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THE INFLUENCE OF THYROXINE ON WOOL GROWTH

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IT HAS LONG BEEN KNOWN that the thyroid glands are necessary for normal wool growth. Thyroidectomy reduces wool growth to about 40 to 50% of normal, if thyroidectomy is complete, (Simpson, 1924; Marston and Pierce, 1932; Ferguson, 1951; Ferguson *et. al.*, 1956). If even a small fragment of thyroid tissue remains after the operation, wool growth is normal. This suggests that thyroxine may have a permissive role and not a regulatory one so far as wool growth is concerned.

More recently evidence has been produced that iodinated casein or thyroxine administered to normal sheep causes a stimulation of wool growth (Maqsood, 1950, 1955; Hart, 1954, 1955, 1957). It is not clear whether such stimulation occurs within the physiological range of thyroid secretion rate or whether it occurs only when the dose of thyroxine reaches hyperthyroid levels, causing a substantial increase in metabolic rate.

However, whether or not thyroxine determines the normal level of wool growth, the question arises as to whether the administration of thyroxine to normal sheep is a means of increasing wool production commercially.

The present experiment was carried out to determine the dose range of thyroxine which stimulated wool growth and the extent to which any stimulation produced was associated with changes in appetite and body weight.

Materials and Methods

Forty-two medium wool Merino ewes housed in individual indoor pens and fed *ad lib.* were used for the experiment. Twenty-three of the ewes had been fed a mixed chaff and concentrate ration containing about 16% crude protein; the remaining nineteen had been fed a mixture containing about 11% crude protein. Sixteen of the ewes on the high protein ration and ten of those on the low protein ration had been in the animal house for some months and were in fatter condition than the remainder which were brought into the animal house just prior to the commencement of the experiment. Four groups were randomly formed except that in each group each

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class of ewe was represented as equally as possible. The same diets were continued throughout the experiment and after a preliminary period of 4 weeks sheep in three groups were injected at the rate of 0.25, 0.5, and 1.0 mg per sheep per day of monosodium-*l*-thyroxine dissolved in 0.9% NaCl brought to pH 9.3 by the addition of NaOH. Injections were given three times per week for 9 weeks—subsequently referred to as Experiment 1. After this, dose rates were increased to 1, 2, and 4 mg per day respectively for a further 8 weeks—subsequently referred to as Experiment 2. The fourth group was maintained as a control in both experiments.

Wool growth was measured by clipping a 10 × 10 cm area defined by tattoo lines on the midside, at 4-weekly intervals except for a 5-weekly period in the first part of Experiment 1. Total wool growth rates were estimated from the ratio of total to sample wool growth estimated from other data. The ratio is $6 \times W^{2/3}$ where W is the body weight in kg at the time the sample area is defined.

The wool samples were washed successively with ether and cold water and dried at 100°C.

The sheep were weighed at weekly intervals. Respiration rate was measured morning and afternoon once a week. Rectal temperature and heart rate were measured in the middle of Experiment 2.

Results

Two control sheep lost their appetites soon after the start of Experiment 1 and the data for these sheep have been excluded from the analysis of both experiments. Towards the end of Experiment 2 two more control sheep lost their appetite and the data for these sheep have been omitted from the analysis of Experiment 2.

Mortality

During the second experiment, 9 ewes on the two higher thyroxine dose levels died after showing symptoms of acute hyperthyroidism. A greater proportion of the deaths occurred in the high protein group (7 out of 11 ewes) than in the low protein group (2 out of 9 ewes).

Feed Intake

Prior to the experiment, the feed intake of the sheep which had been kept in the animal house progressively declined as the sheep became fatter and this decline continued during the experimental periods. The sheep which were brought into the animal house just prior to the experiment had a higher feed intake and they declined slightly more in feed intake during the experiment. Similar results were obtained on both rations.

