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THE UNIVERSITY OF ALBERTA

THE EFFECT OF TEMPERATURE ON DIGESTION IN SHEEP

by

ROBERT WESTRA ©

A THESIS

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled ... The ..... Effect of Temperature on Digestion in Sheep .... submitted by .. Robert Westra .... in partial fulfilment of the requirements for the degree of Master of Science.

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Supervisor

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ABSTRACT

In the first of two experiments, 12 closely shorn yearling wethers receiving hay either in the long form (hay-fed sheep), or in the pelleted form (pellet-fed sheep), were acclimated to temperatures of 0.8, 10.0 and 17.7 C. Measurements were made of the apparent digestibilities of dry matter (DM), energy (E), nitrogen (N), and acid-detergent fiber (ADF). Feed intake was maintained at the same level throughout the experiment. Water consumption was higher in the hay-fed sheep than in the pellet-fed sheep and tended to decrease with decreasing temperature. The apparent digestibilities of DM, E, N and ADF were lower for the pellet-fed sheep than for the hay-fed sheep ($P < 0.001$). The decreases in apparent digestibility (%) of DM, E and ADF per degree (C) drop in environmental temperature were respectively, 0.19, 0.08 and 0.25% for the hay-fed sheep and 0.21, 0.19 and 0.23% for the pellet-fed sheep. The regression coefficients for DM and E in the hay-fed sheep were not statistically significant ($P > 0.05$). Temperature had no significant effect on apparent N digestibility.

In the second experiment, six mature, rumen fistulated and closely shorn sheep received a pelleted-hay ration and were used in experiments to determine the effects of prolonged exposure to 21.2 and 1.3 C on the apparent digestibility of DM, reticulum motility and retention time of feed in the digestive tract. DM digestibility was significantly reduced by 0.18% per degree (C) drop in temperature

($P < 0.05$). Mean retention times, determined from the fecal excretion patterns of Ce^{144} following a single injection of the isotope into the rumen, were significantly ($P < 0.05$) reduced from 38.5 hours in the warm exposed sheep (21.2 C) to 32.5 hours in the cold exposed sheep (1.3 C). The mean reticulum contraction frequency was significantly ($P < 0.0005$) increased from 60 in warm exposed sheep (21.2 C) to 72.5 contractions per hour in cold exposed sheep (1.3 C).

Serum thyroxine (T_4) and triiodothyronine (T_3) concentrations were significantly ($P < 0.05$) higher in sheep exposed to the cold compared to the sheep in the warm temperature treatment.

These experimental determinations suggested that increased reticulo-rumen motility of sheep in a cold environment may be a factor in reducing the mean retention time of digesta in the digestive tract, which, in turn, reduces DM and ADF digestibilities. A possible influence of thyroid hormones on digestive function is discussed.

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INTRODUCTION

Several documented experiments have indicated that cold environmental temperatures appear to have an adverse effect on the digestive efficiency in sheep and cattle. It has been reported that the apparent digestibility of feed decreases in sheep and cattle exposed to decreasing environmental temperatures. However, the physiological basis for this effect of temperature is not understood and it has not been established whether a linear relationship exists between environmental temperature and the apparent digestibilities of dry matter, energy, nitrogen and fiber in sheep and cattle. There is evidence that short-term temperature changes may influence rumen motility in cows and that the mean retention time of digesta in the digestive tract of steers may be affected by environmental temperature. However, the effects of prolonged exposure to various environmental temperatures on reticulo-rumen motility and mean retention time of digesta in the digestive tract have not been simultaneously determined and related to digestibility of feed. Therefore the objectives of this study were to determine, first of all, if a linear relationship existed between environmental temperature and the apparent digestibility of dry matter, gross energy, nitrogen and fiber in sheep fed either a processed or a non-processed ration; and secondly, to determine if the effects of environmental temperature on the apparent digestibility of feed were related to changes in reticulo-rumen motility and the mean retention time of digesta in the digestive tract in sheep.

LITERATURE REVIEW

When sheep are exposed to cold environmental temperatures several physiological changes occur. They include a decreased rate of evaporation from the respiratory tract (Schmidt-Nielsen et al, 1970; Slee, 1973a) and body surfaces (Sykes and Slee, 1968; Blaxter et al, 1959a; Blaxter et al, 1959b), vasoconstriction of blood vessels in the body surface (Bailey et al, 1962; Joyce and Blaxter, 1964; Slee, 1968; Sykes and Slee, 1968; Meyer and Webster, 1971; Slee,1973a), increased muscle tone (Sykes and Slee, 1968; Slee, 1970), increased heart rate (Slee, 1973b; Donnelly et al, 1974), increased food intake (Joyce and Blaxter, 1964; Baile and Forbes, 1974), increased metabolic rate (Slee, 1972), reduced critical temperature (Graham et al, 1959; Webster et al, 1969) and changes in neuroendocrine activities (see Chatonnet, 1967).

Similar physiological adjustments to cold exposure were shown in cattle (Blaxter and Wainman, 1961; Webster et al, 1970; Webster, 1970 and 1971; Berman and Meltzer, 1973; Bell and Thompson, 1974; McDowell, 1974; Ames and Insley, 1975) and in deer, (Moen, 1974).

1. The Effect of Prolonged Exposure to Cold on Sheep (Cold Acclimation)

When sheep were acclimated to a cold environmental temperature the resistance to cold stress increased and there was an increase in resting oxygen consumption which persisted even when the sheep were exposed for short periods to + 8^{o} C (Webster et al, 1969). Slee (1974) confirmed his initial findings (Slee and Sykes, 1967) that acclimation in sheep becomes apparent about 1 to 2 weeks after one or more acute cold exposures (200 - 600 min). It was also observed that there were significant breed differences in sheep in both the initial resistance to cold and to the level of acclimation. Arising from his experimental results, Slee (1974) concluded that the process of acclimation to cold in sheep could be divided into two components: 1. acclimation as a result of an increased peak metabolic rate capability (PMRC), inferred from increased skin temperatures (and heat loss) and increased heart rates and rectal temperatures; and 2. acclimation as a result of an increased resting metabolic rate (RMR) evidenced by increased heart rates at thermoneutrality. Increased PMRC following acute cold treatments did not disappear until about 8 weeks after returning the animals to a thermoneutral environment while increases in PMRC following chronic cold treatments disappeared by about 2 to 4 weeks. However, increased RMR as a result of either chronic, or acute cold treatments disappeared by 8 days after returning the cold acclimitized sheep to a thermoneutral environment.

Slee (1974) concluded that the ability of sheep to retain PMRC for long periods of time was a valuable survival feature for living in long-term fluctuating weather conditions whereas at the same time, a short-term increased RMR response to cold temperature would give sheep the ability to conserve energy during periods of mild weather.

2. The Effects of Cold on Apparent Digestibility of Feed.

Recent investigations (Young and Christopherson, 1974; Warren et al, 1974) indicate that when ruminants are exposed to cold environmental temperatures digestive efficiency appears to be reduced. Graham et al (1959) were among the first investigators to notice an increase in apparent digestibility with an increase in environmental temperature. They observed by regression analysis that the apparent digestibility of food in sheep increased by about 1% for every 10 C increase in environmental temperature. They suggested that the reduction in apparent digestibility in the sheep exposed to cold temperature treatments may have resulted from a decreased fermentation rate within the feces. However, Fuller and Cadenhead (1969) demonstrated that the change in apparent digestibility observed could not be attributed to a differential fermentation rate of the excreted feces prior to collection in cold and warm environmental temperatures.

Blaxter and Wainman (1961) investigated the energy metabolism of steers exposed to cold and observed similar reductions in apparent digestibility with decreasing environmental temperatures. The apparent digestibilities of protein, carbon and energy were reduced by 3.4, 5.1 and 4.4% respectively for one steer (Amos) and 3.4, 5.0 and

4.5% respectively in the other steer (Andy) when the temperature was reduced from 35.1 to 3.8 C. However, when the temperature was reduced further (-4.8 C), the apparent digestibility of protein, carbon and energy was increased by 2.1, 2.4 and 1.7% respectively for Amos and 1.6, 1.5 and 1.1% respectively for Andy. The steers were exposed to each temperature treatment for 4 days before commencement of the digestibility trial.

Interestingly, Bailey (1964) observed that when sheep were exposed to -11 C, after being exposed for a week to 20 C no decrease in DM digestibility occurred. However, when the sheep were returned to the environmental temperature of 20 C for another week, a significant increase in dry matter (DM) digestibility was observed (all the sheep received chopped alfalfa hay).

Moose et al (1969) found that sheep fed a high concentrate ration had a greater coefficient of digestibility when exposed to an environmental temperature of 23 C than at 0 C, but sheep fed a low concentrate diet had a greater coefficient of digestibility at an environmental temperature of 0 C, than at 23 C. In another trial, Moose et al (1969) found the reverse relationship to be true. In cattle, Sharma and Kehar (1961) found DM digestibility to decrease with increasing environmental temperatures. They suggested that the increased water consumption by the heat stressed animals may have caused the digestive tract to be cleared out faster and thus reduce digestibility of feed when exposed to higher temperatures. Graham (1964) found that sheep, fed a low energy ration, had a depressed energy digestibility of 0.47% per degree (C) drop in temperature when exposed to temperature treatments of 10 and 35 C.

Young and Christopherson (1974) collated several of their experimental results from both sheep and cattle and calculated that the apparent digestibility of DM decreased by 0.24% for every 1 C drop in environmental temperature. Their results also indicated that the average decrease in DM digestibility in sheep (0.307% / 1 C) was greater per degree change in environmental temperature than that observed in calves (0.265% / 1 C). The sheep and calves were fed respectively, pelleted and cut feed. Temperature treatments had no effect on the DM digestibility in mature cows fed a long hay ration.

Warren et al (1974) demonstrated that the mean digestibility of DM in Holstein steers, (397 kg, average body wt.) fed a cut hay ration dropped from 67.0% when exposed to 32 C for 7 days to 62.8% when exposed to 18 C for the same length of time. A reduction in the digestibility of ADF, cellulose and neutral-detergent fiber also occurred when the steers were exposed to the colder temperature as compared to the steers exposed to 32 C. Davis and Merilan (1960) found that feed digestibility increased by 4.35% and 6.2% when Holstein cows were moved to an environmental temperature of 32 C and 40% relative humidity and

32 C and 50% relative humidity, respectively from a control environmental temperature of 18 C and 50% relative humidity.

Although a large number of references in the literature suggest that digestibility in ruminants is influenced in a positive manner by temperature, there are also a few exceptions and inconsistencies. The reasons for these exceptions are not readily apparent but might be related to the degree to which a ration is processed, short duration of temperature exposures, or variability in the previous environmental history of the animals. It would clearly be desirable to characterize the relationship between digestibility and prolonged exposure to well defined, controlled environmental temperatures.

3. The Effect of Processing Feed on the DM Digestibility of Feed in Sheep.

It has been shown quite conclusively that processing hay by pelleting or cutting depresses DM digestibility in both sheep and cattle. Balch (1950) was one of the first investigators to show that the digestibility of food was depressed in cows when long hay (non-processed) rations were ground (processed) or when concentrates were added to ground hay rations. Subsequent workers (Meyer et al, 1959; Blaxter and Graham, 1956; Beardsley, 1964) have confirmed Balch's findings and in general show that pelleting a mixture of concentrates and forages not only increased their acceptability and intake but reduced the

DM and crude fiber digestibility (see Blaxter and Graham, 1956; Minson, 1962; Greenhalgh and Wainman, 1972; Greenhalgh and Reid, 1973; Church, 1969). Johnson et al (1964) clearly showed that the pelleting of hay rations fed to sheep depressed the apparent digestibility of DM, organic matter, cellulose, crude fiber and energy. However, sheep fed the pelleted rations compensated for the depressed DM digestibility by increasing feed intake. These differences in apparent digestibility of food in ruminants between processed and non-processed rations have been shown to occur without regard to the environmental temperatures.

Environmental temperature may not affect DM digestibility in ruminants if they are fed non-processed hay rations since, in all the experiments in which temperature was shown to influence digestibility, the animals were consuming diets consisting of either cut or pelleted forages or a mixture of cut forage and grain. The cows used in the experiments by Young and Christopherson (1974) received long-hay rations and showed no difference in DM digestibility when exposed to an environmental temperature of -11 C, or 21 C. This may suggest the possibility of an interaction between physical form of the diet and the effect of temperature on digestibility. This question requires further study.

4. The Effects of Temperature on Water Intake and the Relation of Water Intake and Water Temperature to Digestibility of Feed in Cattle and Sheep.

Water intake increases with increasing environmental temperature as shown by several investigators. Bailey et al (1962) reported mean values of 797 and 1620 ml/day for sheep exposed to temperature treatments of -12 C and 15 C, respectively. Similar determinations were reported by Bailey (1964) and Butcher (1974) for sheep, and by Gengler et al (1970) for cattle. Furthermore, Bailey (1964) reported that the sheep with the smaller water intakes and exposed to the cold treatments had greater urine and smaller apparent insensible water losses than the sheep exposed to the warm treatments.

Bailey et al (1962) reported that, although the temperature of the drinking water (0 C to 30 C) positively influenced the body temperature of the sheep in the cold chamber, no significant differences in water consumption occurred when the water temperatures were varied from 0 to 30 C. The mean rumen temperature of the sheep exposed to the cold treatments (0 C) was not affected by the temperatures of the drinking water. When Cunningham et al (1964) subjected Holstein cows to drinking water at four different temperatures 1, 14, 27 and 39 C, the cows consumed significantly ($P < 0.05$) less 1 C water than 14, 27 or 39 C water, and significantly ($P < 0.05$) more 39 C water than 14 or 27 C water.

However, the temperature of the water consumed, or the amount of water consumed irrespective of its temperature may have very little influence on DM digestibility in cattle or sheep exposed to cold environmental temperatures. In the work of Cunningham et al (1964) DM, energy and crude protein digestibility coefficients did not differ between cows consuming water of different temperatures. But they failed to make any reference to their data that the cows in trial one, which were exposed to an average environmental temperature of 11.7 ± 5.5 C had higher digestibility coefficients than the cows in trial 2, which later on in the year were exposed to an average environmental temperature of 2.8 ± 6.8 C.

It therefore seems reasonable to conclude that sheep tend to drink less water in the cold, and possibly still less water if the water temperatures are close to freezing (Butcher, 1974) with little or no effect on the apparent digestibility of feed.

5. The Effects of Temperature on Retention Time in the Digestive Tract.

A general hypothesis, deduced from the work of several investigators (see Church, pp 94-97, 1969) is that ground and pelleted roughages pass through the alimentary tract faster than long roughages, and because of this principle the ruminant can eat more of the ground, or pelleted roughage per unit time without exceeding the capacity of the gut (see reviews by Church, 1969 and Campling, 1970;

Johnson et al, 1964; Greenhalgh and Ried, 1973; Warren et al, 1974; Grovum and Hecker, 1973). Colder temperatures appear to induce cattle and sheep to eat more, since the demand for energy to keep warm is greater (Baile and Forbes, 1974). The possibility that the increased feed intake of ruminants in the cold is due to an enhanced rate of passage of digesta through the tract has not been investigated. Very little work has been done on the effects of environmental temperature on retention time of digesta in cattle and sheep. Warren et al (1974) demonstrated that in steers exposed to warm environmental temperatures (32 C) compared to the control environmental temperature (18 C), not only was DM, ADF, cellulose and neutral-detergent fiber digestibility increased, but mean retention time of digesta was increased significantly, as well. Therefore, it is possible that changes in the mean retention time of digesta in the digestive tract contribute to the changes in apparent digestibility of feed in ruminants exposed to different environmental temperatures.

6. The Effects of Temperature on Reticulo-Rumen Motility.

Attebery and Johnson (1969) were able to show that the amplitude and frequency of the rumen contractions were significantly ($P < 0.05$ by Tukey's test) increased in Holstein cows exposed to cold (18 C) when compared to Holstein cows exposed to a temperature of 35 C. The average frequency of contraction per minute for cows exposed to 35 C was 1.88, for cows exposed to 18 C was 1.95 to 2.23

and for cows exposed to 2 C was 1.86. In fasted animals similar differences in frequency and amplitude were shown but at proportionately lower magnitudes.

Attebery and Johnson also noted, in cows exposed to high temperatures, a depression in the total volatile fatty acids (VFA). This depression in VFA concentration, they suggested, was probably due to inadequate mixing by the rumen as a result of its decreased activity. Their results, however, might indicate an enhanced absorption at the higher temperatures. Bhattacharya and Warner (1968) showed that feed intake was increased in cows when the rumen was cooled (5 C) with an intraruminal cooling coil. Baile and Mayer (1968 and 1970) reported that feed intake was depressed when relative acetate molar concentrations were increased in the reticulo-rumen fluid and postulated the presence of acetate receptors located on the lumen side of the reticulo-rumen and especially in the dorsal rumen. Propionate depressed feed intake when the concentrations were increased in the portal system, where it was suggested that receptors especially sensitive to propionate are probably located. It was confirmed by Gengler et al (1970) that lower VFA concentrations (Weldy et al, 1964; Kelley et al, 1967) and depressed feed intakes occurred in cows exposed to high temperatures. It is difficult to reconcile the involvement of rumen VFA concentration with the effects of temperature on appetite since the change in VFA concentration induced by heat exposure is opposite to that which would depress appetite. On the other hand, an enhanced absorption of VFA into the portal system at higher temperatures might be expected to depress feed intake. Olbrich et al (1972) observed in Holsteins and Zebus when exposed to ambient temperatures of 31 C (50% relative humidity) for 2 weeks that the total VFA concentrations significantly decreased, but that the microbial activity was similar in both temperature treatments (10 and 31 C). Therefore there is a strong suggestion that variations in reticulo-rumen motility or absorption rather than microbial activity may be the major factors contributing to a change in digestibility of feed or rumen VFA levels in ruminants exposed to changes in environmental temperature.

7. The Effect of Temperature on Thyroid Activity and the Effect of Thyroid Activity on Digestibility and the Rate of Passage of Digesta in the Digestive Tract of Cattle and Sheep.

Yousef and Johnson (1966) demonstrated that injections of L-thyroxine increased metabolic rate, pulse rate and lactation in Holstein cows subjected to environmental temperatures of 18 or 32 C. In a later publication, Yousef et al (1967) found thyroxine I^{131} disappearance and oxygen consumption rate to decrease in cows exposed to 38 C; whereas in cows exposed to a temperature of 1 C, thyroxine I^{131} disappearance and oxygen consumption rates increased.

