

Effect of reduced CuSO₄ inclusion on growth performance, meat yield and economics of grower-finisher pigs

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Abstract

The use of pharmacological levels of copper sulphate (CuSO_4) in pig diets has raised concerns regarding environmental contamination and increasing feed costs. This study evaluated the effects of reducing dietary CuSO_4 inclusion on the growth performance, carcass characteristics, and economic performance of grower-finisher pigs. A total of 352 pigs (176 boars and 176 gilts) with an initial body weight of 33.2 ± 1.06 kg were randomly assigned to four dietary treatments containing 25, 75, 125, or 175 mg CuSO_4 /kg diet in a randomized complete block design. Growth performance was monitored over a 12-week feeding period, after which carcass characteristics and economic indicators, including feed cost, margin over feed cost (MOFC), revenue, and economic efficiency, were evaluated. Dietary CuSO_4 inclusion level had little influence on body weight gain, average daily gain, feed intake, or feed conversion ratio. Likewise, dressing percentage, lean meat percentage, and drip loss were not affected by dietary treatment. However, quadratic regression analysis indicated that cold carcass weight, revenue, and MOFC were maximized at approximately 75 mg CuSO_4 /kg diet. Feed cost increased progressively with increasing CuSO_4 inclusion, while the highest MOFC (R1,233.83/pig), economic efficiency (2.17), and revenue were achieved at the 75 mg/kg inclusion level. Increasing CuSO_4 above 75 mg/kg did not improve productive performance but increased feed costs, thereby reducing economic returns. These findings indicate that dietary CuSO_4 supplementation at 75 mg/kg is sufficient to maintain growth performance and carcass quality while maximizing profitability. Furthermore, reducing CuSO_4 supplementation from conventional higher inclusion levels may decrease copper excretion and contribute to more sustainable pig production.

Introduction

Copper (Cu), commonly supplemented as copper sulphate (CuSO_4), is an essential trace mineral in pig nutrition. It is required for numerous physiological and metabolic processes, including enzyme activity, iron metabolism, immune function, connective tissue formation, and antioxidant defence (Hefnawy and El-Khaiat, 2015). In addition to meeting the nutritional requirements of pigs, pharmacological levels of dietary Cu (100–250 mg/kg) have traditionally been used to promote growth, improve feed efficiency, and enhance gut health, particularly in young pigs (Espinosa and Stein, 2021). These growth-promoting effects are largely attributed to the antimicrobial activity of Cu, which alters the intestinal microbiota and improves nutrient utilisation. Despite these production benefits, the widespread use of pharmacological Cu supplementation has raised significant environmental concerns. Copper is poorly absorbed by pigs (Gonzales-Eguia et al., 2009), with a substantial proportion of dietary Cu being excreted in faeces (Espinosa and Stein, 2021). Estimates suggest that more than 70% of ingested Cu may be excreted, depending on dietary composition, physiological status, and management practices (Izquierdo and Baker, 1986; Close, 2002; Wen et al., 2022). Continuous application of Cu-rich manure to agricultural land results in the accumulation of Cu in soils, where it may impair soil microbial activity, reduce soil fertility, contaminate water resources, and contribute to the co-selection of heavy metal resistance genes (HMRGs) and antimicrobial resistance genes (ARGs) (Baker et al., 2015; Sapkota et al., 2007). Growing environmental concerns and increasing regulatory pressure have prompted researchers to investigate

strategies for reducing dietary Cu supplementation without compromising animal performance. Recent studies indicate that lowering dietary Cu concentrations may substantially reduce Cu excretion while maintaining acceptable growth performance, provided that dietary requirements are met and pigs are managed under appropriate production conditions (Kamunde et al., 2002; Veum et al., 2004; Leeson, 2009). Reducing Cu supplementation may also improve the economic sustainability of pig production by lowering feed costs associated with mineral supplementation and reducing the environmental costs linked to excessive Cu accumulation (Zhang et al., 2026).

Feed accounts for approximately 60–70% of the total cost of pig production, making nutritional optimisation essential for maintaining farm profitability (Maher et al., 2025). Consequently, identifying the minimum effective CuSO₄ inclusion level that supports optimal growth performance and carcass characteristics while maximising economic returns is of considerable importance to the pig industry. Therefore, the objective of this study was to evaluate the effects of reduced dietary CuSO₄ inclusion on growth performance, carcass characteristics, and economic performance of grower-finisher pigs.

