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The Effect of Diet and Body Condition on the Heat Regulating System of the Merino Sheep.

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Introduction.

In all biological investigation the rôle exerted by intercurrent factors is a matter demanding constant recognition and attention. This is also clearly seen in bioclimatological work on animals where the reaction to climatic forces is constantly being influenced by the physiological state of the individual and the extent of its adaptation. In this connection it is to be expected that in addition to the rôle played by species and age the nutritional status of an animal would exert itself as a dominant factor in determining the body response to external environmental conditions including those of climate. From a survey of the literature there is, however, little to indicate in how far the plane of nutrition may affect the reaction of an animal to climatic conditions. In view of this fact a series of experiments was undertaken on merino sheep in which the physiological response of separate groups comprised of well-fed and poorly-fed animals was measured under identical conditions of exposure either to heat or to cold.

Experiment No. 1.

Procedure.

The first experiment was carried out during the winter months of June and July. Sixteen merino sheep (castrated males) of similar stature and age (4 to 6 tooth) were selected, eight as being in good condition and eight in poor condition. The animals were placed in individual feeding pens under a galvanized roof but open at the sides. The better-conditioned sheep were fed 350 gm. yellow maize daily in addition to lucerne hay *ad lib.*, while the poorer sheep received poor quality grass hay *ad lib.* only. All the animals were given 3 gm. NaCl per day and water was unrestricted. The average daily consumption of these diets was (*a*) well-fed group—350 gm. maize and 790 gm. lucerne hay. (*b*) Poorly-fed group—600 gm. grass hay.

After an initial period of one month on the above diets, one half of the well-fed group was given grass hay only and half of the poorly-fed sheep were put on to the maize and lucerne ration. This resulted, therefore, in the following groups:—

1. Lucerne and maize throughout.
2. Lucerne and maize followed by grass hay.
3. Grass hay throughout.
4. Grass hay followed by lucerne and maize.

The Effect of the Diets on Body Weight.

TABLE 1.

Group.	Days in Experiment.	0	30	50
	Diet	—	Good	Good.
1	Av. body weight in lb	104	108	107
	Diet	—	Good	Poor.
2	Av. body weight in lb	110	109	97
	Diet	—	Poor	Poor.
3	Av. body weight in lb	78	67	57
	Diet	—	Poor	Good.
4	Av. body weight in lb	83	75	82

From the above table it will be seen that the diet of maize and lucerne was sufficient to maintain the weight of the good-conditioned sheep and to cause an increase in that of the poor sheep. The hay ration, on the other hand, was inadequate and caused a steady drop in the body weight of all the sheep to which it was fed.

The Effect of Diet on Rectal Temperature.

After the sheep had been on the experimental rations for 21 days, their rectal temperatures were recorded at 8 a.m. and 3 p.m. daily. This was done while the animals were in the feeding pens protected from the direct rays of the sun by the roof.

For the sake of simplicity only groups 1 and 3, i.e., those which received the good and poor rations throughout the experiment respectively, will be dealt with first.

