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Further studies on various aspects of the use of high-copper supplements for growing pigs

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The growth-promoting effect of the addition of 0·1 % copper sulphate (supplying 250 p.p.m. Cu) to a growing-pig diet, reported by Barber, Braude, Mitchell & Cassidy (1955), has since been confirmed in many experiments both in Europe and America.

In the present paper results of four further experiments are given dealing with: (1) the optimal level of copper sulphate to include in the diet; (2) comparison of copper sulphate and copper carbonate, in diets given at two different levels; (3) comparison of the effect of copper sulphate in diets containing dried skim milk as the protein supplement in place of white-fish meal; and (4) effect of system of feeding ('semi-*ad lib.*', wet, or 'fully *ad lib.*', dry) on the response to copper sulphate.

EXPERIMENTAL

Pigs and their management. In all four experiments, weaners from the Shinfield, virus pneumonia-free, Large White herd were used and were all individually fed. Each experiment was designed in randomized blocks, blocks corresponding to litters, and treatments were allocated at random to the pens. In Expts 1–3 the pigs were kept in pens of four or six pigs each, whereas in Expt 4 the pigs were kept individually in separate pens. Expt 2 was designed as a 3×2 factorial and Expt 4 as a 2×2 factorial. There was no direct communication between pigs on different treatments in any experiment. The numbers of pigs on each treatment were fourteen in Expt 1, eight each in Expts 2 and 3 and six in Expt 4.

In Expts 1 and 3 all pigs were given twice daily as much meal as they would consume within 30 min up to a maximum of $6\frac{1}{2}$ lb/day, water at the rate of 3 lb to every 1 lb meal being added immediately before feeding. This system of feeding has been used extensively at Shinfield and has been termed 'semi-*ad lib.*'; it was also used for the pigs on treatments 4, 5 and 6 in Expt 2 and treatments 1 and 2 in Expt 4. Pigs on treatments 1, 2 and 3 in Expt 2 were also given meal twice daily, 3 lb water per 1 lb of meal again being added immediately before feeding, but the amount of meal given was based on live weight and according to a scale (Braude & Mitchell, 1951), a daily maximum of $6\frac{1}{2}$ lb/pig being given to an animal weighing 170 lb. For pigs on treatments 3 and 4 in Expt 4 dry meal was available in unrestricted amounts up to a daily maximum of approximately $6\frac{3}{4}$ lb/pig; water from an automatic bowl was available in each pen.

All pigs were weighed once weekly throughout the experiments, the rations of the pigs on treatments 1, 2 and 3 in Expt 2, which were fed to scale, being adjusted after each weekly weighing. In each experiment, except Expt 4, all the pigs were sent to slaughter individually when their live weight at the weekly weighing exceeded 203 lb. In Expt 4, only those pigs on treatments 3 and 4 were continued on experiment to bacon weight, the remainder finishing after 9 weeks on experiment. At the factory all carcasses, except those from pigs in Expt 4, were commercially graded according to the system in force at the time of slaughter. Pigs in Expts 1 and 2 were graded according to back-fat thickness only, whereas for those in Expt 3 carcass length was also taken into account.

Diets and treatments. Table 1 gives the composition of the basal diets used, and in Table 2 details of the treatments in the four experiments are shown.

Estimation of copper content of the liver. In Expts 1 and 2 a sample of liver tissue adjacent to the bile duct was taken at slaughter from each pig and stored at −20° (see Barber, Braude & Mitchell, 1960). The Cu content of the samples was subsequently determined by the method of Andrus (1955).

Table 1. *Percentage composition of the basal diets*

	Diet no.		
	1*	2†	3‡
Barley meal	52	65	41
Fine miller's offal	38	30	38
White-fish meal	10	5	—
Dried skim milk	—	—	20
Steamed bone flour	—	—	1
Rovimix (Roche Products Ltd) (g/100 lb)§	4·5	2·0	4·5

* Used throughout experimental period for control pigs in Expts 1 and 4, on treatment 1 in Expt 3, and in Expt 2 up to 120 lb individual live weight.

† Used for control pigs in Expt 2 from 120 lb individual live weight to slaughter.

‡ Used throughout experimental period for pigs on treatment 3 in Expt 3.

§ Containing 50 000 i.u. vitamin A and 12 500 i.u. vitamin D_3/g.

RESULTS

The mean results for daily weight gain, food conversion efficiency and rate of food consumption, together with appropriate standard errors for Expts 1, 2, 3 and 4, are given in Tables 3, 4, 6 and 7 respectively.