When the rumen was heated with intra-ruminal heating coils, Yousef et al (1968) found thyroxine I^{131} disappearance and oxygen consumption rates to be depressed compared to control cows. They suggested two mechanisms to account for these responses. 1. The "central warmth receptors" were stimulated via the rumen nerve endings and thus depressed the thyroid releasing factor in the hypothalmus, and 2. by altering the tissue requirement for thyroxine. It is possible, as suggested by Webster (1974) and Lutherer (1969), that thyroid hormones only "potentiate" the effects of catecholamines which are the major mediators to the metabolic response to cold exposure. Webster (1974) concluded with the following statement:

> "Normal thyroid status is essential to ensure the proper actions of catecholamines in mediating response to acute or chronic cold exposure, but the evidence in support of the popular assumption that increased thyroid activity is an integral part of the normal process of adaptation to cold is weak, and the evidence to the contrary is getting stronger."

Gale (1973) collating the work of several investigators conluded that the thyroid hormones appear to act synergistically with the sympathicoadrenomedullary (SAM) catecholamines on the adrenergic receptor sites in various tissues. Citing the work of Andersson, who studied the effects of environmental temperature on the thyroid and SAM systems in thyroidectomized goats, Gale reported that catecholamine secretion increased, especially epinephrine, when the goat was exposed to a thermoneutral environment. When the goat was exposed to the cold (-3C) catecholamine secretion increased markedly. However, when T_4 was administered to produced a hyperthyroid condition catecholamine secretion was suppressed below presurgical levels. Gale (1973) reported similar results in other animals and suggested that the thyroid hormones and catecholamines may interact not only synergistically, but on a common receptor site as well.

When sheep were made hyperthyroid by feeding iodinated casein, Blaxter (1948) found DM and crude protein digestibilities to decrease. He attributed these effects to an increased peristalsis of the gut. Levin (1969) in reviewing the effect of thyroid hormones on intestinal motility reported that gastric emptying was prolonged in hypothyroid animals and was augmented when thyroid hormones were administered. Miller et al (1974) showed that cows with severe iodine -131 thyroid irradiation damage had a prolonged retention of the flow marker in the digestive tract, when compared to similar thyroid damaged cows fed 8 gm thyroprotein daily, or to cows with intact thyroids. Kirton and Barton (1958), investigating the weights of the gastrointestinal tracts and their contents in thyroxine implanted ewes found a significant reduction in weight of the empty gastrointestinal tracts and a significant reduction in intestinal contents. It appears, therefore that the thyroid hormones may be directly involved in changing the digestive function of sheep and cattle. There is also the possibility that thyroid hormones may influence digestibility in animals exposed to different environmental temperatures.

8. Techniques in Studying Retention Time and the Rate of Passage of Digesta Through the Digestive Tract and in Studying Reticulo-Rumen Motility.

Radio-cerium (Ce^{144}) has been used by several investigators (Ellis and Huston, 1968; Huston and Ellis, 1968; Miller and Byrne, 1970; Miller et al, 1971) as a non-absorbable and inert reference substance to study retention time and the rate of passage of digesta and digestibility in the gastrointestinal tract of ruminants. Cerium-144 adsorbs to particulate matter and has been found to remain in close physical association with indigestible residues while in transit through the gastrointestinal tract of ruminants (see review by Kotb and Luckey, 1972). Compared with other inert and non-absorbable substances, Ce^{144} has been shown to be equally accurate besides being easy to use in ruminant digestive studies (Ellis and Huston, 1968).

In conjunction with the above determinations the frequency of reticular contractions merits further study to determine if the physiological behavior of the reticulo-rumen contributed to the direct change in apparent digestibility of DM with environmental temperature. It has been fairly well established now, that the reticulum is the pacemaker for the cyclic movement involved in the reticulo-rumen, with the omasum contributing some influence (Schalk and Amadon, 1928; Balch et al, 1951; Ash & Kay, 1959; Church, 1969). Iggo and Leek (1969) reported that the majority of the reticulo-rumen receptors, located by single unit studies, were found in the region of the reticular wall next to the lips of the reticular groove, and the reticulo-groove itself. The primary wave of contraction appears to be initiated in this region and spreads throughout the reticulum and rumen (Weiss, 1953; Church, 1969). These observations demonstrate that the reticulum is a good indicator of rumen motility.

EXPERIMENTS CONDUCTED AT THE

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Two experiments were conducted to investigate the effects of environmental temperature on the digestibility of a processed and a nonprocessed hay ration, and the effects of temperature on reticulum motility and passage of digesta through the gastrointestinal tract in sheep.

Experimental Procedures and Materials

1. Experiment I

a. Experimental plan and animal management

Twelve yearling Suffolk wethers selected for uniformity of size were randomly divided into three equal sheep units (SU). Within each SU two sheep were fed a long hay ration (hay) and the remaining two sheep were fed a processed pelleted hay ration (pellet). Each sheep unit was exposed to each of three different environmental temperatures in a randomized sequence during 3 trial periods. Thus each sheep served as its own temperature control.

The hay used for both rations was obtained from one crop. One half of this crop was processed into a pelleted form and the other half was fed from the bale. The daily ration for each sheep was calculated according to the following equation which relates the maintenance metabolizable energy requirement to metabolic body size (National Academy of Sciences, --NRC, 1968)

$$Kcal = 112 \times \text{body weight } (Kg)^{0.75} \quad (1)$$

The rations were calculated on the basis of animal weight at the start of the experiment and were held constant thereafter regardless of weight changes.

Since the hay consisted largely of brome grass (Bromus spp.) and some crested wheat grass the metabolic caloric value was calculated to be about 1.6 Kcal/kg (National Academy of Sciences, 1968). The sheep were fed daily at 0800 and 1600 h. Sheep that were fed long hay had their ration increased by 200 to 400 grams above their calculated values to compensate for the amount during feeding that was being thrown out of the feed box into specially designed aprons described on page 21. Any feed refused or thrown out was weighed and subtracted from the ration given for the day. Pellet and hay samples and samples of the refusal were retained for later proximate analysis.

Cobalt-iodized rock salt and water were provided ad lib. Fresh water was given once daily. Calcium phosphate was provided to NRC requirements and put into the feed twice per week. Five hundred thousand I.U. of Vit. A, 75,000 I.U. of Vit. D_3 and 50,000 I.U. of Vit. E[1] were administered intramuscularly at the beginning of the experiment.

The sheep were kept in fiberglass metabolism crates

1. Purchased from Western Brand Products Ltd., Edmonton, Alberta

with floors constructed of one inch expanded metal. Within each temperature controlled room two sheep being fed pellets were placed side by side and the two sheep fed hay were placed side by side.

It was discovered that the hay-fed sheep lost a substantial amount of hay during feeding through the crate floors. Therefore, aprons were constructed from jute feed-sacks to prevent this loss. One end of the feed-sack was attached above the sheep to a 2 x 2 inch, moveable, wooden crossbar which could slide along the top edges of the two adjacent crates. The other end of the feed-sack was attached to the floor of each crate at the base of the feed and water buckets. In the center of the feed-sack a hole was made so that the head of the sheep could pass through and be securely tied.

The pellet-fed sheep were also initially fitted with the aprons, but those in the warm environment (17.7 C) soon developed the habit of consistently chewing and devouring the aprons. This habit appeared to be due to boredom. Therefore to simulate wearing of aprons but avoid the problem of chewing burlap, the pellet-fed sheep were tied with leather collars and chains fastened to the sliding crossbar above them.

Two temperature controlled chambers (rooms) were maintained at 0.8 ± 1.3 and 10.0 ± 1.3, respectively, at the Environmental Laboratory and a third temperature controlled room was maintained at 17.7 ± 5.1 C. These were designated as the cold, intermediate and warm temperature treatments respectively. The average wet bulb temperatures for the rooms maintained at 0.8, 10.0 and 17.7 C were 0.4 ± 1.9, 7.7 ± 1.7 and 9.9 ± 2.5 C, respectively. Each sheep unit was put into one of these rooms, as described above, for 37-41 day (trial period). After this trial period the sheep were moved (as a unit) to another room so that all units were exposed once to every temperature treatment during the experiment. Within the trial period, a 27-31 day acclimation period always preceded a 10 day digestibility trial in which both feces and urine were collected. Incandescent lighting illuminated the rooms 24 h per day. Body weights were recorded the day before and the day after each digestibility trial. Two additional sheep body weights were taken between digestibility trials. The sheep were usually weighed 1 to 4 h after feeding (see table 2).

All sheep were closely shorn (between 4 and 6 mm in depth) 7 to 8 d before and one day after each digestibility trial to maintain a relatively constant fleece depth throughout the three periods. The fleece was weighed after each sheep was shorn.

b. Digestibility trials

(i) Fecal collections

Metal trays lined with nylon window-screening were slid beneath the crate floors for collection of the feces, while the urine was allowed to flow through and into a urine bucket beneath the crate itself. During the digestibility trials, the daily total fecal outputs were collected once every 24 hours at about the same time every day (1700 h). The fecal net weights from each sheep were obtained using a top loading balance to the nearest one-tenth of a gram. A representative fecal sample (5%) was retained for later analysis. A weighed portion of this representative sample (ca 100-150 g) was air dried to constant weight in aluminum pans at 65 C in a forced air oven for 3 days. The remainder of the wet samples were stored at -10 C. Feed samples were collected from each digestibility trial and were dried in the same manner as the fecal samples.

After air-drying, all fecal samples were finely ground in a Christy-Norris grinder[1] before any proximate analyses were done.

Triplicate gross energy (E) determinations using a bomb calorimeter[2] were performed on the fecal, feed and feed refusal samples.

Nitrogen (N) determinations were obtained from each feed and fecal sample using the macro-Kjeldahl method (Association of Official Agricultural Chemists - AOAC, 1975).

1. Model No. 8, Chelmsford, England
2. Model No. 101A made by Parr Instrument Corp., Moline, Ill.

Ether extract determinations were made using the methods described by the AOAC (1975). However, no digestibility coefficient calculations were done since the percent ether extract was less than 3% by weight in both the feed and the feces and since an error of 30 to 40 percent was associated with the estimation of this minor constituent. Considering these preliminary observations it was decided that they would not contribute to an increased understanding of digestive function within this study.

Standard acid detergent fiber (ADF) determinations were done in duplicate by the Alberta Agriculture Soil and Feed Testing Laboratory, Edmonton, according to the procedure of Van Soest (1963).

(ii) Calculation of apparent digestibility coefficients

Apparent dry matter (DM) digestibility coefficients were calculated using the formula:

$$\text{\% Apparent DM digestibility} = 100 \times \frac{\text{feed DM(gm)} - \text{fecal DM(gm)}}{\text{feed DM(gm)}} \qquad (2)$$

Apparent digestibility coefficients for E, N and ADF were calculated by substituting the appropriate intake and excretion values in equation 2.

(iii) Urine collections

Daily total urine was collected and weighed to the closest gram during each digestibility trial. In the first and second digestibility trials 25 ml of 25% H_2SO_4 and in the third digestibility trial 50 ml of 25% H_2SO_4 were added to the urine buckets at the start of each daily collection interval to prevent N loss. The daily total urine was corrected for by subtracting the H_2SO_4 volumes. Five percent aliquots were retained and accumulated in plastic bottles for each sheep and stored at -10 C. At a later date, the urine was equilibrated to room temperature (23 C) and filtered through 4 layers of cheesecloth to remove fecal and feed debris. The specific gravity was determined by weighing urine volumes in 5 ml volumetric flasks. Water output could then be calculated as well. Urine N determinations were obtained by pipetting 5 ml of urine into Kjeldahl flasks using the macro-Kjeldahl method (AOAC, 1975).

(iv) Urine, water and related calculations

Water intake was determined within each digestibility trial by weighing the water consumed for each sheep. In order to describe the pattern of water consumption simultaneous water intake and water temperature determinations were obtained every hour for two consecutive days from two sheep within each unit (one sheep from each ration), during the third digestibility trial. A glass tube inserted near the base of the bucket and calibrated in liters allowed reading of the water level without disturbing the animal.

Daily total water excreted in urine and feces per kg body weight (BW), % DM in the feces, % DM content of the whole diet (Balch, 1950) and apparent water retention calculations were made. Percent DM content of the whole diet was calculated according to Balch (1950) as follows:

$$\text{Percent DM content} = \frac{\text{total DM intake (g)}}{\text{total DM intake (g)} + \text{total water intake (g)}} \times 100 \quad (3)$$

and % apparent water retention by the following formula:

$$\text{\% apparent water retention} = 100 \times \frac{\text{total water in feed} + \text{water intake} - \text{water in feces and urine}}{\text{total water in feed} + \text{water intake}} \quad (4)$$

Percent N retention was calculated using the following formula:

% N ret[illegible] (5)

100 x N in fee[illegible]in feces(g)-N in urine(g) / [illegible]feed(g)

(v) Blood colle[illegible]n and analysis

Blood samples [illegible]e obtained from each sheep within each digestibility [illegible]ial just before and in the first digestibility tria[illegible] during the morning meal (0830 h), using heparinized vacuum tubes. Hematocrit determinations were obtained. The remaining blood was centrifuged at 3000 rpm for 15 min and the plasma removed and stored at -5 C. Later, the plasma was equilibrated to room temperature and protein-bound-iodine (PBI) determinations were done using the Hycel Cuvette PBI technique.[1] The samples were refrozen and thawed at a still later date for the determination of total plasma thyroxine (T_4) and total plasma triiodothyronine (T_3). A Tetralute I^{125} Reagent kit[2] was used for determining plasma T_4 concentrations following the method described by Braverman et al (1971). The procedure was modified by using 22 ml of buffer instead of the suggested 15 ml to obtain a more suitable standard curve. A RIA-MAT circulating T_3 I^{125} kit [3] was used for determining plasma T_3 concentrations; a procedure based on the methods of Larson (1972), Leiblick and Utiger (1972), and Surks et al (1972). The T_4- and T_3-radioactivity was counted by a scintillation detector (model no. DS 202(V))[4] fitted with a 2 inch well-type thallium activated sodium iodide crystal (model No. XT2W0)[5] and monitored by a scaler (model no. 8725)[6], adjusted with both windows completely open and set at a voltage of 875 volts. The samples were all analysed at room temperature (23 C).

(vi) Body and rectal temperature determinations

Rectal temperatures were recorded from each sheep in

1. Hycel Inc., Houston Texas
2. Purchased from Ames Company, Division Miles Laboratories, Inc., Elkhart, Indiana 46514.
3. Purchased from Mallinckrodt Chemical Works, St. Louis, Mo. 63147.

4,5 & 6. Purchased from Nuclear-Chicago Corp., 333 East Howard Ave.

the second digestibility trial using a telethermometer (model no. 46TC)[1]. The probe was inserted into the rectum and held there for 3 min and the temperature read. During the third digestibility trial, temperatures were recorded from selected areas on the left side of the sheep body surface (see figure 1) including the legs and left ear, and from the rectum, using a strip Chart Recorder, a Speed-O-Max (W) 24-point Actuator and type-T copper-constantan thermocouples. Recordings were obtained from one pellet-fed sheep and one hay-fed sheep within each unit for a 3 h time period, beginning at 1100 h. The thermocouples were attached to the closely shaved areas using adhesive tape reinforced with paper contact cement, and one thermocouple was inserted 12 cm into the rectum.

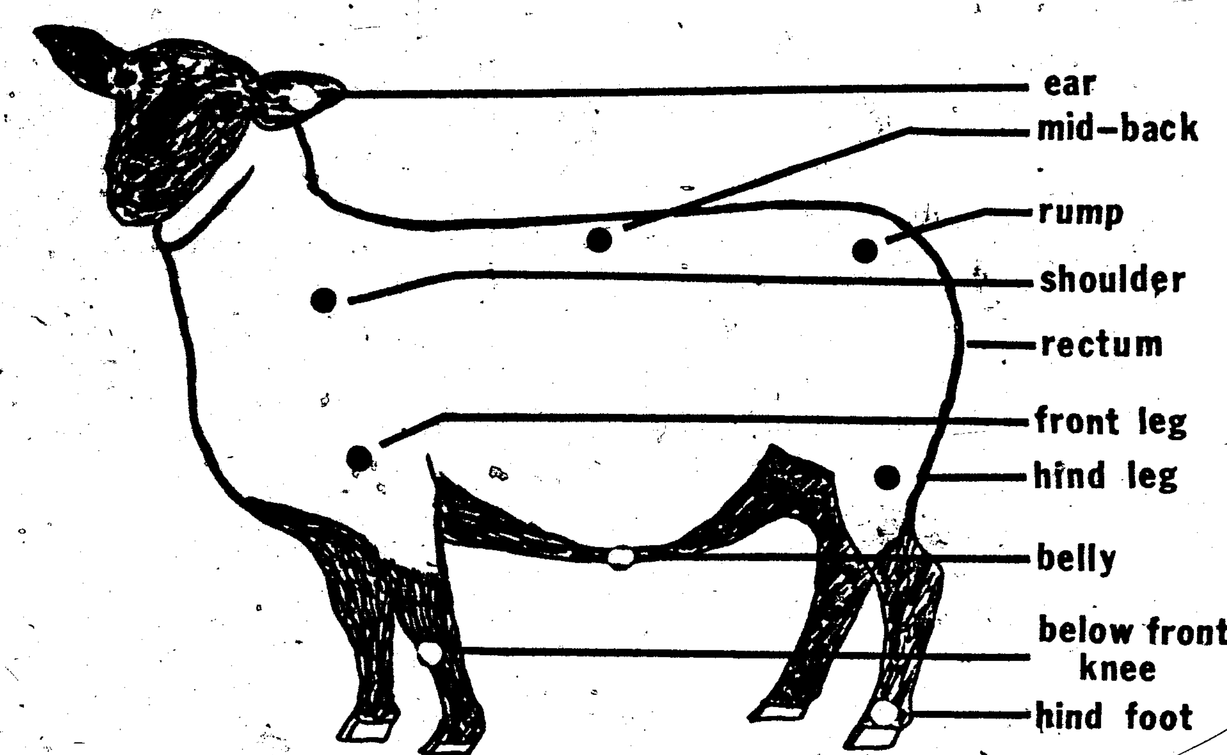
c. Statistical analysis

An analysis of variance was performed to test the statistical significance of each set of determinants by using a special type of p x p x q factorial analysis. The model used for this experimental plan was after Winer (1971) and is as follows:

$$E(X_{ijkmno}) = u + R_k + (U)_m + (R \times U)_{km} + S_{o(m)} + P_i + T_j + PR_{ik} + TR_{jk} + PTR_{ijk}$$

1. Purchased from Yellow Springs Instrument.

FIGURE 1. The body sites where temperatures were taken within the three temperature treatments.



where R = ration

S = sheep

P = period

T = temperature

U = sheep units

Test for comparisons among treatment means were determined using Duncan's New Multiple Range Test according to Steel and Torie (1960). The multiple correlation of environmental temperature and apparent digestibility of DM with ration was also calculated.

