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OCCURRENCE AND CORRECTION OF COPPER DEFICIENCY OF SHEEP IN NORTH-WESTERN QUEENSLAND

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SUMMARY.

The occurrence and correction of copper deficiency in Merino sheep on an affected property in north-western Queensland were studied in three trials in successive years. The effects of copper supplementation on growth of weaner sheep, wool production, wool quality and reproductive performance were examined.

Pasture analyses showed that copper deficiency in sheep was due partly to the low copper and partly to the high molybdenum and inorganic sulphate levels in the predominant vegetation. Some herbage plants, which were abundant in autumn and winter after heavy summer rain, showed particularly high concentrations of molybdenum and inorganic sulphate.

The experimental sheep were 450 weaners approximately 10 months of age at the commencement of the 1953-54 trial. Different groups received 20 and 30 mg. Cu respectively as copper glycinate by subcutaneous injection at 6-monthly intervals, 200 mg. Cu as a copper sulphate drench at 6-monthly intervals, and 200 mg. Cu as a copper sulphate drench at monthly intervals.

Liver copper concentrations were unexpectedly high (mean 160 p.p.m. Cu) at the commencement of the trial. In the controls these levels decreased gradually but were low only during the last few months of this trial. Treatments at 6-monthly intervals maintained fairly satisfactory reserves. Depletion was greatest during autumn-winter, when herbage plants were abundant. Monthly treatments built up and maintained good liver copper reserves. In this trial copper treatments had no influence on body weight or wool growth.

During 1954-55 the experimental sheep were re-distributed into three groups—an untreated control, a group receiving 30 mg. Cu as copper glycinate subcutaneously (in September and December) and a group receiving 280 mg. Cu as copper sulphate drench (in September and December).

Ewes in each group were mated. Copper treatments had no influence on reproductive performance, birth weight, neo-natal mortality or growth rate to marking. All lambs had low liver copper reserves at 3–4 months of age irrespective of the copper status in their dams.

Only the ewes from the drenched group, which consisted predominantly of sheep from the group drenched once a month in the previous trial and thus had good liver copper reserves, showed a marked response in wool production. These ewes produced about 0.5 lb. per head more greasy wool. There was a significantly higher incidence of copper deficiency lesions in fleeces from the untreated control group.

During 1955-56 the lambs born to ewes during the 1954-55 trial were divided into an untreated control group and a group drenched with copper sulphate on two occasions at a month's interval (140 mg. Cu in September, 210 mg. Cu in October) and on a third occasion after five months (280 mg. Cu in March). Copper supplementation did not influence weight gains or wool production, but there was a high incidence of copper deficiency lesions in fleeces from the untreated group.

From these studies recommended treatments to prevent copper deficiency in sheep in this locality are (a) establish a good initial liver copper concentration by three treatments at fortnightly or monthly intervals and then maintain these reserves by 3-monthly treatments; and (b) treat lambs at marking and thereafter at about 3-monthly intervals.

I. INTRODUCTION.

Copper deficiency affecting sheep in Queensland was reported by Lee and Moule (1947), who recognised typical lesions in the wool of sheep that had low concentrations of copper in their blood and liver. Affected animals were located in the Cloncurry, Richmond and Hughenden districts in north-western Queensland.

Harvey (1952) defined three localities in Queensland that account for at least 90 per cent. of the affected wool produced in the State. In each of these localities confirmation was obtained by copper determinations on blood and/or liver. One is a large area around Cloncurry and extending east to Hughenden; the second is the south-easterly portion of the Darling Downs; and the third is a small area from Roma to Muckadilla.

A property situated in the Hughenden–Cloncurry area was selected for studies on copper supplementation of sheep. This property was chosen because it is within the most extensive of the affected areas, it had shown a high incidence of affected fleeces for several years irrespective of season, and it was considered that the smaller size and lower reproductive rate of sheep in this area might be due in part to copper deficiency.

In north-western Queensland, sheep are kept under extensive pastoral conditions (about one sheep to six acres), so topdressing of pastures would be a major undertaking. As shown by Harvey (1952), soils in this area are usually rich in copper, but this copper is not readily available to the predominant pasture plants. Thus only a limited response would be expected from topdressing. As internal parasites seldom affect sheep in this area, drenching with medicaments containing copper is rarely practised. Feed supplements or salt licks containing copper are expensive, difficult to distribute and not eaten readily by all sheep. Copper supplementation through drinking water cannot always be arranged conveniently. It is dependent on the carefully controlled treatment of the drinking water in concrete or proofed iron troughs; on many properties stock drink directly from bore drains, and on others the underground water contains salts that precipitate copper.

The investigations described here extended over three years and embraced the occurrence and correction of copper deficiency in sheep, with particular reference to the effect of copper supplementation on the growth of young sheep; the quality and quantity of wool produced; and the reproduction of adult sheep. Copper supplementation by oral administration of copper sulphate and by subcutaneous injection of copper glycinate (copper aminoacetate) was studied. The work was done in three field trials, which are reported separately.

II. MATERIALS AND METHODS.

(1) Experimental Paddock.

This covers approximately 4,000 acres of rather open undulating downs. The western portion (area A) is of brown soil and the pasture is predominantly *Astrebla* spp. (Mitchell grasses). The eastern portion (area C) is of grey soil and carries a considerable proportion of *Iseilema* spp. (Flinders grasses) as well as Mitchell grasses. A number of stony ridges (area B) lightly timbered with *Acacia cana* (boree) separate these two areas. In certain seasons there are wide varieties of herbage plants (forbs or non-gramineous plants), which predominate on the stony ridges. The locality is one of essentially summer rainfall, which results in an abundance of herbage plants from February to June in most years.

A flowing artesian bore supplies the drinking water, which is reticulated through an extensive bore-drain system.

This experimental paddock was used throughout Trials 1, 2 and 3. Experimental sheep were transferred to small holding paddocks for approximately three days each time body weights were recorded. In Trial 2, ewes were held in a small paddock from Feb. 16 to Mar. 29, 1955 while lambing observations were made.

(2) Soil.

Samples of soil from the experimental paddock were collected with a steel spade. The roots of pasture plants in this area are in the top 6 in., so soil samples were taken to a depth of 6 in. only. Samples were taken from area A and area C of the paddock. Both are clay soils of heavy texture. The stony ridges (area B) were not sampled.

(3) Pasture.

Samples were collected by hand, using stainless steel scissors, care being taken to avoid contamination. At each sampling an attempt was made to collect samples of each plant species that appeared to be abundant and eaten by sheep. All samples were identified by the Government Botanist prior to chemical analysis.

(4) Experimental Sheep.

These comprised 450 Merino weaners 8–10 months of age at the commencement of Trial 1. They were flock sheep born on a neighbouring property and brought to the experimental property for shearing one month before the trial began.