Feed intakes were found to be proportional to body weight rather than to a fractional power of it (Ferguson, 1956). Feed intake per unit body weight was in turn found to be proportional to the corresponding value in the preliminary period.

The effect of thyroxine on feed intake for each wool growth period in both experiments is shown in Fig. 1. Feed intake per unit body weight has been expressed as a percentage of the preliminary period value and in absolute terms adjusted for preliminary period differences.

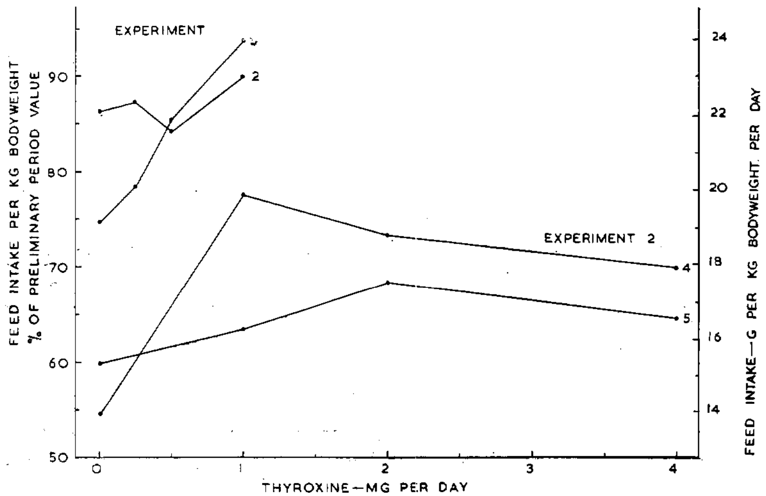

Fig. 1: The influence of thyroxine on feed intake. The figures opposite each curve refer to the wool growth period.

Feed intake was increased by thyroxine treatment up to a dose of 1 mg per day. The response was greater in the second period of each experiment.

With the decline in feed intake throughout the experiment, the response to thyroxine represented a lessening in this decline rather than an increase in intake above the level attained in the preliminary period. The response was similar in the two lots of sheep with different pre-experimental history but both groups had reached a stage of body condition at which appetite was declining and it is difficult to forecast whether thyroxine would have the same effect on the appetite of sheep in leaner condition when the factors limiting appetite may be different.

When the sheep used in the present experiment were leaner, they ate up to 40 g of the same rations per kg body weight.

Body Weight and Maintenance Requirements

Changes in body weight were measured by calculating the regression of body weight on time for both experiments. The regressions were calculated for each wool growth period separately but for the present analysis regressions calculated for the whole of each experiment have been used. Similar results were obtained with both rations.

The effect of thyroxine on the rate of body weight change is shown in Fig. 2.

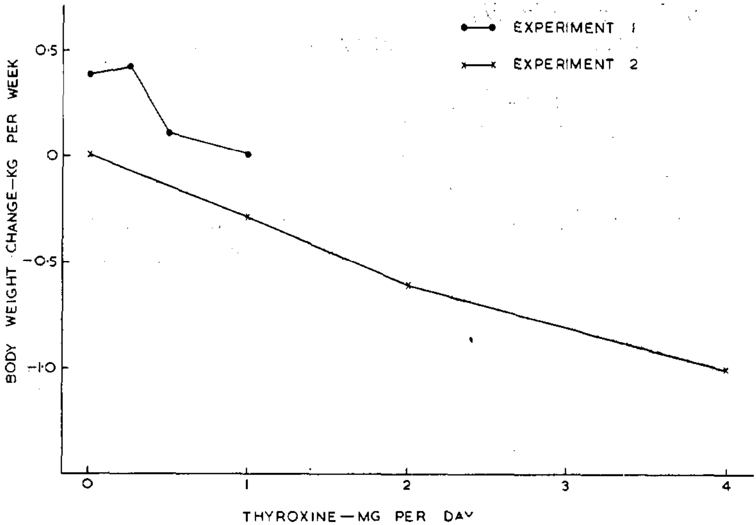

Fig. 2: The influence of thyroxine on body weight change.