The results of the appropriate analyses for Expt 2 (3 × 2 factorial) and for Expt 4 (2 × 2 factorial) are given in Tables 5 and 8 respectively, with the standard errors and statistical significance of the treatment effects and interactions.

In Table 9 the results for those pigs in Expt 4 (treatments 3 and 4) that continued on experiment to bacon weight are shown.

Information about dressing percentage is included in Tables 3, 4 and 6 and about carcass length in Table 6. In Tables 3 and 4 figures for the Cu content of the liver of pigs in Expts 1 and 2 are also given. The standard errors were calculated from

Table 2. *Details of method of feeding and dietary supplements in the four experiments*

	Expt 1			Expt 2			Expt 3			Expt 4		
Treatment no.	Feeding system	Protein supplement	Copper supplement (p.p.m. as sulphate)	Feeding system	Protein supplement	Copper supplement (250 p.p.m.)	Feeding system	Protein supplement	Copper supplement (p.p.m. as sulphate)	Feeding system	Protein supplement	Copper supplement (p.p.m. as sulphate)
1	S	WFM	None	TS	WFM	None	S	WFM	None	S	WFM	None
2	S	WFM	62·5	TS	WFM	As sulphate	S	WFM	250	S	WFM	250
3	S	WFM	125	TS	WFM	As carbonate	S	DSM	None	A	WFM	None
4	S	WFM	250	S	WFM	None	S	DSM	250	A	WFM	250
5	—	—	—	S	WFM	As sulphate	—	—	—	—	—	—
6	—	—	—	S	WFM	As carbonate	—	—	—	—	—	—

S, Semi-*ad lib.*, wet (see p. 507); WFM, white-fish meal; TS, to scale, wet (see p. 507); DSM, dried skim milk; A, *ad lib.*, dry (see p. 507). Copper as sulphate ($CuSO_4.5H_2O$): 45·4 g/100 lb of diet supplies approximately 250 p.p.m. Cu. Copper as carbonate ($CuCO_3.Cu(OH)_2.H_2O$): 21·8 g/100 lb of diet supplies approximately 250 p.p.m. Cu.

randomized block analyses of variance, no adjustments being made for variation in either initial live weight or cold dead weight (see Barber, Braude & Mitchell, 1957). Under our conditions of experimentation the term 'treatment' is confounded with 'pen' but the 'pen' effect has been considered as negligible. The commercial grading results for the pigs in Expts 1, 2 and 3 are presented in Tables 10, 11 and 12 respectively. In Table 13, the responses in rate of gain and efficiency of food utilization to Cu supplementation in the four experiments are expressed as percentages of the results for the corresponding unsupplemented control animals.

The general health of the pigs on the experiments was satisfactory. Of the total of 160 pigs involved in the four experiments, five had to be removed from experiment or died for reasons unconnected with the trials.

Table 3. *Expt 1. Effect of supplementation of diets with different amounts of copper sulphate on mean daily weight gain, food conversion, rate of food consumption, dressing percentage, and liver copper stores*

	Treatment no. and dietary supplement					
	1 None	2 62·5 p.p.m. Cu as sulphate	3 125 p.p.m. Cu as sulphate	4 250 p.p.m. Cu as sulphate	Standard error of means†	Significance of treatment mean square‡
No. of pigs	14	14§	14§	14	—	—
Initial weight (lb)	47·0	46·4	46·7	46·7	—	—
Final weight (lb)	208·1	208·1	207·4	208·6	—	—
Daily weight gain (lb)	1·45	1·52	1·50	1·58	0·023	**
Food conversion (lb meal/lb live-weight gain)	3·51	3·36	3·36	3·32	0·043	*
Rate of food consumption (lb/day)	5·07	5·10	5·03	5·22	0·053	N.S.
Dressing percentage	73·4	74·2	74·6	74·3	0·37	N.S.
Cu in liver (mg/kg dry tissue):						
Value‖	61 (14)	61 (12)	80 (13)	770 (13)	—	—
Range	32–147	38–88	51–147	308–1527	—	—

† Based on 37 degrees of freedom.
‡ N.S., $P > 0·05$; * $0·05 > P > 0·01$; ** $0·01 > P > 0·001$.
§ One pig was taken off experiment for reasons unconnected with the trial, and missing values, calculated by the missing-plot technique (Yates, 1933) were substituted.
‖ Two samples lost. Numbers of livers are shown in parentheses.

Expt 1 (*Tables* 3 *and* 10)

Rate of gain and efficiency of food utilization. Supplementation of the basal diet with copper sulphate at each of the three levels resulted in significant improvements in both rate of gain and efficiency of food utilization. The rate of gain of the pigs given the highest level of Cu (treatment 4, 250 p.p.m. Cu) was significantly greater than that of the pigs on treatment 3 (125 p.p.m. Cu) ($P < 0·05$), but there were no significant differences in the efficiency with which the three groups given Cu utilized their food.