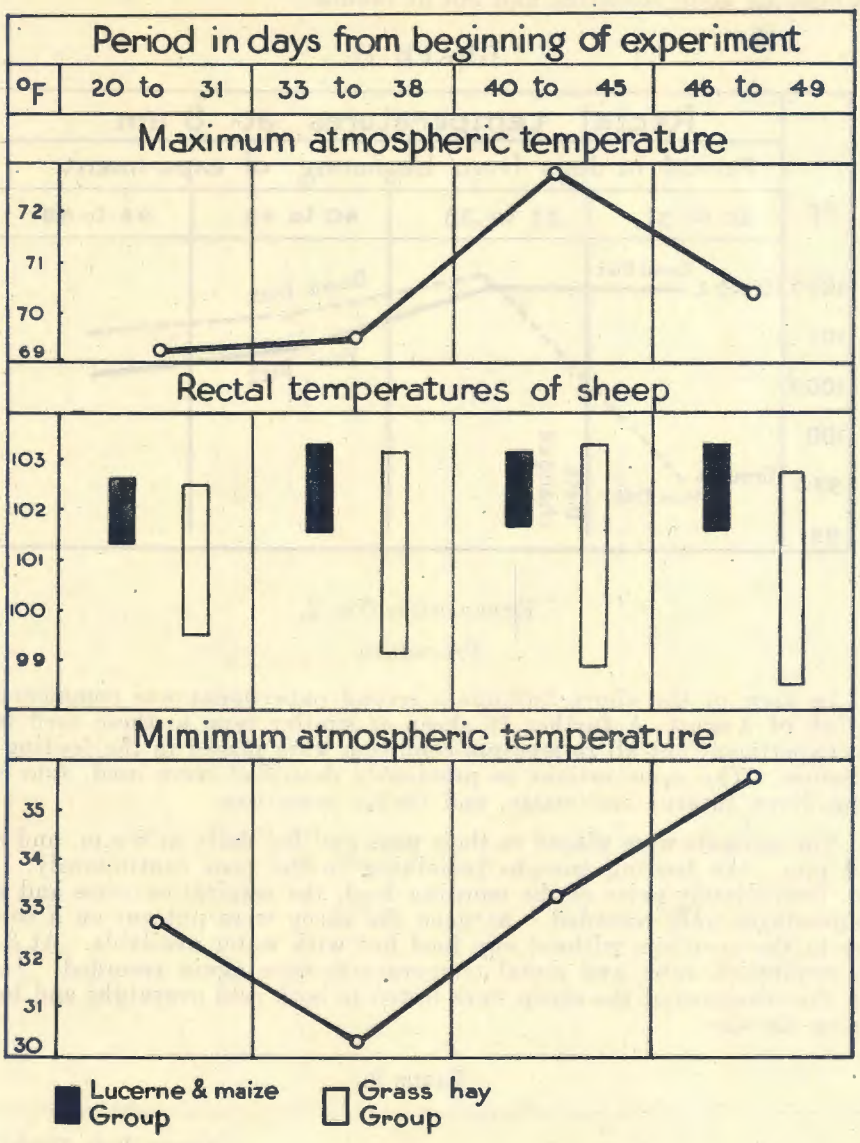
Graph I depicts the average rectal temperatures at 8 a.m. and 3 p.m. respectively of groups 1 and 3 over different periods during the experiment. The bottom end of the columns represent the figures for 8 a.m. and the top end those for 3 p.m. The length of the column, therefore, depicts the range between these two readings. The average maximum and minimum atmospheric temperatures recorded during the same periods are given above and below respectively.

It will be noted from this graph that the rectal temperatures of the poorly-fed sheep (unshaded columns) taken at 8 a.m. were considerably lower than those of their well-fed mates (black columns) and that this difference became steadily accentuated as time passed and the poorly-fed animals became progressively more emaciated. Furthermore this decline in the rectal temperature in the early morning was independent of the slight rise in minimum atmospheric temperatures encountered during the latter part of the experiment and must be attributed either to the poor diet or to the consequent drop in body condition.

The Effect of Change of Diet on Rectal Temperature.

As already indicated, 31 days after the commencement of the experiment, half of the sheep on the maize and lucerne ration was given grass hay only, while half of those previously on the poor ration were fed maize and lucerne. These groups are designated 2 and 4 respectively.

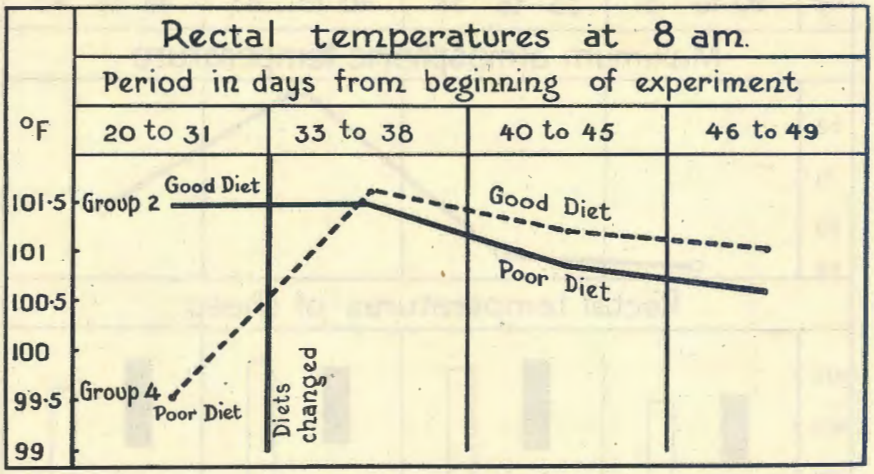
GRAPH I.