All animals were treated with the Mules operation and vaccinated against blackleg, tetanus and *Clostridium septicum* to minimise losses during the course of the experiment. Liver biopsies were made by the technique of Dick (1944, 1950). Samples were partially dried in an oven on the property before being air-freighted to the laboratory.

(5) Chemical Methods.

Copper was determined in soil, pasture, liver and blood by the method of Clare, Cunningham and Perrin (1945). Molybdenum was determined by the method of Dick and Bingley (1951). Inorganic sulphate was determined by a modification of the benzidene sulphate method of J. B. Bingley and A. T. Dick (personal communication 1953).

(6) Copper Treatments.

Copper was given orally as a 4 per cent. solution of copper sulphate in distilled water, using an automatic drenching gun.

Copper was injected subcutaneously with an automatic syringe as an aqueous solution of copper glycinate containing 2·5 mg. copper (Cu) per ml. The solution was injected in the inner aspect of the left thigh, a wool-free site; this permitted subsequent observation of any lesions produced.

On each occasion, copper treatments were not undertaken until the collection of all samples for chemical analysis had been completed.

(7) Body Weight.

Body weight of all experimental sheep was measured with a clock-face spring balance. On each occasion, animals were yarded for approximately the same time prior to weighing. All animals were weighed before the liver biopsy and treatment.

(8) Wool.

All sheep were shorn prior to the commencement of Trial 1 and subsequently at intervals of approximately 12 months. Greasy fleece weight was recorded for each experimental sheep, and wool samples from each animal were sent to the laboratory for determination of clean fleece weight, fibre diameter, staple length, number of crimps per in., and the presence of lesions attributable to copper deficiency.

(9) Lambing.

Lambing observations were made in Trial 2, using the procedure described by Moule (1954). All experimental ewes were transferred to a small paddock on Feb. 16, 1955 and lambed under surveillance. Data recorded were number of ewes lambed and lambs born, birthweight of lambs, number of deaths and weight gain to marking. On Mar. 29, 1955, all surviving ewes and lambs were returned to the experimental paddock.

III. TRIAL 1 (1953-54).

(1) Experimental.

The 450 experimental weaners were distributed at random into five groups of 90 sheep. The procedure was to run all sheep through a race. Distinguishing raddle marks were applied so that a sheep from the first five in the race was allotted to one of the five groups. This was repeated for each successive five sheep in the race. Sheep were individually identified with numbered ear-tags. As each group was weighed, every third sheep was drafted into a sub-group of 30 for liver biopsy. The aim was to obtain liver samples from 25 sheep in each group.

The groups were allotted at random to the treatments as follows:

Group 1. Untreated control.

Group 2. 20 mg. Cu as copper glycinate given subcutaneously at 6-monthly intervals (September 1953 and March 1954).

Group 3. 30 mg. Cu as copper glycinate given subcutaneously at 6-monthly intervals (September 1953 and March 1954).

Group 4. 200 mg. Cu as copper sulphate given orally at 6-monthly intervals (September 1953 and March 1954).

Group 5. 200 mg. Cu as copper sulphate given orally once a month from September 1953 to June 1954 inclusive.

The trial commenced in September 1953 and finished in September 1954. All sheep were weighed in September and thereafter at 3-monthly intervals. Liver biopsy samples were taken every three months from approximately the same 25 sheep in each group.

The sheep were shorn in July 1953 and again in June 1954, approximately nine months after the commencement of the trial.

Pasture samples for chemical analysis were taken from the experimental paddock in September 1953 and thereafter at 3-monthly intervals. Soil samples from this paddock were taken in September 1953 and September 1954.

(2) Results.

The 1953-54 season was particularly favourable for pasture growth, with unusually heavy rain for this locality in February and March (Table 1). This resulted in abundance of herbage plants from February to June. Fig. 1 shows the ample pasture available to sheep in the experimental paddock in March 1954.

Fig. 1.

Photograph Showing the Abundance of Grass and Other Herbage Plants in the Experimental Paddock in March 1954.

Table 1.

RAINFALL RECORDED ON EXPERIMENTAL PROPERTY (INCHES).

Month.	1952.	1953.	1954.	1955.	1956.
January	1·34	4·79	4·66	7·36	5·92
February	·09	12·03	12·25	11·61	5·57
March	·31	·00	11·93	4·46	1·73
April	·10	·00	1·63	2·14	3·58
May	·30	·00	·00	6·41	1·48
June	·00	·00	·45	·41	1·15
July	·00	·00	·00	·00	·66
August	·00	·89	·00	·00	·00
September	·44	·00	·00	·00	·00
October	·17	·00	1·54	·00	·15
November	·71	·14	2·12	·28	·65
December	2·09	·92	1·80	1·97	7·37
Total	5·57	18·77	36·38	34·64	28·26

Sept. 1952—Birth of experimental sheep.
July 1953—Pre-experimental shearing.
Sept. 1953—Commencement of Trial 1.
Sept. 1954—End of Trial 1 and commencement of Trial 2.
Sept./Oct. 1954—Ewes mated.
Feb./Mar. 1955—Lambing observations.
June 1955—End of Trial 2 and commencement of Trial 3.
June 1956—End of Trial 3.

Chemical analyses of soils are shown in Table 2. The brown soil from area A is alkaline; it has a high level of total copper and molybdenum, and is low in nitrogen and rich in available phosphate. The grey soil from area C

Table 2.

PARTIAL CHEMICAL ANALYSIS OF THE TWO MAJOR SOIL TYPES IN EXPERIMENTAL PADDOCK.
(Expressed on dry-matter basis.)

Location.	Date Sampled.	Copper (p.p.m. Cu).	Molybdenum (p.p.m. Mo).	pH.	Nitrogen (%)	Available Phosphate (p.p.m. P_2O_5).
Area A* ..	September, 1953	75	..	8·0	0·07	580
Area A ..	September, 1954	78	31	..	..	..
Area C† ..	September, 1953	32	..	7·4	0·04	400
Area C ..	September, 1954	32	7	..	..	..

* Brown clay soil of heavy texture.
† Grey clay soil of heavy texture.

is only slightly alkaline; the total copper and molybdenum levels are appreciable but lower than in area A; the nitrogen content is low and the available phosphate content is high.

PARTIAL CHEMICAL ANALYSIS OF THE PREDOMINANT VEGETATION IN EACH SECTION OF THE EXPERIMENTAL PADDOCK.

