0.176	<0.001	-0.00275±0.00068	<0.001
"	FI	235	603±8.3	1.339±0.363	<0.001	-0.00446±0.00140	0.002
"	FCR	235	1.75±0.017	4.93E-6±7.39E-4	0.995	0±0.0	0.728
5-<45 kg	ADG	50	557±10.7	0.154±0.468	0.743	-0.00057±0.00186	0.758
"	FI	50	1254±46.3	1.315±2.034	0.521	-0.00509±0.00806	0.531
"	FCR	50	2.24±0.066	0.0019±0.0029	0.524	8.29E-6±1.18E-5	0.486
>20->45 kg	ADG	198	767±8.0	-0.178±0.351	0.612	0.000384±0.00137	0.779
"	FI	150	2501±40.9	-4.000±1.884	0.035	0.01536±0.00727	0.036
"	FCR	150	3.26±0.042	-0.0039±0.0019	0.041	0.000016±0.000007	0.027
45 - >45 kg	ADG	102	789±8.4	-0.228±0.368	0.537	0.00033±0.00143	0.817
"	FI	79	2852±39.9	-4.447±1.887	0.021	0.01609±0.00729	0.030
"	FCR	79	3.58±0.040	-0.0043±0.0019	0.024	1.74E-5±7.29E-6	0.019

Table 2.3 Prediction of added Cu (mg/kg diet) on growth performance (ADG= average daily gain, g/d; FI= average feed intake, g/d; FCR = feed conversion ratio) in different growth phases.

Phase	Variable	0	25	50	75	100	125	150	175	200	250	300
5 - <25 kg	ADG	320	340	356	368	378	383	386	385	380	361	328
"	FI	554	584	609	629	643	651	654	651	643	610	554
"	FCR	1.77	1.77	1.77	1.77	1.76	1.76	1.75	1.74	1.74	1.71	1.69
5-<45 kg	ADG	552	556	559	561	562	563	563	562	560	555	547
"	FI	1216	1246	1269	1286	1296	1301	1299	1290	1275	1226	1152
"	FCR	2.20	2.25	2.28	2.30	2.31	2.31	2.30	2.28	2.25	2.16	2.02
20->45 kg	ADG	778	774	770	767	764	762	760	759	758	758	759
"	FI	2580	2490	2419	2367	2334	2320	2326	2351	2395	2540	2763
"	FCR	3.30	3.21	3.15	3.10	3.07	3.06	3.08	3.11	3.17	3.34	3.60
45 - >45 kg	ADG	808	803	798	793	789	785	782	779	776	772	770
"	FI	2959	2858	2777	2717	2676	2655	2655	2674	2714	2854	3074
"	FCR	3.63	3.54	3.46	3.41	3.37	3.36	3.38	3.41	3.46	3.64	3.90

Table 2.3 shows that in the LW range from 5 to 25 kg at a dose of about 150 mg Cu/kg the maximum response was obtained for feed intake and body gain, but FCR was not significantly affected by the Cu level. In the LW range of 5 to 45 kg the feed intake and growth rate numerically increased to 125 mg Cu/kg, but the effect of Cu level was not significant. In the LW range from 20 to >45 kg and from 45 kg to on average 90 kg, table 2.3 shows that the growth rate slightly decreased with increasing Cu level. From 20 to >45 kg, feed intake decreased and FCR improved to 125 mg Cu/kg but at higher levels than 125 mg/kg feed intake improved but FCR worsened. The same can be concluded for the LW range from 45 to >45 kg.

Figure 2.1a shows that at levels of added Cu between 150 and 200 mg/kg, there is a negative effect on growth performance, which was more pronounced for the growth phases 5 to 25 kg, and 5 to 45 kg.