The effects of these changes in diet on the rectal temperatures at 8 a.m. are shown in Graph II. As the figures for the 3 p.m. readings remained unchanged they are not included in the graph. It will be seen that the better diet caused an immediate rise in the rectal temperatures of the poor sheep while the inadequate diet caused a more delayed and less marked decline in that of the good-conditioned animals. These findings indicate that the food intake of sheep has a direct effect on their ability to maintain the body

temperature during exposure to cold. The changing over of the diets of these two groups also refutes the legitimate objection that the original grouping was done on body condition and not at random.

GRAPH II.



EXPERIMENT No. 2.

Procedure.

In view of the above findings a second experiment was commenced on the 5th of August. A further 16 sheep of similar type to those used in the first experiment but all in medium condition were placed in the feeding pens as before. The same rations as previously described were used, four sheep being given lucerne and maize, and twelve grass hay.

The animals were placed in their pens and fed daily at 8 a.m. and again at 4 p.m., the feeding troughs remaining in the pens continuously. At 8 a.m. immediately prior to the morning feed, the respiration rates and rectal temperatures were recorded. At noon the sheep were put out on a concrete floor in the open sun without any food but with water available. At 3 p.m. the respiration rates and rectal temperatures were again recorded. In this way the reactions of the sheep were tested to both cold overnight and to heat during the day.

TABLE 2.

Ration.	Average Body Weight (lb.).	
	Initial.	After 30 Days.
Maize and Lucerne	70	74
Grass Hay	62	56

The effect of the different diets on the body weights of the animals was similar to that in the first experiment as will be seen from the figures in Table 2.

The Effect of Diet on Rectal Temperature.

The procedure described above was continued for the first 30 days of the experiment, the respiratory rates and rectal temperatures being recorded from the ninth day onwards. The findings are shown in graph III which will be found on page 325 of the text* The period now to be discussed, i.e., from the 9th to the 30th day is designated " Period 1 ". The same system of plotting the rectal temperatures as used in graph I is again employed, that is the 8 a.m. readings are plotted below and the 3 p.m. readings above. The *unbroken columns* represent data from the *well-fed* sheep and the *broken columns* from the *poorly-fed* animals. The letter 3 denotes that a statistically significant difference at 5 per cent. level was found between the rectal temperatures of the two groups on that particular occasion.

It will be seen from graph III that the morning rectal temperatures of the poorly-fed sheep were again consistently lower than those of the well-fed animals, this difference ranging from 0·5 to 2·0° F. Further there was a tendency for the poorly-fed sheep to be more directly affected by variations in the atmospheric temperature.

On the other hand it will be noted that at 3 p.m., i.e., after remaining for three hours in the sun, the undernourished sheep, on warm days, showed an average rectal temperature up to 0·8° F. higher than that of the sheep on a good ration. On the two days (16th and 30th) on which the atmospheric temperature did not exceed 75° F., the thin sheep showed an average rectal temperature below that of the well-fed group. These findings afford evidence therefore that under-nourishment rendered the sheep more thermo-labile with the extremes of environmental temperature reflected to an exaggerated degree in their body temperature.

Period 2.

Thirty days after the experiment was started, four of the sheep receiving grass hay were given the ration of maize and lucerne, thus introducing a third group (indicated by dotted columns on the graph). The time during which these three groups were maintained is designated Period 2 in Graph III. In other respects the experiment was continued as before.

It will be seen from the graph that the relations between the rectal temperatures of the original groups (1 and 2) continued as before. The behaviour of the new group (3) will now be discussed.

Twenty-four hours after the change in diet (32nd day) the average morning rectal temperature of these sheep had risen by 1·4° F. and showed a statistically significant difference (1 per cent. level) from the temperatures of the sheep still receiving the grass hay only. The change from a poor to an adequate diet, therefore, again caused an immediate rise in the rectal temperature after exposure to cold weather (30° F.).