Area.	Plant.	Sept., 1953.	Dec., 1953.	March, 1954.		June, 1954.			Sept., 1954.			June, 1955.		
		Cu.	Cu.	Cu.	Mo.	Cu.	Mo.	SO_4.	Cu.	Mo.	SO_4.	Cu.	Mo.	SO_4.
		p.p.m.	p.p.m.	p.p.m.	p.p.m.	p.p.m.	p.p.m.	%	p.p.m.	p.p.m.	%	p.p.m.	p.p.m.	%
A	*Astrebla* sp.	3·9	1·8	2·1	6·2	3·4	3·2	0·7	1·7	11·6	0·7	2·8	7·2	0·4
	Iseilema sp.	..	..	..	..	..	..	..	..	..	..	3·4	8·7	0·5
	Eriochloa sp.	..	..	..	..	4·3	7·7	1·7	..	..	..	..	..	..
	Digitaria ctenatha	..	..	3·3	2·6	..	..	..	..	..	..	..	..	..
	Sesbania aculeata	..	..	7·5	8·0	..	..	..	..	..	..	10·2	34·2	1·0
	Cucumis tregonis	..	..	9·0	3·5	8·2	2·0	0·5	..	..	..	..	..	..
	Citrullus colocynthis	..	..	8·1	4·8	..	..	..	..	..	..	..	..	..
	Operculina turpethum	..	..	6·1	4·6	..	..	..	..	..	..	..	..	..
	Flaveria australasica	..	..	6·1	19·0	..	..	..	..	..	..	..	..	..
	Ipomoea turpethum	..	..	..	..	8·5	2·1	0·01	..	..	..	..	..	..
	Pterigeron adscendens	..	..	..	..	..	..	..	5·8	15·1	1·7	..	..	..
	Hibiscus ficulneus	..	..	5·9	6·4	..	..	..	..	..	..	..	..	..
	Glycine tomentosa	..	..	..	..	..	..	..	..	..	..	7·9	30·0	0·4
	Rhynchosia minima	..	..	..	..	..	..	..	..	..	..	4·1	18·2	0·3
B	*Astrebla* sp.	..	..	..	..	..	..	..	..	..	..	3·2	6·2	0·4
	Iseilema sp.	..	..	2·4	2·9	3·8	3·6	0·2	3·3	4·4	0·5	2·7	2·5	0·6
	Chloris sp.	..	..	4·5	10·0	3·9	2·0	0·05	..	..	..	..	..	..
	Dactyloctenium radulans	..	..	3·9	3·5	..	..	..	..	..	..	..	..	..
	Acacia farnesiana (pods)	..	4·3	..	..	..	..	..	..	..	..	..	..	..
	Acacia farnesiana (leaves)	..	..	..	..	5·3	1·9	0·01	..	..	..	..	..	..
C	*Astrebla* sp.	..	..	..	..	3·3	3·9	0·5	1·7	3·5	0·5	3·2	2·3	0·2
	Iseilema sp.	6·0	..	1·7	2·2	3·3	4·2	0·4	2·3	4·5	0·3	4·5	1·9	0·2
	Boerhavia diffusa	..	..	3·9	2·9	..	..	..	..	..	..	..	..	..
	Sida acuta	..	..	..	..	..	..	..	..	..	..	5·8	2·9	0·4
	Sida fibulifera	..	..	..	..	..	..	..	..	..	..	15·2	3·4	..
	Morgania glabra	..	..	..	..	..	..	..	..	..	..	10·2	5·5	0·9

Concentrations of Cu, Mo and inorganic sulphate are expressed on a dry-matter basis.

The brown soil (area A) carried predominantly Mitchell grasses; a great variety of herbage was present at the March and June 1954 samplings. The stony ridge (area B) carried little pasture in September and December 1953; there was a considerable amount of *Acacia farnesiana* (prickly bush), the pods of which were eaten avidly in December 1953 and the leaves more particularly in June 1954; Flinders grasses, *Chloris* sp. (a star grass) and *Dactyloctenium radulans* (button grass) were present in March 1954, with Flinders grasses predominating. The grey soil (area C) carried mainly Flinders and Mitchell grasses, with some herbage plants in autumn-winter.

Copper, molybdenum and inorganic sulphate levels in the predominant vegetation in each section of the experimental paddock are shown in Table 3. The copper content was particularly low in the grasses (2–4 p.p.m. Cu D.M.), whereas the herbage plants contained 6–15 p.p.m. Cu D.M. The molybdenum levels were appreciable, being particularly high in some herbage plants from area A. Most plants showed a high concentration of inorganic sulphate.

The mean concentrations of copper in the livers of animals from each group, taken at 3-monthly intervals, are shown in Table 4.

Table 4.

MEAN COPPER CONCENTRATION IN LIVERS OF SHEEP IN TRIAL 1.
(Cu p.p.m. dry-matter.)

Group.	Sept., 1953.	Dec., 1953.	March, 1954.	June, 1954.	Sept., 1954.
1 ..	156 (8)*	115 (29)	63 (60)	21 (100)	22 (100)
2 ..	158 (4)†	266 (0)	123 (20)†	99 (28)	55 (74)
3 ..	172 (12)†	301 (0)	142 (20)†	133 (24)	77 (70)
4 ..	151 (8)†	205 (0)	118 (41)†	112 (11)	49 (77)
5 ..	164 (8)†††	345 (0)†††	315 (0)†††	275 (0)†	238 (8)

* Figures in brackets show percentage of sheep with liver copper concentrations less than 80 p.p.m.
† Indicates treatment with copper, immediately after this liver biopsy.
††† Indicates three treatments with copper at monthly intervals.

The liver copper reserves were unexpectedly high at the commencement of the trial, the mean being 166 p.p.m. Cu, with 8 per cent. of the sheep showing less than 80 p.p.m. Cu and 24 per cent. showing more than 200 p.p.m. Cu.

The untreated Group 1 showed a progressive fall in liver copper concentration. In March 1954, six months after the commencement of the trial, the mean level was 63 p.p.m. Cu, with 60 per cent. of the sheep showing less than 80 p.p.m. Cu. In June 1954, the mean level was 21 p.p.m. Cu and all animals had less than 80 p.p.m. Cu. This low level was maintained in September 1954.

Group 2, which received 20 mg. Cu subcutaneously in September 1953 and March 1954, showed a marked increase in liver copper concentration in December 1953. In March 1954 the liver copper status was below that recorded at the initial sampling six months previously. In June 1954, the liver copper levels were lower than those found in March in spite of re-treatment after the March biopsy. There was a further depletion by September.

Group 3, which received 30 mg. Cu subcutaneously in September 1953 and March 1954, showed changes in liver copper storage similar to Group 2, although the reserves were greater due to the higher dose rate.

Group 4, which received 200 mg. Cu orally in September 1953 and March 1954, showed liver copper levels comparable with those of Group 2.

Group 5, which received 200 mg. Cu orally at monthly intervals, was the only group that maintained adequate liver copper reserves throughout the 12 months.

During this trial 10 sheep were accidentally killed during liver biopsy. The opportunity was thus presented to compare analyses on liver biopsy samples with analyses on larger representative samples taken from these livers at autopsy. For liver copper concentrations ranging from 10 to 400 p.p.m., the experimental error on the biopsy sample was about ± 11 per cent. of the true value.