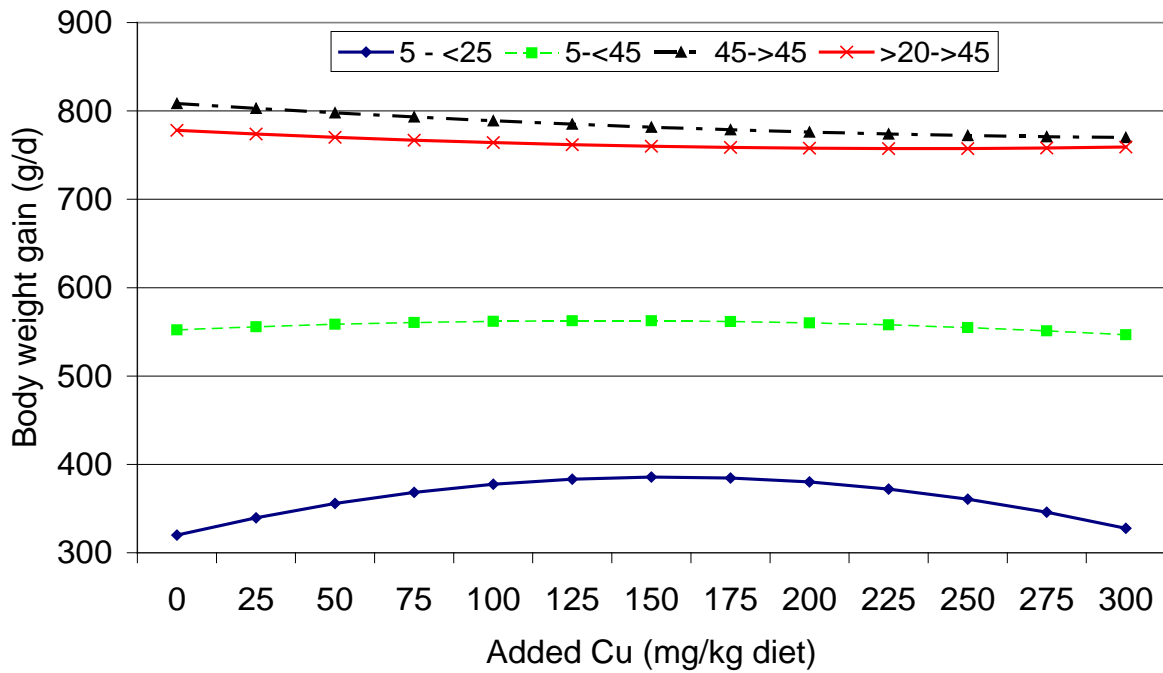


Figure 2.1a Effect of added Cu dose on growth rate (g/d) in different growth phases of pigs.

Figure 2.1b shows that only in the growth phases from 5 to 25 kg, and 5 to 45 kg between 150 and 200 mg/kg feed intake reduced, while for the other growth phases it increased after supplementation of 150 mg Cu /kg diet.

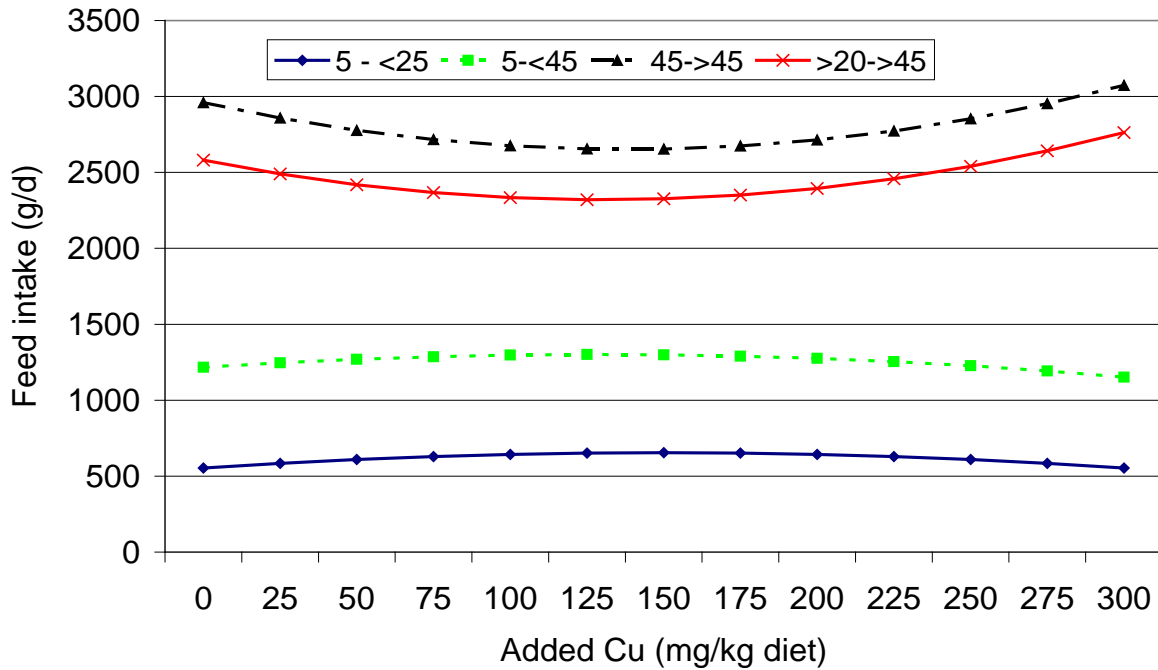


Figure 2.1b Effect of added Cu dose (mg/kg) on feed intake (g/d) in different growth phases of pigs.