Materials and methods

Ethics Statement

The experimental protocol was approved by the University of KwaZulu-Natal Animal Research Ethics Committee (AREC/00008072/2024)

Study site

Animals and experimental design

A total of 352 ten-week-old grower pigs (176 boars and 176 gilts) of the (Large White × Landrace) × Pietrain genotype, with an average initial body weight of 33.2 ± 1.06 kg, were used in this study. Pigs were randomly allocated to 32 pens according to a randomized complete block design comprising four dietary CuSO₄ inclusion levels and two sexes, with four replicate pens per treatment combination.

All pigs were sourced from the weaner unit of the research farm and transferred to the research trial facility. The pigs were housed in open-sided buildings fitted with automated curtain systems and concrete slatted floors. Each pen measured 4.0×2.78 m, providing a stocking density of 1.01 m² per pig, and was equipped with two stainless-steel nipple drinkers and a 55-cm-wide adjustable feeder. Ambient temperature was maintained between 20 and 24°C using an automated curtain system that regulated ventilation in response to environmental conditions. Throughout the experimental period, pigs had continuous access to natural daylight and ventilation.

Experimental diets and feeding

Table 1
Ingredient composition (%) of the basal diets fed to grower-finisher pigs during the four feeding phases

Item	Rations				
	Unit	Phase 1	Phase 2	Phase 3	Phase 4
Ingredients					
Maize	%	70.5	69.3	68.8	73.0
Soya o/c	%	14.3	12.3	11.2	15.2
Bran	%	6.6	9.4	11.5	4.1
Sunflower o/c	%	5.0	6.0	6.0	5.0
Limestone	%	1.3	1.2	1.1	1.0
MDCP	%	0.5	0.3	0.3	0.3
Salt	%	0.5	0.4	0.4	0.4
Lysine	%	0.7	0.5	0.3	0.5
Methionine	%	0.3	0.2	0.1	0.2
Threonine	%	0.2	0.1	0.1	0.1
Tryptophan	%	0.1	0.0	0.0	0.0
Premix	%	0.2	0.2	0.2	0.2

¹The vitamin-mineral premix was identical across all dietary treatments except for the concentration of copper supplied as copper sulphate (CuSO₄), which was included at 25, 75, 125, or 175 mg Cu/kg diet depending on the treatment

The ingredient composition of the basal diets used during the four feeding phases is presented in Table 1. The diets were formulated to meet or exceed the nutrient requirements of grower-finisher pigs at each production stage. Maize served as the primary energy source, while soybean oilcake and sunflower oilcake were the main protein sources. Ingredient proportions were adjusted across the feeding phases to accommodate the changing nutritional requirements of the pigs as they progressed from the grower to the finisher stage. All experimental diets had an identical basal formulation, with the only difference being the source of copper incorporated into the vitamin-mineral premix.

Table 2
Calculated nutrient composition of the basal diets fed to grower-finisher pigs during the four feeding phases

Item	Rations				
	Unit	Phase 1	Phase 2	Phase 3	Phase 4
Crude Protein	g/kg	160.0	155.0	150.0	160.0
Fat	g/kg	35.8	35.8	36.0	37.2
Fibre	g/kg	35.2	39.4	41.1	34.9
Calcium	g/kg	7.5	7.0	6.6	6.0
Sodium	g/kg	2.2	2.1	2.1	1.9
Dig P	g/kg	3.2	3.0	2.9	2.9
NE	MJ/kg	9.8	9.7	9.7	9.9
SID Lys	g/kg	11.0	9.5	8.0	10.0
SID Lys:NE	-	1.1	1.0	0.8	1.0

NE = Net energy (MJ/kg), Dig P = Digestible phosphorus (g/kg), SID Lys = Standardized ileal digestible lysine (g/kg), SID Lys:NE = Ratio of standardized ileal digestible lysine to net energy (g SID Lys/MJ NE), Nutrient values are calculated and expressed on an as-fed basis.

The calculated nutrient composition of the basal diets for each feeding phase is presented in Table 2. The diets were formulated to meet or exceed the nutrient requirements of grower-finisher pigs throughout the experimental period. Nutrient concentrations were adjusted across the four feeding phases to accommodate the changing nutritional requirements associated with growth. The dietary formulations provided appropriate levels of crude protein, net energy, standardized ileal digestible (SID) lysine, calcium, digestible phosphorus, sodium, fat, and fibre. The nutrient composition was identical across all dietary treatments, with the only variation being the concentration of copper supplied as copper sulphate (CuSO₄).

