A study of the effects of dietary added cupric oxide on the laying, domestic fowl and a comparison with the effects of hydrated copper sulphate

BY N. JACKSON AND MARY H. STEVENSON

Agricultural and Food Chemistry Research Division, Department of Agriculture for Northern Ireland, and The Queen's University of Belfast, Newforge Lane, Belfast BT9 5PX, Northern Ireland

(Received 18 February 1980 – Accepted 27 May 1980)

1. An experiment is reported in which copper, as cupric oxide, was fed to two breeds of laying hen for 336 d at levels equivalent to 150, 300, 450, 600 and 750 mg added Cu/kg diet. The results obtained were compared with those found using similar diets to which the Cu was added as $CuSO_4$. SH_2O .

2. Addition of the CuO had no effect on food intake, food conversion efficiency, body-weight or egg production. The $CuSO_4$ addition caused the quadratic response of food intake and the adverse effects on food intake, egg production and body-weight noted in previous experiments.

3. The CuO had no effect on liver, kidney, ovary, oviduct or gizzard weight per unit body-weight while the CuSO₄ decreased these with the exception of gizzard weight which was significantly increased.

4. CuO addition did not affect liver Cu concentration but CuSO₄ caused a substantial increase of liver Cu especially at the 750 mg Cu/kg level of addition.

5. CuO addition had no effect on liver lipid concentration but this was depressed at the highest level of CuSO₄ addition. Effects on individual fatty acids are presented but no specific conclusions have been reached.

The use of copper compounds as growth stimulants in pig diets has been studied for many years but their effects in poultry have been less thoroughly investigated.

Information about the effects of supplementing laying-hen diets with Cu compounds is limited and has been reviewed recently (Jackson, 1977; Jackson *et al.* 1979; Stevenson & Jackson, 1980*a*, *b*). In these experiments the effects of added dietary copper sulphate on food and water intakes, weight gains, egg production and organ weights have been investigated. In addition effects of the Cu salt on the levels of Cu and other minerals in certain tissues of the laying hen have been studied and pathological effects on organs have also been investigated.

The effects of dietary Cu supplementation on porcine carcass quality have been reviewed by Braude (1967) who concluded that most of the evidence available indicated that Cu had no adverse effects. However, Taylor & Thomke (1964) and Elliott & Bowland (1968) have shown that the back fat of pigs given CuSO₄-supplemented diets is softer than those receiving no Cu supplement. These changes were associated with increases in the oleic acid:stearic acid value in both the inner and outer layers of back fat (Christie & Moore, 1969). Husbands (1972) gave chicks 227 mg added Cu/kg diet and Elliott & Bowland (1972) gave rats 250 mg supplemental dietary Cu. The Cu was given to both species as sulphate and neither showed any significant changes in the fatty acid composition of subcutaneous fat.

In the present study the effects, in the laying hen, of cupric oxide were investigated and compared with the effects of $CuSO_4$. The effects of the supplements on body and liver fat composition were also investigated.

EXPERIMENTAL

The experiment commenced on 30 December 1977 and was carried out for 12×28 d periods. Two hundred and sixty-four 19-week-old laying hens previously vaccinated against Marek's disease, infectious bronchitis and epidemic tremors and comprising 132 white (Shaver 288) and 132 brown (Warren Studler SSL) birds were placed in galvanized-iron cages fitted with individual food troughs and nipple drinkers. The lighting regimen used was 15 h light and 9 h darkness. The battery house was unheated, the minimum recorded winter temperature being 2° and the maximum summer temperature 28°. At 26 weeks of age, when all the hens had been laying for at least 2 weeks, they were randomly allocated to one of eleven treatment groups giving twelve hens of each breed per treatment. The diets, fed *ad lib.*, were the control diet which was essentially that described by Jackson (1977) and this diet to which was added 150, 300, 450, 600 or 750 mg Cu/kg either as AR grade CuO powder (treatments 2–6) or as AR grade CuSO₄. 5H₂O (treatments 7–11) ground to the specification reported by Jackson (1977).

The control diet contained (/kg) 158.5 g crude protein (N \times 6.25), 14 mg Cu, 124 mg zinc, 239 mg iron, 32.2 g calcium, 5.4 g phosphorus and had a calculated metabolizable energy (ME) content of 11.4 MJ/kg. Egg production was recorded daily and the eggs weighed twice weekly. The hens were weighed initially and at the end of each 28 d period and mean body-weight obtained from these observations. Food intake was recorded for each 28 d period. During the last period four eggs from each breed for each treatment were randomly selected and the Cu concentrations in the dry matter, less the shell and membranes, measured.

After 48 weeks, four birds of each breed from each treatment were randomly selected and killed by decapitation. Liver, kidneys, oviduct, ovary and gizzard were removed and weighed. Livers and kidneys were dried at 100°. Liver lipid and lipid from the fatty tissue adhering to the gizzard were extracted by the method of Folch *et al.* (1957). The lipid extracts were subjected to fatty acid analyses using gas-liquid chromatography. Blood serum Cu determination and the food, tissue and egg mineral analyses were carried out as described by Stevenson & Jackson (1980*a*).

The results were subjected to analysis of variance. Log transformations were carried out for those variables which exhibited variance heterogeneity. At zero added Cu the oxide and sulphate treatments coincide and so this level of Cu was omitted in determining the significance of interactions between the factors. However, in determining responses to Cu levels the complete range of Cu from 0 to 750 mg added Cu/kg was used.

RESULTS

Mortality in the experiment was very low (1.9%) and all those birds which died were white (Shaver 288) hens receiving diets high in added CuSO₄.

The results for food intake, egg production and food conversion, expressed as bird means, are presented in Table 1.

Total food intake showed no definite relationship with the level of CuO addition to the diet although it showed a quadratic response (P < 0.001) to added CuSO₄, the production of the white and brown hens being respectively reduced to 51 and 59% of the control values at the 750 mg/kg level of Cu supplementation.

The numbers of eggs produced and the total egg weight were significantly affected by additive treatment (P < 0.001). No evidence of any effect due to the CuO was apparent. The over-all effect on total egg weight was due to the depression of egg production by the CuSO₄ and the negative linear relationship (P < 0.001) between mean period mean egg weight and the level of added dietary CuSO₄.