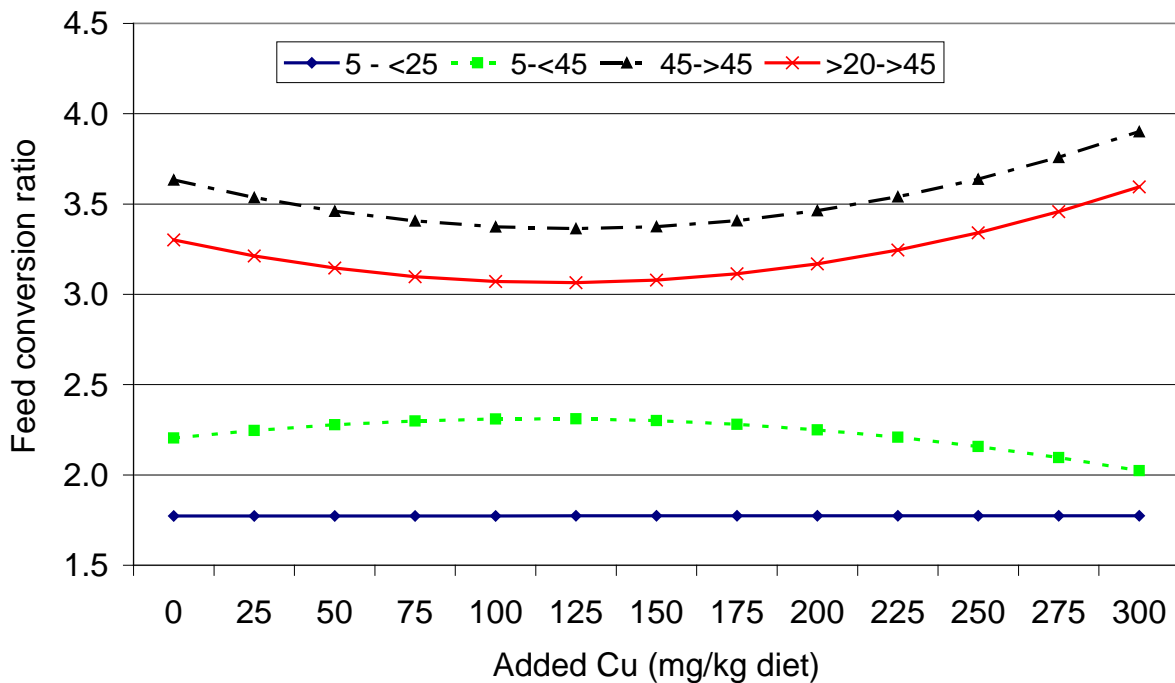


Figure 2.1c Effect of added Cu dose (mg/kg) on FCR in different growth phases of pigs.

FCR in the growth phase from 5 to 25 kg was not affected by the Cu level. In the growth phase from 5 to 45 kg FCR slightly improved (not significant) after 150 mg/kg, while for the other two growth phases FCR was impaired after 150 mg added Cu/kg.

Based on all regression equations in Table 2.2 and irrespective of statistical significance, we estimated the optimal levels of added Cu on growth performance, which are listed in Table 2.4.

Table 2.4 Optimal levels of added Cu (mg/kg diet) on growth performance of pigs.

Growth phase	Growth rate	Feed intake	FCR	Mean
5 - <25	155	150	-	152
5 - <45	134	129	114	126
45 - >45	343 ^a	138	124	131
20 - >45	232	130	120	161

^a unrealistic value

Table 2.4 shows that for all growth phases an optimal level was calculated between 120 and 160 mg added Cu/kg of diet. However, it should be noted that the effect of added Cu was only significant in the growth phase from 5 to 25 kg. The value of 343 mg Cu/kg diet in the weight range of 45 to > 45 kg for growth rate is unrealistically high and beyond the Cu levels studied.

2.4 Discussion

In the past usually a Cu addition of 250 mg/kg to diets of piglets and growing-finishing pigs was applied. For environmental reasons the maximum allowed level of Cu in diets for pigs in the EU has been decreased during the last decades. Nevertheless, in many countries in the world 250 mg Cu/kg of diet is applied in pig diets.

In our study we defined four live weight categories because the effect of pharmacological doses of Cu is higher in young pigs than in older pigs. In the live weight range from 5 to < 25 kg both the linear and the quadratic term were very significant for growth rate and feed intake ($P < 0.01$), while for the other three live weight classes in most cases no significant effects of supplementary Cu on performance could be demonstrated. In addition, in most studies in which pigs were fed high Cu diets in later life (e.g. 45 kg to slaughter), the animals also received a high Cu-diet in early life. Thus, the performance of the pigs is not fully independent when the growth period is separated into different phases of growth.

For the live weight range of 5 to < 25 kg there was a clear optimum for body weight gain and feed intake, while for feed conversion ratio no effect of Cu dose could be demonstrated. An optimum of 146 and 150 mg Cu added/kg diet could be calculated for growth rate and feed intake, respectively. The average optimum is 148 mg Cu added/kg, which is slightly lower than the level of 160 mg Cu which is applied in practice in the EU. From an environmental point of view it would be relevant if benefits of additional Cu can be largely realized at lower dietary Cu levels. Therefore Table 2.5 shows the results of some addition levels on performance for pigs from 5 to < 25 kg.