Table 3
Mineral composition (mg/kg) of the vitamin-mineral premix supplemented to the basal diets containing different dietary copper sulphate (CuSO_4) inclusion levels during the 12-week feeding trial.

CuSO_4 Level (mg/kg)	Mineral Concentration (mg/kg)					
	MnSO_4	FeSO_4	ZnSO_4	CuSO_4	I	Se
25	30.00	75.00	100.00	25.00	1.25	0.30
75	30.00	75.00	100.00	75.00	1.25	0.30
125	30.00	75.00	100.00	125.00	1.25	0.30
175	30.00	75.00	100.00	175.00	1.25	0.30

Values are expressed as mg/kg of complete diet, MnSO_4 = Manganese sulphate, FeSO_4 = Ferrous sulphate (iron sulphate), ZnSO_4 = Zinc sulphate, CuSO_4 = Copper sulphate, I = Iodine, Se = Selenium.

Table 3 presents the mineral composition of the vitamin-mineral premix used in the experimental diets. The concentrations of manganese (Mn), iron (Fe), zinc (Zn), iodine (I), and selenium (Se) were maintained constant across all dietary treatments, while copper (Cu) supplied as copper sulphate (CuSO_4) varied according to the experimental treatments. This ensured that CuSO_4 inclusion level was the only mineral variable among the diets.

Results

Impact of different copper levels on growth performance of growing pigs

Table 4
Effect of four CuSO₄ inclusion levels on overall growth performance of grower-finisher pigs (10 to 22 weeks of age).

CuSO ₄ Level (mg/kg)	BW Gain (kg/pig)		ADG (g/d)		Cum.FI (kg/pig)		ADFI (kg/pig)		FCR	
	M	F	M	F	M	F	M	F	M	F
25	85.08 ± 2.39	81.51 ± 2.39	1038 ± 29.17	994 ± 29.11	198.7 ± 2.08	208.7 ± 4.36	2.42 ± 0.03	2.54 ± 0.05	2.34 ± 0.05	2.56 ± 0.04
75	86.18 ± 1.87	84.34 ± 4.31	1051 ± 22.84	1028 ± 52.57	203.2 ± 2.47	210.8 ± 5.24	2.48 ± 0.03	2.57 ± 0.06	2.36 ± 0.05	2.51 ± 0.15
125	86.56 ± 2.34	84.65 ± 4.21	1056 ± 28.50	1032 ± 51.32	199.4 ± 4.22	211.2 ± 9.65	2.43 ± 0.05	2.58 ± 0.12	2.30 ± 0.04	2.50 ± 0.09
175	82.54 ± 2.82	83.02 ± 2.28	1007 ± 34.42	1012 ± 27.84	199.0 ± 8.24	209.9 ± 9.02	2.43 ± 0.10	2.56 ± 0.11	2.41 ± 0.05	2.53 ± 0.07

Values are presented as mean ± standard error (SE), M = Boars; F = Gilts, BW gain = Body weight gain, ADG = Average daily gain, Cum. FI = Cumulative feed intake, ADFI = Average daily feed intake, FCR = Feed conversion ratio.

The effects of dietary CuSO₄ inclusion level on growth performance are presented in Table 4. Body weight gain (BWG), average daily gain (ADG), cumulative feed intake (Cum. FI), average daily feed intake (ADFI), and feed conversion ratio (FCR) were generally similar across the four dietary treatments in both boars and gilts. Boars consistently exhibited greater BWG and ADG than gilts across all CuSO₄ inclusion levels. Feed intake was also numerically lower in boars than in gilts, resulting in lower FCR values for boars. Although pigs receiving 125 mg/kg CuSO₄ showed numerically greater BW gain and ADG, while those receiving 75 and 125 mg/kg exhibited slightly improved FCR values, these differences were small and did not indicate a consistent response to increasing dietary CuSO₄ inclusion. Overall, growth performance appeared to be unaffected by dietary CuSO₄ level.

Table 5
Effect of different CuSO₄ inclusion levels on meat yield and quality of grower finisher pigs.