The mean body weights for ewes and wethers in each group, recorded at 3-monthly intervals, are presented in Table 5. There were no differences between groups.

Table 5.

MEAN BODY WEIGHTS OF SHEEP IN TRIAL 1.

Group.	Type.	Sept., 1953.	Dec., 1953.	Mar., 1954.	June, 1954.	Sept., 1954.
		lb.	lb.	lb.	lb.	lb.
1	Ewes ..	48·8	52·9	64·5	75·8	80·3
2	Ewes ..	47·1	49·6	63·5	74·7	79·0
3	Ewes ..	43·6	49·5	61·7	73·0	78·1
4	Ewes ..	43·8	50·0	63·1	75·4	79·4
5	Ewes ..	47·6	54·3	65·7	78·2	81·7
1	Wethers ..	52·8	57·9	70·5	83·0	89·4
2	Wethers ..	51·8	54·8	69·9	81·5	88·6
3	Wethers ..	49·2	55·7	68·5	81·3	87·2
4	Wethers ..	45·6	51·9	67·0	81·3	87·2
5	Wethers ..	50·6	55·9	68·9	83·1	91·1

The mean greasy and clean-scoured fleece weights for ewes and wethers in each group are shown in Table 6. There were no significant differences between groups in greasy or clean wool production or in wool quality.

Table 6.

MEAN GREASY AND CLEAN SCOURED FLEECE WEIGHTS OF SHEEP IN TRIAL 1.

Group.	Type.	Mean Greasy Fleece Weight.	Mean Clean Scoured Fleece Weight.
		lb.	lb.
1	Ewes	6·09	3·37
2	Ewes	6·09	3·40
3	Ewes	5·94	3·25
4	Ewes	6·01	3·21
5	Ewes	6·25	3·47
1	Wethers	6·68	3·77
2	Wethers	6·75	3·66
3	Wethers	6·22	3·41
4	Wethers	6·22	3·39
5	Wethers	6·52	3·52

At the conclusion of the trial in September 1954, the body weights of sheep that had been biopsied on four occasions were compared with those of un-biopsied sheep. There were no significant differences, indicating that repeated liver biopsy had no effect on weight gain.

(3) Discussion.

The level of copper is particularly low in the grasses in spite of adequate total copper in soils. This is evident even in area A, where the total copper in soil is high. It would appear that copper in soils in this locality is largely unavailable to the predominant pasture species. As might be expected in alkaline soils, the availability of molybdenum to pasture is high. This is evident particularly in area A, where the molybdenum concentration in soil is high.

From pasture analyses it appears that copper deficiency in sheep in this locality is due partly to the low copper content of the grasses and partly to inhibition of copper metabolism in sheep by molybdenum in the presence of inorganic sulphate as shown by Dick (1952, 1953, 1954). Some herbage species contain up to 34 p.p.m. Mo, which is comparable with levels recorded in the teart pastures of Somerset (Ferguson, Lewis and Watson 1938, 1940). As the molybdenum levels are particularly high in herbage plants, it might be expected that interferences with copper metabolism would be most marked from March to June, when these plants are present in abundance and readily eaten by sheep.

The data on liver copper concentrations support the conclusion that the period of greatest depletion of copper reserves in the animals was from March to June, when herbage plants were abundant. Six-monthly treatment, either orally or subcutaneously at the dose rates used, did not maintain adequate liver copper concentrations. Group 3, receiving 30 mg. Cu as copper glycinate subcutaneously, maintained liver copper reserves slightly better than Group 4, receiving 200 mg. Cu as copper sulphate orally at 6-monthly intervals. The findings of Sutherland, Moule and Harvey (1955) indicate that 30 mg. Cu as copper glycinate subcutaneously and 200 mg. Cu as copper sulphate orally are about the maximum safe doses for sheep of this age.

The unexpectedly high liver copper reserves in sheep at the commencement of the trial may be related to the previous history of the animals. They were born on a neighbouring property during the 1952-53 drought and were brought to the experimental property only in July 1953. In the untreated group it was not until March 1954 that a majority of sheep showed levels in liver below 80 p.p.m. Cu. It was only in June 1954 that all sheep examined in this group showed a low copper status. This was reflected in the absence of lesions of copper deficiency in fleeces examined at shearing in June 1954. On the basis of liver copper reserves, lesions could be expected only in that portion of the wool fibre grown, at most, three months prior to shearing. The same reason could be advanced to explain the absence of significant differences between groups in growth rate or wool production.

IV. TRIAL 2 (1954-55).

(1) Experimental.

This trial was designed to study the effect of oral or subcutaneous copper therapy, firstly on body weight and wool production of the wether portion of the flock and secondly on breeding ewes in terms of body weight, wool production, lamb production and weight of lambs at birth, at marking and at weaning.

The experimental sheep from Trial 1 were re-allocated to three new groups as follows:

Group A. Untreated control (comprising all sheep from Group 1 plus a selection from Groups 2, 3 and 4).

Group B. 30 mg. Cu as copper glycinate given subcutaneously in September and December (comprising a selection from Groups 2, 3 and 4).

Group C. 280 mg. Cu as copper sulphate given orally in September and December (comprising all sheep from Group 5 plus a selection from Groups 2, 3 and 4).

The method of re-allocation of sheep from Trial 1 was based on four considerations:

(i) To keep all the previously untreated sheep (Group 1) in Group A. These were known to have low liver copper reserves in June 1954.

(ii) To keep all the sheep previously treated once a month (Group 5) in Group C. These were known to have good liver copper reserves in June 1954.

(iii) To allot sheep from Groups 2, 3 and 4 to the new Groups A, B and C to give approximately equal numbers of ewes and wethers, and at the same time to ensure that Groups A, B and C each contained a minimum of 20 ewes and 20 wethers whose liver copper concentrations were known from the June 1954 biopsy.

(iv) To allot sheep from Groups 2, 3 and 4 to Groups A, B and C on their body weights.

Group A contained 56 ewes and 69 wethers; Group B 57 ewes and 71 wethers; and Group C 57 ewes and 71 wethers.

Liver biopsy samples were taken from approximately 20 ewes and 20 wethers in each group at the commencement of the trial in September 1954 and at the conclusion of the trial in June 1955.

Groups B and C were injected or drenched in September and December, but the treatment planned for March had to be abandoned because of difficulties imposed by weather conditions.

All sheep were weighed in September 1954 and June 1955.

Ewes were joined with rams for six weeks from Sept. 20, 1954. The ewes lambed under close observation between Feb. 16 and Mar. 29, 1955.

All sheep were crutched in December 1954 and jetted with aldrin in March 1955.

This trial concluded in June 1955, when individual fleece weights were determined and wool samples were taken for laboratory examination.

(2) Results.