Table 2.5 Estimate of effect of added Cu on performance of pigs from 5 to < 25 kg (100 mg Cu is set to 0).

	Added Cu (mg/kg diet)								
	0	20	40	60	80	100	120	140	160
Growth rate, g/d	0	+16	+30	+41	+50	+58	+62	+65	+66
Feed intake, g/d	0	+25	+46	+64	+79	+89	+96	+100	+100
FCR	0	0	0	0	0	0	0	0	0

Table 2.5 shows that if 100 mg Cu/kg rather than 160 mg/kg is added, the calculated growth promoting effect would be 48 instead of 56 g/d, while no difference in FCR would take place. Table 2.5 shows that if 130 or 160 mg Cu/kg of diet are added instead of 100 mg/kg growth rate would be improved 6 and 8 g/day, and feed intake by 9 and 11 g/d, respectively, with no effect on feed conversion ratio. The question is if pig farmers are willing to accept a reduced growth rate of 8 g/day by changing the additional level of Cu from 160 to 100 mg/kg. This would result in a Cu excretion of sows and piglets (26.7 piglets/sow/yr) which is reduced from 156 to 110 g/sow/year.

For all breeding sows in The Netherlands which amount 1,1 million animals (www.lei.nl), the Cu excretion will be reduced by 51 tons of Cu per year. The reduced growth rate means 42 days x 8 g/d =

336 less body weight, which means that the growing period is 0.5 day longer to obtain the same final weight. Furthermore, it is assumed that a supplementary level of 100 mg Cu/kg diet is already high enough to prevent possible health problems compared with 160 mg Cu/kg. This should be verified in further research.

For the other live weight categories, table 2.4 shows that the optimal levels are lower than that of the category from 5 to 25 kg, and range from 120 to 130 mg added Cu/kg of diet. Moreover, effects of Cu on growth performance in these periods were generally not significant. In addition, especially in experiments in which pigs received nursery diets prior to the experimental period, it is likely that these piglets received already a high dietary high Cu level. Thus, piglets receiving a low-Cu control diet in the experimental period would have to adapt to a low Cu-level. As will be shown in the next chapter, growth performance can be decreased substantially when changing from a high to a low dietary Cu level. This may mean the growth performance of the negative control group was biased, so that no real effects of Cu-level were reported. However, in none of the studies we reviewed, it was described what dietary Cu levels were applied before the experiment started.

3 Long-term effects of withdrawal of high copper levels in pig diets on subsequent growth performance

3.1 Introduction

Nowadays in the EU growth-promoting levels of Cu (maximum 170 mg/kg of diet) for pigs are only allowed up to 12 weeks of age, after which a maximum of 25 mg total Cu/kg is allowed (EC, 2003a). For a rational use of this high Cu supplementation it is necessary to know:

- 1) whether the change-over in Cu supply from 170 to 25 mg/kg diet has (negative) effects on pig performance on a short-term and;
- 2) whether the beneficial effect of the high Cu dose on growth performance is sustained until slaughter.

The relevance of these questions is illustrated by Jongbloed et al. (2003) who observed in an experiment that reducing the Cu concentration in a pig diet from 160 to 25 mg Cu/kg in combination with complete withdrawal of 160 mg Salinomycine/kg respectively, resulted in a lower growth performance during the first two weeks after the change-over at 25 kg live weight. Overall (from 7.5 to 105 kg), no difference in growth performance between the negative control group (low Cu, no Salinomycine) and the withdrawal group was found. The growth performance of the supplemented group up to 25 kg was significantly better than the negative control group.

The review of Meyer and Kröger (1973) showed that after withdrawal of a high dietary Cu supplementation, growth rate in the finishing phase was on average 0.7% lower compared to the non-supplemented pigs (50 to 90 kg). However, in this weight range FCR was still 2.7% better than in the non-supplemented pigs. They concluded that the effect of withdrawal of a high Cu-supplement in the finishing pig diet on growth performance is small, although they noted that pigs were more restless after withdrawal of the Cu supplement. In more recent reviews (EC, 2003b) effects of withdrawal of high Cu doses in the diet were not addressed. Therefore, we analysed the literature in which effects of changing diets from high to low Cu levels on growth performance of pigs over the whole growing and finishing phase is described.

3.2 Materials and methods

We used several databases of Wageningen UR Digital Library such as Scopus, Web of Science, Google Scholar and OvidSP. Keywords were: Pig, Copper, Withdrawal, Carry-over, Performance. The number of relevant studies was rather low, even when citations of relevant publications were used. Several studies were performed in which only the decrease of the Cu content in the liver was reported after withdrawal of supplementary Cu in the finishing diet (Lillie et al., 1977; Meyer and Kröger, 1973). The results of the relevant studies were included in an Excel database. Further calculations were performed to compare the growth performance of experimental treatment groups with a reference based on the groups in which a low dose of Cu was supplied throughout the whole growing phase.

