

MEASUREMENT OF WOOL GROWTH AND ITS RESPONSE TO NUTRITIONAL CHANGES

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Summary

Problems associated with the measurement of changes in the rate of wool growth are discussed. In particular, there are large errors due to the "emergence time" of the wool, that is the time required for newly keratinized portions of fibre to move out of the follicles to the point where they can be removed by clipping. The results show how the emergence time may be estimated with the aid of [³⁵S]cystine and how clipping schedules may be altered to give a more accurate measure of changes in the rate of wool growth.

The rates of wool growth in 12 sheep were studied with both clipping and radioautographic techniques. The emergence time varied from 5 to 10 days and was found to decrease by as much as 4 days as a result of increased food intake and faster wool growth.

The biggest changes in the rate of wool growth occurred during the first 2 weeks after changing food intake. The mean diameter and mean length growth rate changed together and in about the same proportion in response to the nutritional changes. The ratio of mean length of wool grown per day to mean diameter ranged from 10 to 16 in the sheep studied, but the ratio for each sheep remained relatively constant during large (up to sixfold) increases in growth rate.

I. INTRODUCTION

Changes in the rate of wool growth in experimental sheep are usually measured by clipping the wool at regular intervals from a defined area of skin. This method is subject to errors due to several factors. Firstly, it is difficult to clip the wool from precisely the same area each time and at exactly the same height above the skin surface. This is especially troublesome in sheep with wrinkly skin. Secondly, exposure of the skin on this area to low temperatures causes a reduction in fibre length growth rate there (Downes and Hutchinson 1969); and thirdly, there is an error due to what may be called the "emergence time", that is the time required for the newly keratinized portions of fibre to move out of the follicles to the point where they can be removed by clipping. This error is particularly important because changes in fibre diameter, which have a large effect on the mass of wool clipped, cannot be detected in clipped samples until the newly synthesized wool appears above the skin surface.

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This paper describes how the average emergence time for the fibres on a sheep can be estimated by administering [^{35}S]cystine and timing the appearance of radioactivity in wool subsequently clipped at various intervals. The method is based on previous results (Downes 1965) which showed that the material undergoing keratinization in wool follicles attains its maximal specific radioactivity during the first day after the administration of an intravenous dose of [^{35}S]cystine. The emergence time may therefore be taken as the time from administration of the dose until successive clippings of wool attain their maximal specific radioactivity.

The results presented show how a clipping schedule can be altered to give a more accurate measure of a change in the rate of wool growth. The amount of wool clipped from a defined area of skin will be referred to as the wool "harvest" for the period of time since the previous clipping, and the true amount of wool produced by the same piece of skin during the same period of time will be called wool "growth". In addition, the results obtained by clipping are compared with those from the measurement of changes in diameter and length growth rate of individual fibres by the radioautographic technique (Downes and Lyne 1959, 1961; Downes, Clarke, and Dagg 1967).

II. EXPERIMENTAL

(a) *Sheep and Diet*

Twelve adult wethers (11 Corriedales and 1 Merino) were used. Eight of the Corriedales were studied during an experiment on the influence of body weight on the energetic efficiency of adult sheep (Graham 1969). The other sheep were kept in cages in a room maintained at $21 \pm 3^\circ\text{C}$ and were fed, watered, and weighed by previously described methods (Till and Downes 1963). The food for all sheep, comprising 50% chopped lucerne hay and 50% whole oats, was given once daily, between 9 and 11 a.m. Water was allowed *ad libitum*.

(b) *Wool Sampling for Estimation of Emergence Time*

Two areas (5 by 5 cm), one on each side of each sheep, were used to determine the emergence times. L-[^{35}S]Cystine (20 μCi ; from the Radiochemical Centre, Amersham, U.K.) was injected into the jugular vein. The wool was clipped from one of these sites at frequent intervals, usually every 2 days, and from the other one on alternate days. On some occasions a small portion of the wool was first clipped ("snippet" samples) and used for the measurement of mean fibre diameter by a microscope method (Chapman 1960). The rest of the wool clipped from these sites on any one day was combined, cleaned with light petroleum (Shell X4, b.p. $60\text{--}80^\circ\text{C}$), dried, and radioassayed (Downes and Till 1963).

(c) *Experiment 1*

Four areas (I, II, III, and IV), two on each side, were defined on each of two sheep (Nos. 1 and 2) by tattooing. The wool was clipped from these areas (8 by 8 cm) with fine Oster animal clippers (No. 40 head); the same clippers were used throughout the experiment. The wool was washed with light petroleum, ethanol, and distilled water, dried overnight at 110°C , allowed to cool over phosphorus pentoxide in a desiccator, and weighed. For an initial 12-week period of constant food intake sheep 1 was given 400 g/day and sheep 2 1400 g/day. During this period the wool was clipped from all four areas on each sheep every 14 days. At the end of this period, corresponding to day 21 on Figures 2 and 3 the daily ration of sheep 1 was increased from 400 to 1000 g/day while the ration for sheep 2 was reduced from 1400 to 500 g/day. Thereafter the wool from two of the areas on each sheep was still clipped at 14-day intervals for 14 weeks (sheep 1) or 10 weeks (sheep 2). The wool from the other two areas on each sheep was clipped at times determined by the emergence times of the doses of ^{35}S .

Doses of L-[^{35}S]cystine were administered intravenously at intervals, as described in the legends to Figures 2 and 3.