During Experiment 1, with higher average feed intakes, the effect of thyroxine was to reduce the rate of body weight increase. In Experiment 2, with lower feed intakes, thyroxine caused a body weight decrease. However, the slope of the curve relating body weight change to thyroxine dosage was similar in both experiments.

The increase in feed intake caused by thyroxine treatment is apparently not sufficient to provide all the energy required for the increased metabolic rate. The relative extents to which the increased energy requirement is met by an increase in feed intake and by a decrease in the amount of body tissue stored may well vary in different circumstances.

An estimate of the increased metabolic rate caused by thyroxine can be made by relating at each dose level the rate of body weight change to feed intake. The feed intake which corresponds to zero body weight change is an estimate of the maintenance feed requirement.

The equation expressing the relation of the rate of body weight change to feed intake should meet two criteria. First, it should express the fact that the maintenance feed intake is proportional to body weight or to a power of it. Secondly, the relation between the rate of body weight change and *feed intake above maintenance* should be independent of body weight.

These requirements are met by an equation,

$$y/W = a + b(x/W)$$

where y = rate of body weight change
W = body weight
x = feed intake
and a and b = constants.

When body weight change is zero, x/W the feed intake per unit body weight equals a/b.

Evidence from other experiments (Ferguson, unpublished) indicates that the maintenance feed intake of sheep in pens may

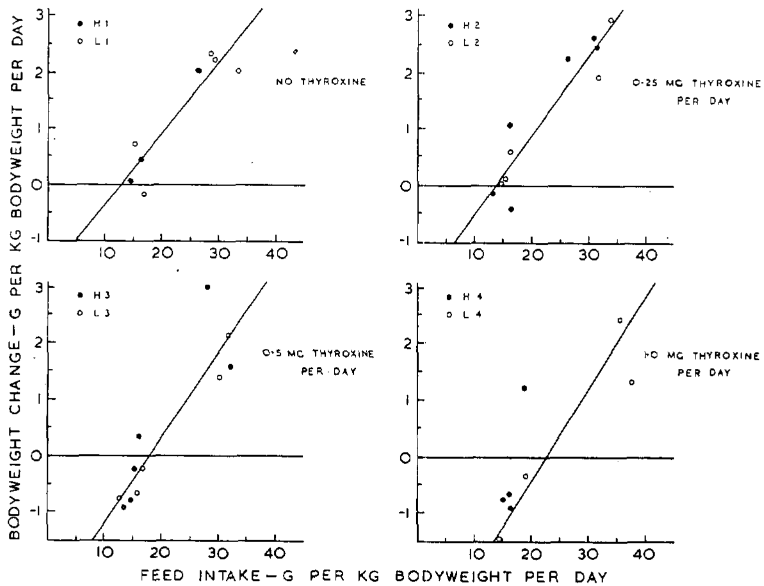

Fig. 3: The relation of body weight change to feed intake—Experiment 1. H1 - H4, high protein ration; L1 - L4, low protein ration.

be proportional to body weight rather than to a fractional power of it. A power of 1 has therefore been used for body weight in the above equation.

The fit of this equation to the data of Experiment 1 is shown in Fig. 3. Figure 4 shows the equation fitted to the data of Experiment 2.

Table 1 shows the values of the constants a and b and of x/W when y is zero for each thyroxine dose level.

TABLE 1: VALUES OF CONSTANTS IN THE EQUATION RELATING BODY WEIGHT CHANGES TO FEED INTAKE.

Experiment	Thyroxine mg per day	a	b	x/W when $y=0$ g/kg B.W./day
1	0	—1.64	0.128	12.8
	0.25	—1.92	0.141	13.6
	0.5	—2.74	0.154	17.8
	1.0	—3.68	0.164	22.5
2	0	—1.37	0.079	17.3
	1	—2.46	0.09	27.1
	2	—4.7	0.165	28.6
	4	—	—	40.0*

*Estimated using value of b for 2 mg thyroxine group.