It will be seen, however, that the temperatures of group 3 taken at 3 p.m. did not for some considerable time differ materially from those of the under-fed sheep, the first significant difference occurring 21 days after the change

* The reader is asked to follow the subsequent discussions on Graph III.

in the diet, i,e., on the 51st day of the experiment. The appearance of this reaction was probably delayed by the cold weather encountered between the 43rd and 49th days of the experiment as shown by the maximal temperatures for that period. In this connection it is of interest to note that during this cold spell the afternoon temperatures of the underfed sheep were markedly depressed and were actually below those of both the groups on an adequate ration.

Period 3.

After the experiment had been running for 45 days the animals in group 1 (maize and lucerne ration throughout) were romoved and the work continued with groups 2 and 3. As will be seen from the graph the animals receiving the adequate ration (group 3) gradually regained their ability to control the rise in body temperature when exposed to heat, the rectal temperature of this group at 3 p.m. becoming significantly lower than that of the poor animals.

The Effect of the Diet on the Respiratory Rate.

Before proceeding to a discussion of the respiratory rates of the three groups it should be emphasized that in sheep as in other ruminant animals respiration assumes special significance owing to the fact that a considerable amount of carbon dioxide normally eliminated from the lungs is derived not only from the tissue metabolism but through absorption from the digestive tract in which active fermentation of carbohydrates is a characteristic feature. Moreover, in the absence of an active sweating mechanism coupled with a thick wool covering, body temperature in merino sheep is largely controlled through changes in respiration.

Respiration at 8 *a.m.*

It will be seen from graph III that, at 8 a.m., the sheep on the poor diet (broken lines) showed respiratory rates approximately one half ($\pm$ 20 per min.) of the well-nourished animals ($\pm$ 40 per min.). As the question of heat elimination need not be considered in the temperatures encountered at this time of the day, this depression in the speed of respiration can be attributed to a decreased tissue metabolism and to a lesser absorption of carbon dioxide from the alimentary tract. It will, however, be seen that rate of respiration of the well-fed group appears to have been more definitely influenced by the level of the minimum atmospheric temperature recorded the previous night, than was the case with the underfed group.

Furthermore it will be noted that when the diet of group 3 (dotted line) was changed from grass hay to maize and lucerne (see Period 2 on graph III) these animals showed a gradual rise in their respiratory rate at 8 a.m. until it was equal to that of group 1 on the 10th day after the change in ration. This rise in respiratory rate did not coincide with the rise in body temperature the latter occurring much more promptly.

The Respiratory Rate at 3 *p.m.*

The undernourished sheep showed a slower respiratory rate ($\pm$40 per min.) than their well-fed mates after three hours' exposure in the sun (80 to 160 per min.). This absence of panting might be considered as being the cause of the higher rectal temperatures simultaneously recorded, but as will

be seen in Period 2, the change in the ration of group 3 caused a prompt rise in their rate of breathing without a corresponding drop in body temperature (from 31 to 34 days). This indicates that in sheep changed from a poor to a good diet the consequent alteration in digestion and metabolism immediately causes a change in the relationship of respiratory rate to body temperature.

Experiment No. 3.

In order to verify these findings in an acute experiment, representative animals from groups 1 and 2 were tested in a hot box. This apparatus consisted of a thermostatically controlled, electrically heated cabinet into which the animal was placed with the head protruding. The temperature inside the box was maintained at between 105° and 108° F. and each animal was kept in it for a period of one hour. The results of such an experiment are shown in Table 3.

Table 3.

Sheep No.	Diet.	Body Weight (lb.).	Prior to entering Box.		After 1 Hr. in Box.		Difference.	
			Resp.	Temp.	Resp.	Temp.	Resp.	Temp.
1	Good....	71	30	103·3	132	104·0	102	0·7
2	Good....	75	36	102·8	106	103·7	70	0·9
13	Poor....	45	20	100·4	20	102·1	Nil	1·7
14	Poor....	50	22	102·9	24	104·6	Nil	1·7

These results afford striking evidence that undernourishment and poverty cause a suppression of the normal panting reflex and marked thermo-lability in experimental sheep.

Discussion.

It has been clearly shown that both general body condition and diet have a marked influence on the heat regulating system of the merino sheep. The effect on the resistance to cold and to heat will be dealt with separately.