CuSO ₄ Level (mg/kg)	WCW (kg/pig)		CCW (kg/pig)		Dressing percentage%		Lean Meat %		Drip Loss %	
	M	F	M	F	M	F	M	F	M	F
25	86.97 ± 1.33	87.50 ± 1.2	83.61 ± 1.29	84.02 ± 0.97	71.29 ± 0.91	73.22 ± 0.51	69.22 ± 0.43	69.71 ± 0.68	2.86 ± 0.09	3.04 ± 0.20
75	89.50 ± 0.50	88.90 ± 1.14	86.60 ± 0.87	85.70 ± 0.49	72.50 ± 0.86	72.66 ± 2.48	69.40 ± 0.39	69.38 ± 0.54	2.32 ± 0.30	2.74 ± 0.56
125	88.13 ± 2.13	88.56 ± 3.82	84.86 ± 2.10	84.88 ± 3.24	71.20 ± 1.19	71.42 ± 1.95	69.24 ± 0.69	69.73 ± 0.73	2.75 ± 0.26	3.12 ± 0.44
175	84.37 ± 2.4	89.89 ± 1.44	81.45 ± 1.93	86.16 ± 1.55	70.72 ± 0.49	73.77 ± 0.57	69.13 ± 0.63	69.35 ± 0.41	2.51 ± 0.65	3.21 ± 0.73

Data are presented as mean ± standard error (SE) of four replicate pens per treatment and sex. M = Male (boars), F = Female (gilts), WCW = Warm carcass weight, CCW = Cold carcass weight, DP = Dressing percentage, LMP = Lean meat percentage.

The effects of dietary CuSO₄ inclusion level on carcass characteristics and meat quality are presented in Table 5. Warm carcass weight (WCW), cold carcass weight (CCW), dressing percentage, lean meat percentage, and drip loss were generally comparable among the four dietary treatments. Numerically, pigs receiving 75 mg/kg CuSO₄ exhibited the greatest WCW and CCW in both sexes, whereas lean meat percentage and dressing percentage showed minimal variation across treatments. Drip loss also remained relatively consistent irrespective of dietary CuSO₄ inclusion level, indicating that reducing or increasing CuSO₄ supplementation had little influence on carcass characteristics or meat quality.

Figure 1 shows a curvilinear (quadratic) relationship between dietary CuSO₄ inclusion level and the cold carcass weight of boars. Cold carcass weight increased as dietary CuSO₄ concentration increased from approximately 25 to 75 mg/kg, reaching a maximum CCW of about 86.5 kg. Beyond this level, further increases in CuSO₄ inclusion were associated with a gradual decline in CCW. This trend suggests that moderate dietary CuSO₄ supplementation may optimize carcass weight, whereas excessive supplementation may reduce performance. The scatter of individual observations around the regression curve indicates biological variability among animals, although the overall pattern supports a non-linear response of CCW to increasing dietary CuSO₄ levels.

Economic parameters

Table 6

Feed cost per tonne, margin over feed cost (MOFC), and economic efficiency (EE) of boars fed four dietary CuSO₄ inclusion levels

CuSO ₄ Level (mg/kg)	Feed Costs (R/T)				MOFC (R/pig)	EE
	Phase1	Phase2	Phase3	Phase4		
25	R5 323.15	R5 155.82	R4 817.40	R5 280.08	R1197.33	2.15
75	R5 332.65	R5 165.31	R4 826.89	R5 289.56	R1233.83	2.17
125	R5 342.13	R5 174.79	R4 836.37	R5 299.05	R1212.63	2.15
175	R5 351.62	R5 184.28	R4 845.87	R5 308.55	R1190.13	2.13
CuSO ₄ = copper sulphate; MOFC = margin over feed cost; EE = economic efficiency (revenue/feed cost); R = South African Rand; R/tonne = Rand per tonne						

Table 6 shows that feed cost per tonne increased progressively with increasing dietary CuSO₄ inclusion across all four feeding phases. The lowest feed costs were observed in the 25 mg/kg treatment, while the highest costs occurred at the 175 mg/kg inclusion level. Despite the increasing feed costs, the highest margin over feed cost (R1,233.83 per pig) and economic efficiency (2.17) were achieved at the 75 mg/kg CuSO₄ inclusion level. Thereafter, both MOFC and EE declined with further increases in CuSO₄ concentration, with the 175 mg/kg treatment recording the lowest MOFC (R1,190.13 per pig) and EE (2.13). These findings suggest that although higher CuSO₄ inclusion increased feed costs, supplementation at 75 mg/kg provided the greatest economic return and feed cost efficiency under the conditions of this study.

Figure 2 illustrates a quadratic relationship between dietary CuSO₄ inclusion level and margin over feed cost (MOFC) in boars. MOFC increased as the dietary CuSO₄ level increased from 25 to approximately 75 mg/kg, reaching a peak value of about R1,275 per pig. Beyond this point, MOFC declined progressively with increasing CuSO₄ supplementation, with the lowest values observed at the 175 mg/kg inclusion level. The distribution of the individual data points around the fitted regression curve indicates some biological variation among animals; however, the overall trend suggests that moderate CuSO₄ supplementation maximized economic returns, whereas excessive supplementation reduced profitability. These findings are consistent with the economic analysis presented in Table 6, where the 75 mg/kg treatment produced the highest margin over feed cost.