For the measurement of length growth rates, samples of wool were clipped from various sites several weeks after the administration of the last dose of ^{35}S . The fibres were radioautographed and measured as described by Downes, Clarke, and Dagg (1967).

(d) *Experiment 2*

The second experiment, with 10 Corriedales (sheep Nos. 3–12), was conducted over a 72-day period. Each sheep was given 13 doses of L- ^{35}S cystine, which were administered intravenously at 6-day intervals so that wool growth during each 6-day period could be measured by the radioautographic method. The daily ration for sheep 3 and 4 was kept constant, while the rations for the other 8 sheep were changed at 24-day intervals. Four of the sheep (Nos. 5–8), each of which initially weighed about 40 kg, were given 200 g of food per day for the first 24-day period. Their daily ration was increased in the second period to either 600 or 1000 g (two sheep each) and to 1500 g for the third period. The other four sheep (Nos. 9–12) were initially in a fat condition (66–80 kg). Their rations were progressively reduced from 1500 to 200 g. However, because of food refusals by the fat sheep throughout the experiment, the planned range of food intakes and hence of wool growth rates was not obtained with these four sheep. For this reason the length and diameter results for each 6-day period will not be presented.

In this experiment the average wool growth during each 24-day period was estimated by cleaning and weighing the wool harvested from tattooed areas, but the clipping schedule was altered on the basis of the results obtained in experiment 1. The wool was clipped from two tattooed areas on each sheep at intervals of 24 days the clippings being performed 7 days after changing the food intakes. In this experiment the emergence time for the first dose of ^{35}S was measured on each sheep, and a second measurement was made in six of the sheep after the administration of the last dose of ^{35}S .

(e) *Experiment 3*

A further experiment to extend the study of the relationship between fibre length and diameter was performed with seven of the Corriedales. At the end of experiment 2 the sheep were put out to pasture for 12 months and then brought back into pens. For the remainder of the experiment sheep Nos. 10–12, which were originally the fat sheep, were fed 200 g per day of the standard food plus 200 g of straw, while Nos. 5–8 were offered 2000 g per day of the standard food. After 3 months on these regimes, the average length growth rate and average diameter of the wool on each sheep was measured during two successive 7-day periods.

III. RESULTS

(a) *Emergence Time*

In the present experiments the emergence time was estimated from graphs relating the specific radioactivity of successive 2-day wool harvests and the time of sampling, as shown in Figure 1(a).

The emergence time may also be measured by an alternative method, in which the wool is first clipped from an area of skin several weeks before administering the dose of L- ^{35}S cystine. Subsequently, daily samples of wool, which become progressively longer, are clipped. From a plot of the specific radioactivity of these samples against time the point of greatest slope indicates the emergence time, as shown in Figure 1(b). The two methods give similar results.

The results from experiment 1 showed that the emergence time was about 10 days for the first two doses in sheep 1 but was shortened to about 8 days for the third dose (Fig. 2), presumably because of the immediate increase in the length growth rate which occurred when the food intake was increased. The emergence time was reduced to about 7 days for doses 4–11 and to 6 days for the later ones.

Thus, for this sheep, the emergence time was about 10 days when the rate of wool growth was low, and about 6 days when the rate was high.

The corresponding results for sheep 2 (Fig. 3) show that the emergence time increased by about 1 day, from 6 days during the control period to 7 days after the main fall in the wool growth rate had occurred as a result of the lowered food intake.

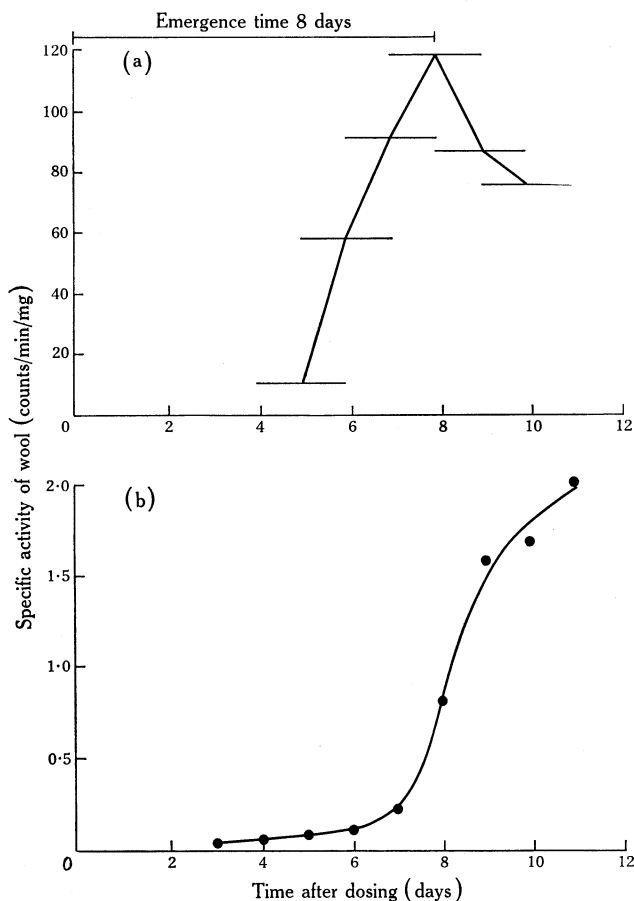


Fig. 1.—Two methods of estimating emergence time of wool: (a) specific radioactivity of wool clipped at 2-day intervals from two adjacent areas of skin of a sheep which had received an intravenous dose of L-[^{35}S]cystine (20 μCi); (b) specific radioactivity of wool clipped each day from different areas of skin of the same sheep; the point of maximum slope (8 days after dosing) corresponds to that of maximal specific activity in (a).