(*a*) *The Maintenance of Body Temperature in a Cold Environment.*

The subnormal rectal temperatures shown by the thin, undernourished sheep after exposure to cold can be attributed to a lack of heat-producing material in the body. One of the objects of this experiment was to ascertain in how far digestion and appetite were affected by a poor diet in conjunction with exposure to cold. It was found, however, that appetite was well maintained while ruminal movements and defaecation were unimpaired and no secondary complications such as nutritional oedema or pneumonia were encountered. In other words the poorly-fed sheep appeared thin but healthy, the only demonstrable effects of exposure to cold being the low rectal temperature and slow respiratory rate. This indicates therefore that, in the merino sheep, the control of body temperature is the first of the vital functions to be impaired by undernourishment, and not digestion itself as had been suspected when these experiments were started.

The immediate rise in body temperature in the early morning shown by poor sheep after being given an adequate diet must be explained as being due to the availability of heat-producing material and to the specific dynamic action of the food. The promptness of the response is of great interest and also of practical value when dealing with emaciated stock in severe winter conditions as it indicates that even poor sheep may respond immediately to a good diet.

On the other hand it was shown in Experiment 1 that good-conditioned sheep when suddenly placed on an inadequate ration were able to utilize their body reserves for the maintenance of body temperature for some considerable time. Under the conditions of the experiment this period was approximately 10 days.

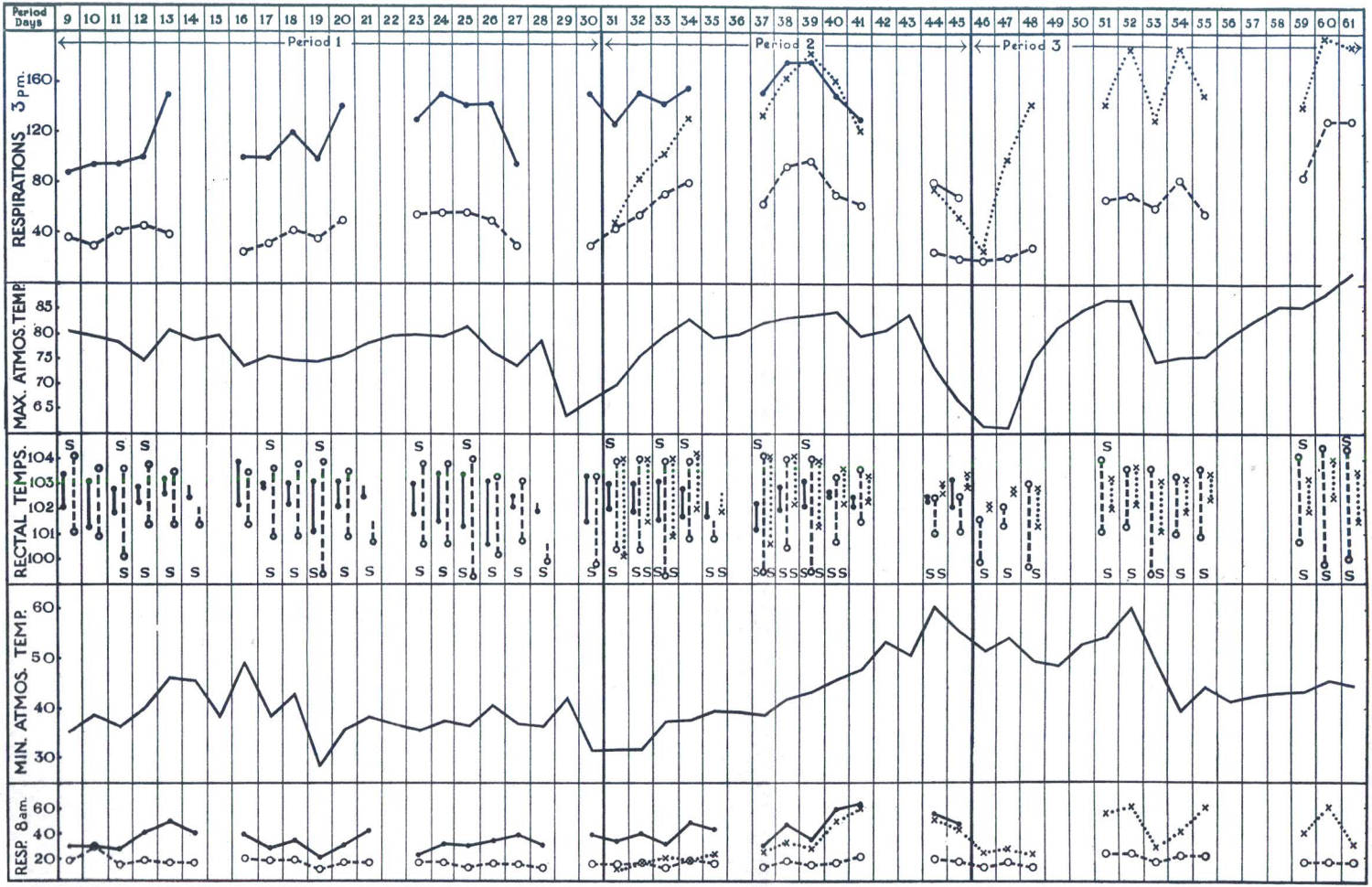
(*b*) *The Control of Body Temperature in a Hot Environment.*