able	[e]	1. 1	Foc	pd	otal ente	egg d d	g weij iets fi	ght or 4	and f 8 wev	ood	conversi	ion o	of la	ying	^c ood intake, egg number, mean period mean and total egg weight and food conversion of laying hens given control and	copper-supplemented diets for 48 weeks
1. Food	l. Food	Food	p		ake, egg number, mean period mean and tı copper-supplem.	ake, egg number, mean period mean and total copper-supplemente	ake, egg number, mean period mean and total egy copper-supplemented d	ake, egg number, mean period mean and total egg wei _t copper-supplemented diets f	ake, egg number, mean period mean and total egg weight . copper-supplemented diets for 4	ake, egg number, mean period mean and total egg weight and f copper-supplemented diets for 48 we.	ake, egg number, mean period mean and total egg weight and food (copper-supplemented diets for 48 weeks	ake, egg number, mean period mean and total egg weight and food convers. copper-supplemented diets for 48 weeks	ake, egg number, mean period mean and total egg weight and food conversion o copper-supplemented diets for 48 weeks	ake, egg number, mean period mean and total egg weight and food conversion of la copper-supplemented diets for 48 weeks	int	
: 1. Food int	l. Food int	Food int	od int	int	, egg number, mean period mean and t copper-supplem	, egg number, mean period mean and total copper-supplemente	, egg number, mean period mean and total eg copper-supplemented d	, egg number, mean period mean and total egg wei _t copper-supplemented diets f	, egg number, mean period mean and total egg weight . copper-supplemented diets for 4	, egg number, mean period mean and total egg weight and f copper-supplemented diets for 48 we.	, egg number, mean period mean and total egg weight and food (copper-supplemented diets for 48 weeks	, egg number, mean period mean and total egg weight and food convers. copper-supplemented diets for 48 weeks	, egg number, mean period mean and total egg weight and food conversion o copper-supplemented diets for 48 weeks	, egg number, mean period mean and total egg weight and food conversion of la copper-supplemented diets for 48 weeks	ake	
. 1. Food intake	l. Food intake	Food intake	od intake	intake	gg number, mean period mean and tı copper-supplem.	gg number, mean period mean and total copper-supplemente	gg number, mean period mean and total eg copper-supplemented d	gg number, mean period mean and total egg wei _l copper-supplemented diets f	gg number, mean period mean and total egg weight . copper-supplemented diets for 4	gg number, mean period mean and total egg weight and f copper-supplemented diets for 48 we	gg number, mean period mean and total egg weight and food (copper-supplemented diets for 48 weeks	gg number, mean period mean and total egg weight and food convers. copper-supplemented diets for 48 weeks	gg number, mean period mean and total egg weight and food conversion o copper-supplemented diets for 48 weeks	gg number, mean period mean and total egg weight and food conversion of la copper-supplemented diets for 48 weeks	е С	
1. Food intake, e	l. Food intake, e _l	Food intake, e _i	od intake, e _l	intake, e _l	number, mean period mean and tr copper-supplem	number, mean period mean and total copper-supplemente	number, mean period mean and total egy copper-supplemented d	number, mean period mean and total egg wei _i copper-supplemented diets fi	number, mean period mean and total egg weight . copper-supplemented diets for 4	number, mean period mean and total egg weight and f copper-supplemented diets for 48 we.	number, mean period mean and total egg weight and food (copper-supplemented diets for 48 weeks	number, mean period mean and total egg weight and food convers. copper-supplemented diets for 48 weeks	number, mean period mean and total egg weight and food conversion o copper-supplemented diets for 48 weeks	number, mean period mean and total egg weight and food conversion of la copper-supplemented diets for 48 weeks	88 1	
1. Food intake, egg	l. Food intake, egg)	Food intake, egg i	od intake, egg i	intake, egg i	ıber, mean period mean and tı copper-supplemı	ıber, mean period mean and total copper-supplemente	rber, mean period mean and total eg copper-supplemented d	rber, mean period mean and total egg wei copper-supplemented diets f	nber, mean period mean and total egg weight . copper-supplemented diets for 4	rber, mean period mean and total egg weight and f copper-supplemented diets for 48 we	nber, mean period mean and total egg weight and food (copper-supplemented diets for 48 weeks	nber, mean period mean and total egg weight and food convers. copper-supplemented diets for 48 weeks	uber, mean period mean and total egg weight and food conversion o copper-supplemented diets for 48 weeks	rber, mean period mean and total egg weight and food conversion of la copper-supplemented diets for 48 weeks	umı	
: 1. Food intake, egg nun	l. Food intake, egg nun	Food intake, egg nun	od intake, egg nun	intake, egg nun	r, mean period mean and t copper-supplem.	r, mean period mean and total copper-supplements	r, mean period mean and total eg copper-supplemented d	r, mean period mean and total egg wei _t copper-supplemented diets f	r, mean period mean and total egg weight . copper-supplemented diets for 4	r, mean period mean and total egg weight and f copper-supplemented diets for 48 we	r, mean period mean and total egg weight and food (copper-supplemented diets for 48 weeks	r, mean period mean and total egg weight and food convers. copper-supplemented diets for 48 weeks	r, mean period mean and total egg weight and food conversion o copper-supplemented diets for 48 weeks	r, mean period mean and total egg weight and food conversion of la copper-supplemented diets for 48 weeks	logi	
1. Food intake, egg number	l. Food intake, egg numbe	Food intake, egg numbe	od intake, egg number	intake, egg numbe	tean period mean and to copper-supplem	tean period mean and total copper-supplements	iean period mean and total eg copper-supplemented d	iean period mean and total egg wei _i copper-supplemented diets fi	tean period mean and total egg weight . copper-supplemented diets for 4	tean period mean and total egg weight and f copper-supplemented diets for 48 we	iean period mean and total egg weight and food i copper-supplemented diets for 48 weeks	tean period mean and total egg weight and food convers. copper-supplemented diets for 48 weeks	tean period mean and total egg weight and food conversion o copper-supplemented diets for 48 weeks	tean period mean and total egg weight and food conversion of la copper-supplemented diets for 48 weeks	, n	
: 1. Food intake, egg number, n	l. Food intake, egg number, n	Food intake, egg number, n	od intake, egg number, n	intake, egg number, n	n period mean and to copper-supplem	n period mean and total copper-supplemente	n period mean and total eg copper-supplemented d	n period mean and total egg wei; copper-supplemented diets f	n period mean and total egg weight copper-supplemented diets for 4	n period mean and total egg weight and f copper-supplemented diets for 48 we.	n period mean and total egg weight and food (copper-supplemented diets for 48 weeks	n period mean and total egg weight and food convers. copper-supplemented diets for 48 weeks	n period mean and total egg weight and food conversion o copper-supplemented diets for 48 weeks	n period mean and total egg weight and food conversion of la copper-supplemented diets for 48 weeks	ıea	
: 1. Food intake, egg number, mea	l. Food intake, egg number, mea	Food intake, egg number, mea	od intake, egg number, mea	intake, egg number, mea	eriod mean and to copper-supplem	eriod mean and total copper-supplemente	eriod mean and total egy copper-supplemented d	eriod mean and total egg wei; copper-supplemented diets f	eriod mean and total egg weight . copper-supplemented diets for 4	eriod mean and total egg weight and f copper-supplemented diets for 48 we.	eriod mean and total egg weight and food (copper-supplemented diets for 48 weeks	eriod mean and total egg weight and food convers. copper-supplemented diets for 48 weeks	eriod mean and total egg weight and food conversion o copper-supplemented diets for 48 weeks	eriod mean and total egg weight and food conversion of la copper-supplemented diets for 48 weeks	nd u	
: 1. Food intake, egg number, mean p	l. Food intake, egg number, mean p	Food intake, egg number, mean p	od intake, egg number, mean p	intake, egg number, mean p	id mean and to pper-supplem	id mean and total pper-supplemente	id mean and total egg pper-supplemented d	nd mean and total egg wei; pper-supplemented diets f	nd mean and total egg weight i pper-supplemented diets for 4	d mean and total egg weight and f pper-supplemented diets for 48 we.	d mean and total egg weight and food i pper-supplemented diets for 48 weeks	d mean and total egg weight and food convers. pper-supplemented diets for 48 weeks	d mean and total egg weight and food conversion o pper-supplemented diets for 48 weeks	d mean and total egg weight and food conversion of la pper-supplemented diets for 48 weeks	erio	3