The estimates of emergence time in experiment 2 were in the range 5–9 days (mean 7 days) and showed the same trend to shorter times with increasing wool growth rates.

growth rate after day 21 and consequent reduction in the emergence time for each dose of ^{35}S . Each of these times is given next to a horizontal line drawn for each dose by the method shown in Figure 1(a). Thus the emergence time changed from 10 to 6 days during the experiment. From day 21 onwards the wool was clipped from areas II and III on days which corresponded approximately to the emergence times of the doses of L-[^{35}S]cystine given on days 21, 35, 49, 63, and 14-day intervals thereafter. The broken lines representing the harvests from II and III give a truer indication of the wool growth responses if they are displaced to the left by about 7 days.

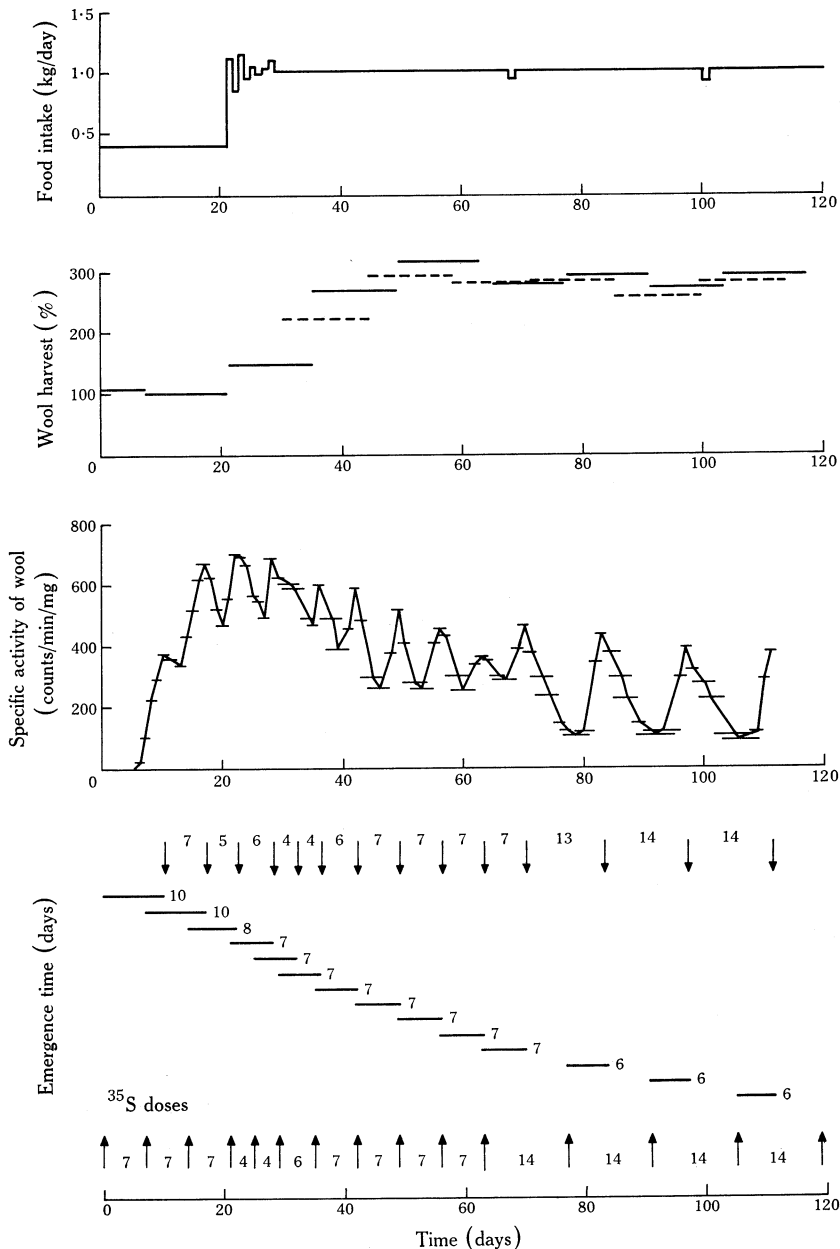


Fig. 2.—Wool growth response and change in emergence time following an increase in food intake (expt. 1, sheep 1). The wool was clipped at 2-week intervals from tattooed areas I and IV. The harvests from these areas, relative to that clipped on day 21, are shown as solid lines. The arrows pointing upwards indicate the timing of the administration of L- ^{35}S cystine, the number of days between successive dosings being shown between the arrows. The specific activity *v.* time curve for wool clipped at frequent intervals enabled specific activity maxima (arrows pointing downwards) to be determined. The number of days between each pair of maxima is not always the same as the number between corresponding doses of ^{35}S because of the rapid increase in length

(b) *Rate of Wool Growth*(i) *Experiment 1: Tattooed Patch Clippings*

The amounts of wool, relative to those obtained on the day on which the food intake was changed (day 21), are shown in Table 1. Because of the large reduction