2. Experiment II

In this experiment, tracer trials using radiocerium 144 (Ce^{144}) to determine rate of passage and retention time of particulate matter in the digestive tract were performed on sheep during exposure to warm and cold temperatures. In addition, motility of the reticulum, methane production, oxygen consumption and DM digestibility measurements were made during exposure to the two temperature treatments.

a. Animal Management

Two mature ovariectomized ewes and four mature wethers were used. All the sheep had rumen fistulae, and, all but two sheep had an exteriorized carotid artery. As to breed, initial weights and other animal differences refer to table 1. All sheep were closely shorn 8-9 days before and one day after the two 11-d experimental periods.

several measurements were made as described below. The first and second experimental periods followed a 44- and a 32-d acclimation period respectively.

TABLE 1. Physical characteristics of the sheep used in experiment II.

Sheep no.	Sheep unit	Sex	Breed	Carotid loop	Other Observations
2523	2	W	Southdown	*	
8236	2	W	Suffolk		
9236	1	W	Lincoln	*	stiffness in legs & joints
8229	1	W	Cross		
0513	2	O	Southdown	*	poor condition leaking fistula
2701	1	O	Southdown	*	

* denotes presence of carotid loop

W - wethers

O - ovariectomized ewes

The 6 sheep were allotted into units of two wethers and one ovariectomized ewe per unit. The sheep were kept in individual metabolism crates in controlled environment chambers at the Environmental Laboratory, The University of Alberta.

All sheep were fed a pelleted hay ration which was processed from the same hay lot as that used in experiment I. The energy of the ration (Kcal/kg) and the dietary energy intakes were estimated at the beginning of the experiment as described for experiment I. Dietary intakes were not readjusted for temperature or period effects after the experiment was underway. Water, cobalt-iodized salt blocks, calcium-phosphate and vitamins ADE were provided as described in experiment I. Feed samples were obtained from each experimental period, air-dried and ground for later DM analysis.

Experiment II was of a simple crossover design. Each unit was randomly allotted to one of the two temperature treatments at the beginning of experiment II. At the end of the first experimental period the temperature treatments were reversed for the two sheep units. For the temperature treatments one room was thermostatically controlled at 1.3 $\pm$ 2.2 C, with a wet bulb temperature of -0.05 $\pm$ 2.3 C, (cold treatment), and a second room was thermostatically controlled at 21.2 $\pm$ 1.7 C with a wet bulb temperature of 13.7 $\pm$ 1.4 C, (warm treatment).

b. Experimental measurements and procedures

(i). Dry matter digestibility was measured as described for experiment I.

(ii). Retention time of particulate matter in the digestive tract.

The retention time of particulate matter in the digestive tract was estimated from the time course of fecal excretion of radiocerium 144 (Ce^{144})[1] following

1. Purchased from New England Nuclear Canada Ltd., 11475 Cole de Liesse Dorval, Liebe (Cat. No. NEZ-016)

the injection of a single dose of labelled Ce^{144} into the rumen. Prior to administration of the Ce^{144} into the rumen of the sheep, a stock solution was made up to about 2 µci/50 ml water for period I and 4 µci/50 ml for period II. A sufficient quantity was made so that each of the six sheep received a 50 ml dose, in addition to leaving a 50 ml sample for later analysis. However, at the onset of experimental period I, two sheep were inadvertantly given 2 oz. (59.1 ml) of Ce^{144} solution. The Ce^{144} solution was administered into the rumen via a rumen fistula using a plastic 50 ml syringe just before the 1600 h feeding. Plastic containers and plastic syringes were used in handling the Ce^{144} solutions except when the original Ce^{144} was measured out. A glass microsyringe was used in this instance, rinsed out several times in the Ce^{144} diluent.

Immediately after injecting the Ce^{144} dose, the metal trays for collecting the feces were slid into place. Twelve hours later the first collection of feces was made. Subsequent fecal collections were made every 3 h for the next 37 h at increasingly extended intervals of 6, 8, 12 and then every 24 h for the remainder of the 5- and 6-day collection periods in the first and second experimental periods respectively.

The fecal collections from each sheep were thoroughly hand-mixed and weighed (hands protected by plastic gloves). A composite sample of ca. 100 g was retained. Weighed samples were air-dried in aluminum pans in a forced-air drying furnace at 65 C for 3 d, reweighed and stored in individual plastic bags. Several days later a portion of the dried fecal samples were ground in a micro-mill grinder[1] inside a 1 x 1 x 1 m plastic covered frame to contain the radioactive dust. Beckman Biogamma vials[2] were weighed, filled with the finely ground fecal material and then reweighed to the nearest ten thousandths of a gram.

Duplicate samples obtained from each collection in experimental period I were counted for 20 min and duplicate samples from each collection in experimental period II were counted for 10 min by a Beckman Biogamma Counting system[3]. The high voltage control setting was adjusted for optimum counting at 540 volts. Both upper and lower discrimination settings were adjusted at 1000 and 0 divisions respectively (wide-open counting windows). The counting time differences were due to higher radioactivity of the stock solution administered to the sheep in experimental period II compared to experimental period I. Duplicate samples of the stock solution within each experimental period were counted at the same time that the respective fecal samples were being counted. Weighed samples of stock solution were also mixed with weighed samples of fresh wet feces and air-dried at 65 C for 3 d

1. Techmar, Model No. A10, Can-Lab Supplies.
2,3. Beckman Instruments, Fullerton, Calif.

and counts were made on this preparation according to the procedure used for feces samples.

Background radioactivity was determined and substracted from the sample counts. Radioactivity concentrations (counts per min/g of feces) were calculated and multiplied by the fecal DM excreted during each interval to give total counts per min (cpm) per fecal collection. The total cpm for each fecal collection was expressed as a percent of the total cpm of Ce^{144} excreted during the 5- and 6-day collection periods, of experimental periods I & II respectively. Cummulative percents were plotted against time. Total cpm per fecal collection were also expressed as a percent of the total cpm of Ce^{144} administered in the rumen.

Regression equations were determined expressing cumulative % of Ce^{144} excreted with time after administration.

Mean retention time (Θ) was calculated (see sample calculation in Appendix figure 2) using the formula:

$$\Theta = \sum_{i=1}^{n} t_i M_i \qquad (6)$$

where t_i is the time elapsed between dosing and the mid-point of the i^{th} time interval and M_i is the fraction of the total amount of marker excreted in the i^{th} time interval (Faichney, 1975).

c. Reticulum Motility

Reticular contraction frequency was obtained immediately after the tracer trial by using a fluid-filled balloon and a pressure transducer recording system. On the end of about 3 m of tygon tubing (I.D. 1/8") a balloon was attached. The balloon was simply a finger from a rubber surgical glove. Within the tygon tubing, at the same end as the balloon, about 1 m of 10-gauge copper wire was inserted to give this end rigidity for the placement of the balloon inside the reticulum through a hole in the pressure stopper of the rumen cannula. The tygon tubing and its attached balloon were filled with 98% ethanol (to prevent freezing of the fluid in the line) and connected to a strain guage pressure transducer, (model no 267 B.C.)[1]. Three way stop-cocks were inserted into this system for bleeding out any air bubbles. Pressure changes in the reticulum transduced by this system were amplified by a carrier preamplifier (model no. 3971)[2] and recorded by a Sanborn Physiological Recorder (model no. 7714)[3]. Proper adjustment of the balloon into the reticulum was determined when the recording traced a biphasic contraction (Church, 1969 and Ali and Singleton, 1974). Two 8- to 12-h continuous recordings were made from each sheep beginning at 1000 h daily. The two continuous motility recordings from each sheep were separated by a period of 3 days. Reticular contractions were counted

1. Purchased from Hewlett-Packard Company, Sanborn Division
2,3. Manufactured by Hewlett-Packard, Pallto Alto, Calif.

for each hour for each sheep.

d. Oxygen consumption and methane production

Rates of oxygen consumption and methane production during a six-hour period were determined using a ventilated hood and an open-circuit respiration apparatus described by Young et al (1975). Two sheep, one from each unit were alternately monitored for 30 min during each hour from 1000 to 1600 h. While one sheep was being monitored by the open-circuit respiration apparatus, the hood of the other sheep was ventilated by a "Surge" vacuum pump system. The oxygen consumption of each sheep was monitored for 5 min each hour, while methane was monitored for 20-25 min per hour. The rates of oxygen consumption and methane production were calculated for each half hour monitored.

e. Sequence of measurement events for experiment II

The Ce^{144} tracer trial and the subsequent collection of feces were the first procedures completed following the temperature acclimation period. After completing the Ce^{144} tracer trial, reticular motility was monitored from two sheep, one from each temperature treatment. Recordings of reticular motility were obtained from each sheep for 2 days. At the same time, oxygen consumption and methane production measurements were obtained from two other sheep, again, one from each temperature treatment, but monitored for only one day.

f. Other experimental determinations

Water consumption and water temperatures were determined according to the procedure described for experiment I. Blood samples were obtained from the jugular vein 3 h after the morning feed in nonheparinized vacuum tubes. The blood was allowed to sit for 2 h and the serum was obtained after centrifuging for 15 min at 3000 rpm and stored at -5 C. Thyroxine, and T_3 were determined as described for experiment I.

g. Statistical tests

An analysis of variance was performed to test for treatment differences. Tests for comparisons among treatment means were determined using Duncan's New Multiple Range Test according to Steel and Torie (1960).

RESULTS - Experiment I

1. Animal Management Observations

Toward the end of April and the beginning of May (at the completion of the second experimental period) all sheep were showing symptoms of botfly (<u>Oestris</u> <u>ovis</u> L.) infestation. Some of these symptoms were vigorous shaking of the head and occasionally the body, pawing the floor of the metabolism crate and grating the teeth. By blowing the nose, mucous and the occasional botfly larva were discharged. The larvae were identified by the Department of Entomology, University of Alberta. Severe symptoms were observed to occur in mid-May (during the third experimental period), and showed less severity in mid-June. During the critical period several botfly larva were recovered.

One sheep (I.D. #9496) developed an abscess on the neck just behind the lower jaw. It was drained 10 days before the second digestibility trial (April 22, 1974). A second sheep (I.D. #9491) showed a slight, loose swelling below the lower jaw, which disappeared during the third digestibility trial (June 16, 1974). No changes in feed intake or feeding behavior occurred in any of the sheep.

The frequency of the sheep lying down within each temperature treatment was not recorded, but some general observations were made. The sheep exposed to the cold treatment were notice[illegible]down very infrequently. The sheep that were expose[illegible] intermediate treatment lay down more freque[illegible]y. [illegible]heep appeared very comfortable in the warm trea[illegible]t a[illegible] consequently were observed to be lying down much o[illegible]he[illegible]me. It was also noted that when the sheep were mov[illegible]m the cold treatment to warm treatment they appeared [illegible]ie down for longer periods of time during the first wee[illegible]than during succeeding weeks.

2. Body Weight Change[illegible]

The mean body wei[illegible]s of the sheep are shown in table 2 and figures 2a, 2b, and 2c (see also the appendix table 5). The average BW of the sheep tended to decrease during exposure to 0.8 [illegible]nd increased during exposure to 17.7 C. During the in[illegible]mediate temperature treatment the hay-fed sheep tended to gain weight while the pellet-fed sheep tended to lose weight. In Figures 2a, 2b, and 2c the weights of the 2 sheep within a ration within a sheep unit (a sheep unit consisted of two pellet-fed and two hay-fed sheep which moved together as a unit across periods and temperature treatments) were averaged and compared with each other. The hay-fed sheep consistently had lower body weights than the pellet-fed sheep, throughout the entire experiment. One hay-fed sheep within sheep unit 3 (figure 2c) followed very closely the weights of the two pellet-fed sheep, but the other hay-fed

FIGURE 2a. The effect of temperature and ration on body weight for sheep within sheep unit 1.

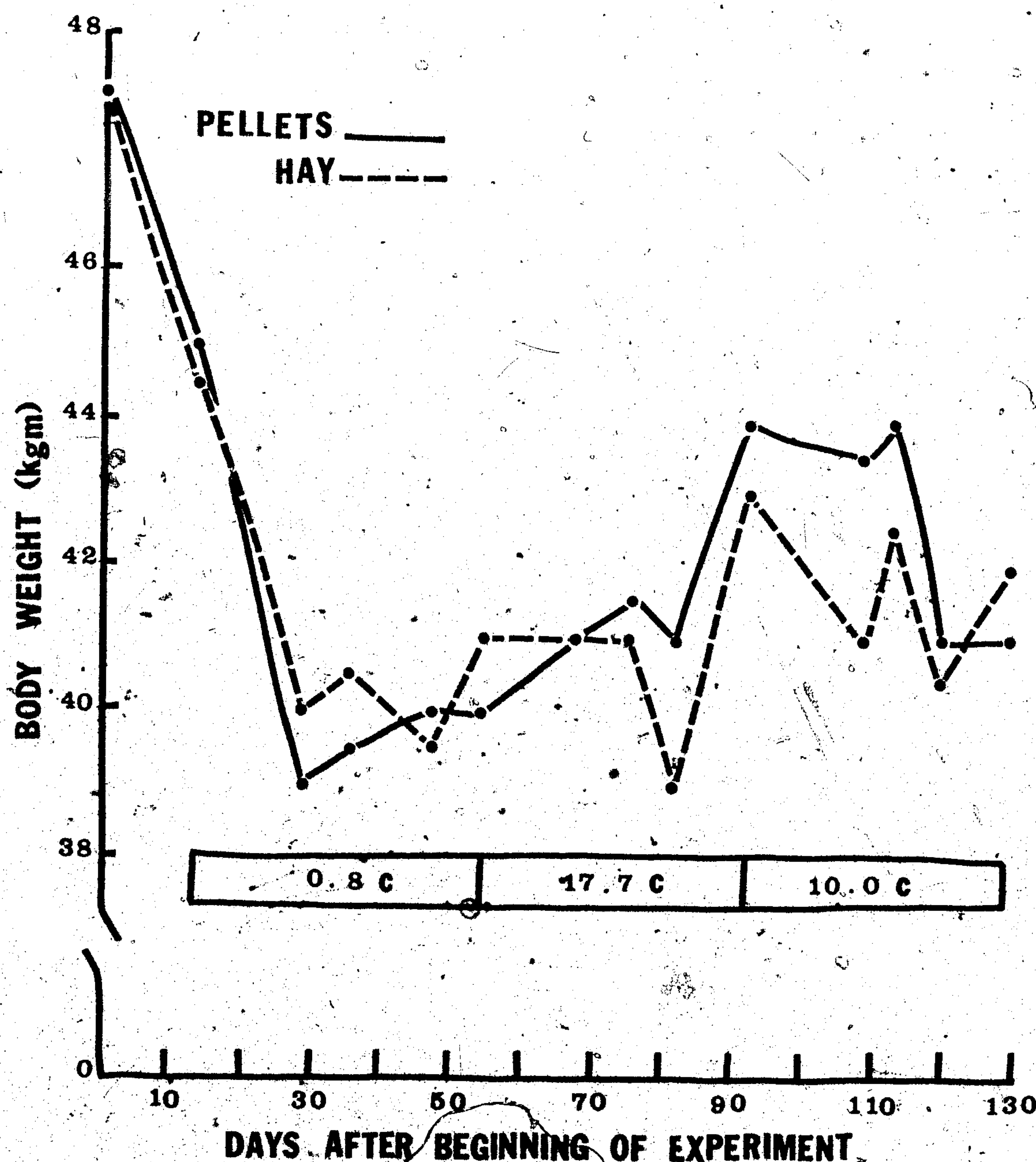


FIGURE 2b. The effect of temperature and ration on body weight for sheep within sheep unit 2.

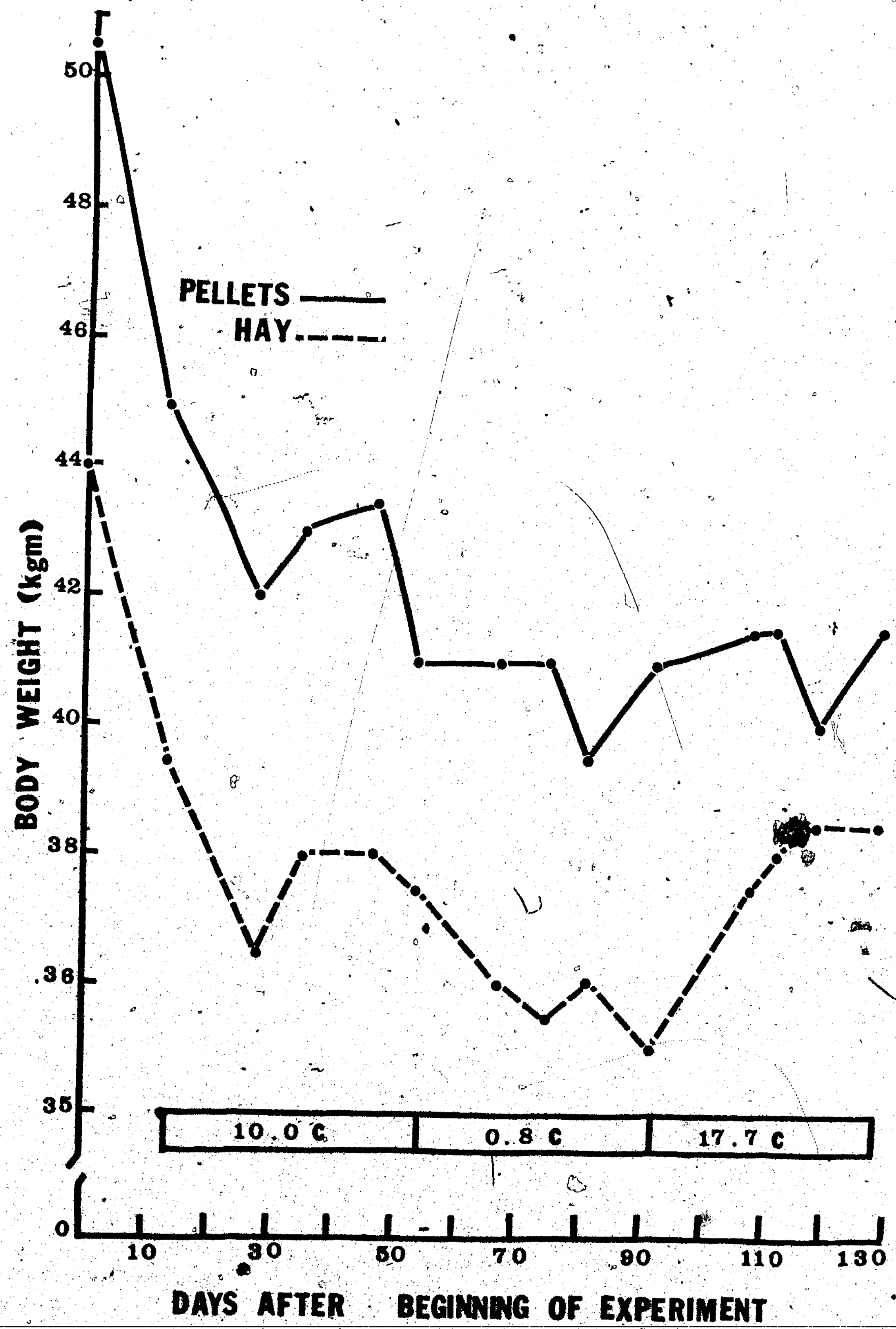


FIGURE 2c. The effect of temperature and ration on body weight for sheep within sheep unit 3.