: 1. Food intake, egg number, mean perio co	l. Food intake, egg number, mean perio co	Food intake, egg number, mean perio co	od intake, egg number, mean perio co	intake, egg number, mean perio co	rean and t _i r-supplem	tean and total r-supplements	iean and total egg r-supplemented d	iean and total egg wei; r-supplemented diets f	tean and total egg weight r-supplemented diets for 4	tean and total egg weight and f r-supplemented diets for 48 wei	tean and total egg weight and food (r-supplemented diets for 48 weeks	tean and total egg weight and food convers. r-supplemented diets for 48 weeks	tean and total egg weight and food conversion o r-supplemented diets for 48 weeks	tean and total egg weight and food conversion of la r-supplemented diets for 48 weeks	d m	ədd
: 1. Food intake, egg number, mean period m coppe	l. Food intake, egg number, mean period m coppe	Food intake, egg number, mean period m coppe	od intake, egg number, mean period m coppe	intake, egg number, mean period m coppe	t and to applement	t and total pplemente	t and total egg applemented d	t and total egg wei pplemented diets f	t and total egg weight of the second second to the second se	t and total egg weight and f upplemented diets for 48 wei	t and total egg weight and food (upplemented diets for 48 weeks	t and total egg weight and food convers. pplemented diets for 48 weeks	t and total egg weight and food conversion o upplemented diets for 48 weeks	t and total egg weight and food conversion of la upplemented diets for 48 weeks	nean	r-51
: 1. Food intake, egg number, mean period mean copper-su	l. Food intake, egg number, mean period mean copper-su	Food intake, egg number, mean period mean copper-su	od intake, egg number, mean period mean copper-su	intake, egg number, mean period mean copper-su	d ti em	d total emente	d total eg emented d	d total egg wei emented diets f	d total egg weight emented diets for 4	d total egg weight and f emented diets for 48 wei	d total egg weight and food emented diets for 48 weeks	d total egg weight and food convers. emented diets for 48 weeks	d total egg weight and food conversion o emented diets for 48 weeks	d total egg weight and food conversion of la emented diets for 48 weeks	1 an	Iddi
1. Food intake, egg number, mean period mean an copper-supp	l. Food intake, egg number, mean period mean an copper-supp	Food intake, egg number, mean period mean an copper-supp	od intake, egg number, mean period mean an copper-supp	intake, egg number, mean period mean an copper-supp		otal ente	otal egg ented d	otal egg wei _j ented diets fi	otal egg weight operation of the second s	otal egg weight and f ented diets for 48 wei	otal egg weight and food o ented diets for 48 weeks	otal egg weight and food convers. ented diets for 48 weeks	otal egg weight and food conversion o ented diets for 48 weeks	otal egg weight and food conversion of la ented diets for 48 weeks	id h	lem
1. Food intake, egg number, mean period mean and total egg weight and food conversion of laying copper-supplemented diets for 48 weeks	l. Food intake, egg number, mean period mean and total egg weight and food conversion of laying copper-supplemented diets for 48 weeks	Food intake, egg number, mean period mean and total egg weight and food conversion of laying copper-supplemented diets for 48 weeks	od intake, egg number, mean period mean and total egg weight and food conversion of laying copper-supplemented diets for 48 weeks	intake, egg number, mean period mean and total egg weight and food conversion of laying copper-supplemented diets for 48 weeks	egg weight and food conversion of laying diets for 48 weeks	z weight and food conversion of laying iets for 48 weeks	ght and food conversion of laying or 48 weeks	and food conversion of laying 8 weeks	ood conversion of laying eks	conversion of laying	ion of laying	f laying	ying		hens	
1. Food intake, egg number, mean period mean and total egg weight and food conversion of laying hens copper-supplemented diets for 48 weeks	l. Food intake, egg number, mean period mean and total egg weight and food conversion of laying hens copper-supplemented diets for 48 weeks	Food intake, egg number, mean period mean and total egg weight and food conversion of laying hens copper-supplemented diets for 48 weeks	od intake, egg number, mean period mean and total egg weight and food conversion of laying hens copper-supplemented diets for 48 weeks	intake, egg number, mean period mean and total egg weight and food conversion of laying hens copper-supplemented diets for 48 weeks	egg weight and food conversion of laying hens id diets for 48 weeks	g weight and food conversion of laying hens iets for 48 weeks	ght and food conversion of laying hens or 48 weeks	and food conversion of laying hens 8 weeks	ood conversion of laying hens eks	conversion of laying hens	ion of laying hens	f laying hens	ving hens	hens	give	
1. Food intake, egg number, mean period mean and total egg weight and food conversion of laying hens give copper-supplemented diets for 48 weeks	l. Food intake, egg number, mean period mean and total egg weight and food conversion of laying hens give copper-supplemented diets for 48 weeks	Food intake, egg number, mean period mean and total egg weight and food conversion of laying hens give copper-supplemented diets for 48 weeks	od intake, egg number, mean period mean and total egg weight and food conversion of laying hens give copper-supplemented diets for 48 weeks	intake, egg number, mean period mean and total egg weight and food conversion of laying hens give copper-supplemented diets for 48 weeks	egg weight and food conversion of laying hens give d diets for 48 weeks	z weight and food conversion of laying hens give iets for 48 weeks	ght and food conversion of laying hens give or 48 weeks	and food conversion of laying hens give 8 weeks	ood conversion of laying hens give eks	conversion of laying hens give	ion of laying hens give	f laying hens give	ying hens give	hens give	n con	
t 1. Food intake, egg number, mean period mean and total egg weight and food conversion of laying hens given co copper-supplemented diets for 48 weeks	l. Food intake, egg number, mean period mean and total egg weight and food conversion of laying hens given con copper-supplemented diets for 48 weeks	Food intake, egg number, mean period mean and total egg weight and food conversion of laying hens given cor copper-supplemented diets for 48 weeks	od intake, egg number, mean period mean and total egg weight and food conversion of laying hens given con copper-supplemented diets for 48 weeks	intake, egg number, mean period mean and total egg weight and food conversion of laying hens given cor copper-supplemented diets for 48 weeks	egg weight and food conversion of laying hens given con d diets for 48 weeks	z weight and food conversion of laying hens given con iets for 48 weeks	ght and food conversion of laying hens given cor or 48 weeks	and food conversion of laying hens given cor 8 weeks	ood conversion of laying hens given cor eks	conversion of laying hens given cor	ion of laying hens given con	f laying hens given con	ying hens given con	hens given cor	itrol	
1. Food intake, egg number, mean period mean and total egg weight and food conversion of laying hens given control copper-supplemented diets for 48 weeks	l. Food intake, egg number, mean period mean and total egg weight and food conversion of laying hens given control copper-supplemented diets for 48 weeks	Food intake, egg number, mean period mean and total egg weight and food conversion of laying hens given control copper-supplemented diets for 48 weeks	od intake, egg number, mean period mean and total egg weight and food conversion of laying hens given control copper-supplemented diets for 48 weeks	intake, egg number, mean period mean and total egg weight and food conversion of laying hens given control copper-supplemented diets for 48 weeks	egg weight and food conversion of laying hens given control diets for 48 weeks	g weight and food conversion of laying hens given control iets for 48 weeks	ght and food conversion of laying hens given control or 48 weeks	and food conversion of laying hens given control 8 weeks	ood conversion of laying hens given control eks	conversion of laying hens given control	ion of laying hens given control	f laying hens given control	ying hens given control	hens given control	ang	
1. Food intake, egg number, mean period mean and total egg weight and food conversion of laying hens given control and copper-supplemented diets for 48 weeks	l. Food intake, egg number, mean period mean and total egg weight and food conversion of laying hens given control and copper-supplemented diets for 48 weeks	Food intake, egg number, mean period mean and total egg weight and food conversion of laying hens given control and copper-supplemented diets for 48 weeks	od intake, egg number, mean period mean and total egg weight and food conversion of laying hens given control and copper-supplemented diets for 48 weeks	intake, egg number, mean period mean and total egg weight and food conversion of laying hens given control and copper-supplemented diets for 48 weeks	'egg weight and food conversion of laying hens given control and d diets for 48 weeks	z weight and food conversion of laying hens given control and iets for 48 weeks	ght and food conversion of laying hens given control and or 48 weeks	and food conversion of laying hens given control and 8 weeks	ood conversion of laying hens given control and eks	conversion of laying hens given control and	ion of laying hens given control and	f laying hens given control and	ving hens given control and	hens given control and		