Rate of food consumption. The mean figures indicated that the rate of food consumption of the pigs given 250 p.p.m. Cu in their diet was higher than that of the other three groups. Although the treatment mean square for this variable was not quite significant

Table 4. *Expt 2. Effect of supplementation with either copper sulphate or copper carbonate of diets given either to scale, wet (TS) or semi-*ad lib., *wet (S) (see p. 507) on mean daily weight gain, food conversion, rate of food consumption, dressing percentage and liver copper stores*

	Treatment no. and dietary supplement							
	1 (TS) None	2 (TS) 250 p.p.m. Cu as sulphate	3 (TS) 250 p.p.m. Cu as carbonate	4 (S) None	5 (S) 250 p.p.m. Cu as sulphate	6 (S) 250 p.p.m. Cu as carbonate	Standard error of means†	Significance of treatment mean square‡
No. of pigs	8§	8§	8	8	8	8§	—	—
Initial weight (lb)	49·0	52·1	51·3	52·5	50·4	52·1	—	—
Final weight (lb)	207·6	211·3	211·8	206·5	208·6	207·6	—	—
Daily weight gain (lb)	1·36	1·44	1·47	1·42	1·58	1·56	0·033	***
Food conversion (lb meal/lb live-weight gain)	3·33	3·22	3·17	3·42	3·17	3·15	0·071	N.S.
Rate of food consumption (lb/day)	4·49	4·61	4·67	4·84	5·00	4·92	0·089	**
Dressing percentage	72·6	74·5	73·5	73·4	75·0	72·9	0·46	**
Cu in liver (mg/kg, dry tissue):								
Value‖	52 (7)	843 (7)	624 (8)	61 (7)	779 (6)	383 (5)	—	—
Range	31–76	496–1571	313–1061	34–102	358–1194	296–561	—	—

† Based on 32 degrees of freedom.
‡ N.S., $P > 0·05$; ** $0·01 > P > 0·001$; *** $P < 0·001$.
§ One pig on each of treatments 1, 2 and 6 died or was taken off experiment shortly after the beginning of the trial for reasons unconnected with the experiment, and missing values, calculated by the missing-plot technique (Yates, 1933), were substituted.
‖ Five samples lost. Numbers of livers are shown in parentheses.

Table 5. *Expt 2. Treatment means and their standard errors, and statistical significance of the treatment effects and interactions*

	Dietary supplement					System of feeding				
	None (*a*)	250 p.p.m. Cu as sulphate (*b*)	250 p.p.m. Cu as carbonate (*c*)	Standard error of means†	Significance of treatment mean square‡	To scale, wet (*d*)	Semi-*ad lib.*, wet (*e*)	Standard error of means†	Significance of treatment mean square‡	Significance of interaction‡ (*f*)
Daily weight gain (lb)	1·39	1·51	1·52	0·023	***	1·42	1·52	0·019	***	N.S.
Food conversion (lb meal/lb live-weight gain)	3·38	3·19	3·16	0·051	*	3·24	3·25	0·041	N.S.	N.S.
Rate of food consumption (lb/day)	4·66	4·81	4·79	0·063	N.S.	4·59	4·92	0·052	***	N.S.
Dressing percentage	73·0	74·7	73·2	0·33	***	73·5	73·7	0·27	N.S.	N.S.

(*a*) Mean of treatments 1 and 4.
(*b*) Mean of treatments 2 and 5.
(*c*) Mean of treatments 3 and 6.
(*d*) Mean of treatments 1, 2 and 3.
(*e*) Mean of treatments 4, 5 and 6.
(*f*) Between diet and system of feeding.

† Based on 32 degrees of freedom.
‡ N.S., $P > 0·05$; * $0·05 > P > 0·01$; *** $P < 0·001$.

at the 5 % level, a *t* test indicated that the differences between treatment 4 (250 p.p.m. Cu) and treatments 1 (control) and 3 (125 p.p.m. Cu) were statistically significant ($P < 0.05$).

Dressing percentage. Differences in dressing percentage were not significant, although the mean figures indicated a trend for a small increase in dressing percentage when the basal diet was supplemented with copper sulphate at either of the three levels.

Liver copper stores. There was little or no increase in liver Cu stores at slaughter when diets supplemented with either 62·5 or 125 p.p.m. Cu were given, but with a supplement of 250 p.p.m. Cu (treatment 4) there was a marked increase.