3.3 Results

The most relevant results of the studies are presented in Table 3.1. This table shows that except for the experiment of Van der Aar et al. (1986; Cu01) the number of replicates was very low. Therefore, no firm conclusions from these experiments can be drawn. Furthermore, most experiments are rather old (1963 to 1975). In most studies the high Cu supplement was withdrawn at a live weight of 50 to 70 kg. We describe the experiments listed in Table 3.1 in more detail below.

Van der Aar et al. (1986; Cu01) supplied pigs with a grower and finisher diet with 20 or 160 mg Cu/kg from 22 to 100 kg or a grower diet with 160 mg Cu/kg from 22 kg until 40 kg followed by a finisher diet with 20 mg/kg or with 80 mg Cu/kg. Although not described in the paper, it is highly likely that before starting the experiment, the piglets received a diet with a high Cu content. Growth performance of the pigs receiving 160 mg Cu/kg during the whole experimental period was significantly better than those receiving 20 mg Cu/kg during the whole experimental period or after a change-over at 40 kg body weight. The treatment with a change-over from 160 mg Cu/kg to 20 mg Cu/kg resulted in a lower growth performance than the treatment with continuous use of 20 mg Cu/kg. The treatment with a change-over from 160 mg Cu/kg to 80 mg Cu/kg resulted in a slightly better growth performance than the treatment with continuously 20 mg Cu/kg. The conclusion of the authors was that a high Cu level

in the grower diet and reducing the dietary Cu content in the course of the experiment did not improve performance compared with continuous supply of 20 mg Cu/kg. The benefit of extra Cu for growth performance had been lost completely after changing to 20 mg Cu/kg at 40 kg of live weight. In the withdrawal group, especially from 40 to 60 kg live weight, feed intake, growth rate and FCR were 97.5, 95.9 and 98.3% (is worse), respectively, compared with the treatment with continuously 20 mg Cu/kg. This is illustrated in Figure 3.1. This observation corroborates with that of Jongbloed et al. (2003).

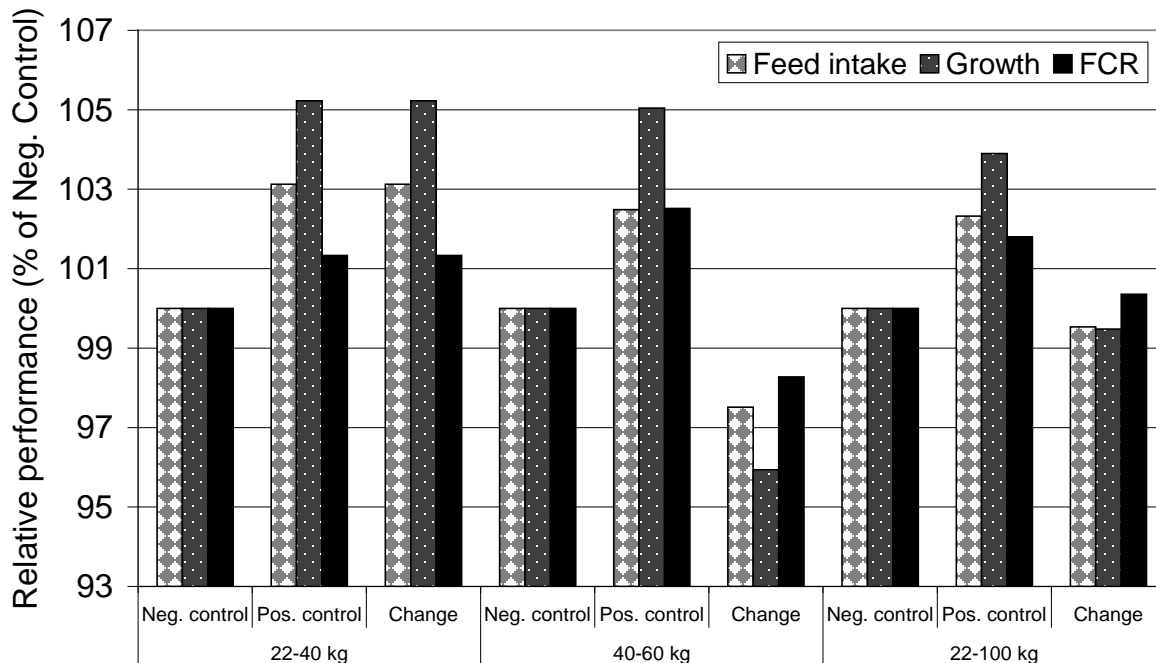


Figure 3.1 Relative performance of pigs in different live weight phases after changing Cu content at 40 kg (Van der Aar et al., 1988).