(Values are the means of twelve observations)

	ć			Added Ci	ı in diet (mo/k	(4)				Ngnincanc	e ol elleci	
Rrand						6		1		Ecorn of	Ż	
	punod	0	150	300	450	600	750	Response	Breed	Cu O	level	form of Cu
				Food	l intake (kg)							
White	CuO	41.02	38 ·87	38 ·77	37.92	38-34	39-78	Over-all	***	***	•••	::
	CuSO ₄	70 14	39-03	36.65	.31-47	27-84	20-96	Linear	ł	ł	***	***
Rrown	CuO	41.30	42-85	39-99	39-57	39-34	41-16	Quadratic	I	ſ	SN	***
	CuSO,	5	38 ·35	38-61	34-03	32-38	24-20	,		SEM 1	·112	
				-	Egg no.							
White	CuO	760	282	280	270	261	267	Over-all	SN	***	***	***
	CuSO ₄	607	257	263	202	163	93	Linear	ł	[***	:
Recourt	CLO	716	267	263	267	256	281	Quadratic	ł	[**	***
TIMOIO	CuSO,	2	247	264	233	190	131	,		SEM 1	1.3	
				Mean perio	d mean egg wt	(g)						
White	CuO	58.4	58.3	58.4	58.3	59.5	59-3	Over-all	:	***	***	*
	CuSO,	7	60·3	57-7	57-4	53-4	52.6	Lincar	I	[***	***
Grown	CuO	62.1	62·3	63.7	59-2	0.09	62·1	Quadratic	ļ	١	SN	NS
	CuSO,	1 70	59-8	60·5	57-1	58-0	58·1	,		SIEM	ģ	
		-		Total	egg wt (kg)							
White	CuO	15.6	16-5	16-2	15-6	15-5	15-8	Over-all	#	:	***	***
	CuSO,		15-4	15.1	11.6	ŝ	4·9	Linear	ł	1	:	:
Rown	CuO	17-0	16.5	16-5	15-7	15-3	17-3	Quadratic	ļ	1	NS	***
	CuSO,	>	14-7	15.8	13·2	10-9	7-6			SEM 0	·68	
			,	Food conversi-	on (kg eggs/kg	food)						
White	CuO	0.284	0-424	0.420	0.411	0-402	0.397	Over-all	SN	Ŧ	***	***
	CuSO4		0-396	0-410	0-367	0-307	0.230	Linear	ł	1	***	***
rown	CuO	1140	0.387	0-414	0.398	0-389	0-421	Quadratic	ļ	!	•	*
	CuSO,		0-381	0-413	0-396	0-334	0-316			SEM 0-	0182	

Effects of dietary CuO in the laying hen

NS, non-significant • P < 0.05, ** P < 0.01, *** P < 0.001.

	ć			5-664						Significance	s of effect	
	5 į			Added	Cu in alet (mg,	(Kg)				Eorm of	Ē	
lreed	punod	0	150	300	450	600	750	Response	Breed	Cn	level	form of Cu
				A	uitial body-wt (k	(g						
	070 O	1.40	1-37	1-39	1-45	1-42	1-51	Over-all	:	SN	SN	SN
	Curso,	-	1-49	1-49	1-46	1. 40	1-43	Linear	ł	I	SN	SN
	000	0.00	2-01	1-99	1-96	1-94	2-01	Quadratic	I	1	SN	NS
ILMOI	CuSO,	<u>8</u> .7	1-95	1-97	2.00	2-03	1-97	,		SEM 0.	050	
	•			Ħ	inal body-wt (k	Z)						
1. i.i.	On O	1.60	1-59	1.61	1.67	1.65	1.77	Over-all	***	:	SN	NS
Inte	CuSO,	90. I	1-68	1-60	1.55	1-41	1-33	Linear	1	I	***	:
	on Cho	2.17	2.23	2.07	2-07	2-07	2.13	Quadratic	I	I	SN	SN
IMI	CuSO,	11.7	2-13	2-03	1-96	1-92	1·82	,		SEM 0-	069	
	•			Me	an body-wt (kg	4						
This.	CnO	1.63	1.53	1.57	1.61	1.56	1.71	Over-all	***	***	:	:
	CuSO.	70.1	1.61	1-55	1-48	1-35	1-24	Linear	I	I	***	***
	S S	1 .13	2.18	2.06	2-07	2-01	2-09	Ouadratic	I	I	SZ	•
IOWI	CuSO,	CI.7	2-06	2-07	2.02	1.88	1.76	,		SEM 0-	059	
	•			Da	uly ME intake (N	6						
للدنية. ال	C ⁿ O	1.20	1-32	1-32	1.29	1.30	1.35	Over-all	***	**	***	***
	CuSO,		1-32	1-24	1-07	0-94	0-71	Linear	ł	1	***	***
	On On O	1.40	1-45	1-36	1:34	1·33	1-40	Quadratic	I	ļ	SN	***
IMO	CuSO,	2	1-30	1-31	1.15	1·10	0-82			SEM 0	038	
				Daily c	rude protein int	ake (g)						
1. is .	CnO	10.4	18-3	18-3	17.9	18.1	18.8	Over-all	***	***	***	:
anc	CuSO,	+ K I	18-4	17-3	14.8	13-1	6.6	Linear	1	1	:	**
	CnO CnO	10.5	20·2	18-9	18-7	18-6	19-4	Quadratic	ł	1	SN	***
IMO	CuSO,	C.41	18-1	18·2	16-1	15-3	11-4	,		SEM 0	-52	

Table 2. Mean initial and final body-weights, mean body-weights, mean daily metabolizable energy (ME) and crude protein (nitrogen × 6-25) intakes of laying hens given control and copper-supplemented diets for 48 weeks

102

https://doi.org/10.1079/BJN19810082 Published online by Cambridge University Press

Two, non-sugnation. • P < 0.05, ** P < 0.01, *** P < 0.001. † Mean of initial, final and eleven intermediate body-weights.