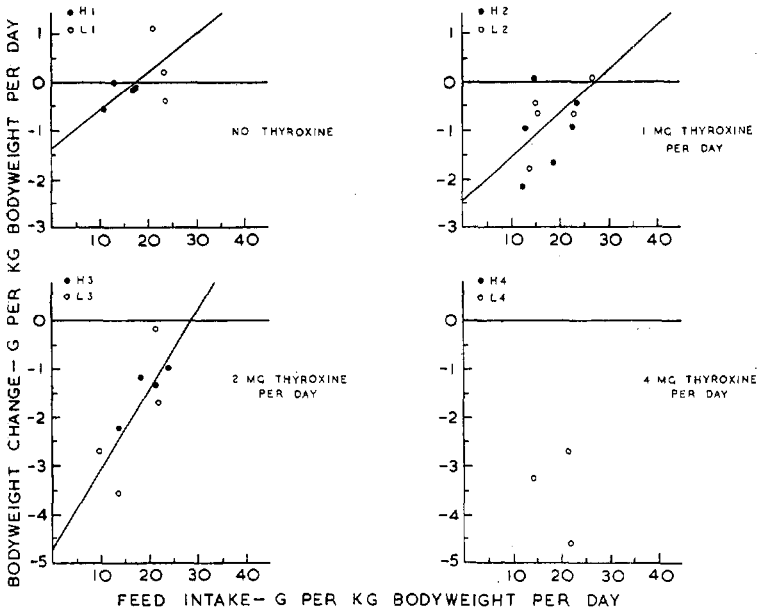

Fig. 4: The relation of body weight change to feed intake—Experiment 2. H1 - H4, high protein ration; L1 - L4, low protein ration.

Insufficient data were available to fit the equation to the group on 4 mg thyroxine per day and the maintenance intake has been estimated in this group using the value of b obtained from the group on the next highest thyroxine level.

In both experiments the estimates of maintenance feed intake rose with increasing thyroxine dosage. In Experiment 2 the maintenance feed intake of the control group is higher than in Experiment 1. This may be due to the fatter condition of the sheep in the second experiment. Other evidence indicates that the maintenance intake of sheep under pen conditions varies with the body condition (Ferguson, unpublished).

The value of b is an estimate of the body weight change per unit of feed intake above or below maintenance. The low values of b for the control group suggest that the body weight changes were largely in fat content and that there was a high heat increment associated with feed intake increase. Much higher values of b are obtained with sheep in leaner condition or with growing sheep (Ferguson, unpublished).

The higher values of b found with increasing thyroxine dosage suggest body weight changes of lower energy content or a reduction in the heat increment of feed intake increase. However, little is known of the effect of thyroxine on digestibility in the sheep.

Supporting evidence of the increase in metabolic rate induced by thyroxine is given by the data on respiration rate, heart rate and rectal temperature. Figure 5 shows these characteristics and also the maintenance feed intake plotted against thyroxine dosage. Increasing evaporation from the respiratory surfaces by increasing respiration rate is an important mechanism for increasing heat loss in the sheep. The data in Fig. 5 indicate that the increase in metabolic rate caused by thyroxine requires a substantial use of the mechanisms of heat loss and must lower the tolerance of the sheep to an external heat load.