The 1954-55 season was again particularly favourable for pasture growth from November to June, with much more than the average rainfall for this locality (Table 1). As in the 1953-54 trial, there was an abundance of grass and a variety of green herbage from February to June.

The chemical analyses of pasture from the experimental paddock at the commencement of the trial in September 1954 and at the conclusion in June 1955 are shown in Table 3. The copper, molybdenum and inorganic sulphate contents of the predominant vegetation were similar to those found at the comparable periods in 1953 and 1954.

Table 7 records the mean copper concentrations in livers of sheep. The method of re-grouping of sheep from Trial 1 resulted in the mean liver copper concentration of both ewes and wethers at the commencement of the trial (September 1954) being low in Group A, moderately low in Group B, and fairly satisfactory in Group C. Samples taken in June 1955 showed a further fall in liver copper reserves in the untreated Group A, an improvement in the copper status of the injected Group B, and a fall in the liver copper levels in the drenched Group C. In June 1955, liver biopsies were made on a random selection of 9 lambs from Group A ewes, 9 lambs from Group B ewes and 7 lambs from Group C ewes. All these lambs showed a low copper status.

Table 7.

MEAN COPPER CONCENTRATIONS IN LIVERS OF SHEEP IN TRIAL 2.
(Cu p.p.m. dry-matter.)

Group.	Type.	Sept., 1954.	June, 1955.
A	Wethers	34 (100)*	16 (100)
	Ewes	29 (94)	15 (100)
	Lambs		11 (100)
H	Wethers††	60 (70)	128 (53)
	Ewes††	69 (67)	109 (31)
	Lambs		16 (100)
C	Wethers††	187 (40)	120 (47)
	Ewes††	183 (22)	113 (53)
	Lambs		25 (100)

* Figures in brackets show percentage of sheep with liver copper concentrations less than 80 p.p.m.
†† Indicates treatment with copper in September and December.

In June 1954 blood analyses were made on a random selection of 9 ewes from Group A, 8 ewes from Group B and 6 ewes from Group C. The mean results were:

Group.	Blood Molybdenum. (μg. Mo/100 ml.)	Blood Copper. (mg. Cu/100 ml.)	Liver Copper. (p.p.m. D.M.)
A—ewes	4	0·05	13
B—ewes	4	0·10	95
C—ewes	5	0·09	120

In ewes from Group A the copper concentration is low in both liver and blood. In ewes from Groups B and C treatments have resulted in fair liver copper reserves and blood copper levels lie within the normal range. The data or pasture (Table 3) indicate that these blood molybdenum levels are attributable to the very high sulphate intake limiting blood molybdenum in spite of high molybdenum intake. This was shown by Dick (1954) in pen-fed sheep.

The breeding performance of the ewes and the weights of lambs at birth and at marking are shown in Table 8. There were no significant differences between groups in numbers of lambs born, birth weight, survival to marking or daily weight gains of lambs. Daily inspections during the lambing period (Feb. 16 to Mar. 29) revealed symptoms of ataxia in one lamb from Group A.

Table 8.

Numbers and Mean Body Weights at Birth and Marking of Lambs from Ewes in Trial 2.

—	Group A.	Group B.	Group C.	Total or Mean.
Number of ewes mated	71	69	69	209
Number of ewes lambed	53	54	52	159
Number of lambs born	53	54	52	159
Number of lambs died in neo-natal period ..	9	7	4	20
Number of lambs died neo-natal to marking ..	9	16	18	42
Lambs marked—Number	35	31	30	96
Per cent.	49	45	43	46
Mean birth weight of lambs (lb.)	5·74	5·83	5·84	5·80
Mean birth weight of lambs died in neo-natal period (lb.)	4·57	4·33	6·37	4·88
Mean birth weight of lambs marked (lb.) ..	6·14	6·20	6·23	6·19
Mean daily gain of lambs that survived to marking (lb.)	0·373	0·361	0·369	0·368

Mean body weights of ewes and wethers in each group and the number of sheep used to calculate each mean are shown in Table 9. The ewes in each group were considered in three classes—ewes that did not lamb; ewes that produced a lamb that died before marking; and ewes that had lambs present at shearing. There were no significant differences between groups. Within each group the influence of lambing performance on the body weight of ewes was highly significant ($P < 0\cdot001$).

Table 9.

NUMBERS AND MEAN BODY WEIGHTS (LB.) AND MEAN GAINS (LB.) OF WETHERS AND DIFFERENT CATEGORIES OF EWES IN TRIAL 2.

—	Wethers.	Ewes.		
		Did not lamb.	Lambed, lost lamb.*	Lambed, reared lamb.**
Group A—				
Number	49	16	16	31
Weight—				
Sept. 1954	90	84	78	79
June 1955***	102	92	82	72
Gain	+11·8	+7·8	+3·5	−6·6
Group B—				
Number	47	11	12	33
Weight—				
Sept. 1954	87	73	77	79
June 1955***	98	80	80	72
Gain	+10·5	+7·3	+3·5	−6·6
Group C—				
Number	55	14	15	27
Weight—				
Sept. 1954	90	81	80	82
June 1955***	103	85	84	79
Gain	+12·6	+4·1	+4·3	−3·1

* Lamb died before marking age.

** Lamb present at shearing.

*** Immediately after shearing.

Body weights of lambs after shearing in June 1955 were adjusted to a standard age of 116 days (Table 10). The mean weight gain for all groups was 0·27 lb. per lamb per day, and there were no significant differences between groups before or after adjustment.

Table 10.

LAMBS BORN TO EWES IN TRIAL 2.
NUMBERS AND MEAN BODY WEIGHT, IMMEDIATELY AFTER SHEARING IN JUNE, 1955.

Group.	Type.	Number of Lambs.	Mean Body Weight (lb.).	
			Unadjusted.	Adjusted.*
A	Ewes	19	36·3	35·9
B	Ewes	18	34·4	34·3
C	Ewes	17	32·8	32·7
A	Wethers	12	35·3	34·9
B	Wethers	13	33·9	35·0
C	Wethers	11	36·1	36·5

* Adjusted to a standard age of 116 days.

The mean greasy and clean fleece weights are shown in Table 11. There were no differences in wool production of wethers from each group but ewes from Group C produced significantly more greasy wool than ewes from Groups B and A. The level of significance ($P < 0 \cdot 05$) was obtained after adjustment for lambing performances. Ewes were considered in the same categories as for body weight—ewes that did not lamb, ewes that lambed but lost the lamb before marking, and ewes that had lambs present at shearing. The differences in fleece weight among ewes due to lambing performance were highly significant ($P < 0 \cdot 001$).

Table 11.

NUMBERS AND MEAN GREASY AND CLEAN FLEECE WEIGHTS (LB.) OF WETHERS AND DIFFERENT CATEGORIES OF EWES IN TRIAL 2.