Figure 3 illustrates a quadratic relationship between dietary CuSO₄ inclusion level and revenue generated per pig. Revenue increased as the dietary CuSO₄ inclusion level increased from 25 to approximately 75 mg/kg, where the highest predicted revenue of about R2,320 per pig was achieved. Beyond this level, revenue declined progressively with further increases in CuSO₄ supplementation, with the lowest values observed at the 175 mg/kg inclusion level. Although individual observations varied around the fitted regression curve, the overall trend indicates that moderate CuSO₄ supplementation maximized revenue, whereas excessive supplementation reduced economic returns. These findings suggest that a dietary

CuSO₄ inclusion level of approximately 75 mg/kg was the most economically advantageous under the conditions of this study.

Discussion

The present study evaluated the effects of reducing dietary copper sulphate (CuSO₄) inclusion on the growth performance, carcass characteristics, and economic performance of grower-finisher pigs. Overall, reducing dietary CuSO₄ from the conventional higher inclusion level of 175 mg/kg to 75 mg/kg did not adversely affect growth performance or carcass quality while improving economic returns. These findings indicate that lower dietary CuSO₄ concentrations may be sufficient to maintain productive performance under commercial production conditions. Growth performance variables, including body weight gain, average daily gain, feed intake, and feed conversion ratio, were generally similar across all dietary treatments. Although pigs receiving 75 and 125 mg/kg CuSO₄ showed numerically greater body weight gain and slightly improved feed conversion efficiency, these differences were small and inconsistent, suggesting that increasing dietary CuSO₄ beyond 75 mg/kg conferred little additional growth benefit. These findings agree with Espinosa and Stein (2021), who reported that pharmacological copper supplementation does not consistently improve growth performance once the animals' physiological copper requirements have been met. Similarly, Pérez et al. (2011) demonstrated that reducing dietary copper supplementation did not impair growth performance provided adequate dietary copper was supplied. The absence of a clear growth response in the present study may also reflect the excellent health status and management conditions of the pigs, as the growth-promoting effects of pharmacological copper are often more pronounced under conditions of greater microbial challenge.

Carcass characteristics were likewise minimally affected by dietary CuSO₄ inclusion level. Warm carcass weight, cold carcass weight, dressing percentage, lean meat percentage, and drip loss remained comparable among treatments, although pigs receiving 75 mg/kg CuSO₄ produced numerically heavier carcasses than those receiving either lower or higher copper concentrations. The quadratic regression further indicated that cold carcass weight peaked at approximately 75 mg/kg before declining at higher inclusion levels. These observations suggest that moderate CuSO₄ supplementation may support optimal nutrient utilisation and carcass deposition, whereas excessive dietary copper offers no additional advantage. Previous studies have similarly reported limited effects of copper supplementation on carcass composition in grower-finisher pigs, indicating that carcass traits are generally less responsive to dietary copper than growth performance (Zhao et al., 2014; Coble, 2015; Schmitt, 2018). The economic evaluation demonstrated that feed cost per tonne increased progressively as dietary CuSO₄ inclusion increased because of the greater cost associated with copper supplementation. Despite the higher feed costs, the greatest margin over feed cost (MOFC), economic efficiency, and revenue were achieved at the 75 mg/kg CuSO₄ inclusion level. Quadratic regression analysis further confirmed that both revenue and MOFC were maximised at approximately 75 mg/kg before declining with increasing copper inclusion. These findings indicate that excessive CuSO₄ supplementation reduced profitability by increasing production costs without producing corresponding improvements in growth or carcass

performance. Consequently, moderate copper supplementation provided the best balance between production efficiency and feed expenditure.

Beyond the economic benefits, reducing dietary CuSO_4 supplementation also has important environmental implications. Copper is poorly absorbed by pigs, with a substantial proportion excreted in manure (Espinosa and Stein, 2021). Excessive dietary copper therefore contributes to soil accumulation of heavy metals following repeated manure application, posing risks to soil microorganisms, water quality, and the development of antimicrobial resistance (Sapkota et al., 2007). The present findings demonstrate that reducing CuSO_4 supplementation to approximately 75 mg/kg can maintain productive and economic performance while potentially reducing copper excretion and the associated environmental burden. This supports current efforts to improve the sustainability of pig production through more efficient trace mineral nutrition.