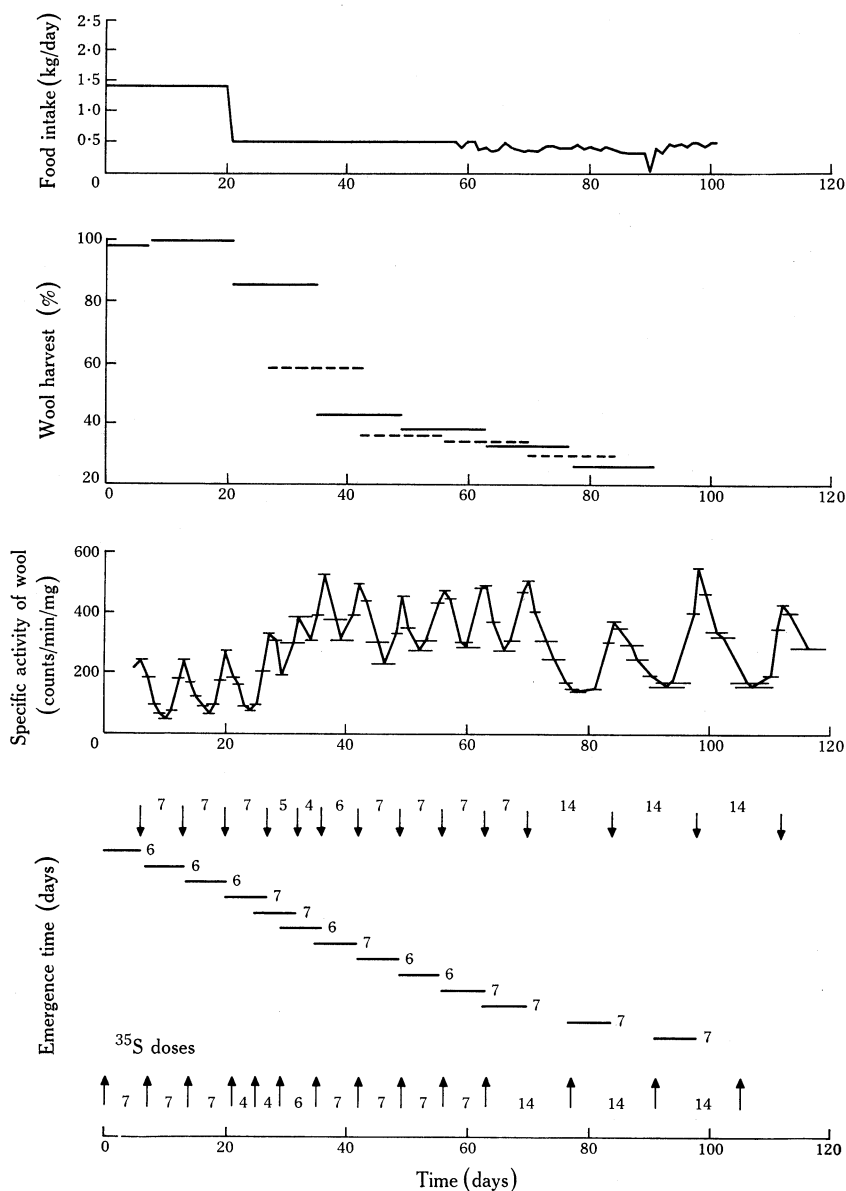


Fig. 3.—Wool growth response and change in emergence time following a decrease in food intake (expt. 1, sheep 2). The emergence time increased from 6 to 7 days during the experiment (see legend to Fig. 2).

in the emergence time of the wool from sheep 1, areas II and III were not clipped soon enough to reveal the true wool growth response but the results show that the amount of wool clipped on day 44 was 123% higher than the amount clipped on day 21. The emergence time results show that the wool clipped on day 44 must have been grown 2–16 days after increasing the food intake. The 123% increase was much higher than the 46% increase shown for areas I and IV clipped on day 35. The 123% increase indicates the approximate average response for the first 2 weeks of higher food intake. By the end of the first 2 weeks the increase in wool growth rate must have been about 180%, the approximately constant value obtained for five subsequent periods.

TABLE 1
RELATIVE WOOL HARVESTS FROM TATTOOED AREAS
Experiment 1

Sheep No.	Areas I and IV		Areas II and III		
	Clipping Period (days)*	Wool Harvest†	Clipping Period (days)*	Corresponding Estimated Growth Period (days)‡	Wool Harvest†
1	21–35	146	30–44	23–37	223
	35–49	268	44–58	37–51	293
	49–63	315	58–71	51–64	283
	63–77	280	71–85	64–79	283
	77–91	293	85–99	79–93	258
	91–105	295	99–113	93–107	282
	105–119	295			
2	21–35	86	27–42	21–35	63
	35–49	43	42–56	35–49	37
	49–63	38	56–70	49–63	34
	63–77	34	70–84	63–77	30
	77–91	27			

* See time scales in Figures 2 and 3.

† Mass of clean dry wool as percentage of mass clipped on day 21 (when ration was increased from 400 to 1000 g for sheep 1 and decreased from 1400 to 500 g for sheep 2). Mean of duplicate results.

‡ From study of specific activity *v.* time curves in Figures 2 and 3, it was estimated that the wool harvested from areas II and III had actually undergone keratinization in the follicles during the times indicated.