					<i>copper-</i> . (Valu cs	supplementers are the means	d diets for s of four obs	• 48 weeks servations)				
	5			Added						Significance	of effect	
				nonnu	rn macı (m£/₹	8)						
Breed	punod	0	150	300	450	909	750	Response	Breed		level	Cu level × form of Cu
					Liver wt							
White	CuO	20.7	23-9	22.0	18-9	22-7	20-5	Over-all	***	***	•	SN
	CuSO,	2	15-6	18-5	15.1	21-6	13-4	Linear	J	1	•	SN
Rrown	CuO	15.1	19-0	19-4	15-1	18-4	17-1	Quadratic	J	1	SN	•
	CuSO,		16-3	16-2	17-5	13-9	12-2	,		SEM 1	·62	
	I			1	Kidney wt					I		
White	On O	8.Y	6-9	6-8	6-4	6.3	6-9	Over-all	***	NS	•	NS
	CuSO,	2	6.3	6-2	6-5	7-5	5:4	Linear	ļ		•	SN
Rrown	CnO	5.1	5.1	5.2	5-S	4.5	4.7	Ouadratic	1	I	•	-
	CuSO,	1	5:2	5.5	6.5	4·S	4.7	,		SIEM O	·46	
	1			J	Dviduct wt						2	
White	CnO	34.8	38-0	29-8	39-4	42-5	27-8	Over-all	:	NS	***	NS
	CuSO,	2	48.7	39-4	32.2	36-5	6.6	Linear	1	ļ	:	•
Rrown	CuO	31.2	35-2	33-0	31-0	26-3	32.6	Ouadratic	1	1	SN	SN
	CuSO	4 17	24-9	23.6	32-4	30-7	16-8	,		SEM 4	59	2
				-	Ovary wt							

Table 3. The fresh weights (g/kg body-weight) of liver, kidneys, oviduct, ovary and gizzard of laying hens given control and

NS, non-significant.
P < 0.05, ** P < 0.01, *** P < 0.001.

https://doi.org/10.1079/BJN19810082 Published online by Cambridge University Press

Effects of dietary CuO in the laying hen

SZSZ

: S.

1 | |

SII

Quadratic

216 5.8 19.8 10-5

294 147 268 268

13 23 28 6 2 23 25 6 2 5 0 5 6

28-7 23-3

White

Brown

308 20-9 22-9 25-2 25-2 25-2 13-8 11-8 11-8 11-8 11-6

Over-all Linear SEM 4-02

• : : 2

:: 2

1 | |

• | |

Over-all Linear Quadratic

156 130 130

13.4 18.6 12.0

14-9 15-1 12-7 16-8

13:3 13:3 13:1

Brown

13-8 16-1

White

SEM 1-32

. The concentration and total copper in liver, egg Cu concentration, serum Cu levels and liver lipid concentrations of laying hens given	control and copper-supplemented diets for 48 weeks
5 4. TI	
Tablé	

0	
f.	1
	1
5	
2	-
	- 1
55	- 1
Ξ.	- 1
3	7
•	
8	1
Ξ.	į.
2	4
ົ	4
2	
	1
۲.	_ !
5	- 1
5	-
5	
2	4
5	1
5.	
5	-
5	
5	
	_
3	1
5	2
3	ς
-	
5	
5	

104				N	I.	J	١C	ĸ	sc)N	Á	N	D	N	Í A	R	Y	ŀ	I.	S	ГЕ	V	EN	15	10	V									
		Cu level ×	form of Cu		***	:	SN						444		NIC	CV.						NS	NS	NS			***	SN	NS			SN	SN	SN	
	e of effect	อี้	level		***	***	NS					·0831			NIC					0757		*	*	SN	6.4		*	•	•	164		:	NS	NS	3.4
	Significanc	Form of	Cu		***						I	SEM 0	***		1	l				SEM ()		•			SEM 2		•	l	١	SEM 0-		:	1	ł	SEM 4
			Breed		•	I	I						4	•)							NS	I	ł		•	SN	I	I			*	ł	I	
vations)		. "	Response		Over-all	Linear	Quadratic	,					1 C	Uver-all	Cuedantia Oredantia	Quadratic						Over-all	Linear	Quadratic			Over-all	Linear	Quadratic			Over-all	Linear	Quadratic	
of four obser		- - - -	750		14-8	(I·171)	373-3	(2·572)	14.3	(1·154)	153-9	(2·187)	155	(101-0) (101-0)	(761.7)	(212.2)	(cic.c)	4 1 2 1 2 1 2 1 2	1012	(3-005)		310	265	325	285		3.20	3.15	3-31	2.62		198	601	167	Ξ
are the means			600	DM)†	12.5	(1-097)	81.6	(116-1)	11.3	· (1·052)	30.7	(1-487)	150	001	(011.7)	(150.C)	(164.7)	142	(7C1.7)	(2.430)		370	330	373	317	DM)	3·32	3·33	2-94	3-35	(hia 1	255	257	284	167
(Values	in diat (malba	94/9ml mm m	450	ntration (µg/g	13-9	(1·142)	60.7	(1·783)	16.1	(1·206)	39-0	(1-590)		871	(201.7)		(140.7)	138	(CC1-7)	(2.485)	um Cu (µg/l)	333	288	310	335	itration (µg/g	3.25	2-98	4-49	3-17	entration (g/kg	250	162	131	117
	Added Cu		300	iver Cu conce	12·2	(1-085)	31.6	(1-499)	11.0	(1.041)	30-0	(1-477) Totol li:		142 (0,157)	(201.2)	107	(100+.7)	951 (011/0	010	(2.379)	Blood ser	293	305	373	350	Egg Cu concer	3·28	3·31	3.41	3.30	iver lipid conc	168	143	248	151
			150		9-8	(166-0)	16-2	(1.211)	13-9	(1·142)	14-2	(I·153)	146	(14)	(201.2)	(080.0)	(200.7)		(261-2)	(2·122)		370	367	375	328		3·13	3-36	3-19	3.46	E	388	208	167	203
			0			12-1	(1-082)	,		16.0	(1·203)				151.0	(761.7)		<u> </u>	(121) (121)			202	200	305			3.41		3.10	2		256		113	
	Ē	-HOO	punod		CuO		CuSO ₄		CuO		CuSO ₄		Ċ	CIIC	Co.C	CubCa		CEO	CuSO.			CuO	CuSO ₄	Cn0	CuSO ₄		CnO	CuSO,	CuO	CuSO ₄		CuO	CuSO,	CuO	CuSO,
		1	Breed			White				Brown				White				Brown				White		Brown			White		Brown			White		Brown	

NS, non-significant. • P < 0.05, ** P < 0.01, *** P < 0.001. † Analysis of variance carried out using log transformation. The mean values presented are the antilogs of the means of the log transformations. The values in parentheses are the means of the log values.