Castell et al. (1975; Cu13) started two experiments (Exp. 1 and Exp. 2) at 23 and 12 kg live weight, respectively. They did not describe the dietary Cu level before the experiments started, but for Exp. 1 it is likely that the pigs received a high Cu level before 23 kg live weight. They changed the dietary Cu content at 68 kg live weight. Remarkably, in their first experiment the pigs receiving 10 mg added Cu/kg had a better growth performance than those receiving 125 or 200 mg supplemental Cu/kg. Unfortunately, they did not provide data on growth performance until change-over. In their second experiment this was not the case. They concluded from their experiments that there were negligible differences in growth performance between pigs receiving supplementary Cu for the whole growing-finishing period or until 68 kg live weight. Furthermore, they concluded that the most noticeable effect of withdrawal of the added Cu from the finishing diets, compared with continuous inclusion to market weight, was the reduction in liver Cu concentrations.

Elliot and Amer (1973; Cu26) used only one pen with four pigs per treatment. They did not describe the dietary Cu level before the experiment started and only monitored growth rate in their experiment. Growth performance of pigs on the high-Cu level before change-over was higher than that of animals receiving the low-Cu diets. The presence of supplemental Cu in the diet for any period or at any level did not significantly improve overall growth rate of the pigs from start of the experiment until slaughter; in fact growth rate until 92 kg body weight of pigs receiving the high-Cu diet was lower than of the non-supplemented pigs. The authors, concluded that withdrawal of Cu from the diet reduced growth rate of pigs compared with the negative control diet. These authors quote the research of Teague and Grifo (1966) who reported that elimination of supplemental Cu from the diet during the period from 46 kg live weight to slaughter resulted in a lower rate of growth and poorer FCR when compared with the negative control animals. Also Lucas and Calder (1957) reported that when the supplemental Cu was removed from the diet during the finishing period, growth rate of previously Cu-fed pigs dropped to that of the negative controls, whereas the greater growth rate of pigs receiving extra Cu during this period was maintained.

Miller et al. (1973; Cu48) did not describe what the dietary Cu level was before the experiment started. They only used one pen with 10 pigs per treatment from 17 to 94 kg live weight. They fed increasing levels of Cu (0, 125, 187 or 250 mg Cu/kg) from 17 to 46 kg after which in one half of the pens supplemental Cu was withdrawn (Table 3.1). Surprisingly, within groups with the same amount of supplemented Cu, performance of the group of which the Cu had to be withdrawn, feed intake was already lower before the diet change-over. Their conclusion was that a level of Cu in the growing ration up to 250 mg/kg stimulated feed consumption and growth. Withdrawal of the high Cu level from the finishing ration did not affect growth performance.

Bunch et al. (1963; Cu75) started an experiment with pigs of three weeks of age at weaning. Thus, it is likely that the piglets did not receive diets with a high dietary Cu level before the experiment started. They observed that the positive control group with 250 mg Cu/kg had almost similar growth performance as the negative control group. The change-over group had a lower feed intake, a higher growth rate and a better feed conversion ratio than the other groups (Table 3.1).

Stansbury et al. (1990; Cu65) fed a control diet and a Cu-supplemented diet (13 vs. 125 mg Cu/kg) from 6 to 64 kg BW. They reported a significantly higher ADG for the high Cu-group. When the copper was withdrawn in the finisher diet after 64 kg body weight, no difference in performance was found thereafter from day 57 to day 112 ($P>0.20$).

3.4 Discussion

This review shows that most experiments studying the effect of a change-over of a diet from high to low copper levels are rather old (1963 to 1975). In most experiments, withdrawal of a high Cu level from the diet took place at a live weight between 40 and 70 kg. Furthermore, the basis for the firm conclusions made by several authors is rather weak because of the low number of replicates per treatment (Table 3.1).

Because it is known that the growth-promoting effect predominantly occurs in the post-weaning period (EC, 2003b), the effect of withdrawal of a high dietary Cu level at around 25 to 35 kg of live weight (approximately 10 to 12 weeks of age) on subsequent growth performance may be substantially different from withdrawal between 50 to 70 kg live weight. In the experiment of Van der Aar et al. (1986) it was clearly shown that withdrawal of extra Cu from the diet at 40 kg body weight, reduced the growth performance mainly during the first four weeks after withdrawal. The overall growth performance of the withdrawal group was similar to the non-supplemented group.

It has been suggested that the reduction in growth performance just after the change-over may also be affected by the change in the ingredient composition of the diets. In the experiments by Van der Aar (1987) and Bunch et al. (1963), indeed the composition of the grower and finisher diets was substantially different. However, this was also the case for the other treatment groups. It is only important if there is an interaction between change of dietary Cu content and change of diet formulation, which has not been studied in the published experiments.