Similarly, with sheep 2, the harvest of wool on day 35, 14 days after reducing the food intake, showed a decrease of about 14% whereas the estimated true fall in wool growth during this period was 37% (Table 1). The later results for this sheep also show that the biggest fall in the wool growth rate must have occurred during the first 14 days after reducing the food intake.

(ii) *Experiment 1: Radioautography*

The average length growth rates and diameters for 50 fibres from each sheep are shown in Figure 4. The mean length growth rate of the wool from sheep 1 increased

from about 200 to 240 $\mu\text{m}/\text{day}$ during the first 4 days of increased food intake, and continued to increase during the next 10 days, but after that a new steady rate, about 40% faster than the initial rate, was maintained during the following 84 days.

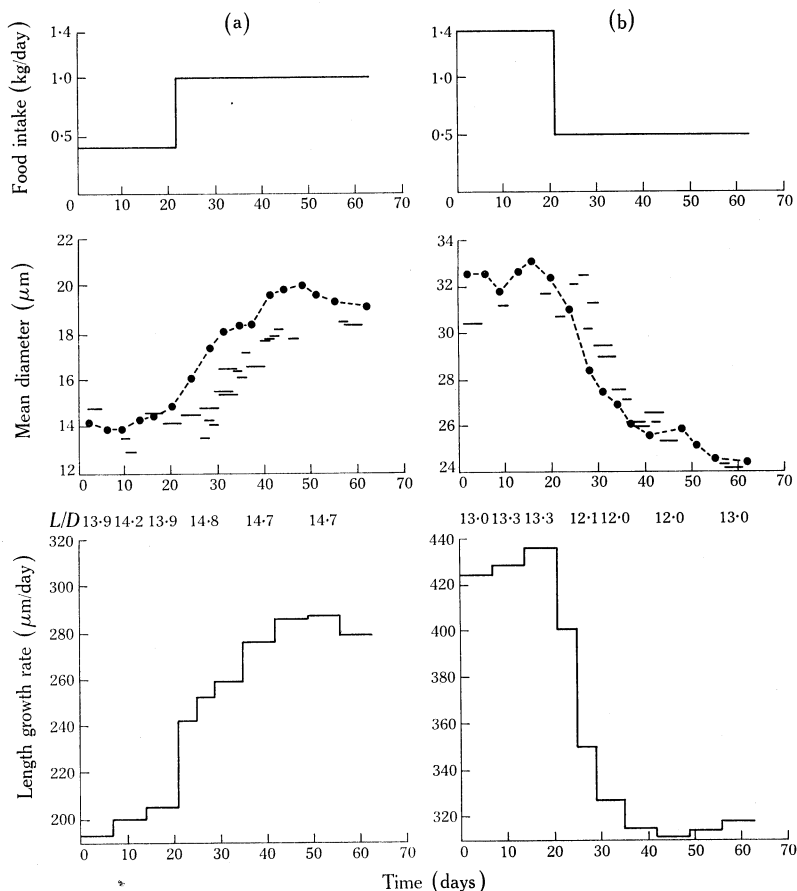


Fig. 4.—Effect of nutritional changes on the length growth rate (L), diameter (D), and the L/D ratio of the wool from (a) sheep 1 and (b) sheep 2 (expt. 1). The mean results, measured on radioautographs of 50 fibres (10 fibres taken at random from each of five sites on each sheep), are shown for the first 63 days of the experiment (see Figs. 2 and 3). The diameters ($\bullet - - \bullet$) were measured at various positions on each radioautographed fibre. The lengths of the horizontal lines representing length growth rates correspond to the timing of the ^{35}S doses (Figs. 2 and 3). The horizontal bars representing mean diameters of snippet samples show a delayed response due to the emergence time. The L/D ratios, calculated from the radioautographic results, are shown for various stages of the experiment.

The mean diameter rose from 14.4 to 19.5 μm , most of this increase occurring during the first 14 days of the period of increased food intake [Fig. 4(a)]. Even within the first 4 days the mean diameter increased to more than 16 μm . The mean diameters of the snippet samples were similar (increase from 14 to 18.5 μm) [Fig. 4(a)] and confirm the rapidity of the response, when allowance is made for the emergence

time delay. The ratio of mean length growth rate to mean diameter changed by less than 8% during the experiment.

The radioautographic results for sheep 2 [Fig. 4(b)] showed that both mean diameter and mean length growth rate fell rapidly after the food intake was reduced. Although these decreases were apparent in the first 4 days' growth after reducing the food intake, the biggest decrease occurred during the second 4-day period. Within 14 days the length growth rate was reduced to a reasonably constant value 27% lower than the initial value. The mean diameter fell by 23%, from 32.5 to 25 μm . Most of this change occurred during the first 14 days, the mean diameter again remaining approximately proportional to the length growth rate. The measurements of the mean diameter of the snippet samples showed a similar trend, after allowing for the delay due to the emergence time [Fig. 4(b)].

TABLE 2

COMPARISON OF RELATIVE RATES OF WOOL GROWTH CALCULATED FROM RADIOAUTOGRAPHIC AND FROM CLIPPING RESULTS

Sheep No.	Radioautography		Clipping		
	Time of Sampling (days)*	$10^{-3} \times$ Mean Fibre Volume Growth Rate ($\mu\text{m}^3/\text{day}$)†	Relative Mean Volume‡	Estimated Growth Period (days)§	Wool Harvest
1	4	47.4	135	2-16	223
	8	57.9	169		
	14	67.4	200		
	21	79.1	238	16-30	293
	28	89.0	269		
	35	87.5	268	30-43	283
	42	80.5	245		
2	4	324	91	0-14	63
	8	242	68		
	14	194	54		
	21	170	48	14-28	37
	28	157	44		
	35	150	42	28-42	34
	42	149	42		

* After changing ration. See time scale for ^{35}S doses on Figures 2 and 3.