There was no evidence of any effect of the CuO on food conversion efficiency while for CuSO₄ addition there was a quadratic relationship (P < 0.01), the maximum food conversion occurring at 178 mg added Cu/kg diet.

The mean initial and final body-weights, mean body-weights, daily ME intakes and daily crude protein intakes are shown in Table 2.

The mean initial weights of the white and brown birds were 1.44 and 1.98 kg respectively. Although dietary treatment depressed final body-weight (P < 0.001) no specific effect was noted due to added CuO in the diet. The added CuSO₄ showed a linear relationship (P < 0.01) with final body-weight. The mean final body-weights for the white and brown birds were 1.60 and 2.05 kg respectively. The addition of the two highest levels of CuSO₄ caused a marked fall in body-weight between treatment periods 4 and 10 which is reflected in the mean body-weights.

The fresh weights of liver, kidneys, oviduct, ovary and gizzard/kg body-weight are given in Table 3.

The CuO had no significant effect on liver fresh weight or kidney weight per unit body-weight. The negative linear relationship of liver fresh weight to additive (P < 0.05) was obviously mainly due to the quadratic response to CuSO₄ (P < 0.05) and was more pronounced in the white than in the brown birds. The former had the greater liver mass per unit body-weight (P < 0.001). The over-all effect of additive on kidney fresh weight per unit body-weight was quadratic (P < 0.05) and this effect was also due to the quadratic response to CuSO₄ (P < 0.05).

The CuO had no statistically significant effect on the oviduct, ovary or gizzard weights. The additive effect on oviduct weight was linear (P < 0.001) the CuSO₄-fed hens showing a very marked oviduct weight depression at the highest level of addition. This effect was also seen in the ovary the over-all relationship being quadratic (P < 0.05). Gizzard weight per unit body-weight was increased linearly by the CuSO₄ (P < 0.001).

The Cu analytical values are presented in Table 4 together with the liver lipid concentrations. CuO had no significant effect on either liver Cu concentration or content but the CuSO₄ had a very dramatic positive linear effect (P < 0.001) on both these factors in both breeds.

Over-all, a negative linear relationship was found between the additive and blood serum Cu (P < 0.05), the respective mean values of the oxide- and sulphate-fed birds being 343 and 317 μ g/l. The effect of the additive on egg Cu concentration is not readily evident although the relationship was quadratic (P < 0.05).

The liver lipid concentration was affected by level of additive (P < 0.01). The CuO had no effect but in the instance of the sulphate it was depressed at the 750 mg Cu/kg level of addition.

Tables 5 and 6 contain the proportions of certain fatty acids present in the triglycerides of the liver and body fat respectively. The 14:0 and 16:0 fatty acids show a linear decrease with additive level (P < 0.01 and P < 0.001 respectively) while the 18:0, 18:3 and 20:4 fatty acids increased (P < 0.05, P < 0.05 and P < 0.01 respectively). In the instance of the 18:2 fatty acid a quadratic response (P < 0.05) was found, the levels of the additive corresponding to 450 and 600 mg Cu/kg diet resulting in the two lowest proportions of this acid. The over-all effect of additive on the 18:1 fatty acid was significant (P < 0.01).

In the body fat the 18:0 and 18:1 fatty acids showed a positive linear response to the additives (P < 0.01) while the 16:0 fatty acid showed a positive quadratic response and the 18:2 fatty acid showed a negative quadratic response (both P < 0.05). The 20:4 fatty acid in the body fat was unaffected by additive but was significantly lower in the white than in the brown birds (P < 0.01).

48	
for	
ets j	
l di	
ntec	
me	
ple	
-sul	
per	
cop	
and	ons)
rol	vati
onti	bsei
u c	ur o
give	of fo
ens	ans
f h	eme
er c	e th
liv	s an
the	alue
'n	S
icids	
ty c	
fat	
of	
ions	
ort	
rop	
he f	
E.	
e 5	
abl	
Ļ	

	ć			C habb	and the state of the					Significance	of effect	2 	
					n in dict (mg/k	6		I		Form of	ā	Cu level x	
Breed	punod	0	150	300	450	009	750	Response	Breed	Cn Ci	level	form of Cu	
	:			ł	14:0								
W.L.t.	CnO	2.276	0-407	0-345	0-305	0-276	0-262	Over-all	•	•	•	SN	
	CuSO,	C7C-N	0-263	0-255	0-353	0-273	0.160	Linear	1	1	#	SN	
	CnO	0100	0-289	0-345	0-174	0-275	0-285	Quadratic	1	1	SN	SN	
DEOWI	CuSO,	0.172	0-283	0-302	0-171	0-239	0.184	,		SEM 0.0	J481		-
	ç		2.26	1.30	16:0 34.1	13.5	3.40	10 C	NIC	NIC	***	NG	
White		26.3	9.97 0.07	- 07 - 9C	24.1	2.52	C.42	Uvci-all				SN SN	
I		• • •	25.5	207 28:3	5.5 2.5 2	7.4 0	8.40	Onadratic			NZ Z		
Brown	CuSO.	25.2	24.3	22.5	240	24-1	22.2			SEM 1	-0-	2	_
	•		•	l	18:0	1							
White	CuO	16.7	13-9	17-5	18-1	16-0	18-6	Over-all	NS	:	:	SN	
ALLE	CuSO,	1.01	17-6	17-2	19-4	16.6	24.5	Linear	I	1	•	SN	_
Decount	Cuo	10.4	15.6	16-5	20-3	14.5	15-0	Quadratic	I		NS	*	
TMOIO	CuSO,	-	17-2	20-2	20-5	16-8	24-5			SEM 2-	98		
					18:1								
White	CuO	40.7	45-4	35-0	42.5	44-9 0	33-8	Over-all	SN	•	:	NS	
	CuSO,	Â	34.4	36.1	38-3	43.5	25-7	Linear	1	1	SN	SN	
Rrown	CnO	21.8	37-8	37-5	30-2	43-6	38-5	Quadratic	1	I	SN	SN	
	CuSO ₄		36.9	31.7	31-0	39-4	27-3			SEM 3-	80		
					18:2								
White	CuO	10.5	8.6	12-3	9.6	9.8	14-0	Over-all	NS	SN	•	SN	
	CuSO		12.9	11.0	8-3	6.4	14-3	Linear	I	I	SN	SN	
Rrown	Cro	14.7	11-6	10-5	13.8	9 .4	12-9	Quadratic	ļ		*	SN	
	CuSO,		12-0	12-4	10-6	9.6	10-8			SEM 1.	74		
	ç		0.000	202.0	18:3 0.724	0.333	0.110		JI.	-	e	NIC	
White		0·178	0.219	146-0	167.0	676-0 0-448	0.800	Uver-au Linear	2	. 1	•	s v	
	CnO	0110	0.289	0.192	0-431	0-191	0.273	Ouadratic	1	I	SN	NS	
DIUWII	CuSO,	0.110	0-386	0-481	0.515	0-327	0-668	,		SEM 0.14	456		
	c c		0		20:4	t		=	•	•		9	
White		3.5	0 4 7	4 v - v	ų v v	7.7	0 0 0 0	Uver-all I inear	:		:	n v Z	
		Ċ	5.4	4 0 4	6.6	- 		Ouadratic	I	1	SN	SN	
Brown	CuSO,	ŕ.	5.8	6.9	10-4	6.5	12.1			sew 1.	57	-	