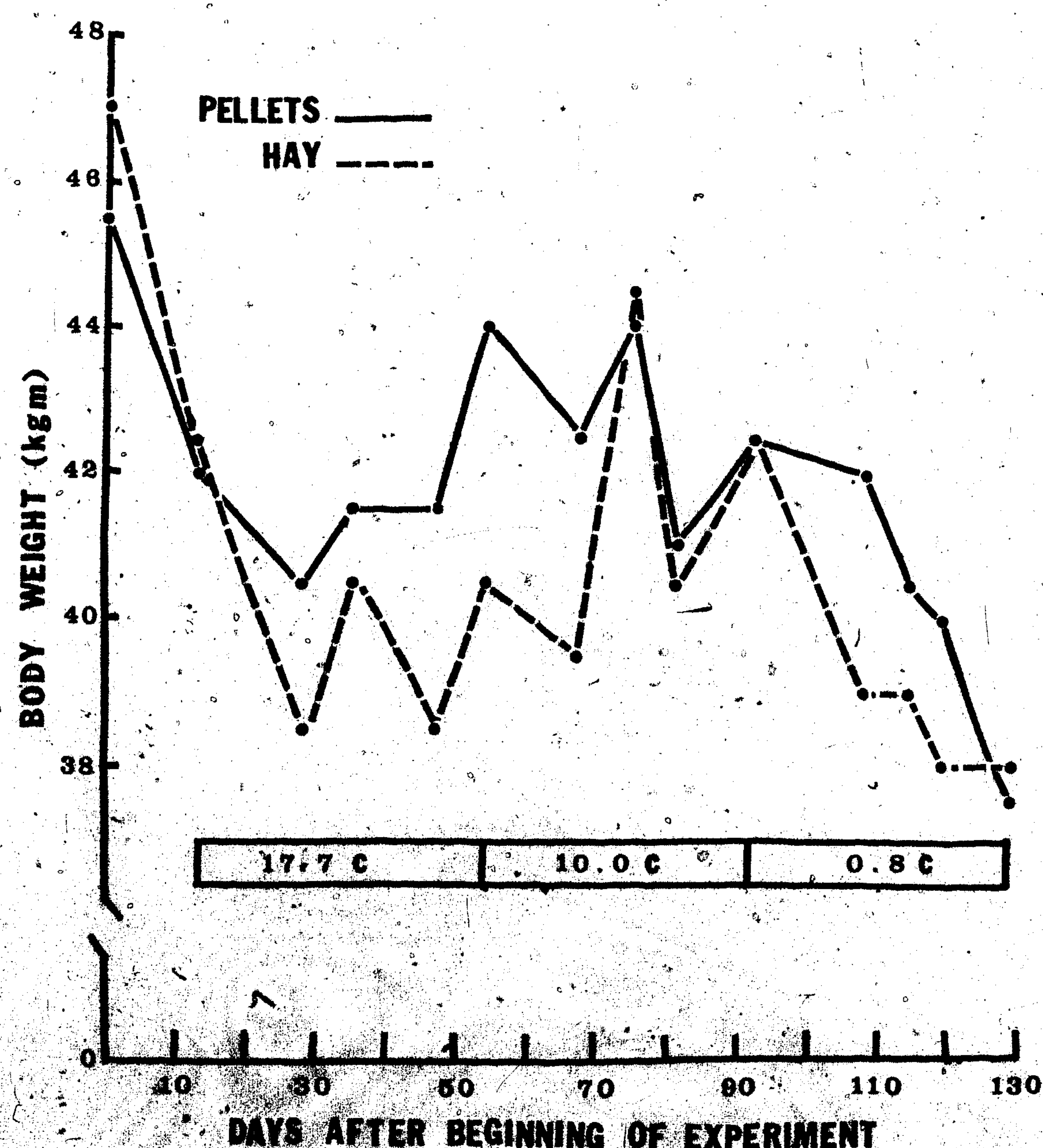


TABLE 2. Effect of temperature and ration on body weight, DM, N, ADF and water intake mean values. (numbers in brackets are standard deviations)

Ration	P	H	P	H	P	H
Room Temperature (C)	0.8	0.8	10.0	10.0	17.7	17.7
BW at beginning of trial period (kg)	40.6 ($\pm$1.9)	39.0 ($\pm$3.3)	42.7 ($\pm$0.82)	39.0 ($\pm$2.7)	41.0 ($\pm$1.3)	39.0 ($\pm$2.4)
BW at end of trial period (kg)	39.5 ($\pm$2.1)	38.1 ($\pm$3.6)	41.5 ($\pm$1.2)	40.7 ($\pm$3.4)	42.2 ($\pm$1.6)	40.7 ($\pm$3.1)
Average BW during digestibility trial (kg)	39.7 ($\pm$1.3)	38.3 ($\pm$3.4)	41.7 ($\pm$0.98)	40.2 ($\pm$2.7)	42.0 ($\pm$1.2)	39.7 ($\pm$2.6)
DM intake (gm) per BW (kg)$^{3/4}$ d^{-1}	75.55_{kj}	80.83_{k}	73.58_{j}	74.95_{kj}	73.25_{j}	75.37_{kj}
N intake (gm) per BW (kg)$^{3/4}$ d^{-1}	1.48_{ab}	1.72_{c}	1.44_{a}	1.63_{bc}	1.42_{a}	1.56_{abc}
ADF intake (gm) per BW (kg)$^{3/4}$ d^{-1}	25.58	26.76	24.93	24.93	24.80	24.88
Total water intake (gm) per BW (kg) d^{-1}	54.27_{ab}	50.95_{ab}	65.05_{bc}	48.00_{a}	76.48_{c}	67.25_{bc}
DM percentage intake (%)	36.0_{bc}	39.0_{c}	31.5_{ab}	38.3_{c}	27.7_{a}	31.1_{ab}

a,b,c-values with different subscript in same row are significantly different ($P<0.01$)
j,k-values with different subscript in same row are significantly different ($P<0.05$)
(Duncan's New Multiple Range Test). P = pellet-fed sheep H = hay-fed sheep

sheep was about 4 kg less than the average weight of the 3 other sheep within the same sheep unit (see appendix table 5). Otherwise the average BWs of the sheep within each ration and sheep unit were very similar.

3. Feed and Water Intakes

Temperature had no effect upon DM, N, and ADF intakes in sheep (table 2). However, between rations there was a significant ($P < 0.01$) difference in N intake at both the 0.8 and 10.0 C temperature treatment (table 2). The analysis of variance (ANOVA), (appendix table 8) also indicated that there was a significant ($P < 0.0005$) effect on N intake.

Dry matter intake did not vary significantly between rations within any of the temperature treatments or between temperature treatments for either ration (table 2). As shown in table 3, the pellet-fed sheep received a relatively constant DM intake across experimental periods, although the hay-fed sheep progressively increased their DM intake from period 1 through 3. The slightly larger DM intake per $BW^{3/4}$ at 0.8 C compared to the other temperatures was attributed in part to slightly greater consumption of DM during the cold temperature treatment, but was also due to a loss in body weight in the cold.

There were no significant effects of temperature or ration on ADF intakes.

Water intakes tended to increase with increasing temperature ($P < 0.05$) and were higher in the pellet-fed sheep

TABLE 3. Mean daily DM intake

Period	*Ration	Average DM intake (gm)	**S.D.
1	P	1193.8	± 56.0
	H	1187.3	±121.5
2	P	1196.9	± 37.1
	H	1194.0	± 68.1
3	P	1217.6	± 37.3
	H	1249.3	±122.9

*P = pellet-fed sheep H = hay-fed sheep

** Standard Deviation

than in the hay-fed sheep at the intermediate temperature ($P<0.05$). When the DM intake was calculated as a percent of the total water (water in feed plus water ad lib) intake plus DM intake (DM percentage intake) the pellet-fed sheep had a relatively greater total DM percentage of the diet ($P < 0.01$) when exposed to the cold treatment than when exposed to the warm treatment. The hay-fed sheep in the cold and intermediate treatments had greater DM percentage intakes ($P<0.01$) than the same sheep exposed to the warm treatment. There were no significant differences between the hay- and pellet-fed sheep within either the cold or the warm treatments, although the hay-fed sheep tended to have a greater DM percentage intake than the pellet-fed sheep within these temperature treatments. Within the intermediate treatment the hay-fed sheep had a significantly greater DM percentage intake of the diet than the pellet-fed sheep. Variation between sheep within rations and within sheep between periods was significant as shown in appendix table 8. The data indicates that the sheep exposed to cold treatments drank relatively less water than the same sheep exposed to warm treatments, and that pellet-fed sheep tended to drink more water across temperature treatments than the hay-fed sheep. It appears then, that water intake was directly related to temperature and that processing of feed appeared to increase water consumption per unit of dry matter consumed.

Summarized in table 4 are the average water temperatures and volumes of water consumed by 6 individual sheep

TABLE 4. Drinking water temperatures and times of day water was consumed by the sheep within each temperature and ration treatment.

	Temp(C)	0.8		10.0		17.7	
	Ration	P	H	P	H	P	H
Time(h)	Sheep #	9496	9489	9494	9488	9498	9499
900-1100	vol(ml)	900	1250	3050	1050	1450	600
	*temp(C)	11	9.4	15.5	18.2	14	14
1030-2130	vol(ml)	750	0	0	100	0	900
	*temp(C)	3	3.5	11	12.5	19	19
2130-**800	vol(ml)	0	150	0	0	0	450
	*temp(C)	1.5	2	11	11	19	19

* temp(C) = water temperature; ** 800 h the next day

at different times of day. Most of the water was consumed two to three hours after the morning meal; when consumed it was approximately the same temperature across all temperature and ration treatments. (A more complete record for each individual sheep is seen in appendix table 16).

4. The Effect of Temperature and Ration on Apparent Digestibility of Feed.

There was a direct relationship between digestibility of feed by sheep and environmental temperature. The effects of temperature and ration on the apparent digestibilities of DM, energy (E), nitrogen (N) and acid detergent fiber (ADF) are outlined in table 5.

a. Dry matter digestibility

Pellet-fed sheep exposed to cold treatments had a mean apparent DM digestibility coefficient (digestibility) of 53.2% which was significantly lower ($P<0.05$) than the digestibility value of 56.7% during exposure to the warm treatment. A similar reduction in DM digestibility occurred in hay-fed sheep exposed to the cold treatments as compared to the same sheep exposed to the warm treatments. Dry matter digestibility was significantly ($P<0.0001$) greater across all temperature treatments for the hay-fed sheep than for the pellet-fed sheep. Sheep within each ration when exposed to the intermediate treatments had DM digestibilities intermediate to but not significantly different ($P<0.05$) from the other two temperature treatments. There

TABLE 5. The effect of temperature and ration on the apparent digestibility means of dry matter, gross energy, nitrogen and acid detergent fiber.

Ration	P	H	P	H	P	H	P	H
Room Temperature (C)	0.8	0.8	10.0	10.0	17.7	17.7	r^2	r^2
DM Digestibility (%)	53.2_i	63.3_k	55.6_j	65.3_{kl}	56.7_j	66.6_l	0.407	0.154
E Digestibility (%)	52.3_i	61.5_k	54.4_{ij}	63.3_k	55.8_j	62.9_k	0.299	0.023
N Digestibility (%)	59.2_i	68.8_j	60.7_i	71.4_j	60.3_i	71.4_j	0.01	0.09
ADF Digestibility (%)	45.5_i	58.8_k	48.9_j	61.3_{kl}	49.3_j	63.1_l	0.26	0.28
DM in feces (%)	40.0	43.1	38.8	46.9	36.9	39.3		

i,j,k,l - when subscripts are different within the rows, the values are significantly different P= <0.05. When subscripts are absent the values are not significantly different. (Duncan's New Multiple Range Test).

P = pellet-fed sheep

H = hay-fed sheep

was a positive relationship (r^2=0.407) between DM digestibility and temperature in the pellet-fed sheep (figure 3a). In the hay-fed sheep only 15% of the variation in DM digestibility could be explained by the temperature treatments (r^2=0.15). When the DM digestibility of pellet-fed sheep was regressed on environmental temperature the following equation was derived:

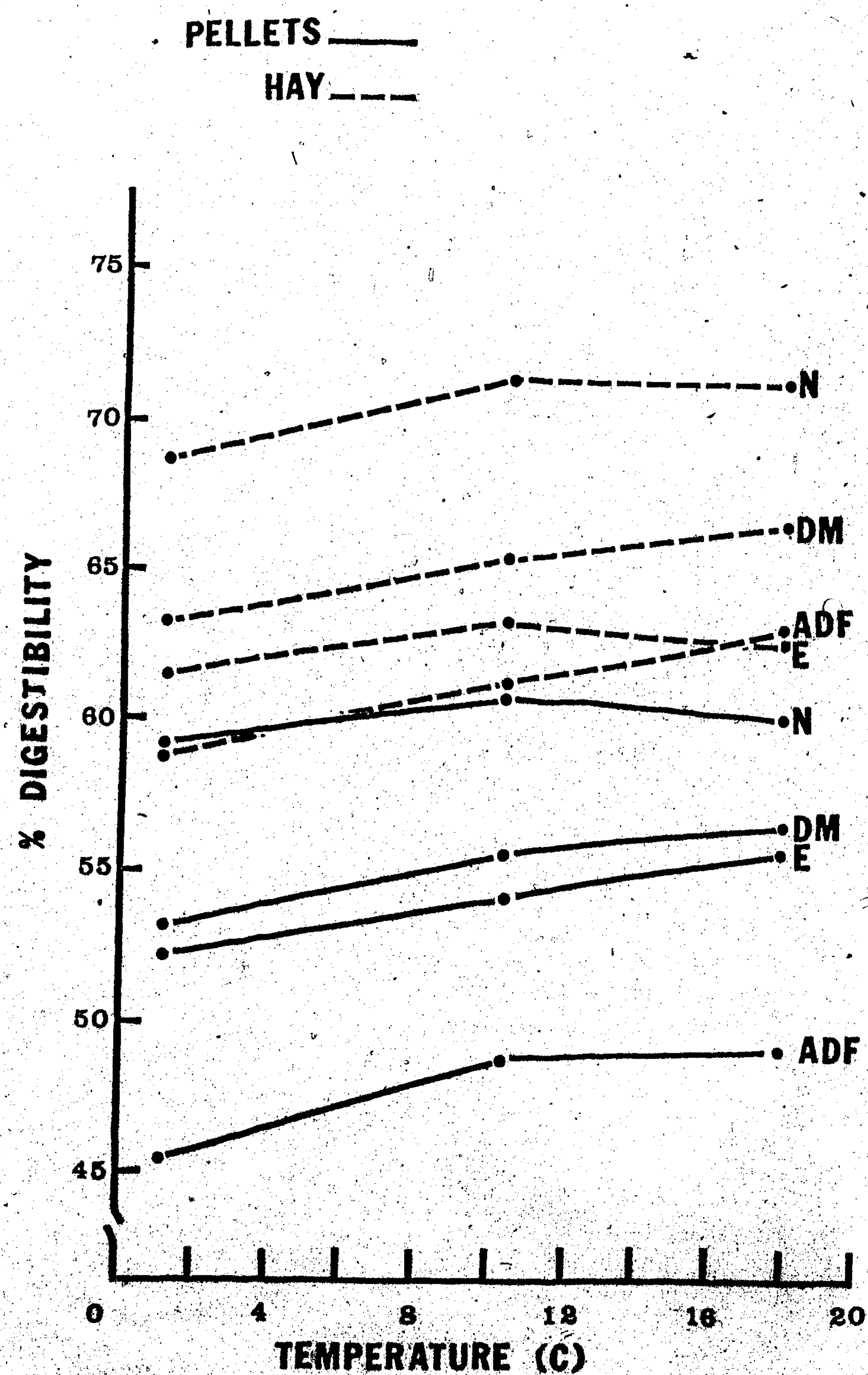
DM digestibility = 53.16 + 0.213 temperature (T)

which means that DM digestibility was significantly ($P < 0.005$) depressed by 0.21% for every degree (C) drop in temperature (see table 5). By regressing DM digestibility on environmental temperature for the hay-fed sheep, DM digestibility was depressed 0.19% for every degree (C) drop in temperature but was not significant ($P > 0.05$) (see table 6).

b. Gross energy (E) digestibility

The digestibility of E closely paralleled the linear curve of the DM digestibility for the pellet-fed sheep. Shown in table 5 and Figure 3a the mean E digestibility of the pellet-fed sheep exposed to the cold treatment was significantly lower ($P < 0.05$) than the mean E digestibility of the same sheep exposed to the warm treatment. This was not the case for the hay-fed sheep. No significant changes ($P > 0.05$ - ANOVA) were observed between the E digestibility means across temperature treatments for the hay-fed sheep, even though E digestibility tended to be

FIGURE 3a. The effect of temperature and ration on the apparent digestibility of dry matter (DM), energy (E), nitrogen (N), and acid detergent fiber (ADF) in sheep.



depressed in the cold treatments when compared to the E digestibility of the same sheep within the intermediate and warm treatments. A large variation between individual E digestibility values and the low mean E digestibility of sheep in the warm treatment appeared to contribute to the non-linearity of the digestibility-temperature curve for the hay-fed sheep. Shown in figures 3b, 3c and 3d, the digestibility values for each of the proximate nutrients (appendix table 6) were averaged for the 2 sheep within each ration within each sheep unit (SU) and graphically related to environmental temperature for comparison purposes. Shown in figure 3b, E digestibility of the 2 hay-fed sheep within SU 1 were shown to be greatly depressed in the warm treatment and contributed to the low mean value shown in table 5. (DM digestibility was also slightly depressed in the sheep exposed to the warm treatment when compared to the same sheep in the previous cold treatment.) In figure 3d, E digestibility in hay-fed sheep within SU 3 was augmented 1.8% when the sheep were moved from a warm treatment to an intermediate treatment. When the same sheep were moved from the intermediate treatment to the cold treatment E digestibility was reduced only slightly (0.42%). (DM digestibility increased to nearly the same level when the sheep were exposed in the warm treatment).

The digestibility [illegible] DM and E in SU 2, shown in figure

FIGURE 3b. The effect of temperature and ration on the apparent digestibility of dry matter (DM), energy (E), nitrogen (N), and acid detergent fiber (ADF) in sheep within sheep unit no. 1.