—	Wethers.	Ewes.		
		Did not lamb.	Lambed, lost lamb.	Lambed, reared lamb.
Group A—				
Number	48	16	16	32
Weight greasy fleece ..	10·16	8·76	8·56	7·88
Weight clean fleece ..	6·30	5·10	5·17	4·58
Group B—				
Number	47	12	11	34
Weight greasy fleece ..	10·25	8·81	8·69	8·00
Weight clean fleece ..	6·23	5·20	5·17	4·75
Group C—				
Number	54	15	15	29
Weight greasy fleece ..	10·30	9·25	8·88	8·59
Weight clean fleece ..	6·17	5·80	5·41	4·97

Table 12.

Numbers and Mean Greasy and Clean Fleece Weights (lb.) of Selected Sub-groups of Ewes in Trial 2.

Group.	Did not lamb.	Lambed, lost lamb.	Lambed, reared lamb.
A—from Group 1 of Trial 1—			
Number	12	13	18
Greasy fleece weight	8·78	8·60	7·76
Clean fleece weight	5·05	5·22	4·54
B—from Group 3 of Trial 1—			
Number	2	2	13
Greasy fleece weight	9·26	9·05	7·87
Clean fleece weight	5·32	5·66	4·73
C—from Group 5 of Trial 1—			
Number	10	9	20
Greasy fleece weight	9·98	9·13	8·89
Clean fleece weight	6·06	5·60	5·13

Comparisons in terms of greasy and clean fleece weight were made also between selected sub-groups—ewes from untreated Group 1 of Trial 1 now in Group A; ewes from Group 3 (30 mg. Cu as glycinate) of Trial 1 now in Group B; and ewes from Group 5 (monthly sulphate group) of Trial 1 now in Group C. (These selected sub-groups had low, moderate and high liver copper concentrations at the beginning of Trial 2 as a result of their previous treatments during Trial 1.) These data are given in Table 12. Comparison on this basis emphasised the superior wool production in the proportion of Group C ewes from the originally copper-adequate Group 5. There was also a trend for Group B ewes to produce more wool than Group A ewes.

Table 13.

Numbers and Mean Greasy and Clean Fleece Weights (lb.) of Ewe and Wether Lambs Born to Ewes in Trial 2.

Group.	Type.	Number of Lambs.	Mean Greasy Fleece Weight.		Mean Clean Fleece Weight.	
			Unadjusted.	Adjusted.*	Unadjusted.	Adjusted.*
A	Ewes	32	1·45	1·34	0·81	0·80
B	Ewes	17	1·28	1·25	0·72	0·73
C	Ewes	20	1·36	1·37	0·75	0·75
A	Wethers	11	1·25	1·22	0·70	0·73
B	Wethers	16	1·30	1·59	0·75	0·79
C	Wethers	12	1·37	1·45	0·82	0·83

* To compensate for minor differences in average ages, fleece weight was adjusted to a standard age of 116 days.

The fleece weights of lambs were adjusted to a standard age of 116 days (Table 13). There were no differences in fleece weight of lambs born to ewes in each of the three groups.

Fibre diameter, staple length and crimps per in. were determined on wool samples taken at the end of the trial in June 1955. The results are shown in Tables 14, 15 and 16. The findings were considered in terms of ewes and wethers from each of the three Groups A, B and C and in terms of selected sub-groups based on previous treatments during Trial 1. Ewes were considered also according to whether they did not lamb, lambed but lost lamb, or lambed and reared lamb. On wool from lambs, fibre diameter only was determined.

There was a suggestion that fibre diameter was greater in ewes from Group C, but this did not attain significance. The differences among wethers and among lambs were not significant. The fibre diameter of wool from ewes that reared lambs was very significantly ($P < 0{\cdot}001$) smaller than that of the other two categories of ewes.

Table 14.

Mean Fibre Diameter (Microns) of Wool from Ewes, Wethers and Lambs in Trial 2.

Group.	Type.	Wethers or Dry ewes.	Lambed, lost lamb.	Lambed, reared lamb.
A	Ewes ..	21·0 (15)*	21·8 (17)	19·9 (33)
B	Ewes ..	21·0 (11)	21·8 (11)	19·5 (32)
C	Ewes ..	21·9 (17)	21·6 (16)	20·5 (30)
A, from Group 1, Trial 1 ..	Ewes ..	21·3 (12)	21·9 (13)	19·7 (18)
B, from Group 3, Trial 1 ..	Ewes ..	22·0 (2)	21·2 (2)	19·9 (13)
C, from Group 5, Trial 1 ..	Ewes ..	22·6 (11)	21·6 (10)	20·6 (21)
A	Wethers ..	21·8 (46)		
B	Wethers ..	22·2 (46)		
C	Wethers ..	21·5 (53)		
A, from Group 1, Trial 1 ..	Wethers ..	21·7 (34)		
B, from Group 3, Trial 1 ..	Wethers ..	22·3 (16)		
C, from Group 5, Trial 1 ..	Wethers ..	21·8 (31)		
A	Ewe lambs ..	18·0 (22)		
B	Ewe lambs ..	17·6 (17)		
C	Ewe lambs ..	18·2 (18)		
A	Wether lambs	17·2 (11)		
B	Wether lambs	17·8 (15)		
C	Wether lambs	18·0 (13)		

* Figures in brackets indicate the number of animals in each group on which the assessment was made.

Table 15.

MEAN STAPLE LENGTH (CM.) OF WOOL FROM EWES AND WETHERS IN TRIAL 2.

Group.	Type.	Wethers or Dry ewes.	Lambed, lost lamb.	Lambed, reared lamb.
A	Ewes	8·9 (15)*	9·4 (17)	8·9 (33)
B	Ewes	8·8 (11)	8·6 (11)	8·6 (32)
C	Ewes	8·9 (17)	9·0 (16)	8·7 (30)
A, from Group 1, Trial 1	Ewes	8·9 (12)	9·3 (13)	9·2 (18)
B, from Group 3, Trial 1	Ewes	9·0 (2)	8·8 (2)	8·5 (13)
C, from Group 5, Trial 1	Ewes	9·2 (11)	9·0 (10)	8·8 (21)
A	Wethers	9·1 (45)		
B	Wethers	8·8 (46)		
C	Wethers	8·8 (53)		
A, from Group 1, Trial 1	Wethers	9·1 (34)		
B, from Group 3, Trial 1	Wethers	8·8 (16)		
C, from Group 5, Trial 1	Wethers	8·7 (31)		

* Figures in brackets indicate the number of animals in each group on which the assessment was made.

Table 16.

MEAN CRIMPS PER INCH OF WOOL FROM EWES AND WETHERS IN TRIAL 2.