106

weeks

NS, non-significant. * P < 0.05, ** P < 0.01, *** P < 0.001.

ł

The proportions of fatty acids in the body-fat of hens given copper-supplemented diets for 48 weeks	(Values are the means of four observations)
The pro	
Table 6.	

	ć			C Popp	the first for the					Significanc	e of effect	
					n in uici (ing/kg					Eorm of	5	Cu level v
Breed	punod	0	150	300	450	600	750	Response	Breed	Cr.	level	form of Cu
					16:0							
White	OnO CuO	1.10	20-5	21-3	21.2	21-7	20-2	Over-all	* .	:	:	•
31114	CuSO,	1.17	22-3	22·1	26.6	25-9	24.8	Linear	1	1	:	:
Regime	CnO	20.1	20-8	20-5	19-5	22·1	20-7	Quadratic	I	I	•	NS
	CuSO.	1 07	19.8	23·1	23.6	23-2	24-2			SEM (-94	
					18:0							
White	0n0	5.4	4 ·S	6.2	5.8	6.2	8:3	Over-all	SN	#	*	SN
	CuSO	•	5.7	7.6	9.3	9.6	6-6	Linear	ŀ	1	:	SN
Rrown	On O	6 .3	5:3	8.3	7-8	5-7	6-5	Quadratic	1	I	SN	SN
TMOTO	CuSO	2	6-3	8.7	6.8 8	7-0	9.3			SEM 1	·16	
					18:1							
White	0 NO	42.3	45-0	42-3	44-0	42-7	42-7	Over-all	NS	***	•	NS
2011	CuSO,		41.7	47·1	44.6	47-8	47-9	Linear	1	I	:	•
Brown	0n0	46.1	42-8	42-9	4 -8 8-14	44-6	45-5	Quadratic	ļ	1	SN	SN
	CuSO,	-	46.3	41.3	47.8	49-6	47-8			SEM]	49	
					18:2							
White	Cno	23-2	21.5	23.0	21.6	23·1	21-5	Over-all	SN	*	:	
	Cuso	1	23·1	15.9	11:2	9-7	10-3	Linear	1	1	**	÷
Rrown	On O	4.10	23-8	21.5	23·1	19-1	20-0	Quadratic	1	1	•	:
	CuSO,	1	20-8	18.8	12.8	12·2	9.4			SEM 1	99	
	Ċ		0-072	0-217	20:4 0.114	0.151	0.030	Over-all	:	SN .	SN	N
White		0-059	0.100		0.00	0.251	0.213	l inear	. I	2		S Z
,			114	0-252	0-337	60-0	0-193	Oundratic	1	ļ	Z	SZ
Brown	Cuso,	0-171	0.209	0-738	0-432	0-252	0-236			SEM O.	1082	2

Effects of dietary CuO in the laying hen

NS, non-significant • P < 0.05, *• P < 0.01, *•• P < 0.001.

DISCUSSION AND CONCLUSIONS

The mortality results suggest that the white birds were more susceptible than the brown birds to the toxic effects of the added $CuSO_4$.

The lack of effect on food intake resulting from the CuO addition is in contrast to the depression caused by the CuSO₄; an effect which is already well documented (Jackson, 1977; Jackson *et al.* 1979; Stevenson & Jackson, 1980*a*, *b*).

With regard to egg numbers, mean egg weight and total egg weight, again the lack of response to CuO contrasted to the effects of the $CuSO_4$. The occurrence of an increase in egg numbers and total egg weight at lower values (maximum 257.5 eggs at 75 mg added Cu/kg diet) and the severe depression observed at the higher levels of $CuSO_4$ agrees with the observations of Jackson (1977), Jackson *et al.* (1979), and Stevenson & Jackson (1980*a*, *b*). The depressing effect of $CuSO_4$ on mean period mean egg weight is in accord with the results of Thomas *et al.* (1974) and Jackson *et al.* (1979).

The lack of response of food conversion efficiency to the CuO may be at variance with the results of Mehring *et.al.* (1960) who reported an increased efficiency of food conversion in broilers fed a copper oxide at levels below 600 mg Cu/kg diet. However, it is not clear if the oxide used by these authors was the divalent oxide. Guenthner *et al.* (1978) added cuprous oxide to the diets of turkey poults and found at fairly low levels (up to 240 mg Cu/kg diet) that an improved food conversion ratio occurred up to 15 weeks of age. The quadratic effect of CuSO₄ on food conversion efficiency agrees with the results of Jackson *et al.* (1979) in the laying hen and Fisher *et al.* (1971) in the broiler.

The contrasting effects of CuO and CuSO₄ on body-weight and egg production appear to be mainly due to the fact that the CuSO₄ caused a severe depression of food intake above 300 mg added Cu/kg diet. The depression of mean period mean egg weight is a factor in total egg weight reduction and may result from the effect of CuSO₄ on lipid synthesis. The effect of depression of intake is clearly demonstrated when the values for ME and crude protein intake (Table 2) are compared with the Agricultural Research Council (1975) requirements for maintenance and production. The existing results do not indicate whether the effects on production are merely due to the reduced intakes and a direct effect on lipid synthesis or whether there is another effect, for example, on the hormonal systems involved. However, results of paired-feeding experiments with broilers (Fisher *et al.* 1971) show that reduced growth was due to lower intakes resulting from CuSO₄ addition.

The depressing effect of $CuSO_4$ on liver weight (Table 3) in the domestic fowl has been observed previously (Jackson, 1977; Jackson *et al.* 1979; Stevenson & Jackson 1980*a*, *b*). The lack of a coincidental response in kidney weight is surprising but agrees with the results of other experiments reported previously.

Of the eighty-eight birds examined, twelve were not laying in the week before slaughter. Only one of these was on the CuO treatment while seven were in the groups receiving the two highest levels of CuSO₄. The lack of effect of CuO on the oviduct and ovary was to be expected in view of the lack of effect on egg production. The oviduct regression at the highest level of CuSO₄ addition agrees with previous observations (Jackson, 1977; Jackson *et al.* 1979; Stevenson & Jackson, 1980*a*, *b*). The low ovary weights for the brown birds given CuSO₄ equivalent to 300 and 750 mg added Cu/kg diet indicate that some of these birds were going out of lay, oviduct regression being less advanced than ovarian regression.