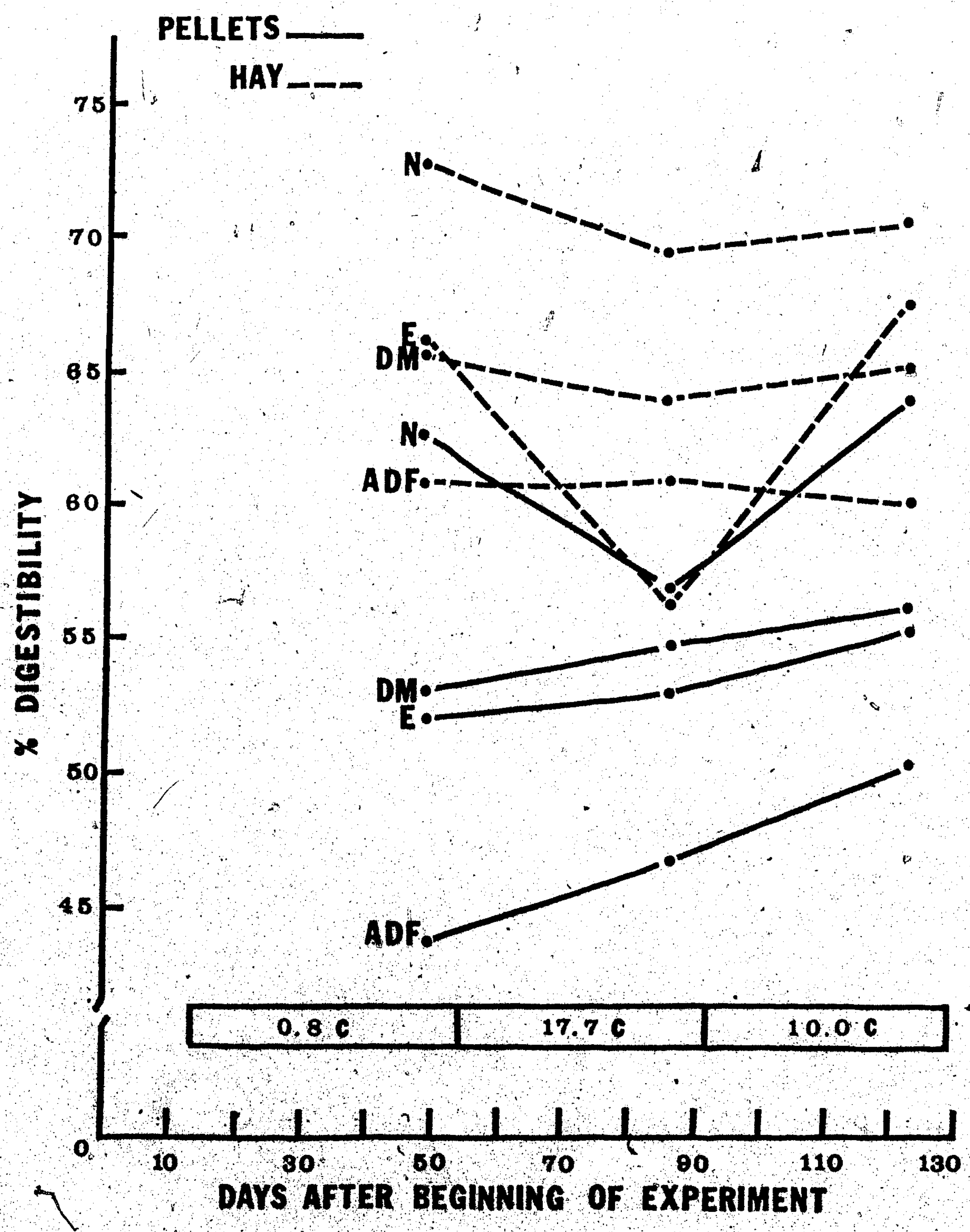


FIGURE 3c. The effect of temperature and ration on the apparent digestibility of dry matter (DM), energy (E), nitrogen (N), and acid detergent fiber (ADF) in sheep within sheep unit no. 2.

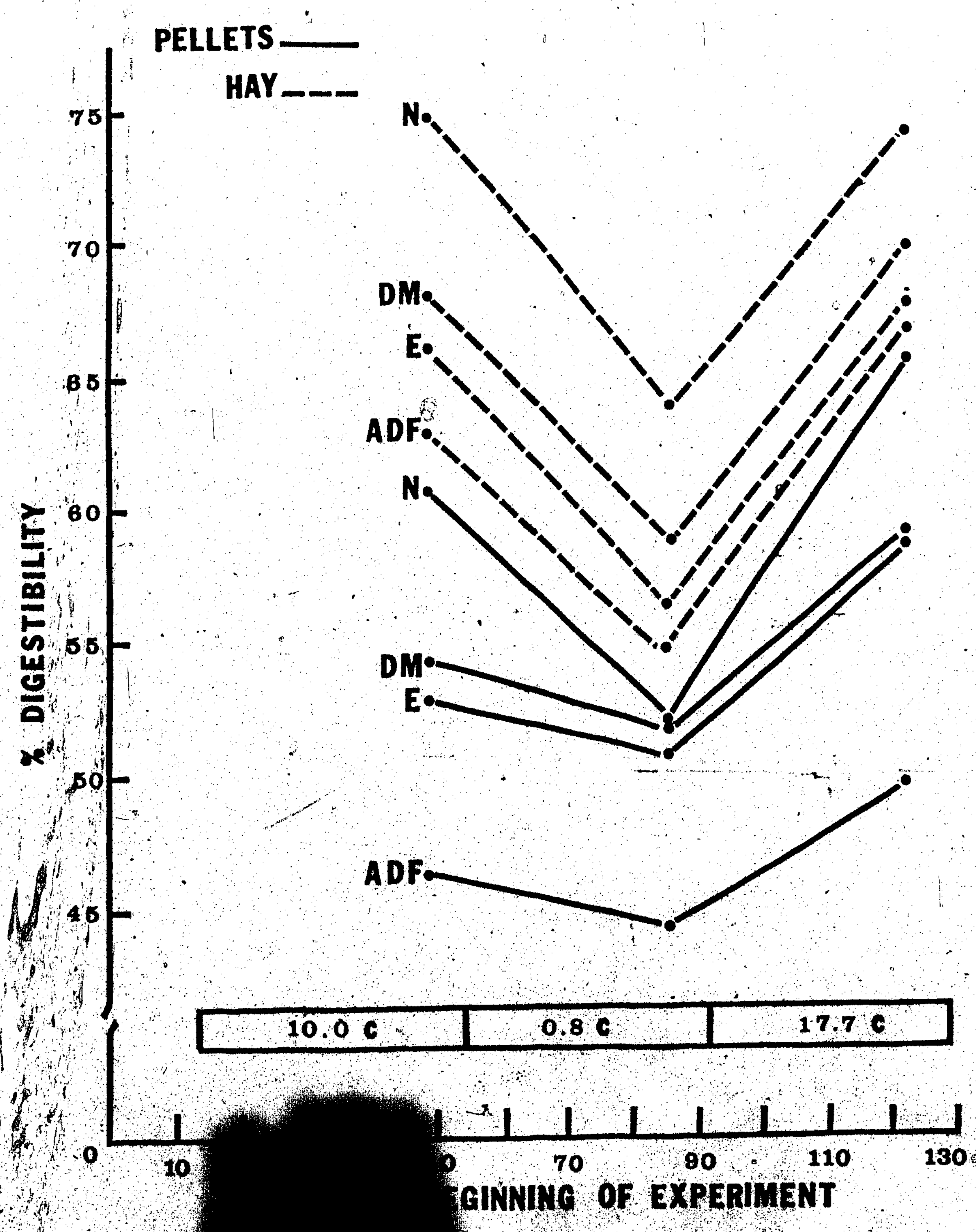
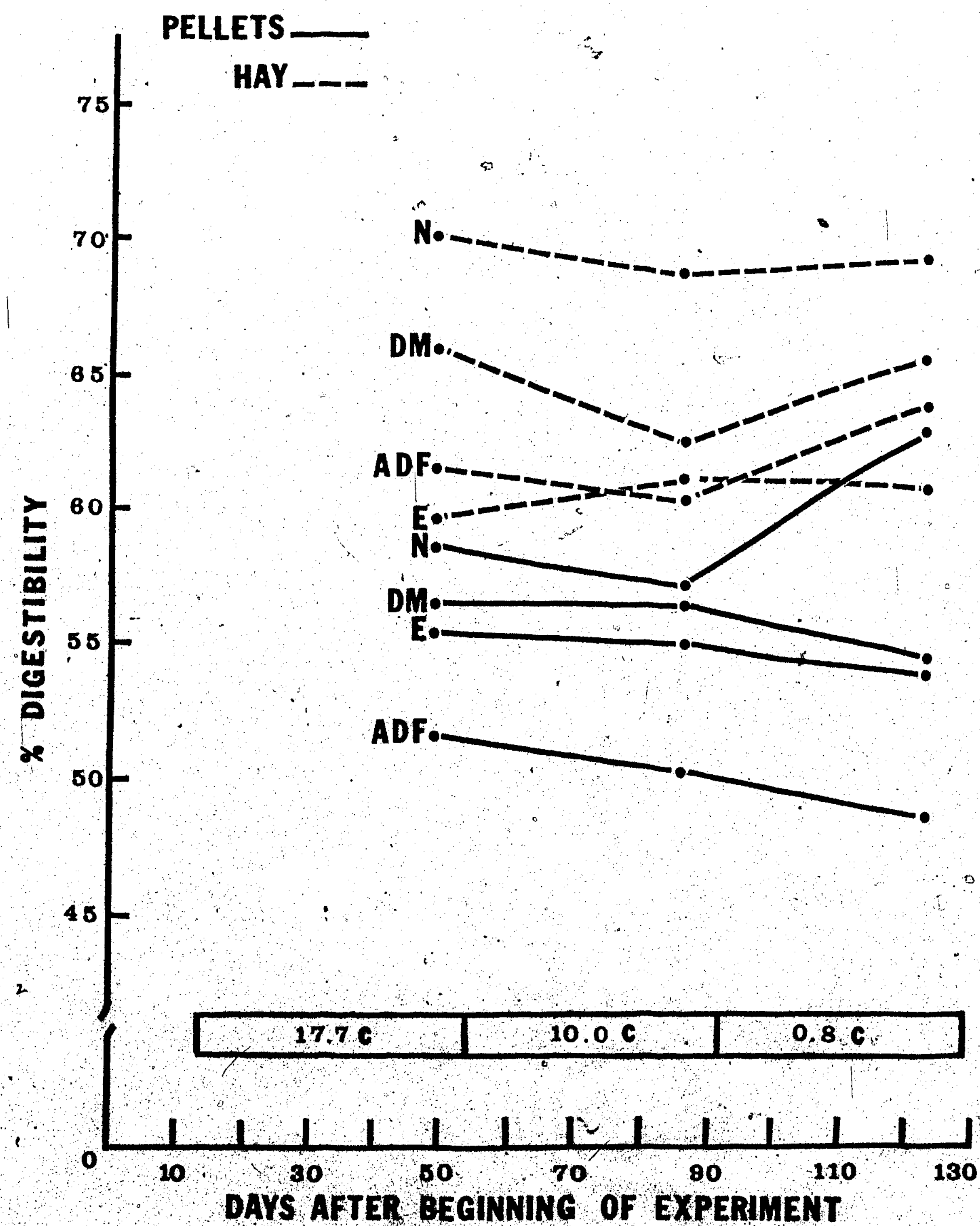


FIGURE 3d. The effect of temperature and ration on the apparent digestibility of dry matter (DM), energy(E), nitrogen (N), and acid detergent fiber (ADF) in sheep within sheep unit no.3.



3c, closely paralleled each other for both rations, the hay-fed sheep showing a smaller variation between the intermediate and warm treatments than the pellet-fed sheep. The DM and E digestibilities also showed a greater depression in the hay-fed sheep than in the pellet-fed sheep. Therefore, the order in which the sheep entered the various temperature treatments (and to some degree, the ration) appeared to modify the effect of temperatures on digestibility of nutrients. This factor was recognized when an ANOVA was done (appendix table 9). Within sheep between periods accounted for a significant amount ($P<0.005$) of variation to DM and E digestibility. Sheep units did not account for any significant variation. Although a significant amount of variation was contributed in the period-temperature-ration interaction for E digestibility ($P<0.025$), period effect accounted for most of the variation. Therefore it appears that most of the variation in DM and E digestibility of sheep was a result of period effect. Whether this result was due to the stress of the botfly infestation is still unclear, although this may have accounted for the depression in digestibility of feed during period 2.

Only the pellet-fed sheep had a significant ($P<0.025$) depression in E digestibility per degree (C) drop in environmental temperature (see table 6). The hay-fed sheep showed no significant ($P>0.05$) change in E digestibility

TABLE 6. The relationship of the digestibility coefficients within each ration with environmental temperature.

Digestibility Coefficient	Slope(b-value)		Standard Error		Y - intercept		P.L.	
	P	H	P	H	P	H	P	H
DM	0.21	0.19	1.88	3.34	53.2	63.2	<0.005	N.S.
E	0.19	0.08	2.12	3.97	52.5	61.8	<0.025	<0.10
N	0.07	0.16	4.76	3.57	59.4	69.0	N.S.	N.S.
ADF	0.23	0.25	2.91	3.01	45.7	58.6	<0.05	<0.05
Other								
*N. Ret.	0.52	0.48	7.79	9.48	8.5	23.5	N.S.	N.S.

*N. Ret. - nitrogen retention

P.L. - Probability level at which $b \neq 0$.

across temperature treatments.

c. Nitrogen (N) digestibility and retention

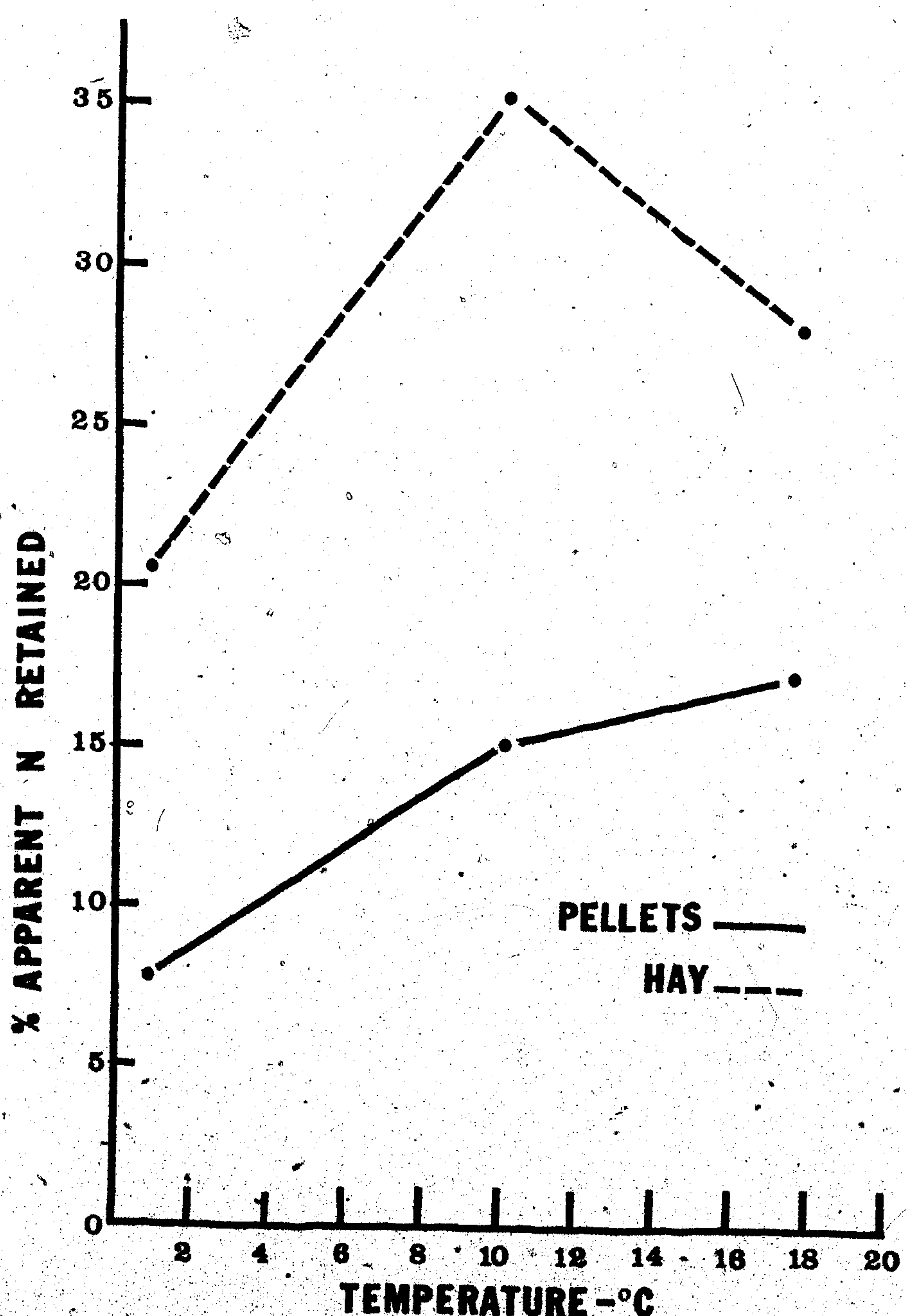
Temperature had no significant effect on N digestibility although a slight depression was observed when the sheep were exposed to the cold environmental temperature (see table 5 and figure 3). Ration, however, had a significant effect on N digestibility (see appendix table 9). The changes in N digestibility in sheep within each SU appeared to be conflicting at times. Within SU 1, shown in figure 3b, N digestibility of the hay-fed sheep exposed to the cold treatment was quite high (73.1%) compared with the sheep in the other SUs. When the same sheep were acclimated to the warm treatment following the cold treatment N digestibility was reduced, and rose slightly when followed by the intermediate treatment. Pellet-fed sheep within the same SU also had a higher N digestibility (62.7%) compared to the other two SUs when exposed to the cold treatment, but decreased by 6% when followed by the warm treatment. When the sheep were exposed to the intermediate treatment N digestibility was augmented to a level of 63.8% compared with 56.7% in the previous warm temperature treatment.

For sheep unit 3, nitrogen digestibility in the hay-fed sheep was slightly depressed (69.3%) during the cold treatment compared to the digestibility during the warm treatment (70.3%), (figure 3d). In the pellet-fed sheep N digestibility decreased slightly when moved from the warm to the intermediate treatment but increased by nearly 6% when followed by a cold treatment exposure -- a very similar behavior to that seen in SU 1, of figure 3b. In sheep unit 2 (figure 3c) the effects of temperature on N digestibility in both hay-fed and pellet-fed sheep was opposite to that seen in sheep unit 1 (figure 3b). The trends in sheep unit 3 (figure 3d) were intermediate between those of sheep units 1 and 2. As shown in the ANOVA (appendix table 9) N digestibility showed significant variation ($P < 0.005$) between periods. During period 2 the sheep suffered the greatest depression in N digestibility. The botfly infestation which appeared to cause the sheep the most discomfort during this period may have contributed to a reduction in N digestibility.