Conclusion

Reducing dietary CuSO_4 inclusion did not adversely affect the growth performance or carcass characteristics of grower-finisher pigs. Although growth responses were generally similar across treatments, supplementation at 75 mg/kg consistently produced the highest cold carcass weight, margin over feed cost, economic efficiency, and revenue. Increasing CuSO_4 inclusion beyond 75 mg/kg increased feed costs without providing additional biological or economic benefits. Therefore, a dietary CuSO_4 inclusion level of 75 mg/kg appears to be the optimum level under the conditions of this study, as it maintained productive performance while maximizing profitability. Furthermore, reducing CuSO_4 supplementation from conventional higher levels may decrease copper excretion into the environment, contributing to more sustainable and environmentally responsible pig production.

Limitations

This study was conducted at a single commercial research farm, which may limit the generalizability of the findings. In addition, copper digestibility, tissue accumulation, and faecal copper excretion were not measured; therefore, the environmental benefits of reduced CuSO_4 supplementation were not directly quantified. Future studies should evaluate these parameters under different production systems and compare alternative copper sources.

Declarations

Author contributions

S.M- Conceptualization, methodology, investigation, data curation, formal analysis, visualization, writing original draft preparation. **P.S**-Methodology, investigation, data curation, writing review and editing. **W.S**- Investigation, data collection and analysis. Resources, writing review and editing. **N.C and Z.K-R**- Conceptualization, supervision, project administration, writing review and editing.

Data availability statement

The datasets generated and analysed during the current study are available from the corresponding author upon reasonable request.

Euthanasia method

At the end of the experimental period, the pigs were transported to a registered commercial abattoir for slaughter. Animals were handled and slaughtered in accordance with the abattoir's standard operating procedures and applicable animal-welfare requirements. Prior to slaughter, the pigs were humanely restrained and stunned using the abattoir's approved stunning procedure, followed by exsanguination. The slaughter process was conducted by trained abattoir personnel under commercial conditions. Following slaughter, carcasses were processed according to standard commercial abattoir procedures, and samples were collected as described below.

Ethics approval

This study was conducted under the guidance of the University of KwaZulu-Natal ethics committee number: **AREC/00008072/2024**

consent to participate

Not applicable

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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Figures