Table 6. *Expt* 3. *Effect of supplementation with copper sulphate of diets containing either white-fish meal (WFM) or dried skim milk (DSM) as the protein supplement on mean daily weight gain, food conversion, rate of food consumption, dressing percentage and carcass length*

	Treatment no. and dietary supplement					
	1 (WFM) None	2 (WFM) 250 p.p.m. Cu as sulphate	3 (DSM) None	4 (DSM) 250 p.p.m. Cu as sulphate	Standard error of means†	Significance of treatment mean square‡
No. of pigs	8	8	8	8	—	—
Initial weight (lb)	47·2	48·4	47·9	47·8	—	—
Final weight (lb)	210·1	208·6	210·6	209·9	—	—
Daily weight gain (lb)	1·53	1·57	1·57	1·76	0·032	***
Food conversion (lb meal/lb live-weight gain)	3·24	3·22	3·10	3·02	0·067	N.S.
Rate of food consumption (lb/day)	4·94	5·03	4·85	5·29	0·072	**
Dressing percentage	73·4	74·1	73·4	73·8	0·49	N.S.
Carcass length (mm)	791	784	784	784	6·0	N.S.

† Based on 21 degrees of freedom.
‡ N.S., $P > 0·05$; ** $0·01 > P > 0·001$; *** $P < 0·001$.

Table 7. *Expt* 4 (*a*). *Effect of supplementation with copper sulphate of diets given either semi-*ad lib., *wet* (*S*) *or* ad lib., *dry* (*A*) (*see p.* 507) *to pigs on experiment for* 9 *weeks after weaning on mean daily weight gain, food conversion and rate of food consumption*

	Treatment no. and dietary supplement					
	1 (S) None	2 (S) 250 p.p.m. Cu as sulphate	3 (A) None	4 (A) 250 p.p.m. Cu as sulphate	Standard error of means†	Significance of treatment mean square‡
No. of pigs	6	6	6	6	—	—
Initial weight (lb)	43·8	45·0	45·5	45·8	—	—
Final weight (lb)	133·8	147·3	130·2	140·0	—	—
Daily weight gain (lb)	1·43	1·62	1·35	1·49	0·045	**
Food conversion (lb meal/lb live-weight gain)	3·04	2·94	3·35	3·17	0·073	**
Rate of food consumption (lb/day)	4·31	4·78	4·49	4·72	0·13	N.S.

† Based on 15 degrees of freedom.
‡ N.S., $P > 0·05$; ** $0·01 > P > 0·001$.

Table 8. *Expt* 4 (*a*). *Treatment means and their standard errors, and statistical significance of the treatment effects and interactions*

	Dietary supplement			System of feeding				
	None (*a*)	250 p.p.m. Cu as sulphate (*b*)	Significance of treatment mean square†	Semi-*ad lib.*, wet (*c*)	*Ad lib.*, dry (*d*)	Significance of treatment mean square†	Standard error of means‡ (*e*)	Significance of interaction† (*f*)
Daily weight gain (lb)	1·39	1·56	**	1·52	1·42	*	0·031	N.S.
Food conversion (lb meal/lb live-weight gain)	3·20	3·05	N.S.	2·99	3·26	**	0·052	N.S.
Rate of food consumption (lb/day)	4·40	4·75	*	4·55	4·60	N.S.	0·090	N.S.

(*a*) Mean of treatments 1 and 3.
(*b*) Mean of treatments 2 and 4.
(*c*) Mean of treatments 1 and 2.
(*d*) Mean of treatments 3 and 4.
(*e*) Of (*a*), (*b*), (*c*) and (*d*).
(*f*) Between diet and system of feeding.

† N.S., $P > 0·05$; * $0·05 > P > 0·01$; ** $0·01 > P > 0·001$.
‡ Based on 15 degrees of freedom.

Commercial grading (*Table* 10). There were no marked differences in the commercial grading, based on back-fat thickness, of the carcasses from the four groups of pigs.

Expt 2 (*Tables* 4, 5 *and* 11)

Rate of gain. Supplementation of the basal diet with 250 p.p.m. Cu either as the sulphate or as the carbonate increased the rate of gain of the pigs whether fed to scale or semi-*ad lib.* These differences were all statistically significant except that pigs fed to scale and given a diet supplemented with Cu as the sulphate (treatment 2) did not grow significantly faster than the corresponding controls (treatment 1). The values in Table 5 show that both Cu salts were equally effective in increasing the rate of gain, and that the rate of gain of the pigs fed semi-*ad lib.* was significantly greater than that of the pigs fed to scale ($P < 0.001$).