Group.	Type.	Wethers or Dry ewes.	Lambed, lost lamb.	Lambed, reared lamb.
A	Ewes	12·1 (15)*	12·0 (17)	12·8 (33)
B	Ewes	10·0 (11)	11·9 (11)	12·1 (32)
C	Ewes	10·6 (17)	10·9 (16)	11·6 (30)
A, from Group 1, Trial 1	Ewes	12·2 (12)	11·6 (13)	13·2 (18)
B, from Group 3, Trial 1	Ewes	11·0 (2)	10·0 (2)	11·9 (13)
C, from Group 5, Trial 1	Ewes	10·1 (11)	10·8 (10)	11·7 (21)
A	Wethers	11·7 (45)		
B	Wethers	10·8 (46)		
C	Wethers	12·2 (53)		
A, from Group 1, Trial 1	Wethers	11·6 (34)		
B, from Group 3, Trial 1	Wethers	10·8 (16)		
C, from Group 5, Trial 1	Wethers	12·2 (31)		

* Figures in brackets indicate the number of animals in each group on which the assessment was made.

There were no significant differences in staple length between groups or selected sub-groups.

In the ewes, after adjustment for lambing performance, Group A had significantly ($P < 0.01$) more crimps per in. than Group C. In the wethers, Group B had significantly ($P < 0{\cdot}05$) fewer crimps per in. than the other two groups. This difference is not understood and as it occurred in Group B cannot be related to the copper status of wethers. Ewes that reared their lambs had significantly ($P < 0 \cdot 01$) more crimps per in. than the other two groups.

The incidence of lesions in wool attributable to copper deficiency in each group at shearing in June is summarised in Table 17. Evidence of copper deficiency was obvious in 11 out of 110 fleeces in the untreated Group A, 2 out of 104 fleeces in Group B, and 1 out of 113 fleeces in Group C. These groups also contained 30, 15 and 15 fleeces respectively that showed slight evidence of copper deficiency.

Table 17.

NUMBER OF FLEECES SHOWING LESIONS OF COPPER DEFICIENCY IN TRIAL 2.

—	Group A.			Group B.			Group C.		
	Copper Deficiency Lesion.			Copper Deficiency Lesion.			Copper Deficiency Lesion.		
	Obvious.	Slight.	Normal.	Obvious.	Slight.	Normal.	Obvious.	Slight.	Normal.
Ewes did not lamb	2	3	1	..	2	10	..	3	12
Ewes lost lamb ..	2	8	6	..	2	10	..	1	14
Ewes reared lamb	1	7	23	1	3	29	..	2	27
Wethers	6	12	30	1	8	38	1	9	44
Totals—									
Number ..	11	31	69	2	15	87	1	15	97
Per cent. ..	10	27	63	2	14	84	1	13	86

A summary of the analyses of variance of data from Trial 2 is given in Table 18.

Table 18.

SUMMARY OF ANALYSES OF VARIANCE OF DATA FROM TRIAL 2.

Source of Variation.	Degrees of Freedom.	Mean Squares.					
		Gain in Body Weight Sept. 54—June 55.	Greasy Fleece Weight.	Clean Fleece Weight.	Fibre Diameter.	Crimps per Inch.	Staple Length.
Between groups (elim. fertility)	2	28·4	5·33*	3·02†	7·0	25·9**	1·79
Between fertility states (elim. groups)	2	2504·2***	10·48***	6·79**	58·1***	21·7**	1·32
Interaction ..	4	73·6*	0·27	0·29	0·20	3·63	0·92
Residual	171	27·8	1·21	1·04	2·61	4·41	0·82

† Approaching 5% probability level.
* Significant at 5% probability level.
** Significant at 1% probability level.
*** Significant at 0·1% probability level.

The essential findings on the effects of copper treatment upon wool production and quality, as detected in this trial, were:

(*a*) In wethers, there was no effect on clean or greasy fleece weights, fibre diameter, staple length or crimps per in.

(*b*) In ewes, clean and greasy fleece weights were increased by copper treatment, and this increase was enhanced when previous copper treatments in Trial 1 were considered.

(*c*) In ewes, copper treatment tended to increase fibre diameter, significantly reduced crimps per in. and had no influence on staple length.

(*d*) In both ewes and wethers, copper treatment reduced the incidence of visible copper-deficiency lesions in wool.

(3) Discussion.

In the 1954-55 season the summer rains started earlier and persisted longer than usual. This resulted in abundant pasture growth and a wide variety of herbage plants in autumn-winter.

The predominant vegetation again showed a low copper status. The molybdenum concentrations were appreciable, being particularly high in some herbages. The inorganic sulphate content was high. As in the previous trial, copper deficiency was attributable partly to the low copper content of grasses and partly to inhibition of copper metabolism in sheep by molybdenum in the presence of inorganic sulphate.

The treatment of these animals in Trial 1 had a marked influence on the liver copper reserves at the commencement of this trial. About two-thirds of the sheep in Group A were from the untreated control group in Trial 1, so the liver copper reserves were low in September. Group B, composed of previously treated Groups 2, 3 and 4 from Trial 1, showed moderately low copper reserves. Group C, composed largely of sheep from the monthly-treated Group 5, showed fair copper reserves.

At the conclusion of Trial 2 in June 1955, all animals in Group A showed a very low copper status. Although the mean levels were fairly satisfactory in Groups B and C, about half the animals examined in each group showed less than 80 p.p.m. Cu. As in Trial 1, treatment by subcutaneous injection tended to maintain slightly better liver copper concentrations than oral treatment at the same intervals. It was again apparent in this trial that treatments at 6-monthly intervals did not ensure adequate copper reserves.

In June 1955, liver copper concentrations were low in lambs born to ewes in each of the three groups. Sheep in Groups B and C received copper treatments in September and December 1954. It would therefore be expected that ewes in these two groups would have had good copper reserves both at mating and during pregnancy, and that lambs from these ewes would have good reserves at birth. The low liver copper levels found in these lambs in June indicate that liver copper reserves present at birth were seriously depleted by four months of age.

The percentage of lambs marked to ewes mated was low in all groups. Poor fecundity and high neo-natal mortality are a feature of sheep breeding in north-western Queensland (Moule 1954). Ewes from the untreated control Group A had low liver copper reserves at the time of mating and even lower reserves nine months later in June 1955. Copper treatments given to Groups B and C in September and December would have ensured an adequate copper status during pregnancy. As there were no significant differences between groups in numbers of lambs born, birth weight, survival to marking or daily weight gain of lambs, it is concluded that copper supplementation did not influence reproductive performance in this trial.

As in Trial 1, copper supplementation had no measurable effect on body weight.

Ewes from Group C produced significantly more wool than those from Groups B and A. About two-thirds of the sheep in Group C were from the group drenched monthly during Trial 1 and thus had much higher liver copper reserves initially. Fleece weights were therefore examined in terms of the original untreated controls now in Group A, the original 30 mg. copper glycinate ewes now in Group B, and the original monthly drenched ewes now in Group C. Comparison on this basis enhanced the superior wool production of Group C and showed a tendency for Group B ewes to produce more wool than Group A. These findings emphasise the desirability of repeated copper treatments to build up good initial copper reserves, which could be then maintained by treatments given at intervals of about three months when sheep are normally handled for other purposes.