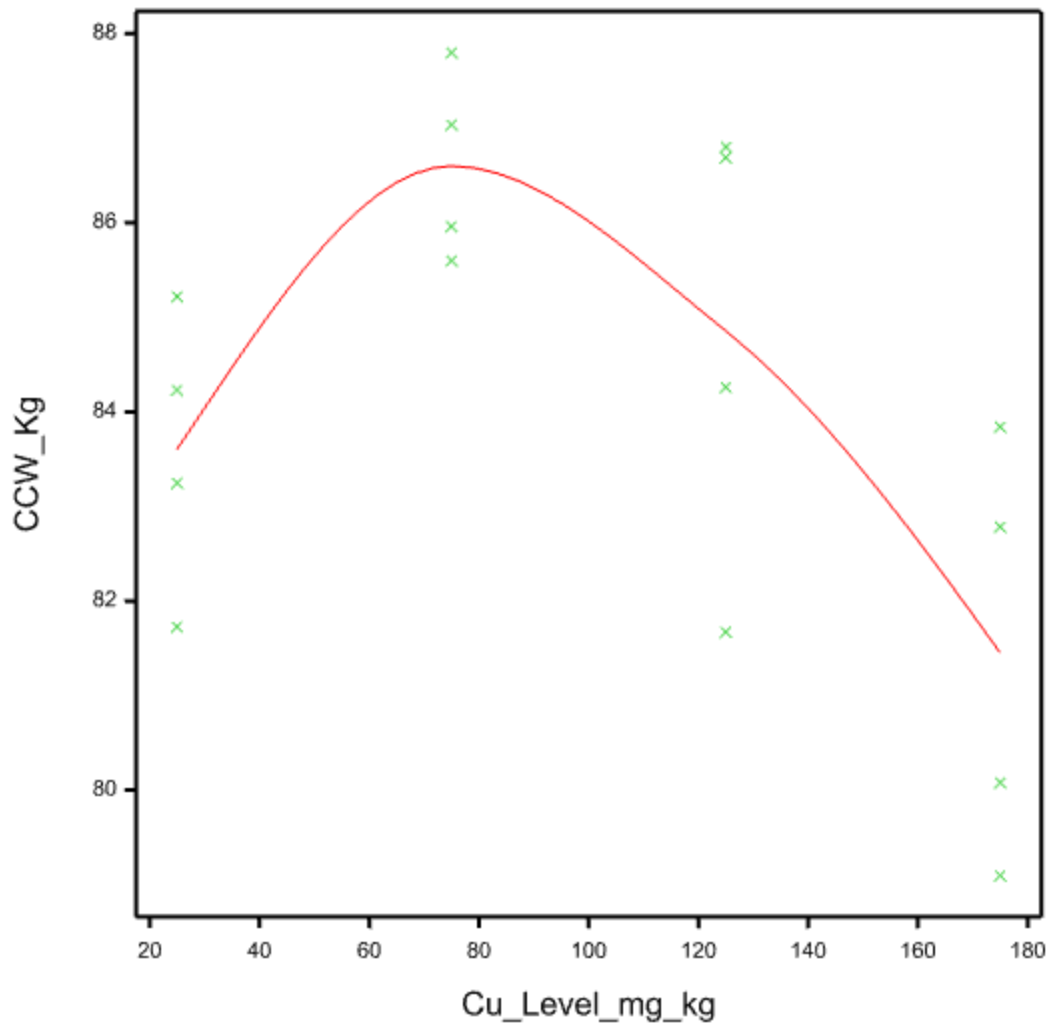


Figure 1

Quadratic regression showing the relationship between dietary copper sulphate (CuSO_4) inclusion level (mg/kg) and cold carcass weight (CCW, kg) of boars