The inability of the poor sheep to control body temperature when exposed to heat depends upon the general body condition probably through the physiological state of the central heat-regulating mechanism together with the peripheral vasomotor control and not on the calorific value of the diet at the time of the test. This statement is based on the fact that when thin animals were placed on a good diet (Exp. 2, Group 3) there was an interval of 21 days before there was any significant difference between the rectal temperatures of these sheep and those of their counterparts still receiving the poor ration, after exposure to the sun. Table 4 summarizes this aspect of the results.

TABLE 4.

Duration of Experiment (Days).	Average Body Weight.			Remarks. (See Graph III).
	Gr. 1 (Well Fed).	Gr. 2 (Poor Diet).	Gr. 3 (Poor Diet).	
0	70	63	—	—
9	—	—	—	Body temp. Group 2 significantly higher than Group 1 at 3 p.m.
11	70	57	—	Body temp. Group 2 significantly lower than Group 1 at 8 a.m.
25	74	57	53	—
30	—	—	(Well Fed)	Ration Group 3 changed.
31	—	—	—	Body temp. Group 3 significantly higher than Group 2 at 8 a.m.
33	76	54	51	—
51	75	51	61	Body temp. Group 3 significantly lower than Group 2 at 3 p.m.

GRAPH III.


Period Days
9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61
Period 1
Period 2
Period 3
RESPIRATIONS 3 p.m.
160
120
80
40
MAX. ATMOS. TEMP.
85
80
75
70
65
RECTAL TEMPS.
104
103
102
101
100
S
MIN. ATMOS. TEMP.
60
50
40
30
RESP. 8 a.m.
60
40
20
Lucerne & maize group.
Grass hay group.
Grass hay ration changed to Lucerne & maize

It will be seen from the above that the poorly-fed sheep (group 2) showed an excessive rise in body temperature when exposed to the sun at about the time that their average body weight fell below 60 lb. Conversely well-fed animals (group 3) displayed an increased power to prevent a rise in rectal temperature when their average body weight had increased to a similar figure. It would, therefore, appear that under the conditions encountered in this experiment and for the class of sheep used, 60 lb. can be looked upon as a critical body weight, under which a breakdown in the resistance to heat may be expected.

Summary.

1. It is clearly shown that the diet and general body condition of sheep markedly influenced their heat-regulating mechanism.

2. The maintenance of the body temperature of thin sheep in a cold environment was found to be closely associated with the calorific value of the diet at the time of exposure.

3. Moderately conditioned sheep maintained their body temperature when exposed to cold for a period of 10 days after being placed on an inadequate ration.

4. The control of temperature in a hot environment was found to depend largely on general body condition.

5. When the sheep were exposed to heat the following observations were made:—

(*a*) Thin sheep on a poor diet showed a suppressed panting reflex and an excessive rise in body temperature.

(*b*) Thin sheep on a good diet showed a normal panting reflex but also an excessive rise in rectal temperature. This anomaly cannot as yet be fully explained. The ability to control the body temperature returned when the general body condition improved.

6. Contrary to expectation, continued poor feeding of sheep in conjunction with repeated exposure to cold failed to cause any clinical disturbance either in digestion or in the normal appetite of such animals. The effect of this treatment on the heat regulating system of the body, however, was both clear and pronounced.

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