It may also be questioned if the lower growth performance of pigs receiving the negative control diet may also be due to the change of a high Cu content to a low Cu content at approximately 20 to 25 kg, prior to the experimental period. However, in none of the cited references it was described what dietary Cu level was supplied before the actual experiment started. In experiments designed to study the effect of withdrawal of a high dietary Cu content on subsequent growth performance, no reduction of the dietary Cu content should take place prior to the experimental period.

Some experiments listed in Table 3.1 showed that growth performance of the pigs receiving diets with the high Cu level was equal or even worse than pigs of the non-supplemented groups. This complicates a good interpretation of the effect of withdrawal on growth performance. It can be concluded from the results we reviewed, that there is not much literature available in which the effect of withdrawal of a high dosage of Cu in the diet on subsequent growth performance is demonstrated. The effect of withdrawal on growth performance over the whole growing period is variable and may depend on the weight of the pig at the time of withdrawal.

There are two options to overcome the possible depression of growth performance after a reduction in dietary Cu content. :

- 1) To reduce the high dietary Cu levels from weaning to 12 weeks of age and feed nursery diets with lower Cu levels or;
- 2) To gradually reduce the high dietary Cu level during grower period to overcome the depression in growth performance thereafter.

Studies are recommended to determine the effect of (gradual) withdrawal of high dietary Cu levels between 25 and 35 kg live weight on subsequent growth performance.

4 Conclusions

A meta-analysis was carried out to quantify the dose-response relationships between dietary Cu level and growth performance of pigs in different growth phases. Furthermore, the effect of withdrawal of a high dietary Cu level on subsequent growth performance of pigs was reviewed. In the live weight range from 5 to < 25 kg both the linear and the quadratic effects of Cu addition were highly significant for growth rate and feed intake ($P < 0.01$), while for the other live weight classes above 25 kg no consistent effects of supplementary Cu on performance could be demonstrated.

For the live weight range of 5 to < 25 kg there was a clear optimum for body weight gain and feed intake of 146 and 150 mg Cu added/kg diet, respectively, while for feed conversion ratio no effect of Cu dose could be demonstrated. The average optimum of 148 mg Cu added/kg is slightly lower than the level of 160 mg Cu which is applied in practice in the EU. The question can be raised whether lower addition levels of Cu can be used for this pig category with marginal loss of performance, in order to take environmental aspects into consideration.

There is hardly any literature available in which the effect of withdrawal of a high dosage of Cu in the diet on subsequent growth performance is studied. The effect of withdrawal on growth performance over the whole growing period is variable and may depend on the weight of the pig. In the majority of the experiments studying the effect of withdrawal of high Cu levels it was shown that the overall performance of the withdrawal group was similar to or lower than of the negative control group. Important information is lacking e.g. regarding the levels of Cu before experiments started, so that no firm conclusions can be drawn. Studies are recommended to determine the effect of withdrawal of high dietary Cu levels between 25 and 35 kg live weight on subsequent growth performance.

Based on the results of these two studies it would be relevant to determine whether reducing the supplementary Cu level in diets for piglets in the nursery phase from 160 to 100 mg Cu/kg would be adequate for a growth promoting effect and might have less negative effect on performance of pigs until slaughter weight after withdrawal.

Report

Table 3.1. Relative growth performance of pigs when changing the dietary Cu content in the course of the growing period (negative control diet = 100; > 100 is better; IW=initial weight; FW=final weight; FI=feed intake; GR=growth rate).