The differences in fleece weight among wethers were not significant, even when allowance was made for the previous treatments of the sheep in Trial 1. There was virtually no difference in fleece weights between biopsied and un-biopsied wethers, indicating that the operation had no adverse effect on wool growth. In lambs the mean rate of wool growth was 0·014 lb. per head per day, and this was unaffected by the sex of the lamb or by the group to which its dam belonged.

Wool samples from all fleeces were examined for fibre diameter, staple length and crimps per in. There was a suggestion that fibre diameter was greater in ewes from Group C. Ewes from Group A had significantly more crimps per in. than Group C. No other differences that could be attributed to copper treatments attained significance.

There were marked differences between groups in terms of incidence of lesions in wool indicative of copper deficiency. However, some fleeces from the treated Groups B and C showed evidence of slight copper deficiency, indicating that copper treatments at 6-monthly intervals did not ensure an adequate copper status in sheep in this locality.

Within each group of ewes, lambing performance and lactation had a significant influence on body weight, fleece weight, and the fibre diameter and crimps per in. in wool.

V. TRIAL 3 (1955-56)—GROWTH OF LAMBS AFTER WEANING.

A feature of Merino sheep in north-western Queensland is the smaller size compared with sheep of the same breeding in south-western Queensland. This has been attributed to poor growth of lambs. In Trial 1 the experimental sheep were 8–10 months of age at the commencement of the trial, and their liver copper concentrations were unexpectedly high (mean 160 p.p.m. Cu). No response in body weight was recorded from any of the copper treatments, but it was only during the last three months of the trial (June to September 1954) that liver copper reserves in the control group might be regarded as deficient, so no conclusions on the influence of copper supplementation on growth of sheep in this locality could be drawn.

In Trial 2 there were no significant differences between lambs born to copper-deficient and copper-treated ewes in birth weight, weight gain to marking age or body weight at a standard age of 116 days. In June 1955, liver copper reserves of a representative number of lambs, four months of age, were low irrespective of whether lambs were born to copper-supplemented or untreated ewes.

In September 1955, the 91 lambs born in Trial 2, now approximately seven months of age, were divided at random into two groups by allotting alternate sheep to each group as they were driven through a race. The two groups were:—

Group I. Untreated controls consisting of 26 ewes and 18 wethers.

Group II. Treated group consisting of 27 ewes and 20 wethers.

The treated group was drenched with copper sulphate solution equivalent to 140 mg. Cu in September 1955, 210 mg. Cu in October 1955, and 280 mg. Cu in March 1956.

The lambs were weighed after shearing in June 1955 and again in October 1955, March 1956, and after shearing in June 1956, as shown in Table 19. There were no significant differences in weight gains.

Table 19.

MEAN BODY WEIGHTS (LB.) OF WEANER LAMBS IN TRIAL 3.

Group.	Type.	June 1955.*	October 1955.	March 1956.	June 1956.*
I	Ewes	34·7	52·5	74·9	75·0
II	Ewes	34·8	53·5	71·4	72·0
I	Wethers	35·9	54·1	78·7	74·0
II	Wethers	35·8	54·2	77·8	73·0

* Immediately after shearing.

The data on wool produced by these lambs at shearing in June 1956 are presented in Table 20. There were no significant differences between groups in terms of greasy or clean wool produced, but 10 out of 37 fleeces from the control group showed obvious evidence of copper deficiency, whereas none of the 35 fleeces from the treated lambs showed lesions.

Table 20.

MEAN GREASY AND CLEAN FLEECE WEIGHTS AND NUMBER OF FLEECES SHOWING LESIONS OF COPPER DEFICIENCY AMONG WEANER LAMBS IN TRIAL 3 AT JUNE 1956.

Group.	Type.	Number of Sheep.	Greasy Fleece (lb.).	Clean Fleece (lb.).	Copper Deficiency Lesions.		
					Obvious.	Slight.	Normal.
I	Ewes	21	8·9	5·0	9	7	5
II	Ewes	18	8·8	4·6	..	6	12
I	Wethers ..	16	9·5	5·1	1	10	5
II	Wethers ..	17	9·6	5·3	..	5	12

Thus, three copper sulphate drenches given during 12 months to weaner lambs which initially had very low liver copper concentrations (Table 7) were sufficient to substantially prevent visible copper-deficiency lesions in the wool but had no effect on body weight or greasy or clean wool production.

VI. GENERAL DISCUSSION.

In this locality of north-western Queensland, copper deficiency in sheep was found to be due partly to the low copper and partly to the high molybdenum and inorganic sulphate content of the predominant vegetation. The period of greatest depletion of liver copper reserves in sheep was autumn-winter, when herbage plants high in molybdenum and very high in inorganic sulphate were abundant and readily eaten by sheep.

In these trials copper supplementation of ewes had no influence on reproductive rate, birth-weight of lams, neo-natal mortality or growth rate of lambs to marking. Copper supplementation of weaners did not affect their growth rate.

Fleece weights of sheep receiving copper were higher than those of control sheep, but the differences were slight except in orally treated ewes. After eliminating differences due to lambing, orally treated ewes produced about 0·5 lb. per head more greasy wool than the controls. This orally treated group comprised mainly sheep with high initial liver copper levels resulting from treatment once a month during Trial 1, and the findings thus tend to indicate a response to *prolonged* copper treatment rather than the superiority of oral treatment.

There was a much lower incidence of lesions in wool due to copper deficiency in the fleeces of sheep from all treated groups, indicating that copper supplementation had improved wool quality.

Six-monthly treatment of sheep, either orally or by subcutaneous injection, did not ensure an adequate liver copper reserve, particularly in the months when herbage plants predominated.

In spite of copper treatments of ewes which should have ensured adequate liver copper reserves in lambs at birth, the liver copper concentrations were low in lambs at four months of age.

Based on these trials, recommendations for the prevention of copper deficiency in sheep in this area are as follows:

(1) Establish a good initial reserve of copper by three treatments at fortnightly or monthly intervals.

(2) Maintain these copper reserves by treatment at approximately 3-monthly intervals at times when sheep are normally handled—e.g., for shearing, crutching, jetting, marking and weaning.

(3) Lambs must be treated at marking and thereafter at 3-monthly intervals.

At the dose rates used in these trials copper glycinate given subcutaneously was not markedly superior to copper sulphate given orally. Sutherland, Moule and Harvey (1955) showed that there was some risk of toxicity to weaners at dose rates exceeding 30 mg. Cu as copper glycinate subcutaneously or 200 mg. Cu as copper sulphate orally.

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