Wool Growth

Wool growth responses to thyroxine were similar for the sheep on both rations and also for the sheep of different pre-experimental history when the data were expressed as percentages of the corresponding values in the preliminary period. The responses were a little greater in the second period of each experiment. However, the data for both periods in each experiment have been combined in the following analysis since essen-

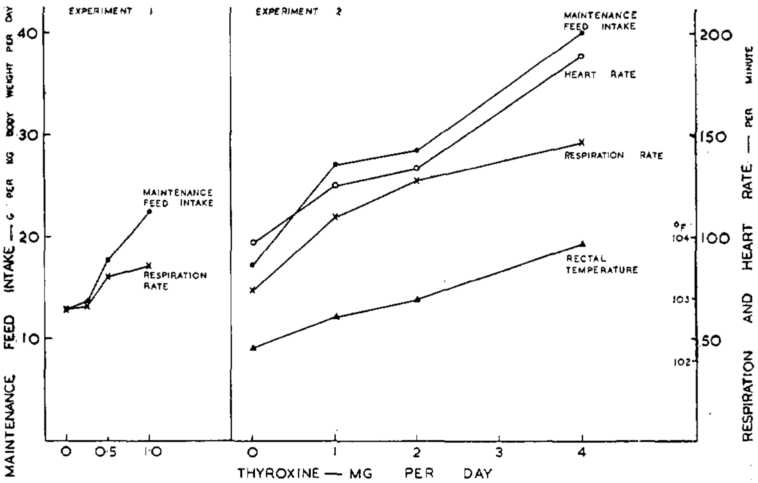

Fig. 5: The influence of thyroxine on maintenance feed intake, respiration rate, heart rate, and rectal temperature.

tially similar results were obtained from the analysis of each period separately.

The combined data are shown in Fig. 6 in which wool growth, feed intake and the gross efficiency of wool growth are plotted against thyroxine dosages for both experiments. Wool growth as a proportion of the crude protein intake has been termed the gross efficiency.

During Experiment 1, wool growth increased with increasing thyroxine dosage to 16% above the control level. In Experiment 2 the maximum response of 25% above the control level was produced at a dosage of 2 mg of thyroxine per day.

The Efficiency of Wool Growth

Figure 6 shows an increase in gross efficiency of 10% with thyroxine treatment in Experiment 1 and an increase of 13% in Experiment 2.

This increase in efficiency has occurred despite an increase in feed intake which normally causes a decrease in gross efficiency (Ferguson, 1956). The increase in efficiency with thyroxine treatment could arise from two sources. First, it could arise from an increase in wool growth for which nutrients are supplied from the difference in rate of body weight change between thyroxine treated and control sheep.

Secondly, it could arise from a true increase in the efficiency with which the wool follicles convert both sources of nutrients into wool.

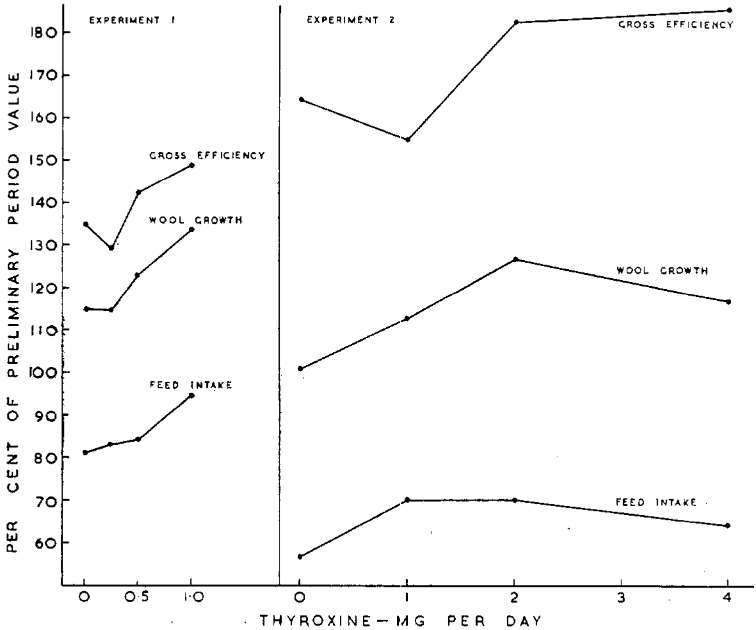

Fig. 6: The influence of thyroxine on wool growth, feed intake and gross efficiency of wool growth.