The percentage improvement in rate of gain due to the copper supplement was greater when feeding was semi-*ad lib.* than when it was to scale (see Table 13).

Efficiency of food utilization. Supplementation of the diet with either copper

Table 9. *Expt* 4 (*b*). *Mean results for treatments* 3 *and* 4 (*see Table* 7) *from weaning to bacon weight*

(The amount of meal fed dry to both groups was limited to a daily maximum of 6¾ lb/pig)

	Treatment no. and dietary supplement: 3 None	4 250 p.p.m. Cu as sulphate	Standard error of means†	Statistical significance of difference in means‡
No. of pigs	6	6	—	—
Initial weight (lb)	45·5	45·8	—	—
Final weight (lb)	206·6	209·0	—	—
Daily weight gain (lb)	1·41	1·54	0·034	*
Food conversion (lb meal/lb live-weight gain)	3·84	3·59	0·074	N.S.
Rate of food consumption (lb/day)	5·43	5·49	0·093	N.S.
Cu in liver (mg/kg dry tissue):				
Value§	28 (6)	343 (4)	—	—
Range	17–42	109–500	—	—

† Based on 5 degrees of freedom.
‡ N.S., $P > 0.05$; * $0.05 > P > 0.01$.
§ Two samples lost. Numbers of livers are shown in parentheses.

Table 10. *Commercial grading of pigs on Expt* 1

Copper supplement (p.p.m.)	No. of pigs: Total	With loin fat grading: A	B	C	F	With shoulder fat grading: A	B	C	F	With mid-back fat grading: A	B	C	F
None	14	7	3	3	1	7	3	3	1	10	3	0	1
62·5	13	7	4	1	1	7	6	0	0	12	1	0	0
125	13	7	4	0	2	8	2	3	0	10	1	1	1
250	14	9	2	2	1	6	3	4	1	10	4	0	0

sulphate or copper carbonate similarly and significantly ($P < 0.05$) improved the efficiency of food utilization (Table 5). The values in Table 4 show, however, that the difference in food utilization was not statistically significant for the pigs fed to scale but was so, as judged by a *t* test, when the pigs were fed semi-*ad lib.* ($P < 0.05$). The system of feeding (to scale or semi-*ad lib.*) had no significant effect on the efficiency of food utilization (Table 5).

Table 11. *Commercial grading of pigs on Expt 2*

Copper supplement (p.p.m.)	System of feeding	No. of pigs: Total	With loin fat grading: A	B	C	F	With shoulder fat grading: A	B	C	F	With mid-back fat grading: A	B	C	F
None	To scale, wet	7	5	1	0	1	5	1	0	1	6	1	0	0
250 as sulphate		7	3	3	1	0	3	2	2	0	6	1	0	0
250 as carbonate		8	5	3	0	0	5	2	1	0	6	2	0	0
None	Semi-*ad lib.*, wet	8	5	3	0	0	5	2	1	0	8	0	0	0
250 as sulphate		8	5	2	1	0	6	1	0	1	7	1	0	0
250 as carbonate		7	6	0	0	1	4	1	2	0	7	0	0	0
Total for:														
No supplement		15	10	4	0	1	10	3	1	1	14	1	0	0
250 p.p.m. Cu as sulphate		15	8	5	2	0	9	3	2	1	13	2	0	0
250 p.p.m. Cu as carbonate		15	11	3	0	1	9	3	3	0	13	2	0	0
Fed to scale, wet		22	13	7	1	1	13	5	3	1	18	4	0	0
Fed semi-*ad lib.*, wet		23	16	5	1	1	15	4	3	1	22	1	0	0

Table 12. *Commercial grading of pigs on Expt 3*

Protein supplement	Copper supplement (p.p.m.)	No. of pigs: Total	AA+	AA	A	Total A and above	B+	B	C	F	Grade A on: Loin	Shoulder
White-fish meal	None	8	2	2	1	5	2	0	1	0	5	7
	250	8	1	2	1	4	4	0	0	0	4	5
Dried skim milk	None	8	1	2	2	5	2	1	0	0	5	8
	250	8	2	2	0	4	0	0	2	2	4	7

The percentage improvement in efficiency of food utilization due to the Cu supplement was greater when feeding was semi-*ad lib.* than when it was to scale (see Table 13).

Rate of food consumption. Although the mean rate of food consumption was increased as a result of supplementing the diet with Cu as either sulphate or carbonate, the mean differences were not statistically significant for either the pigs fed to scale or those fed semi-*ad lib.*

Rate of food consumption was significantly higher ($P < 0.001$) for the pigs fed semi-*ad lib.* than for those fed to scale (Table 5).