There tended to be greater losses of N in the urine in sheep exposed to the cold treatment compared with sheep exposed to the warmer treatments, as shown in table 7. This also applied to N losses in the urine and feces combined. There were significant (appendix table 10) differences between periods for both N losses in the urine ($P < 0.005$) and the loss of N in the urine and feces combined ($P < 0.01$). Variations due to temperature and between SUs also had a significant ($P < 0.01$ and $P < 0.034$ respectively - appendix table 10) effect on the N losses in urine and feces combined.

The mean values for apparent retention of N are shown in table 7 and figure 4. Nitrogen retention tended to be

FIGURE 4. The effect of temperature and ration on mean apparent N retention in sheep.



depressed by the cold temperature treatment, but the regression of N retention on temperature was not significant ($P > 0.05$). Again, there was a significant period effect. The N retention values for the pellet-fed sheep (shown in table 7) were not significantly affected by temperature ($P > 0.05$), but in general the cold sheep tended to retain less N than the warm sheep (sheep exposed to the cold and warm treatments, respectively). The hay-fed sheep, when exposed to the intermediate treatment, had a significantly higher N retention than during exposure to the cold treatment.

TABLE 7. The effect of temperature and ration on N retention in sheep.

Ration	P	H	P	H	P	H
Room Temperature (C)	0.8	0.8	10.0	10.0	17.7	17.7
Average daily N in urine (mg N/gm urine)	12.1_{bc}	12.6_{c}	11.0_{abc}	9.5_{a}	10.1_{ab}	11.7_{bc}
Average daily N in urine & feces (g. N /g. urine & feces	21.5_{c}	20.7_{bc}	20.3_{bc}	16.9_{a}	19.3_{b}	19.4_{bc}
Apparent N Retention (%)	8.4_{a}	20.6_{ab}	15.1_{ab}	35.4_{c}	17.1_{ab}	28.0_{bc}

a,b,c - when subscripts are different within the rows the values are significantly different at $P < 0.05$. (Duncans New Multiple Range Test).

P = pellet-fed sheep

H = hay-fed sheep

d. Acid detergent fiber (ADF) digestibility

The changes in ADF digestibility in response to temperature and ration were similar to the changes in DM digestibility (figure 3a). ADF digestibility was directly related to temperature in sheep fed either ration ($P < 0.02$) as shown in figure 3a. Mean ADF digestibilities in the cold treatment were, 45.5 and 58.8% and in the warm treatment 49.3 and 63.1% for pellet-fed and hay-fed sheep, respectively (see table 5). The ADF digestibility values differed significantly between cold and warm treatments ($P < 0.005$) and between ration treatments ($P < 0.00001$).

The changes in ADF digestibility within each sheep unit are shown in figures 3b, 3c, and 3d. Within SU 1 (figure 3b), the cold treatment depressed ADF digestibility to 43.8% for the pellet-fed sheep and to 60.9% for the hay-fed sheep. In the second period, when the sheep were exposed to the warm treatment, ADF digestibility increased by 2.9% for the pellet-fed sheep and increased only 0.1% for the hay-fed sheep. The reason for the small change in the hay-fed sheep was that one of the sheep (#9488) showed a depressed digestibility of 2.8% while its partner showed an increased digestibility of 2.6% (see appendix table 6). (The same behavior was true for DM and E digestibility). When SU 1 was exposed to the final temperature treatment (intermediate treatment) the pellet-fed sheep increased their ADF digestibilities (similarily for DM & E digestibilities) even higher, while the hay-fed sheep experienced a slight depression or no change in ADF digestibility. Sheep within SU 2 (figure 3c) showed changes in ADF digestibilities that were directly related to temperature treatments. The same was true for the pellet-fed sheep in SU 3 (figure 3d). But the hay-fed sheep in SU 3 increased their ADF digestibilities when exposed to the cold treatments in contrast to the preceeding temperature treatments (the same was true for DM digestibility in the hay-fed sheep).

The reductions in ADF digestibilities per degree C drop in environmental temperature determined by regression analysis were 0.23% and 0.25% for the pellet-fed and hay-fed sheep, respectively (table 6). Both regression coefficients were significant ($P < 0.05$).

5. The Effect of Temperature and Ration on % DM In The Feces.

Environmental temperature had no significant ($P > 0.05$) effect on % DM in the feces, although the sheep exposed to the cold tended to excrete dryer feces than the same sheep exposed to the warm treatments (table 5). The hay-fed sheep tended to have greater % DM in the feces than the pellet-fed sheep, but the difference was not significant ($P > 0.08$, appendix table 10).

6. The Effects of Temperature and Ration on Water Utilization.

Mean values for water intake have already been presented in section 3 of the results (table 2). The average daily water excreted in the feces and urine (total water excreted) per kg BW is summarized in figure 5 and table 8 and the ANOVA is given in appendix table 11. The hay-fed sheep in the intermediate treatment excreted significantly less water ($P < 0.05$) than the pellet-fed sheep in any of the temperature treatments; and in the warm treatment the hay-fed sheep excreted significantly less water ($P < 0.05$) than the same sheep exposed to either the cold, or the intermediate treatments (table 8). Not only did the hay-fed sheep tend to excrete less water in the urine and feces per kg BW, but (as discussed above) they also tended to drink less water per kg BW than the pellet-fed sheep across temperature treatments (compare table 2), as shown in figure 5. There was no significant ($P > 0.05$) effect of temperature on urine excretion in sheep within rations (appendix table 11). Water excretion in the urine of sheep showed a significant variation between periods ($P < 0.005$) and between rations ($P < 0.006$).

Figure 6 shows the effect of temperature and ration on apparent water retention in sheep. The ANOVA is given in appendix table 12. Table 8 contains the comparisons among means by Duncan's New Multiple Range Test. The hay-

FIGURE 5. The effect of temperature and ration on water consumption per kgm body weight (BW) and water excretion per kgm BW in sheep.

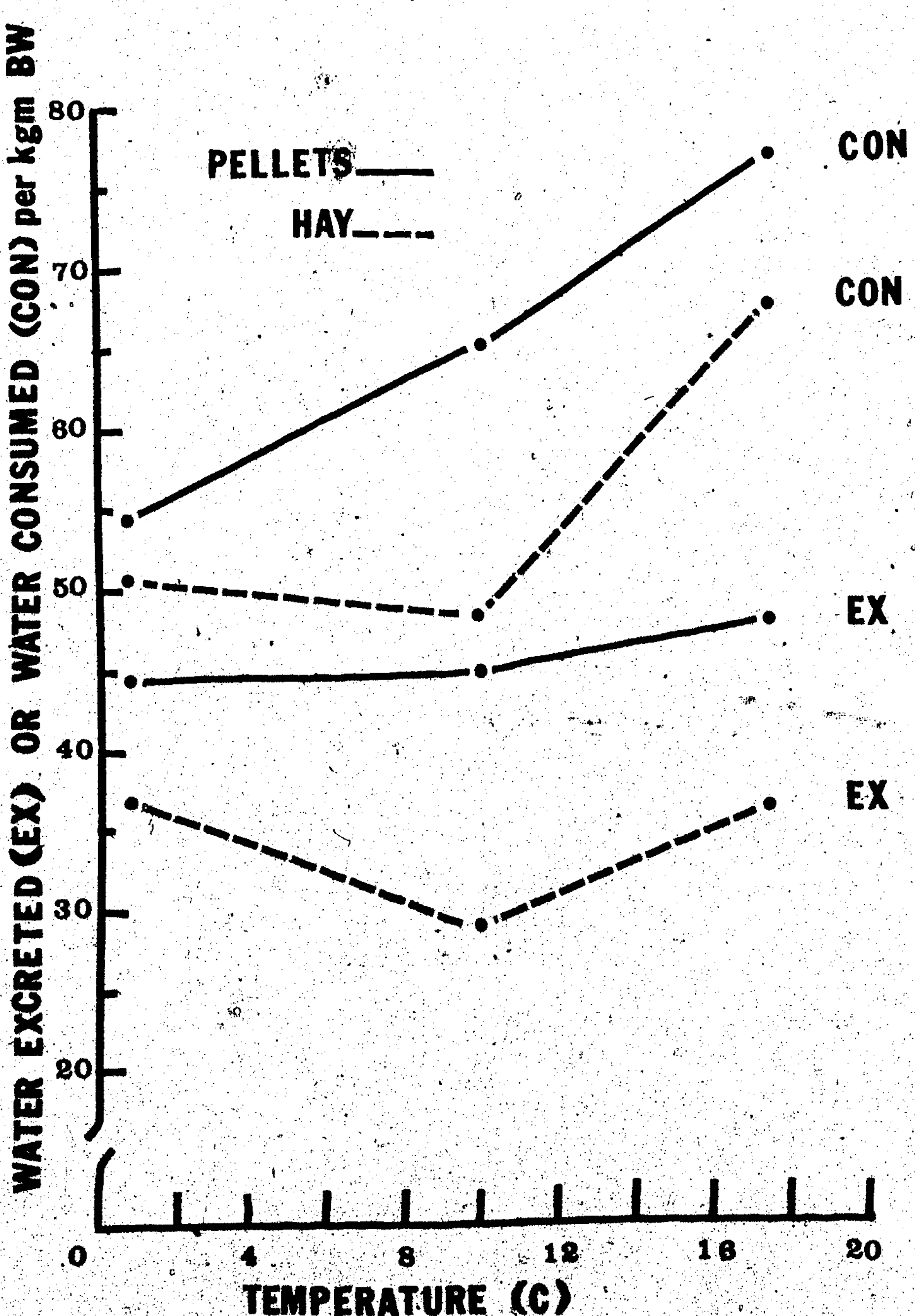


FIGURE 6. The effect of temperature and ration on apparent water retention in sheep.

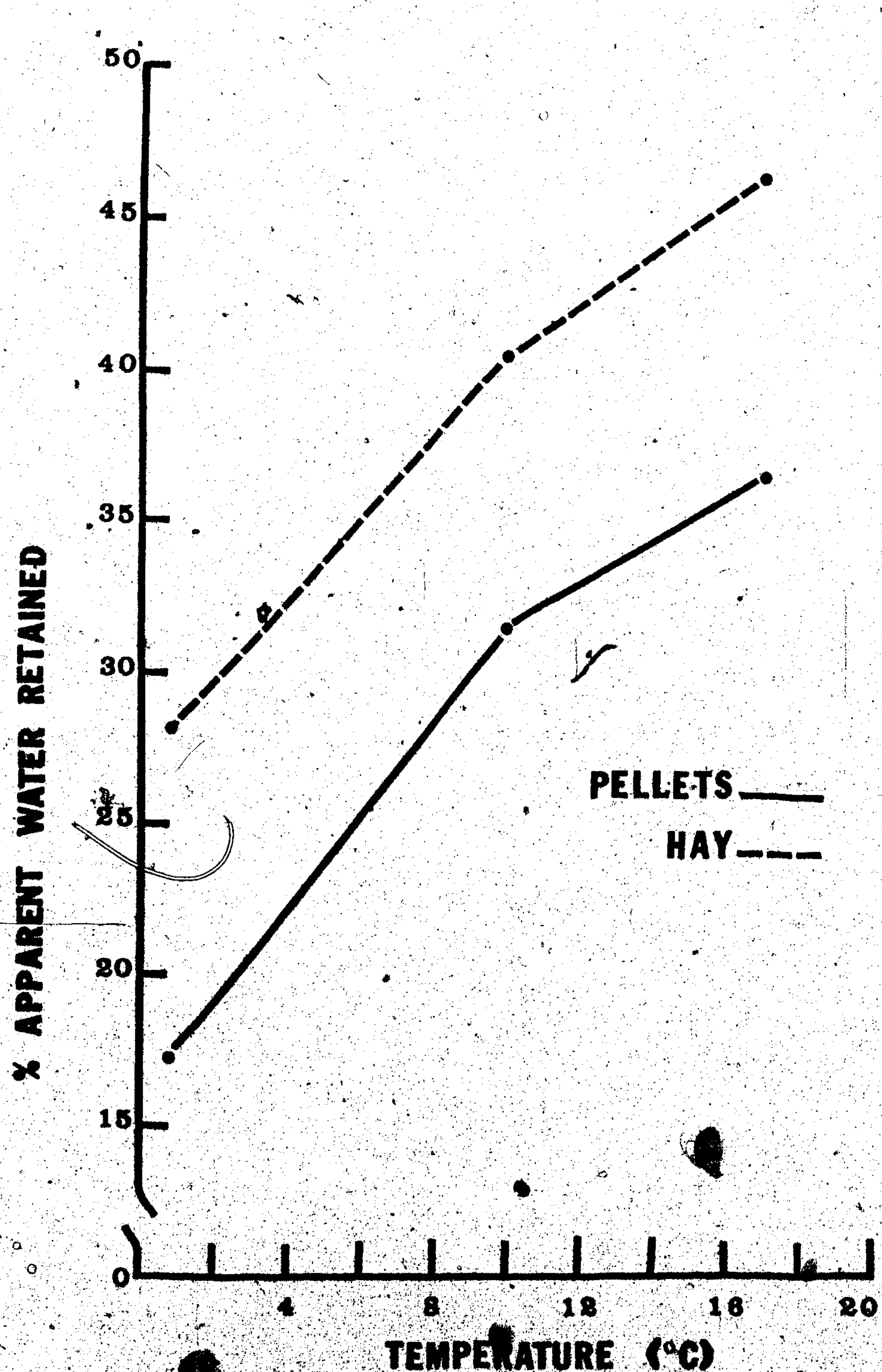


TABLE 8. The effects of temperature and ration on water metabolism in sheep.

Ration	P	H	P	H	P	H
Room Temperature (C)	0.8	0.8	10.0	10.0	17.7	17.7
Apparent water retention (%)	17.3_{a}	28.1_{b}	31.4_{bc}	40.4_{cd}	36.4_{bc}	46.2_{d}
Average daily total water excreted (g) per kg BW	44.3_{jk}	36.6_{ijk}	44.6_{jk}	28.6_{i}	47.9_{k}	36.0_{ij}

a,b,c,d - when subscripts are different within the rows the values are significant at 0.01 level (Duncan's New Multiple Range Test).

i,j,k - when subscripts are different within the rows the values are significant at 0.05 level (Duncan's New Multiple Range Test).

fed sheep retained significantly more water than the pellet-fed sheep ($P < 0.01$) within the warm and cold temperature treatments. Although not significant, the hay-fed sheep also tended to retain more water than the pellet-fed sheep within the intermediate treatment.

Sheep within a ration and exposed to the cold treatments retained significantly ($P < 0.01$) less water than the same sheep exposed to the intermediate and warm treatments. Significant variations were obtained between sheep within SUs and within sheep between periods (see appendix table 12).

7. The Effect of Temperature and Ration on Plasma Thyroxine (T_4) Triiodothyronine (T_3), PBI Concentrations and Blood Hematocrit.

The thyroid hormones T_3 and T_4 tended to be increased when sheep were exposed to the cold treatment. Shown in table 9, the mean total thyroxine (T_4) concentration in the plasma of the pellet-fed sheep exposed to the cold treatment was 12.76 micrograms (mcg)%. The same sheep in the warm treatments had significantly lower ($P<0.05$) mean T_4 concentrations (8.70 mcg %). When exposed to the intermediate treatment, the mean T_4 concentrations were not significantly different from, but were intermediate to the other two mean values. The T_4 concentrations in the hay-fed sheep were not significantly ($P>0.05$) affected by the temperature treatments, although the sheep in the warm treatments had depressed T_4 concentrations as compared with the sheep exposed to the cold and intermediate treatments (see table 9). As shown in table 10, the hay-fed sheep not only had a smaller change in T_4 concentration per degree C, but also had a lower r^2 value than the pellet-fed sheep. Only 19% of the variation in T_4 concentration was explained by the environmental temperature for the hay-fed sheep, while 42% of the variation in T_4 concentration was explained by the environmental temperature in the pellet-fed sheep (appendix table 13).

TABLE 9. The effect of temperature and ration on plasma thyroxine (T_4), triiodothyronine (T_3), protein-bound iodine (PBI) concentrations and blood hemotocrit (HCT).

Ration	P	H	P	H	P	H
Room Temperature (C)	0.8		10.0		17.7	
Mean Values:						
T_4 (mcg %)	12.76_k	10.56_{ijk}	11.85_{jk}	10.06_{ijk}	8.70_{ij}	7.30_i
T_3 (ng %)	241.70_k	119.70_{ij}	192.00_{jk}	161.30_{ijk}	123.20_{ij}	73.00_i
PBI (mcg %)	3.72	2.79	4.06	2.84	3.77	2.79
HCT (%)	36.10	33.30	35.20	33.10	31.70	32.30

i,j,k - values within the rows having the same subscripts or none at all are not significantly different ($P < 0.05$) from each other (Duncan's New Multiple Range Test).

TABLE 10. Regression analysis of total plasma T_4 and T_3 concentrations in sheep with environmental temperature.

Thyroid hormone	ration	b	a	r^2	$S_{y.x}$
T_4	pellets	-0.24	13.3	0.42	1.90
	hay	-0.19	11.1	0.19	2.56
T_3	pellets	-6.96	251.7	0.48	50.3
	hay	-2.53	142.0	0.09	55.6

Total plasma triiodothyronine (T_3) concentrations in sheep across treatments showed changes similar to those described for the T_4 concentrations. The pellet-fed sheep in the cold treatment had significantly higher ($P < 0.05$) T_3 concentrations than the same sheep in the warm treatment, as well as higher T_3 concentrations than the hay-fed sheep in the cold and warm treatments (table 9) (see also appendix table 13). Regression analysis indicated that 48% of the variation in T_3 concentrations was contributed by temperature (table 10). As in the plasma T_4 concentration pattern, the hay-fed sheep showed no significant differences between temperature treatments. Interestingly, the hay-fed sheep exposed to the intermediate treatments tended to have higher T_3 concentrations than the same sheep in the cold treatments; contrary to what was observed in the pellet-fed sheep.

Shown in table 9, temperature had no significant effect on serum protein-bound iodine (PBI) concentrations in the sheep, although a significant ration effect was noted in the ANOVA (appendix table 13).

No significant ($P > 0.05$) changes in blood hematocrit (HCT) were seen in sheep between temperature and ration treatments (table 10). However, the mean blood HCMs tended to decrease with increasing environmental temperature within each ration. In addition, the mean blood HCT of the pellet-fed sheep in the cold and intermediate treatments tended to be higher than the mean blood HCTs in the hay-fed sheep exposed to the same temperature treatments.