† Calculated from Figure 4.

‡ Volume expressed as a percentage of volume over first 21-day period (when ration was increased from 400 to 1000 g for sheep 1 and decreased from 1400 to 500 g for sheep 2).

§ Estimated for wool clipped from areas II and III after ration changed. It is the time interval during which wool harvest had undergone keratinization in the follicles.

From the mean length growth rates and mean diameters the mean volumes of wool grown per day during each period was calculated, assuming that the fibres were cylindrical. These results are shown in Table 2, which also compares the relative rates of wool growth calculated from the radioautographic measurements and from the wool harvests (Table 1).

The mean volume of fibre grown per day by sheep 1 increased by 160% as a result of increasing the food intake, compared with the 180% increase determined from the wool harvests. Almost half of the increase occurred during the first 8 days. The mean volume of fibre grown per day by sheep 2 was reduced by 58% after reducing the food intake, whereas the corresponding reduction calculated from the wool harvests was 66%. In view of all the errors involved, the agreement between the results obtained by the two methods is considered satisfactory.

(iii) Experiment 2

The mean length growth rates and mean diameters of the wool samples from sheep 3 and 4 during the 72-day period of constant food intake are shown in Figure 5.

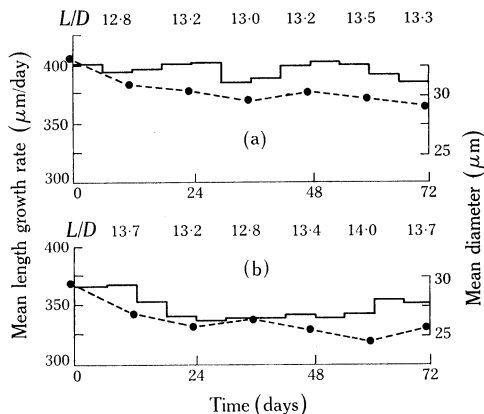


Fig. 5.—Constancy of mean length growth rate (L) (—), mean diameter (D) (● - - ●), and the L/D ratio of wool from (a) sheep 3 and (b) sheep 4 (expt. 2) during a period of 72 days of constant food intake. Doses of L - $[^{35}\text{S}]$ cystine were administered intravenously at 6-day intervals. Seven measurements of diameter were made along each fibre, at positions corresponding to the time of giving every second dose of ^{35}S . Mean results for 50 fibres from each sheep.

After an initial decrease during the first 24 days, the rate of wool growth varied during the rest of the experiment by no more than $\pm 10\%$ of the mean. In sheep Nos. 5–8 (Fig. 6) the wool growth rate quickly responded to the changed food intake, the largest response usually occurring in the first 6 days. As in the first experiment, the ratio of length growth rate to diameter remained reasonably constant (within $\pm 10\%$ of mean) for each sheep, even during changes of more than fivefold in the mean volume of fibre produced.

The mean volumes of fibre grown per day during each 24-day period were calculated from the mean diameters and length growth rates. Thus the rates of wool growth in the second and third periods could be expressed relative to those for the first period. Similarly the relative wool growth rates were calculated from the tattooed patch harvests. As shown in Figure 7, which includes results for all 10 sheep in experiment 2, the two methods gave similar results.

(iv) *Experiment 3*

The results in Table 3 show the ratios of mean length of wool grown per day to mean diameter, measured before and after the large changes in the rate of wool