Dressing percentage. Dressing percentage was significantly increased when the diet was supplemented with copper sulphate ($P < 0.001$), but not with copper carbonate, under either system of feeding (Table 5). The system of feeding itself had no effect on the dressing percentage.

Liver copper stores. Supplementation of the diet with either copper sulphate or copper carbonate resulted in large increases in the amount of Cu present in the livers at bacon weight, the former giving increases of similar magnitude to those obtained in Expt 1 when 250 p.p.m. Cu as sulphate were added. There was some indication that the increase in liver Cu stores was not so great when Cu was given as the carbonate instead of as the sulphate, particularly with semi-*ad lib.* feeding.

Interaction between diet and system of feeding. For none of the variables studied was there any significant interaction ($P > 0.05$).

Commercial grading (Table 11). The commercial grading of the carcasses, based on back-fat thickness, was very similar for all groups, neither supplementation with copper nor system of feeding having any consistent effect.

Table 13. *Expts 1–4. Improvement due to copper supplementation expressed as a percentage of the performance of corresponding controls not given copper*

Expt no.	Copper supplement (p.p.m.) and system of feeding	Improvement: Daily weight gain	Improvement: Efficiency of food utilization
1	62·5 as sulphate (S)	4·8	4·3
	125 as sulphate (S)	3·4	4·3
	250 as sulphate (S)	9·0	5·4
2	250 as sulphate (TS)	5·9	3·3
	250 as carbonate (TS)	8·1	4·8
	250 as sulphate (S)	11·3	7·3
	250 as carbonate (S)	9·9	7·9
3	250 as sulphate (white-fish meal diet) (S)	2·6	0·6
	250 as sulphate (dried skim-milk diet) (S)	12·1	2·6
4 (*a*)	250 as sulphate (S)	13·3	3·3
	250 as sulphate (A)	10·4	5·4
4 (*b*)	250 as sulphate (A)	9·2	6·5

All figures are for an experimental period from about 9 weeks of age to bacon weight with the exception of those for Expt 4 (*a*) which are for a 9-week experimental period from weaning.

(S), semi-*ad lib.*, wet (see p. 507); (TS), to scale, wet (see p. 507); (A), *ad lib.*, dry (see p. 507).

Expt 3 (Tables 6 and 12)

Rate of gain. Supplementation with 250 p.p.m. Cu of a diet containing dried skim milk as the protein supplement resulted in a rate of gain significantly higher than that obtained when the same diet was given unsupplemented (treatment 3) or when a diet with white-fish meal with or without a copper supplement (treatments 1 and 2) was given ($P < 0.001$). Supplementation of the white-fish meal diet with Cu resulted in an improvement in rate of gain of only 2·6 %, a difference which was not statistically significant, compared with the improvement of 12·1 % when the dried skim-milk diet was supplemented with copper sulphate.

Efficiency of food utilization. Although the treatment mean square was not significant, a *t* test indicated that the pigs given the dried skim-milk diet supplemented with copper sulphate (treatment 4) utilized their food significantly more efficiently than pigs given the white-fish meal diet, with or without a Cu supplement ($P < 0.05$).

Rate of food consumption. The pigs on treatment 4 (dried skim-milk diet with 250 p.p.m. Cu) had a rate of food consumption significantly higher than that of the pigs on either of the other three treatments. The small increase in rate of food consumption arising from supplementation of the white-fish meal diet with Cu (treatments 1 and 2) was not statistically significant ($P > 0.05$).

Dressing percentage and carcass length. There were no significant differences between any of the treatments in either dressing percentage or carcass length.

Commercial grading (*Table* 12). There were no consistent differences in grading results, based on back-fat thickness and carcass length, between the four groups of pigs except that there was some indication of an increase in back-fat thickness in some of the pigs given the dried skim-milk diet with the Cu supplement.

Expt 4 (*Tables* 7, 8 *and* 9)

(*a*) *For* 9 *weeks experimental period from weaning* (*Tables* 7 *and* 8)

Rate of gain. Addition of 250 p.p.m. Cu as sulphate to the diet resulted in a significant increase in rate of growth with both semi-*ad lib.* wet and *ad lib.* dry feeding. Rate of growth on the former system of feeding was significantly greater ($P < 0.05$) than on the latter (Table 8).

Efficiency of food utilization. Supplementation with copper sulphate tended to improve the efficiency of food utilization with both systems of feeding, but the differences were not significant at the 5% level. The food consumed was, however, utilized significantly more efficiently ($P < 0.01$) when given semi-*ad lib.* wet than when given *ad lib.* dry (Table 8).