8. The Effect of Environmental Temperature and Ration on the Temperature of Various Body Sites.

Body surface temperatures monitored from one sheep within each ration and within each SU during the third period are shown in figures 7a, 7b, and 7c. The sheep within the cold treatment generally had colder body surfaces than the sheep within the intermediate treatment which had colder body surfaces than the sheep within the warm treatments (see also appendix table 17).

A series of rectal temperatures were recorded from each sheep for 8 consecutive days within the second period (see appendix table 14). A summary is shown in table 11, below.

TABLE 11. The effect of environmental temperature and ration on the mean rectal temperature of sheep during the second trial period.

Environmental Temperature (C)	0.8	10.0	17.7
Rectal temperature hay-fed sheep	38.65	39.40	39.05
Pellet-fed sheep	39.0	39.05	39.30
Mean	38.83	39.23	39.18

Differences between means were not significant (see appendix table 15), although rectal temperature tended to be slightly depressed at the cold environmental temperature.

FIGURE 7a . The effect of temperature (0.8 C) and ration on the temperature of the various body sites of two sheep.

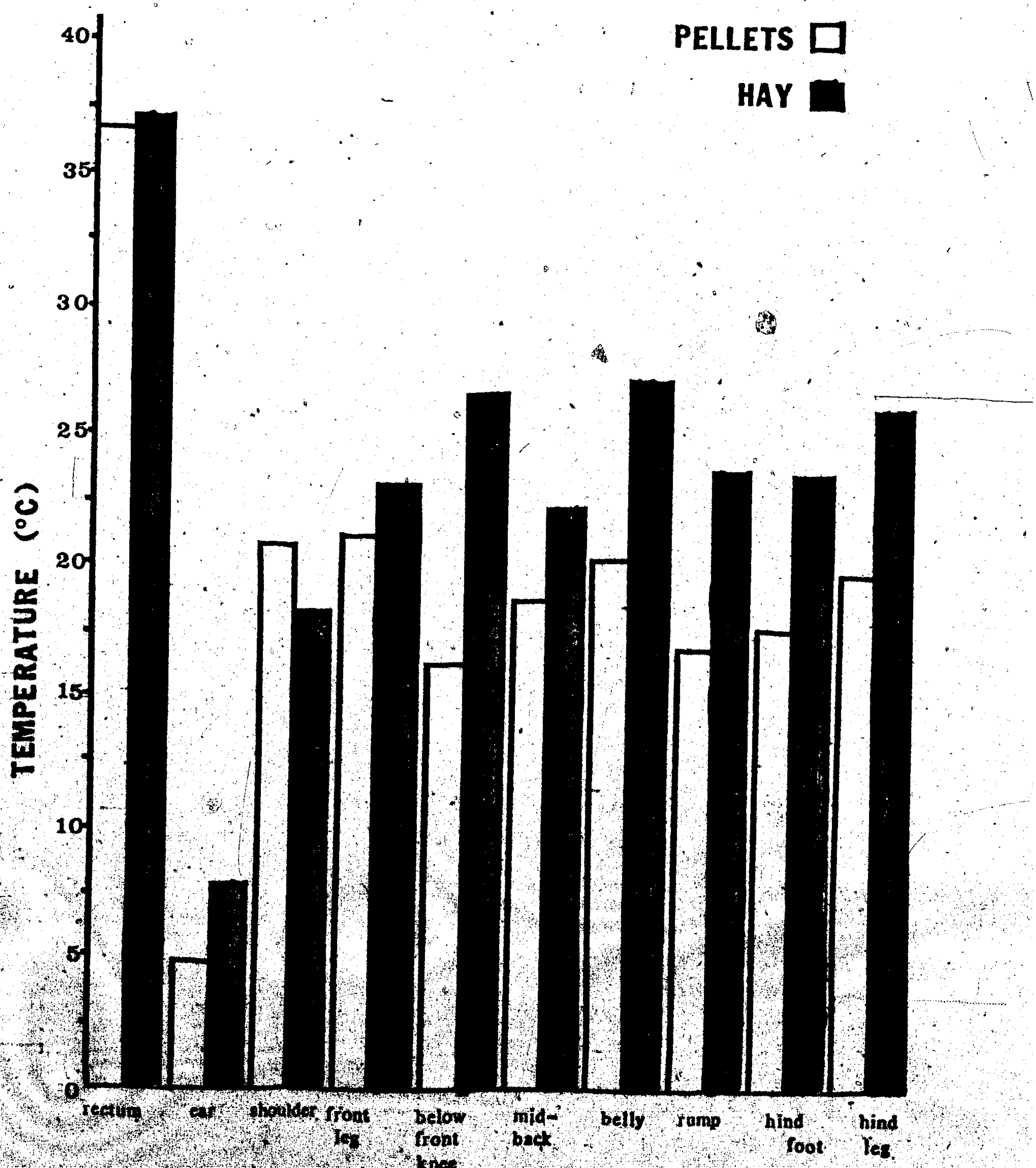


FIGURE 7b. The effect of temperature (10.0C) and ration on the temperature of the various body sites of two sheep.

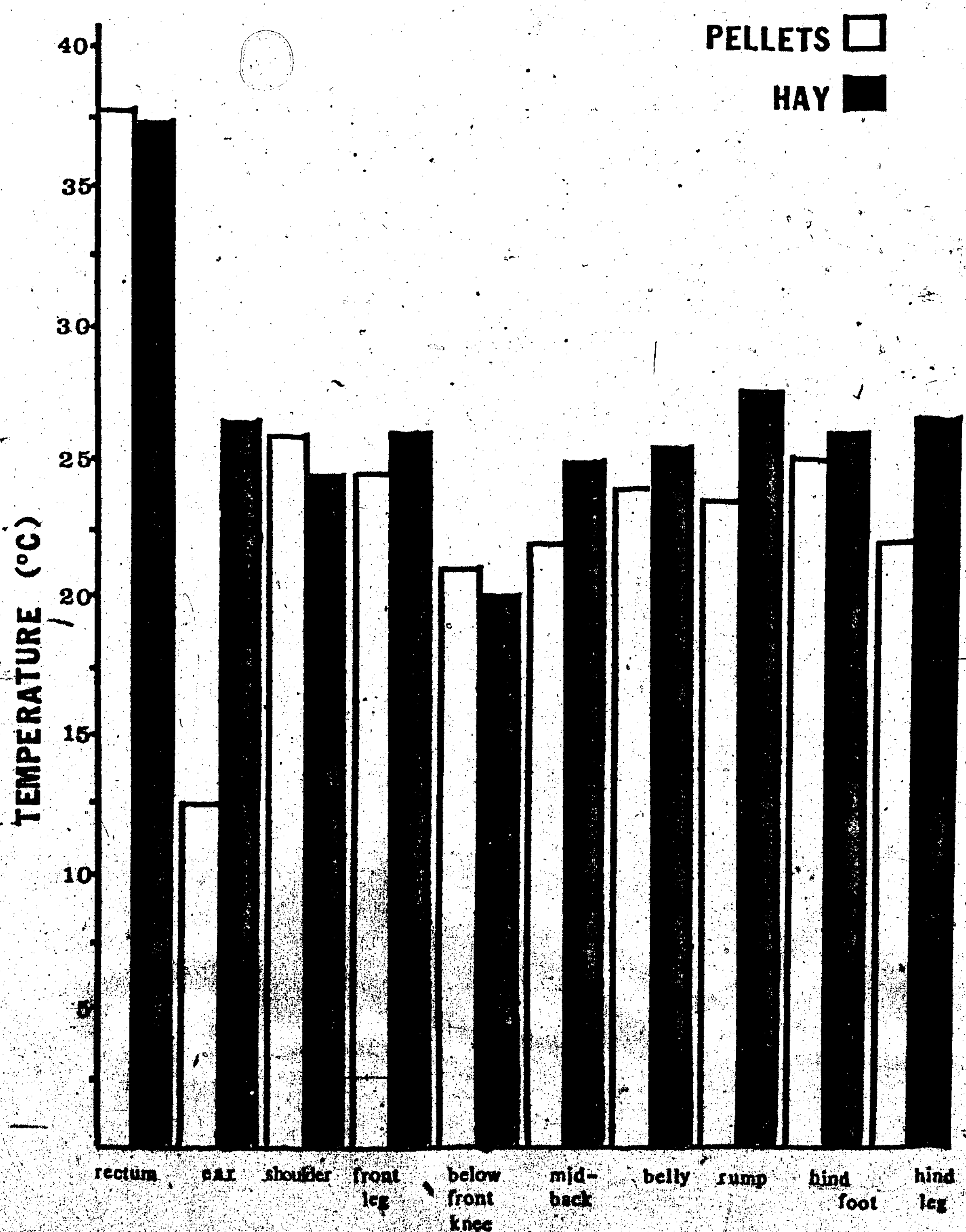
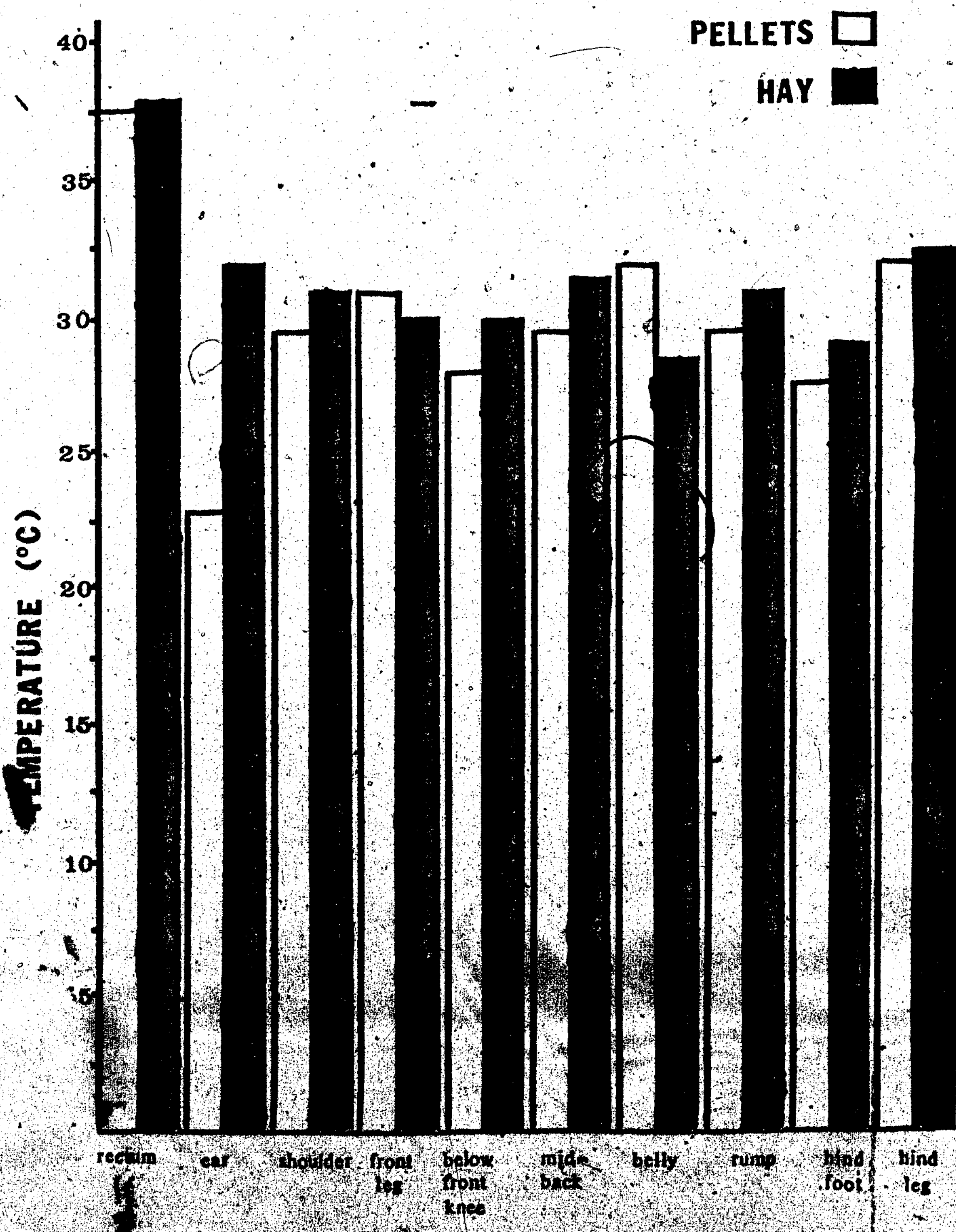


FIGURE 7c. The effect of temperature (17.7 C) and ration on the temperature of the various body sites of two sheep.



RESULTS - Experiment II

1. Animal Management

Approximately 5 days before Ce^{144} was administered in the first experimental period one wether which showed arthritic symptoms refused to consume its full ration. It was removed from its crate and moved about in the warm (21.2 C) laboratory for 2 to 3 hours per day and then returned to its crate in the cold treatment. This was repeated for 2 consecutive days after which it returned to a normal feed intake.

Shown in table 12, the sheep appeared to consume more feed in the cold treatments than in the warm treatments. But this trend occurred due to the loss in body weight (BW) when the sheep were exposed to the cold treat-

TABLE 12. The effect of temperature on the mean feed intake in sheep.

	cold (1.3C)	warm (21.2C)
	g DM/kg $BW^{3/4}$	g DM/kg $BW^{3/4}$
SU 1	72.1 ± 0.9	69.3 ± 1.0
SU 2	67.1 ± 3.2	62.1 ± 3.6
	g /day	g /day
SU 1	1450	1469
SU 2	1255	1238

ments and the gain in BW when exposed to the warm treatments (see appendix table 18), similar to what was observed in experiment I.

The temperature of the water and the time of the day that it was consumed by the sheep in the cold treatment were similar to the values observed in experiment I. Shown in table 13, the sheep drank most of their daily

TABLE 13. The effect of temperature on water intake.

Sheep I.D.	# 2701		# 8229	
	Period 1			
Time (x100 h)	Average water temp (C)	Average consumption (ml)	Average water temp (C)	Average consumption (ml)
8 - 12	9.3	2300	10.2	1575
17 - 21	3.0	450	3.2	775
	Period 2			
	# 2523		# 0513	
8 - 12	10.9	1300	9.5	3900
17 - 21	3.4	850	2.2	2825

water soon after they consumed their morning (830h) ration, at an average water temperature of approximately 10 C. Following the consumption of the evening (1600 h) ration, the sheep drank only about one-half the amount they drank in the morning. By this time, the water had cooled to about 3 C. No water was consumed between 2100 h, and 800 h the following day.

The sheep exposed to the warm treatments lay down in their crates 36 to 78% of the time between 1000 and 2100 hours each day. The sheep exposed to the cold treatments did not lay down at all between 1000 and 2100 hours (see appendix table 33).

2. The Effect of Temperature on Oxygen Consumption, Methane Production, DM Digestibility and DM in the Feces.

The degree of cold stress experienced by the sheep in the cold treatment was reflected by a significantly ($P < 0.05$) greater oxygen consumption, (or heat production (Hp)), compared to the same sheep exposed to the warm treatments (table 14). However, no significant ($P > 0.05$) change in methane production was observed.

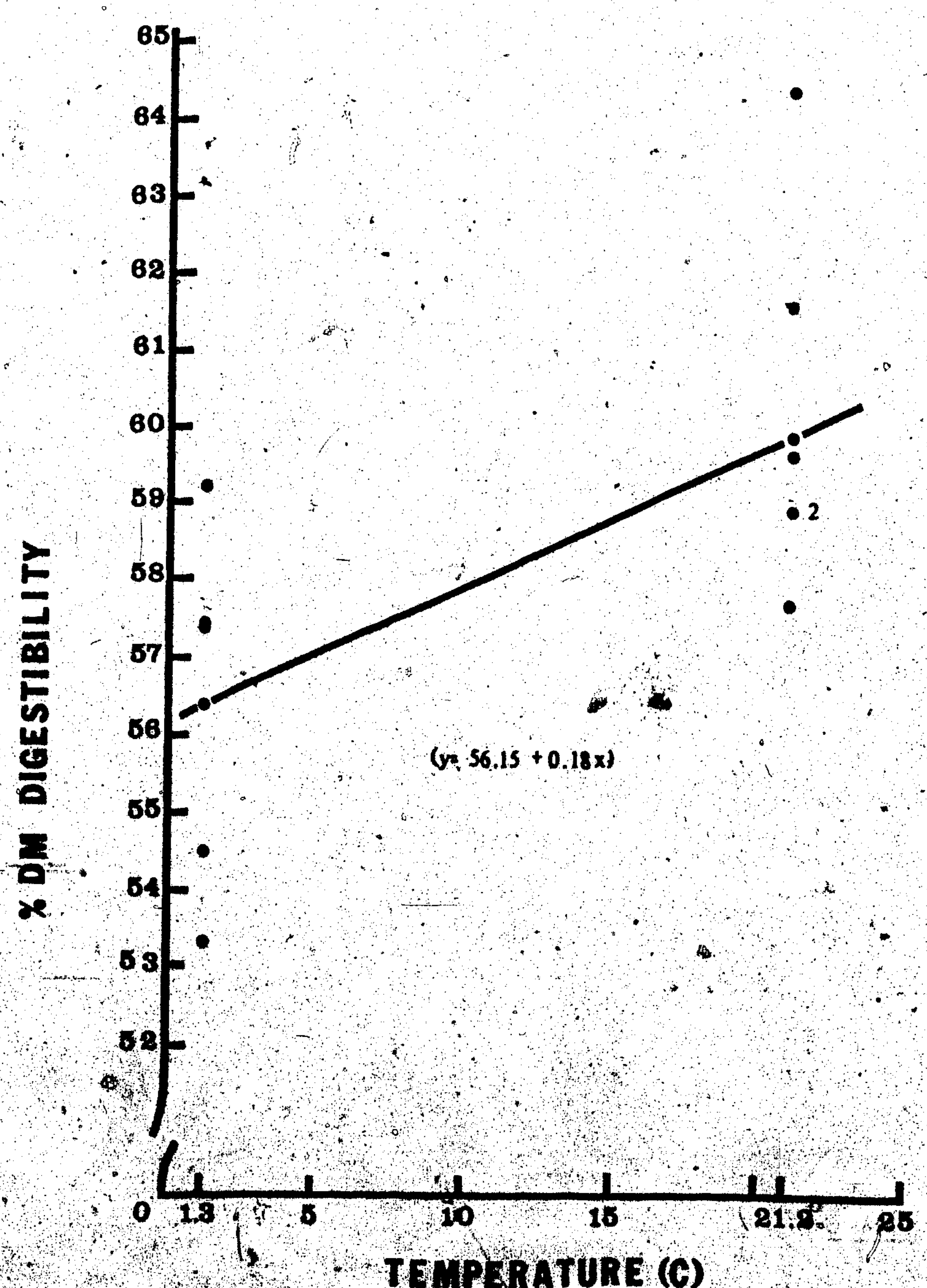
Environmental temperature had a significant ($P < 0.05$) effect on DM digestibility (table 14). There was also a

TABLE 14. The effect of temperature on oxygen consumption, methane production, DM digestibility and DM in feces.