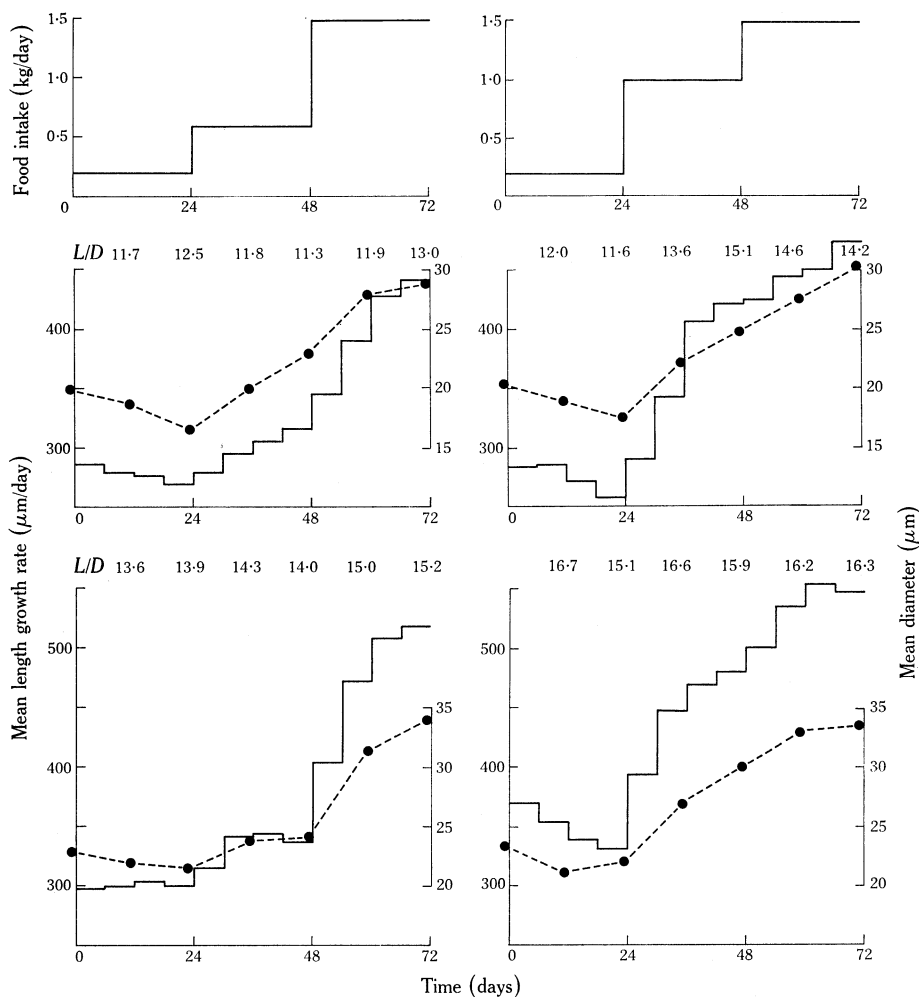


Fig. 6.—Effect of increased food intake on the length growth rate (L) (—), diameter (D) (● --- ●), and the L/D ratio of wool from sheep 5–8 (expt. 2) during a 72-day period. See legend to Figure 5 for further details. Mean results for 50 fibres from each sheep.

growth had occurred in seven sheep between experiments 2 and 3. The ratio for each sheep remained relatively constant, the value ranging from 10 to 16 for the different sheep.

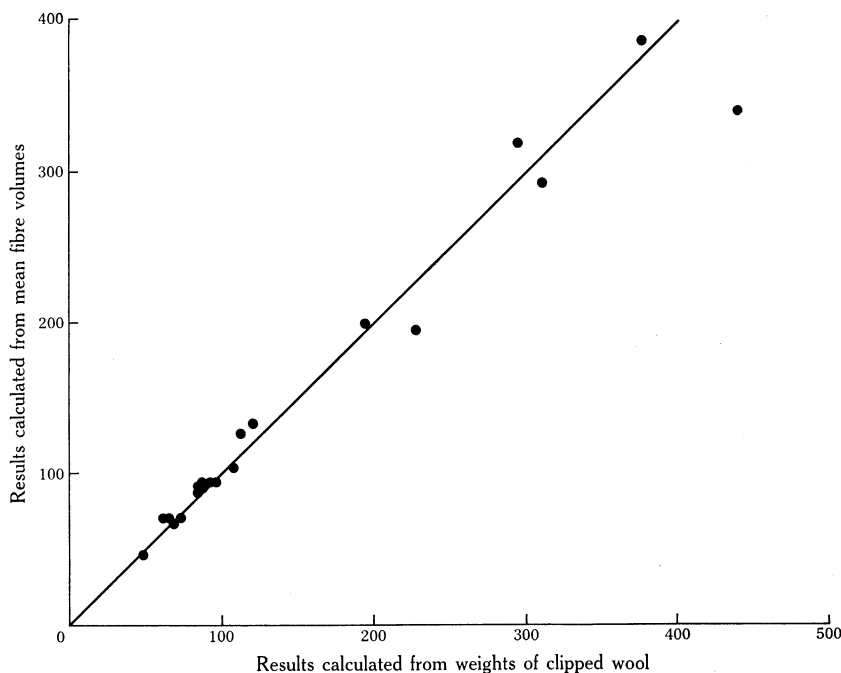


Fig. 7.—Changes in the rate of wool growth during experiment 2, as measured by two methods: (1) Calculation of the mean fibre volume from the lengths and diameters measured on radioautograms. (2) Clipping and weighing the wool from tattooed areas at 24-day intervals, with a 7-day delay to allow for the emergence time. The results for the second and third 24-day periods, as a percentage of those for the first are shown. The line of 45° slope is drawn.

TABLE 3
CONSTANCY OF RATIO OF WOOL FIBRE LENGTH TO DIAMETER

Sheep No.	Wool Growth (g/day)*			Length/ Diameter†	Wool Growth (g/day)	Length/ Diameter
	Period 1	Period 2	Period 3			
	Experiment 2				Experiment 3	
5	4.4	5.2	13.7	12.0±0.6	23	12.5
6	4.1	4.6	12.1	14.3±0.6	22	14.2
7	2.8	5.4	10.6	13.6±1.2	19	13.7
8	‡	‡	‡	16.1±0.6	20	15.5
10	11.3	9.7	7.6	10.3±0.3	3.5	11.3
11	9.1	8.5	6.1	10.0±0.3	4.3	9.8
12	8.5	5.3	4.1	12.5±0.7	4.7	12.0

* Mean for each 24-day period.

† Ratio (mean fibre length per day/mean diameter) ±S.D. Lengths and diameters are means for 40 fibres. Each ratio is mean of six determinations (two per 24-day period, as shown in Fig. 5).

‡ Not measured, but probably less than 10 g/day.