Rate of food consumption. With both feeding systems, Cu supplementation tended to result in a higher rate of food consumption, and the increase was statistically significant ($P < 0.05$) for the combined results (Table 8). The system of feeding had no significant effect on rate of food consumption.

Interaction between diet and system of feeding. For none of the variables studied was there any significant interaction ($P > 0.05$).

(*b*) *For experimental period from weaning to bacon weight for pigs fed* ad lib. *on dry meal to a maximum of* $6\frac{3}{4}$ *lb/pig daily* (Table 9)

Supplementation of the diet with copper sulphate resulted in a significant increase in live-weight gain, and a tendency for improved efficiency of food utilization which was not significant at the 5% level. The rate of food consumption was very similar in both groups.

When the diet was supplemented with copper sulphate there was a marked increase in mean liver copper stores at slaughter.

DISCUSSION

The marked growth-promoting effect of supplementing a growing-pig diet with Cu was again confirmed. The magnitude of the responses was similar to that usually obtained previously (see Barber *et al.* 1960), except for the pigs in Expt 3, given the diet with white-fish meal as the protein supplement. The performance of the animals given a white-fish meal diet supplemented with copper sulphate was very similar in all respects in the four experiments, whereas the performance of the control pigs in Expt 3 was markedly superior to that of the control animals in the other three experiments. This finding suggests that the failure to show any significant response to the addition of Cu to the white-fish meal diet in Expt 3 was due, at least in part, to the fact that, for unknown reasons, the general level of performance of the control pigs was appreciably better than normal in this particular trial (see Barber, Bowland, Braude, Mitchell & Porter, 1961). In spite of it, however, a very marked response was obtained in this experiment when the diet containing dried skim milk, instead of white-fish meal as the protein supplement, was supplemented with copper sulphate. Although the total crude-protein content of the white-fish meal and dried skim-milk diets (diets 1 and 3, Table 1) was about the same, the energy value of the skim-milk diet was about 5% higher and the diet differed from the fish-meal diet in that it contained lactose. Further work is now in progress to investigate the possible significance of these dietary differences in relation to the use of supplementary Cu.

Although all three levels of copper sulphate used in Expt. 1 gave significant increases in growth rate and efficiency of food utilization, the best response was obtained with the highest level (250 p.p.m. Cu). Lucas & Calder (1957) reported no significant difference in the performance of pigs given either 125 or 250 p.p.m. Cu, but Dammers & van der Grift (1959) concluded that 125 p.p.m. Cu was not quite sufficient to give the optimal response, since either 187·5 or 250 p.p.m. Cu gave rather better responses, there being no difference between the two latter levels.

The large increase in liver Cu stores shown in Tables 3, 4 and 9 when a diet with 250 p.p.m. Cu added was given, is in agreement with previously reported results (see Barber *et al.* 1961). It is clear from all our results, and from those reported by other workers, that there can be very wide variation in the liver Cu levels both between individual pigs in any one experiment and between groups of pigs in different experiments, both with pigs given low-Cu control diets and those given Cu-supplemented diets. Average figures for liver Cu content can, therefore, be misleading. The absence of any increase in liver Cu when only 62·5 p.p.m. Cu were added to the diet, and the relatively small increase when 125 p.p.m. Cu were added, as compared with the large increase resulting from the addition of 250 p.p.m. Cu, was also found by Lucas & Calder (1957) and by Dammers & van der Grift (1959). The latter workers also obtained evidence that the increase in liver copper content after the addition of 187·5 p.p.m. Cu was very appreciably less than that when 250 p.p.m. Cu were added to the diet. It appears that quite high levels of dietary Cu can be fed to pigs without any appreciable liver storage taking place, but that once storage begins it increases markedly with increasing levels of dietary Cu.

Barber *et al.* (1960) concluded that when pigs are fed in a way that allows some expression of appetite the improvement in rate of growth resulting from supplementing the diet with Cu was the direct consequence partly of an improvement in the efficiency with which the food consumed was utilized and partly of an increase in the rate of food consumption. The results of the four experiments reported here support this conclusion, although in one or two instances mean differences in these two variables between the control and supplemented groups were relatively small and not statistically significant at the conventional level. In Expt 2, for example, Cu supplementation resulted in only small, statistically not significant, increases in rate of food consumption both with the pigs fed to scale and those fed semi-*ad lib.* In the former, theoretically no expression of appetite should be possible at all. In practice, however, the pigs given one of the Cu-supplemented diets tended to eat completely their daily allocation of food soon after the beginning of the experiment, whereas the control pigs often refused small amounts of food daily for several days after the trial began. Hence some slight appetite effect was unavoidably introduced. Nevertheless, the figures in Table 13 indicate that a greater response to Cu supplementation both in rate of gain and efficiency of food utilization may be expected when pigs are fed on the semi-*ad lib.* system (as defined on p. 507) instead of according to live weight and the scale used in these experiments.