Reference	Exp	IW, kg	FW, kg	No. obs.	Pigs/pen	Change-over, kg	FI, pre change	GR, pre change	FCR, pre change	Cu added Phase1	Cu added Phase2	Overall FI	Overall GR	Overall FCR
Cu01	1	22	100	6	6	no	100.0	100.0	100.0	20	20	100.0	100.0	100.0
Cu01	1	22	100	6	6	no	103.1	105.2	101.3	160	160	102.3	103.9	101.8
Cu01	1	22	100	6	6	40	103.1	105.2	101.3	160	20	99.5	99.5	100.4
Cu01	1	22	100	6	6	40	103.1	105.2	101.3	160	80	101.4	101.7	100.7
Cu13	5	22	90	2	4	no	-	-	-	10	10	100.0	100.0	100.0
Cu13	5	22	90	2	4	no	-	-	-	125	125	105.5	95.4	90.4
Cu13	5	22	90	2	4	68	-	-	-	125	10	104.9	107.1	102.1
Cu13	5	22	90	2	4	no	-	-	-	200	200	103.0	94.0	91.5
Cu13	5	22	90	2	4	68	-	-	-	200	10	102.3	101.2	99.0
Cu13	5	22	90	2	4	79	-	-	-	200	10	106.1	101.9	96.1
Cu13	6	12	90	4	4	no	-	-	-	10	10	100.0	100.0	100.0
Cu13	6	12	90	4	4	no	-	-	-	125	125	89.6	101.1	112.8
Cu13	6	12	90	4	4	68	-	-	-	125	10	91.7	102.4	111.6
Cu13	6	12	90	4	4	no	-	-	-	200	200	99.9	100.9	101.0
Cu13	6	12	90	4	4	68	-	-	-	200	10	95.0	100.4	105.7
Cu26	1	14	92	1	4	no	-	100.0	-	10	10	-	100.0	-
Cu26	1	14	92	1	4	no	-	-	-	250	250	-	93.2	-
Cu26	1	14	92	1	4	23	-	102.6	-	250	10	-	91.6	-
Cu26	1	14	92	1	4	46	-	101.9	-	250	10	-	97.0	-
Cu26	1	14	92	1	4	69	-	101.7	-	250	10	-	89.3	-
Cu48	1	17	94	1	10	no	100.0	100.0	100.0	0	0	100.0	100.0	100.0
Cu48	1	17	94	1	10	no	107.6	114.6	106.1	125	125	102.5	103.8	101.3
Cu48	1	17	94	1	10	46	91.0	103.6	113.9	125	0	94.0	99.2	105.6
Cu48	1	17	94	1	10	no	103.1	111.8	108.7	187	187	104.4	101.5	97.3
Cu48	1	17	94	1	10	47	98.6	107.3	108.7	187	0	103.8	103.8	100.6
Cu48	1	17	94	1	10	no	104.9	112.7	107.8	250	250	100.0	105.3	99.1
Cu48	1	17	94	1	10	48	91.0	108.2	119.1	250	0	106.2	103.0	102.2
Cu75	1	6	91	3	6	no	100.0	100.0	100.0	10	10	100.0	100.0	100.0
Cu75	1	6	91	3	6	no	95.7	107.0	102.4	250	250	98.2	100.0	101.9
Cu75	1	6	91	3	6	57	108.4	113.2	104.4	250	10	95.7	106.5	111.3

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Appendices

Appendix 1. Survey of the data collected in the study on growth-promoting effect of Cu in diets for pigs

Column	Item
A	Reference abbreviated
B	Year of publication
C	Code reference
D	Experiment in the publication
E	Sub-experiment
F	Period: different growth phases (1, 2 and 3)
G	Reliability: 1=okay; 0=not reliable
H	Length of experiment, days
I	Initial weight, kg
J	Final weight, kg
K	Sex: 3=barrow&gilt; 4=barrow; 5=boar&gilt; 6=gilt
L	Number of pigs per pen
M	Number of replicates
N	Antimicrobials: 0=no; 1=yes
O	Animal protein: 0=no; 1=yes
P	Level of feeding: 1=ad libitum; 2=restricted; 3=semi-ad libitum
Q	Type of diet: CS=corn-soybean meal; O=other types of diets
R	Source of Cu: Basal=basal diet; CuSul= copper sulphate; CuProA=copper proteinate; CuCl=copper chloride; CuLys=copper lysine; CuCit= copper citrate
S	Total Cu content in diet, mg/kg
T	Total Zn content in diet, mg/kg
U	Total Fe content in diet, mg/kg
V	Feed intake, g/day
W	Growth rate, g/day
X	Feed conversion ratio
Y	Added Cu to the diet, mg/kg
Z	Added Zn to the diet, mg/kg
AA	Added Fe to the diet, mg/kg
AB	Added Mn to the diet, mg/kg
AC	Organic acid: 0=no; 1=yes
AD	Survival rate, %
AE	Ulcer score
AF	Dry matter content feces, g/kg DM
AG	Visual score feces: 0=firm, 4=very wet=diarrhoea
AH	Dressing percentage, %
AI	Carcass length, cm
AJ	Backfat thickness, mm
AK	Meat percentage, %
AL	Loin area, cm ²
AM	Cu in liver, mg/kg dry matter
AN	Fe in liver, mg/kg dry matter
AO	Zn in liver, mg/kg dry matter
AP	Cu in kidney, mg/kg dry matter
AQ	Fe in kidney, mg/kg dry matter
AR	Zn in kidney, mg/kg dry matter
AS	Cu in muscle, mg/kg dry matter
AT	Cu in faeces, mg/kg dry matter
AU	Hemoglobin content, mg/dl
AV	Hematocrit, %
AW	Serum or plasma Cu, mg/L
AX	Serum or plasma Zn, mg/L
AY	Serum or plasma Fe, mg/L
AZ	Ceruloplasmin content, IU/L
BA	Cu in bone, mg/kg DM
BB	Fe in bone, mg/kg DM
BC	Zn in bone, mg/kg DM
BD	Remarks



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