The likely source of the increase in gross efficiency with thyroxine treatment is indicated by an analysis of other data, which will be published more fully elsewhere, on the relation between wool growth, crude protein intake and the body weight change.

Ferguson *et al.* (1949) showed that the relation between wool growth and crude protein intake followed an exponential with increasing crude protein intake (Ferguson, 1956). Originally it was considered that the fall in efficiency might be due to saturation of the various intermediary processes in the conversion of feed crude protein into wool. However, an alternative view might be taken that above a maintenance energy intake the products of protein digestion are partly converted into body tissue and a smaller proportion of the nutrients are available for wool growth thereby reducing the gross efficiency; below maintenance the efficiency of wool growth is increased by the wool produced from the nutrients supplied by the catabolism of body tissues.

The following equation expresses this latter view:

$W/i = E - k(y/i)$

where W = wool growth rate
i = crude protein intake
E = net efficiency of wool growth
y = rate of body weight change
and k = a constant.

E, the net efficiency, equals the gross efficiency when body weight remains steady, that is, when the sheep is on a maintenance feed intake. An average value of 0.01978 was found for the constant k.

Without discussing the equation fully here, it is of interest that the linear relation between gross efficiency and rate of body weight change implies that the storage of the products of feed crude protein as body tissue at intakes above maintenance and its subsequent conversion into wool at intakes below maintenance is no less efficient than the conversion of feed crude protein into wool under maintenance conditions. This does not necessarily imply that there is no wastage in the storage of feed as body protein with subsequent conversion into wool. With the decline in feed intake which necessitates the catabolism of body tissues, there is probably an increase in the efficiency of utilization of feed crude protein which offsets any wastage. However, there appears to be little information by which such wastage may be assessed. Since the products of protein digestion are probably normally synthesized into plasma proteins for transport, the storage of protein in the tissues prior to breakdown and synthesis into wool may not involve additional loss.

Applying the above equation to the present investigation, an estimate of the constant k was found for the control sheep from the ratio of differences in efficiency to differences in the rate of body weight change between Experiments 1 and 2. The value obtained was close to the value given above which has been used to estimate the net efficiency of wool growth of the sheep in both experiments.

The value for E was found to be similar in Experiments 1 and 2 for the control sheep but a lower value was obtained for the preliminary period. This probably reflects a seasonal increase in E, although the estimate of body weight change in the short preliminary period is subject to greater error than the estimates for the two experimental periods. However, the

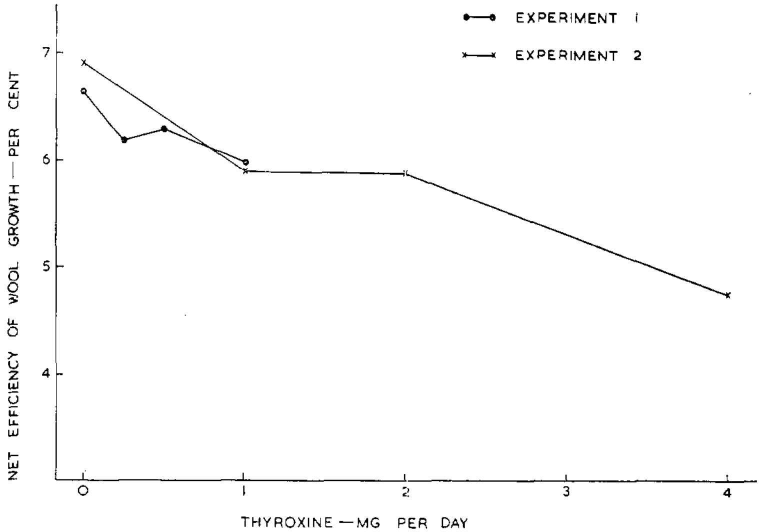

Fig. 7: The influence of thyroxine on the net efficiency of wool growth.

values of E in Experiments 1 and 2 were proportional to the corresponding values in the preliminary period.