The lack of effect of CuO on gizzard weight is presumably due to the fact that the oxide is virtually insoluble in the pH range (2.0-3.5) in the gizzard (Sturkie, 1976). The gizzard weight increase in the presence of the CuSO₄ has previously been noted (Jackson *et al.* 1979; Stevenson & Jackson 1980*a*, *b*) and may be attributed to effects resulting from the high solubility of the salt at the pH of the gizzard. Associated pathological effects have been noted in broilers (Fisher *et al.* 1973), in chicks (Poupoulis & Jensen, 1976) and in laying hens (Stevenson & Jackson, 1980*a*, *b*).

It seems apparent that the failure of CuO to affect liver Cu concentration is related to its lack of solubility even under the wide ranges of pH encountered in the digestive tract (Sturkie, 1976). Although the liver Cu concentration values (Table 4) suggest some increases at the lower levels of CuSO₄ addition the results support the findings of previous work that a threshold exists in the region of 250–600 mg added Cu as CuSO₄/kg diet above which liver Cu concentration rises sharply (Jackson *et al.* 1979; Stevenson & Jackson, 1980*a*). A similar phenomenon has been reported for other species (Milne & Weswig, 1968; Ritchie *et al.* 1963).

The blood serum Cu levels showed considerable variation and although the over-all additive response was linear it is difficult to ascribe specific effects to the additives. Previous experiments have also led to rather similar inconclusive effects (Jackson, 1977; Jackson *et al.* 1979; Stevenson & Jackson, 1980*a*). Difficulty also prevails in passing comment on the quadratic response of egg Cu concentration to additive. Thomas *et al.* (1974) and Griminger (1977) did not find any significant effect of dietary CuSO₄ on egg Cu concentration.

The lack of effect of CuO on liver lipid concentration is not surprising since the depression of the liver lipid is obviously related to effects on the oviduct, ovary and egg production. The decrease in liver lipid caused by high dietary $CuSO_4$ has been observed previously in this laboratory (Jackson *et al.* 1979; Stevenson & Jackson, 1980*a*, *b*). This is attributed to the fact that in the fowl the liver is the main site of fatty acid synthesis (Goodridge, 1968; O'Hea & Leveille, 1969) and of the lipids associated with oestrogen-induced lipidaemia (Ranney & Chaikoff, 1951).

In earlier studies on the pig (Elliott & Bowland, 1968; Christie & Moore, 1969) it was found that when Cu was added to the diet as $CuSO_4$ a softer back fat was found which was due to the presence of an increase in the 16:1 and 18:1 fatty acids. In the present experiment it is difficult to state whether the observed effects on lipid composition are direct effects mainly due to the dietary $CuSO_4$ or secondary effects due to reduced food intake.

The fact that the $CuSO_4$ was responsible for most of the effects observed in this experiment may be attributed to the solubility and availability differences between the predominantly insoluble CuO and the ionizable $CuSO_4$ under the conditions occurring in the digestive tract of the domestic fowl. A similar relationship between the solubility of these two salts has been reported by Willingham & Hill (1970). The fact that it is the Cu ion rather than the sulphate which causes a growth stimulus in the pig has been shown by Hawbaker *et al.* (1959). However, although the results of the present experiment show that dietary CuO has very little pharmacological activity in the laying hen it fails to demonstrate if the activity observed for CuSO₄ is due to the Cu or sulphate ion.

The authors thank Mrs R. Park, Mr G. McC. Kirkpatrick and Mr W. Graham for technical assistance, their colleagues in the Agricultural Biometrics Division for assistance with statistical analyses and the Trustees of the Agricultural Research Institute, Hillsborough, Co. Down for providing facilities for the laying experiment.

REFERENCES

Agricultural Research Council (1975). The Nutrient Requirements of Farm Livestock No. 1, Poultry. London: H.M. Stationery Office.

Braude, R. (1967). World Rev. Anim. Prod. 3, 69.

Christie, W. W. & Moore, J. H. (1969). Lipids 4, 345.

Elliott, J. I. & Bowland, J. P. (1968). J. Anim. Sci. 27, 956.

Elliott, J. I. & Bowland, J. P. (1972). Can. J. Anim. Sci. 52, 97.

Fisher, C., Laursen-Jones, A. P., Hill, K. J. & Hardy, W. S. (1973). Br. Poult. Sci. 14, 55.

Fisher, C., Wise, D. & Filmer, D. G. (1971). 14th Wld's Poult. Congr. Madrid p. 759.

Folch, J., Lees, J. & Sloane Stanley, C. H. (1957). J. biol. Chem. 226, 497.

Goodridge, A. F. (1968). Am. J. Physiol. 214, 897.

Griminger, P. (1977). Poult. Sci. 56, 359.

Guenthner, E., Carlson, C. W. & Emerick, R. J. (1978). Poult. Sci. 57, 1313.

Hawbaker, J. A., Speer, V. C., Jones, J. D., Hays, V. W. & Catron, D. V. (1959). J. Anim. Sci. 18, 1505 Abstr.

Husbands, D. R. (1972). Br. Poult. Sci. 13, 201.

Jackson, N. (1977). Br. J. Nutr. 38, 93.

Jackson, N., Stevenson, M. H. & Kirkpatrick, G. McC. (1979). Br. J. Nutr. 42, 253.

Mehring, A. L., Brumbaugh, J. H., Sutherland, A. J. & Titus, H. W. (1960). Poult. Sci. 39, 713.

Milne, D. H. & Weswig, P. H. (1968). J. Nutr. 95, 429.

O'Hea, E. K. & Leveille, G. A. (1969). Comp. Biochem. Physiol. 30, 149.

Poupoulis, C. & Jensen, L. S. (1976). Poult. Sci. 55, 113.

Ranney, R. E. & Chaikoff, I. C. (1951). Am. J. Physiol. 165, 600.

Ritchie, H. D., Luecke, R. W., Baltzer, B. V., Miller, E. R., Ullrey, D. E. & Hoefer, J. A. (1963). J. Nutr. 79, 117.

Stevenson, M. H. & Jackson, N. (1980a). Br. J. Nutr. 43, 205.

Stevenson, M. H. & Jackson, N. (1980b). Br. J. Nutr. 43, 551.

Sturkie, P. D. (ed.) (1976). In Avian Physiology, 3rd ed. p. 196-209. New York: Springer-Verlag.

Taylor, M. & Thomke, S. (1964). Nature, Lond. 201, 1246.

Thomas, M. C., Norvell, M. J., Calvert, C. C. & Goatcher, W. D. (1974). Poult. Sci. 53, 1984 Abstr.

Willingham, H. E. & Hill, C. H. (1970). Proc. Maryland Nutr. Conf. Fd Mfr. p. 32.

Printed in Great Britain