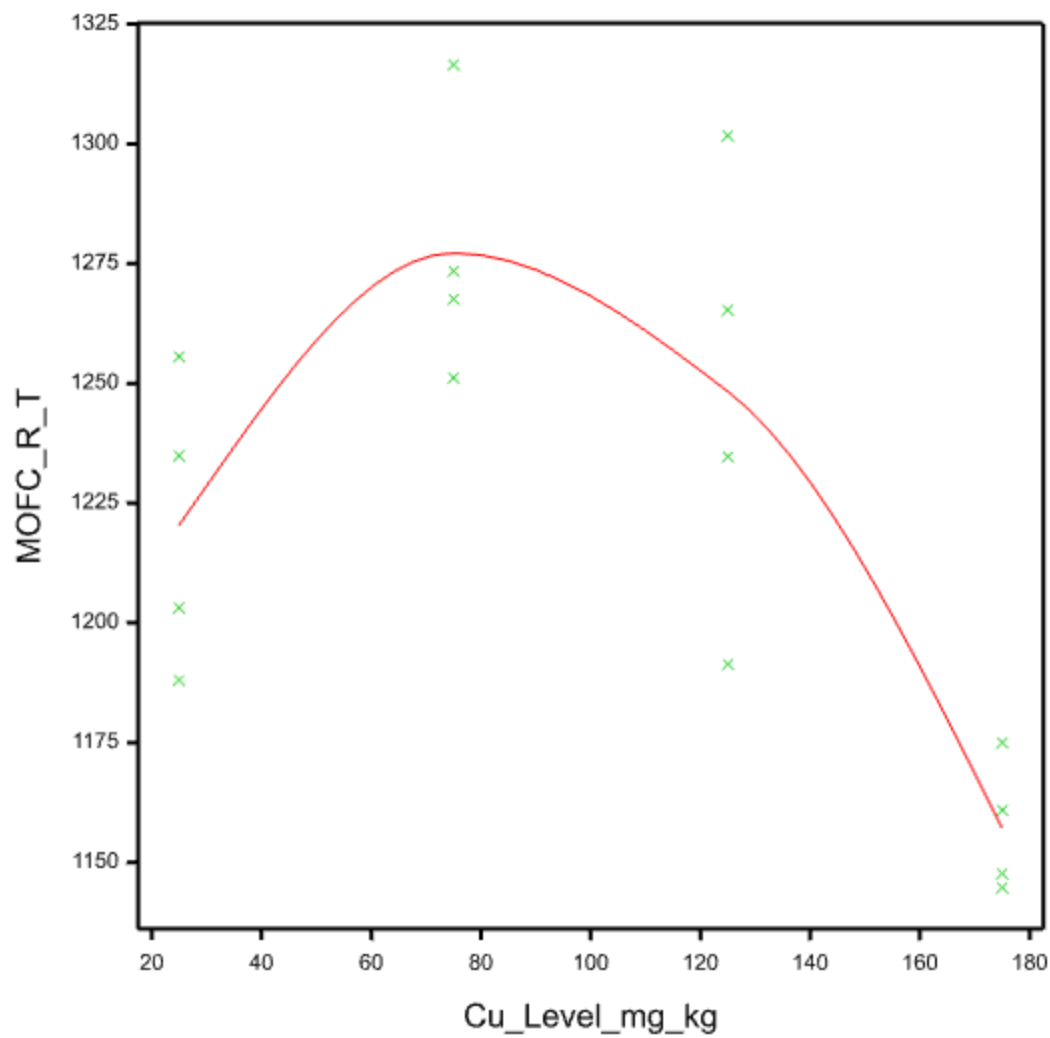


Figure 2

Quadratic regression showing the relationship between dietary CuSO_4 inclusion level (mg/kg) and margin over feed cost (MOFC; R/pig) in boars

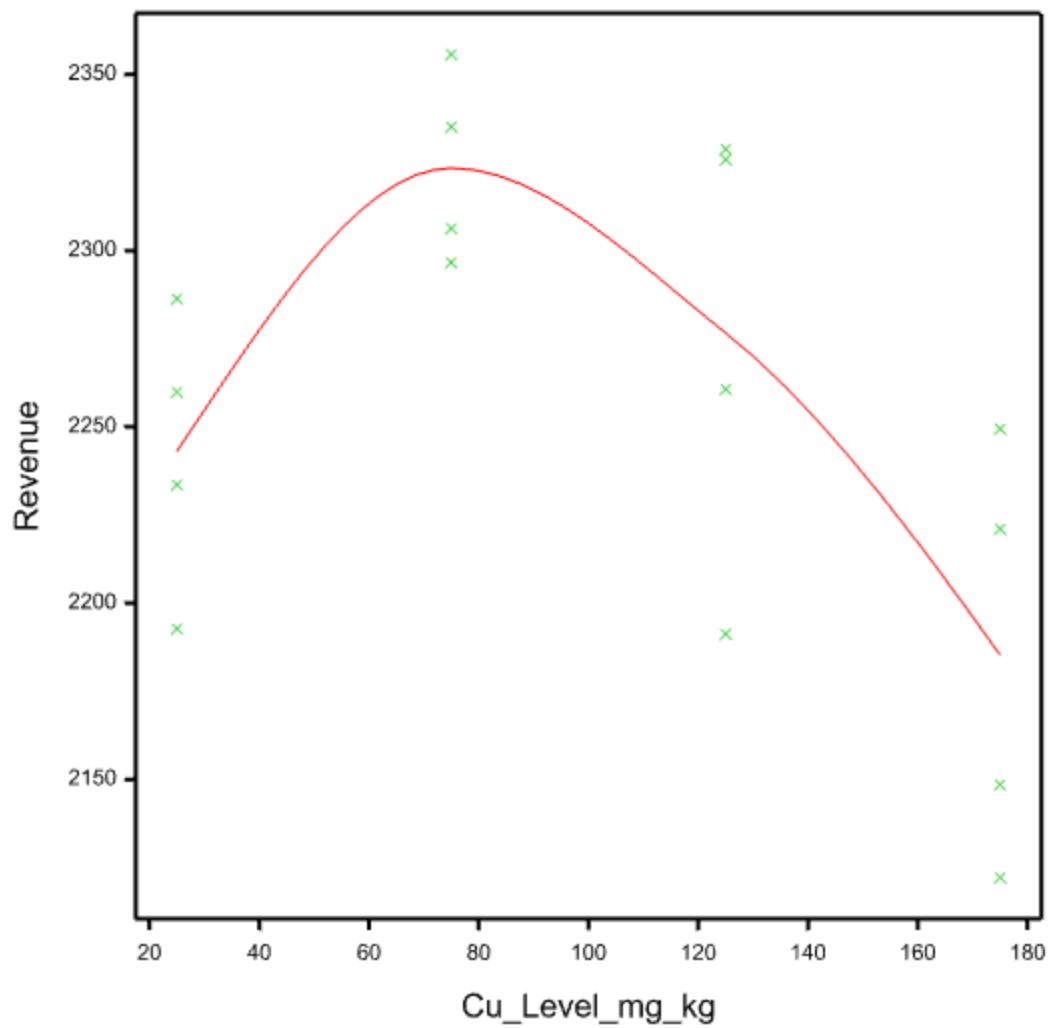


Figure 3

Quadratic regression showing the relationship between dietary CuSO_4 inclusion level (mg/kg) and revenue (R/pig) of boars.