On the other hand, the magnitude of the response to Cu supplementation on semi-*ad lib.* wet and fully *ad lib.* dry feeding was similar with both systems of feeding. Rate of growth, however, was significantly better with the semi-*ad lib.* system of feeding (see Table 8). This difference was apparently the result of a significantly better efficiency of food utilization, since there was no difference in rate of food consumption between the pigs on the two systems of feeding. Owing to the small number of animals involved in this particular comparison, and the fact that the experiment covered a period of only 9 weeks from weaning, further work is necessary before any conclusions can be drawn about these apparent differences between semi-*ad lib.* wet and *ad lib.* dry feeding.

Barber *et al.* (1961) discussed the reported observations on the effect of Cu supplementation on dressing percentage and considered that the evidence available indicated that there was a real increase in dressing percentage associated with the growth response obtained with high-Cu diets. Further confirmation of this trend was obtained in the experiments now described, although some mean differences were small. Results obtained in Expt 2 suggested that the increase in dressing percentage may be less, or perhaps not occur at all, when copper carbonate instead of copper sulphate is used. Further results must be obtained to determine whether this apparent difference in the effects of the two Cu salts is a real treatment effect, because if confirmed it might prove to be a finding of some importance in relation to studies on the mode of action of Cu. In this connexion, Wacker, Heyl, Büechl & Holthoff (1956) suggested that the growth-promoting effect of copper sulphate that they observed in chicks may be due, at least in part, to the increased sulphur content of the diet. The identical growth responses to supplements of either copper sulphate or copper carbonate obtained in Expt 2 provide convincing evidence that, in pigs at any rate, it is Cu itself that is responsible for the observed effects.

The absence of any consistent effect of Cu supplementation on commercial grading results is in agreement with the results of the majority of previously reported experiments. In one experiment, however, reported by Barber *et al.* (1961), Cu supplementation was accompanied by a marked down-grading of the carcasses, which reflected an increase in thickness of fat along the back. In one of the trials reported by Dammers & van der Grift (1959) there was also a marked increase in the back-fat thickness of carcasses from pigs given a diet with either 125 or 250 p.p.m. Cu added. There was a suggestion of a similar trend in the one experiment reported here in which Cu was added to the diet containing dried skim milk instead of white-fish meal as the protein supplement. It would appear that under certain conditions Cu supplementation of growing-pig diets may be associated with some increase in carcass fatness, although the evidence obtained so far suggests that usually no such adverse effects result. Further work is now in progress on this important problem.

SUMMARY

1. One-hundred-and-sixty individually fed, virus pneumonia-free Large White weaners were used in four experiments to determine the effects of dietary supplements of copper given either as the sulphate or the carbonate, at various levels, and under different feeding systems as shown in detail in Table 2. In all experiments except Expt 4, the experimental period continued from weaning to bacon weight. In Expt 4, some of the pigs were on experiment for 9 weeks only from weaning.

2. The marked growth-promoting effect of Cu was again confirmed. In general, this effect on growth rate was associated with an improvement in efficiency of food conversion and with an increase in the rate of food consumption.

3. Levels of 62·5, 125 and 250 p.p.m. supplementary Cu in the diet all resulted in significant improvements in both growth rate and efficiency of food utilization. The highest rate of growth occurred in the pigs given the diet with the highest level of Cu.

4. Copper carbonate was equally as effective as copper sulphate in improving the performance of the pigs.

5. The percentage improvement in performance resulting from the addition of dietary Cu with either 'semi-*ad lib.*' wet, or '*ad lib.*' dry, feeding tended to be slightly higher than with 'to scale' wet feeding.

6. The highest rates of growth and efficiency of food utilization were obtained when a diet containing dried skim milk, instead of white-fish meal as the protein supplement, was supplemented with Cu.

7. There were very large increases in the amount of Cu in the liver at slaughter when a diet with 250 p.p.m. Cu added was given. When the level of Cu added was 62·5 or 125 p.p.m., no, or only very small, increases in liver Cu stores occurred. There were very wide variations in liver Cu levels between individual pigs both within and between experiments.

8. Supplementation of the diet with copper sulphate tended to increase the dressing percentage. Dietary supplementation with Cu had no consistent effect on the commercial grading of the resulting carcasses, with the exception that there was a

suggestion that back-fat thickness was increased in some pigs when a diet containing dried skim milk was supplemented with Cu.

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