IV. DISCUSSION

The above results illustrate some of the difficulties in obtaining accurate measurements of changes in the rate of wool growth by conventional clipping methods. The emergence time varies from sheep to sheep and from time to time in the same sheep, depending on the rate of wool growth. The emergence time for the wool from the sheep studied varied from 5 to 10 days, but larger variations may possibly occur with the other sheep, for example those producing wool at very low or high rates. Variations due to wrinkly skins or to the use of different types of clippers may also occur.

Changes in length growth rate may quickly alter the emergence time and hence the mass of wool clipped, but corresponding changes in diameter can never have an immediate effect on the mass of wool clipped. The results of experiment 1 show that a more reliable estimate of the true changes in the rate of wool growth would have been obtained by a schedule in which the wool was clipped 7 days after imposing the experimental change and this was confirmed in experiment 2. The only way to obtain more accurate results would be to determine the emergence time whenever an experimental change is imposed. In practice this is not warranted because of the other errors in clipping wool from the same area reproducibly. However, the improved accuracy obtained by delaying the clipping by a period of, say, 7 days is worth while.

Another consequence of variation in emergence time is that incorrect correlations of length growth rate and diameter may be obtained. For example the lengths and diameters of short pieces of wool representing a few weeks' harvest would give the wrong relationship unless the rate of wool growth remained constant during the total period of the emergence time plus the time between the two clippings. This must at least partly explain the observations (Story and Ross 1960) that the maximal and minimal length growth rates in the seasonal cycle of wool grown by Romney ewes in New Zealand occur some weeks before the corresponding maximal and minimal diameters. Their conclusion, that the mechanisms controlling fibre length and diameter are at least partly independent of one another, may not be warranted on their evidence alone.

The mean diameters obtained for the radioautographed fibres agree well with those obtained by the snippet method, when allowance is made for the emergence time effect. This shows that the mean diameter of a number of fibres may be accurately determined on radioautographed fibres at points corresponding to accurately known times and hence to experimental treatments.

The radioautographic method in which both length growth rate and diameter are measured is probably the most sensitive one for determining changes in wool growth rate over short periods. Such results can only be converted to values for the total amount of wool growth by measuring the mass of wool grown during at least one period of time, preferably when the rate of wool growth is constant, or by the even more difficult alternative of estimating the total number of fibres on the sheep. However, for many experiments relative growth rates are sufficient.

The biggest changes in wool growth rate occurred during the first 2 weeks after changing the food intake. From then on there was comparatively little further

change. The fastest rate of change occurred in the first 4 days in the sheep whose food intake was increased, and in the second 4-day period in the other sheep (expt. 1). This difference in behaviour could be due to the presence of a pool of wool keratin precursors in the skin (Downes 1961) which enables wool growth to continue for a few days at approximately the same rate until the reduction in food intake begins to have its effect.

The results show that the mean diameters and length growth rates changed together and in about the same proportions in response to the nutritional changes. This contrasts with the variable effects of large amounts of some hormones on wool growth (Downes and Wallace 1965), and with the effect of exposing the skin to low temperatures, which reduces length growth rate without markedly affecting diameter (Downes and Hutchinson 1969; Lyne, Jolly, and Hollis 1970). The ratio of mean length of wool grown per day to the mean diameter ranged from 10 to 16 for the sheep used in the present experiments, but the relative constancy in the ratio for each sheep, even when the rate of wool growth was changed several-fold, is striking. The fact that the ratios were the same a year later, after large changes in body weight and wool growth rate had occurred, provides further evidence of the constancy of the length : diameter ratios and suggests that the ratio has a characteristic value for each sheep. The possibility of using either length or diameter measurements alone to assess wool growth responses is being examined in other experiments.

V. REFERENCES

- CHAPMAN, R. E. (1960).—In "The Biology of the Fleece". Tech. Pap. Anim. Res. Lab. CSIRO Aust. No. 3. p. 102.
- DOWNES, A. M. (1961).—*Aust. J. biol. Sci.* **14**, 109.
- DOWNES, A. M. (1965).—In "Biology of the Skin and Hair Growth". (Eds. A. G. Lyne and B. F. Short.) p. 345. (Angus and Robertson Ltd.: Sydney.)
- DOWNES, A. M., CLARKE, W. H., and DAGG, T. C. (1967).—*Atom. Energy, Sydney* **10**(2), 2.
- DOWNES, A. M., and HUTCHINSON, J. C. D. (1969).—*J. agric. Sci., Camb.* **72**, 155.
- DOWNES, A. M., and LYNE, A. G. (1959).—*Nature, Lond.* **184**, 1884.
- DOWNES, A. M., and LYNE, A. G. (1961).—*Aust. J. biol. Sci.* **14**, 120.
- DOWNES, A. M., and TILL, A. R. (1963).—*Nature, Lond.* **197**, 449.
- DOWNES, A. M., and WALLACE, A. L. C. (1965).—In "Biology of the Skin and Hair Growth". (Eds. A. G. Lyne and B. F. Short.) p. 679. (Angus and Robertson Ltd.: Sydney.)
- GRAHAM, N. MCC. (1969).—*Aust. J. agric. Res.* **20**, 375.
- LYNE, A. G., JOLLY, M., and HOLLIS, D. E. (1970).—*J. agric. Sci., Camb.* **74**, 83.
- STORY, L. F., and ROSS, D. A. (1960).—*N.Z. Jl agric. Res.* **3**, 113.
- TILL, A. R., and DOWNES, A. M. (1963).—*Lab. Pract.* **12**, 1008.