The mean value for E for each group adjusted accordingly for differences in the preliminary period is shown plotted against thyroxine dose in Fig. 7. The values of E have been multiplied by 100 to give percentage efficiency. It can be seen that the net efficiency of wool growth falls with increasing thyroxine dose. The increase in gross efficiency brought about by thyroxine treatment can thus be attributed to the effects on the storage of protein in body tissues, and it is unnecessary to postulate an increase in efficiency of the wool follicles. The decrease in net efficiency with increasing thyroxine dosage is possibly due to an increase in the maintenance crude protein requirement with increasing metabolic rate.

Discussion.

The results of the present investigation do not support an hypothesis that the thyroid has a regulatory role in determining the wool growth of a sheep. The variability in wool growth between untreated sheep was many times greater than the variability which could be produced by thyroxine treatment. Furthermore, there was no evidence in untreated sheep of any relation between wool growth and the measures of metabolic rate used.

Complete assessment of the commercial possibilities of thyroxine treatment in wool production obviously cannot be made on the basis of one pen experiment. The quantitative responses of other breeds of sheep or of sheep in leaner condition may be different from those of the sheep used in the present investigation. Furthermore, the method of thyroxine administration used is inappropriate for commercial use.

However, the results may be of some use in the interpretation of field trials. Thyroxine treatment increased wool growth by increasing appetite and by reducing the storage of protein in body tissues, there being a decrease in the net efficiency of wool growth. These results emphasize that differences in feed intake and body weight changes must be taken into account in assessing the economic significance of thyroxine treatment from field experiments.

The average stocking rate is ultimately determined by the maintenance, growth and lactational requirements of the sheep and it is not valid to compare the wool production of thyroxine treated and untreated sheep stocked at the same rate. Such a comparison takes account neither of the relatively greater depletion of the pasture by the treated sheep nor of the differences in body weight produced by the treatment. The latter is important in view of the evidence that body tissue protein can be subsequently converted into wool with no loss of efficiency.

Unless pasture intake is restricted either by pasture conditions or by some form of restricted grazing, it is not possible to equalize both the total feed consumption and the body weight changes of treated and untreated sheep to make a valid comparison for economic purposes. Under pasture conditions allowing *ad lib.* intakes, the rate of body weight increase for thyroxine treated sheep will be less than for untreated sheep whatever the relative stocking rates.

Such considerations make it difficult to evaluate the field trial reported by Hart (1957) in which neither body weight changes nor relative pasture intakes of treated and control sheep are known.

In times of unusually flush growth it may be argued that the increase in appetite induced by thyroxine treatment makes use of pasture which is otherwise wasted. However, the increment of wool from this increment of pasture will be mostly offset by the overall decrease in net efficiency produced by thyroxine treatment. Furthermore, at the time thyroxine treatment is started it will be only an assumption that pasture wastage will occur.

Summary

The wool growth, feed intake and body weight responses to increasing doses of monosodium-*l*-thyroxine were observed.

Thyroxine treatment caused an increase in feed intake and in the metabolic rate as measured by the feed intake necessary to maintain body weight. The increase in feed intake was not sufficient to prevent decreases in body weight relative to untreated sheep.

Wool growth was increased by thyroxine treatment. This increase could be attributed to the extra nutrients supplied by the increase in appetite and by the decrease in the storage of protein in body tissues.

Estimates were made of the wool growth equivalent of body weight change. When adjustment of the data was made accordingly, the net efficiency of wool growth was found to decline with thyroxine treatment. It is suggested that this is due to an increase in the crude protein maintenance requirement with metabolic rate.

The results do not support the view that thyroxine has more than a permissive role in determining the normal wool growth rate of a sheep. The commercial use of thyroxine treatment in wool production is discussed.

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DISCUSSION

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