	Cold	Warm	P.L.
Exposure Temperature (C)	1.3	21.2	
Oxygen Consumption l/kg/h	0.3579	0.2327	<0.05
Hp (Kcal/kg/day)	41	27	<0.05
Methane Production l/kg/h	0.02149	0.01986	N.S
DM Digestibility	56.5	59.9	<0.05
DM in Feces	44.1	47.2	<0.05

P.L. - probability level (Duncan's New Multiple Range Test)

FIGURE 8. The effect of temperature on dry matter (DM) digestibility in sheep.



significant ($P < 0.025$) variation in DM digestibility between sheep as shown in the appendix table 27. The DM digestibility was reduced by 0.18% per degree (C) drop in temperature (figure 8) a change similar to that observed in experiment I.

The feces excreted by the sheep exposed to the cold contained a significantly ($P < 0.05$) lower % DM content than feces from the sheep exposed to the warm treatments (Table 14). By regression analysis, it was found that the % DM in the feces was reduced by 0.16% per degree (C) drop in temperature, but the regression was not statistically significant (see appendix table 30).

3. The Effect of Temperature on the Rate of Passage and Retention Time of Ce^{144} in the Digestive Tract.

The accumulative excretion of Ce^{144} for individual sheep expressed as a percent recovery of the Ce^{144} infused into the rumen, ranged from 153.8 to 164.8% in the first experimental period and from 129.3 to 134.6% in the second experimental period (appendix tables 22a - 22*l*). Within each period there was little variation between sheep or temperatures in percent recovery suggesting that the error in recovery was constant and not influenced by treatment. The above recovery rates were calculated on the basis of Ce^{144} infusate counted in the form of an aqueous solution whereas the Ce^{144} in the feces was counted in samples of the dry particulate matter of the feces. In order to determine whether the medium in which the infusates were counted had any influence on the actual counts recorded by the gamma counter, Ce^{144} infusates from each experimental period were added in different proportions to samples of fresh (non-radioactive) sheep feces and dried to constant weight prior to counting. These counts are given in appendix table 24. The number of counts per g of infusate were not different when counting was done on infusates in a medium of dried feces than when counting was done on the infusate in an aqueous medium.

In the second experimental period the infusate had twice the radioactivity as the infusate in the first experimental period and the percent recovery was smaller by 28%. It appeared that the infusate with the lower radioactivity may have resulted in a larger error. However, the reason for this error was not established.

The cumulative excretion curves for Ce^{144} are shown in figures 9a - 9f. Each figure displays two excretion curves for one sheep exposed to each temperature treatment. In all the animals Ce^{144} was excreted in the feces more rapidly during cold than during warm exposure treatments. Various equations were tested for their ability to accurately describe the excretion curves. The data for accumulative excretion of Ce^{144} for each sheep appeared to fit quite well the multiple regression equation,

$$Y = b_o + b_1x + b_2x^2 + b_3x^3$$

FIGURE 9a. Accumulative excretion curve for Ce^{144} administered into the rumen of sheep 9236.

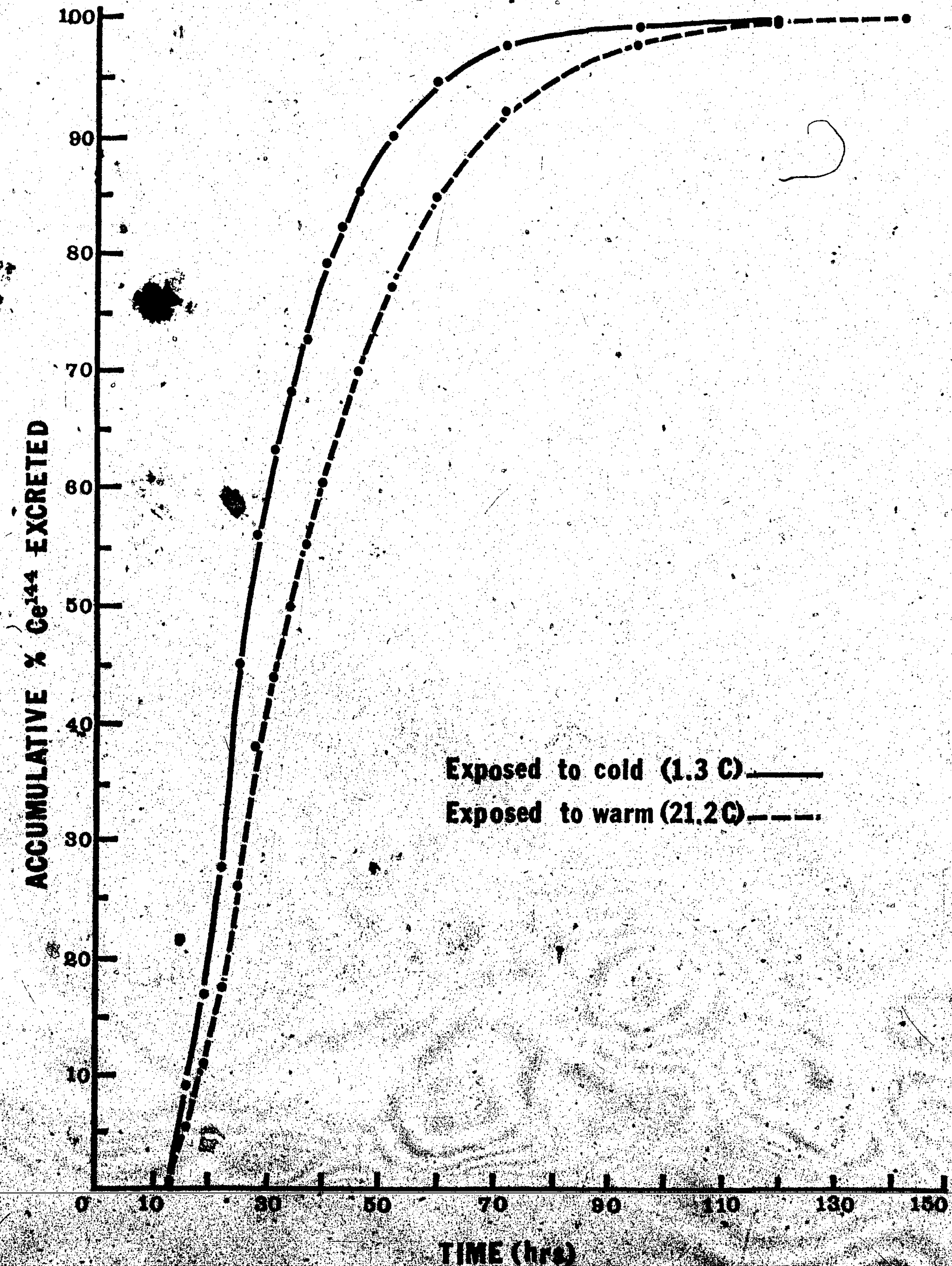


FIGURE 9b. Accumulative excretion curve for Ce^{144} administered into the rumen of sheep 8229.

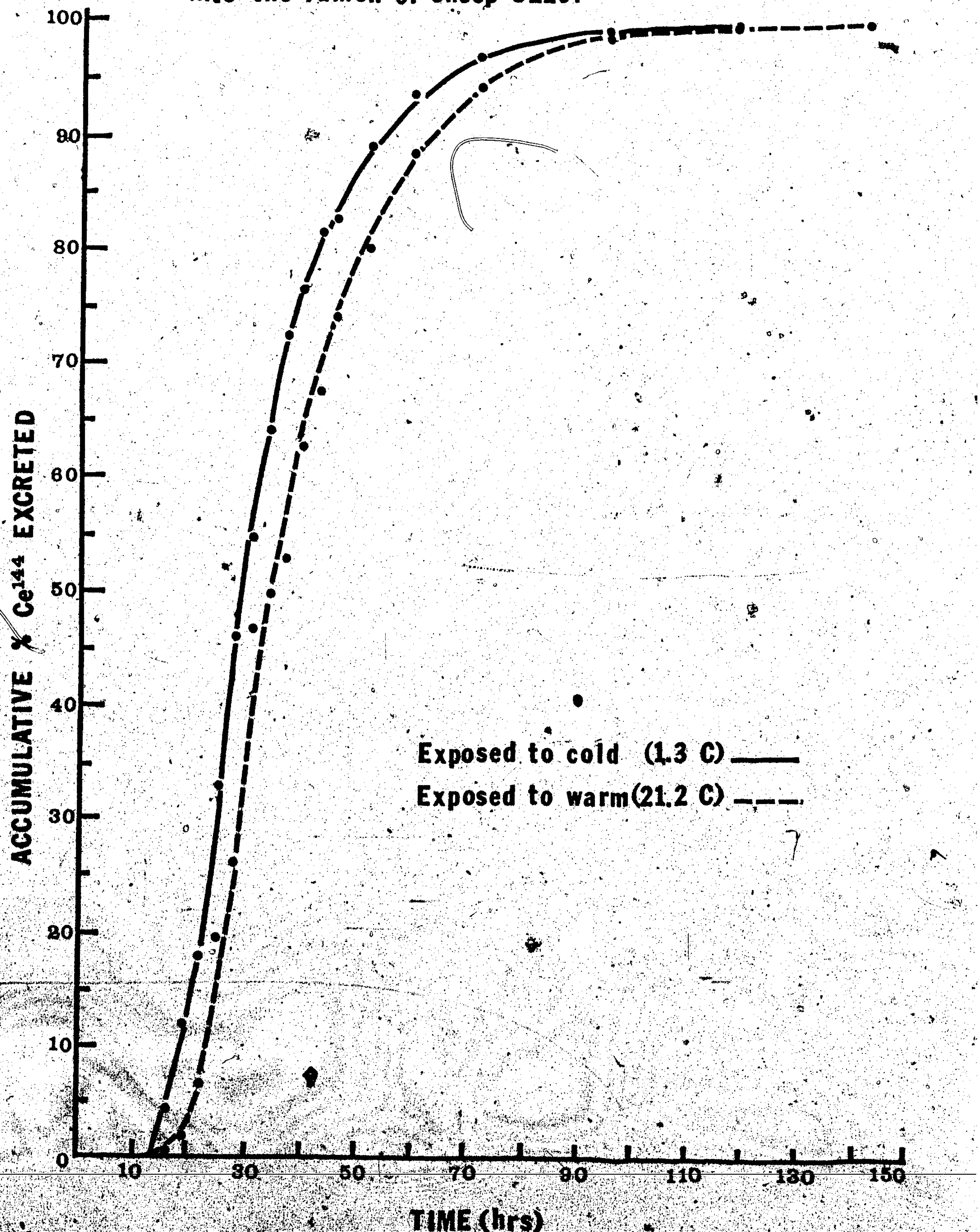


FIGURE 9c. Accumulative excretion curve for Ce^{144} administered into the rumen of sheep 8236.

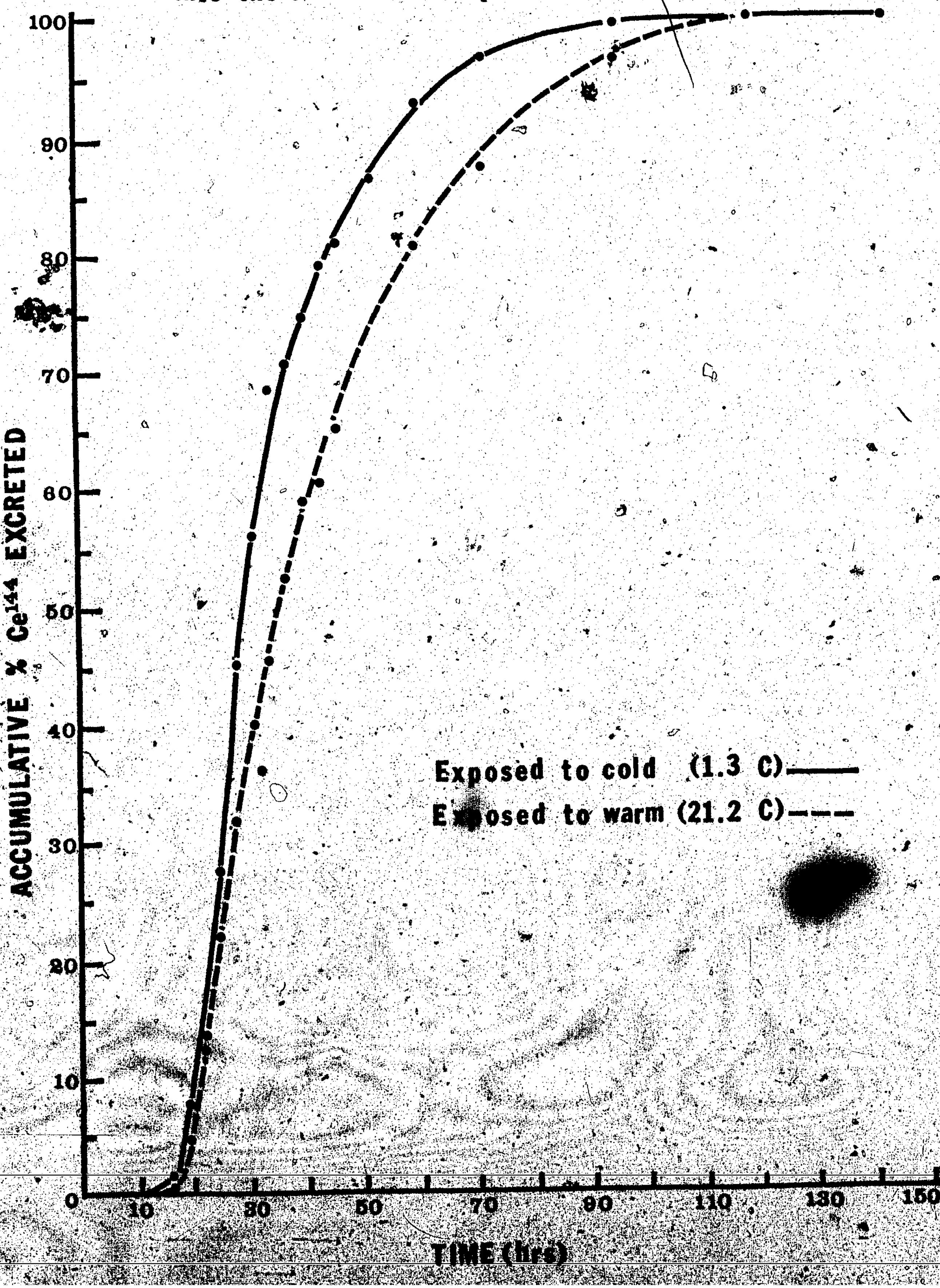


FIGURE 9d. Accumulative excretion curve for Ce^{144} administered into the rumen of sheep 2523.

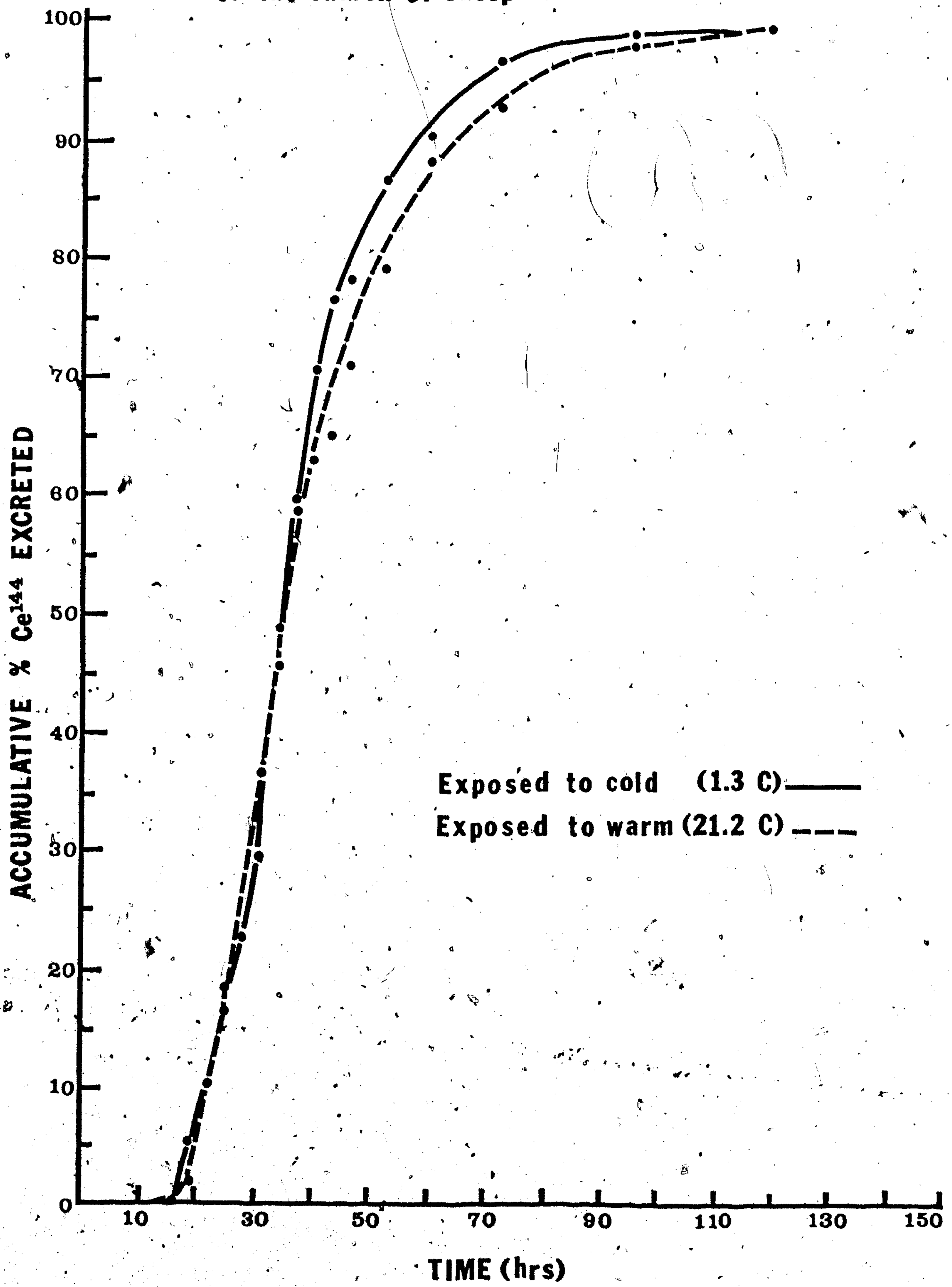


FIGURE 9e. Accumulative excretion curve for Ce^{144} administered into the rumen of sheep 0513.

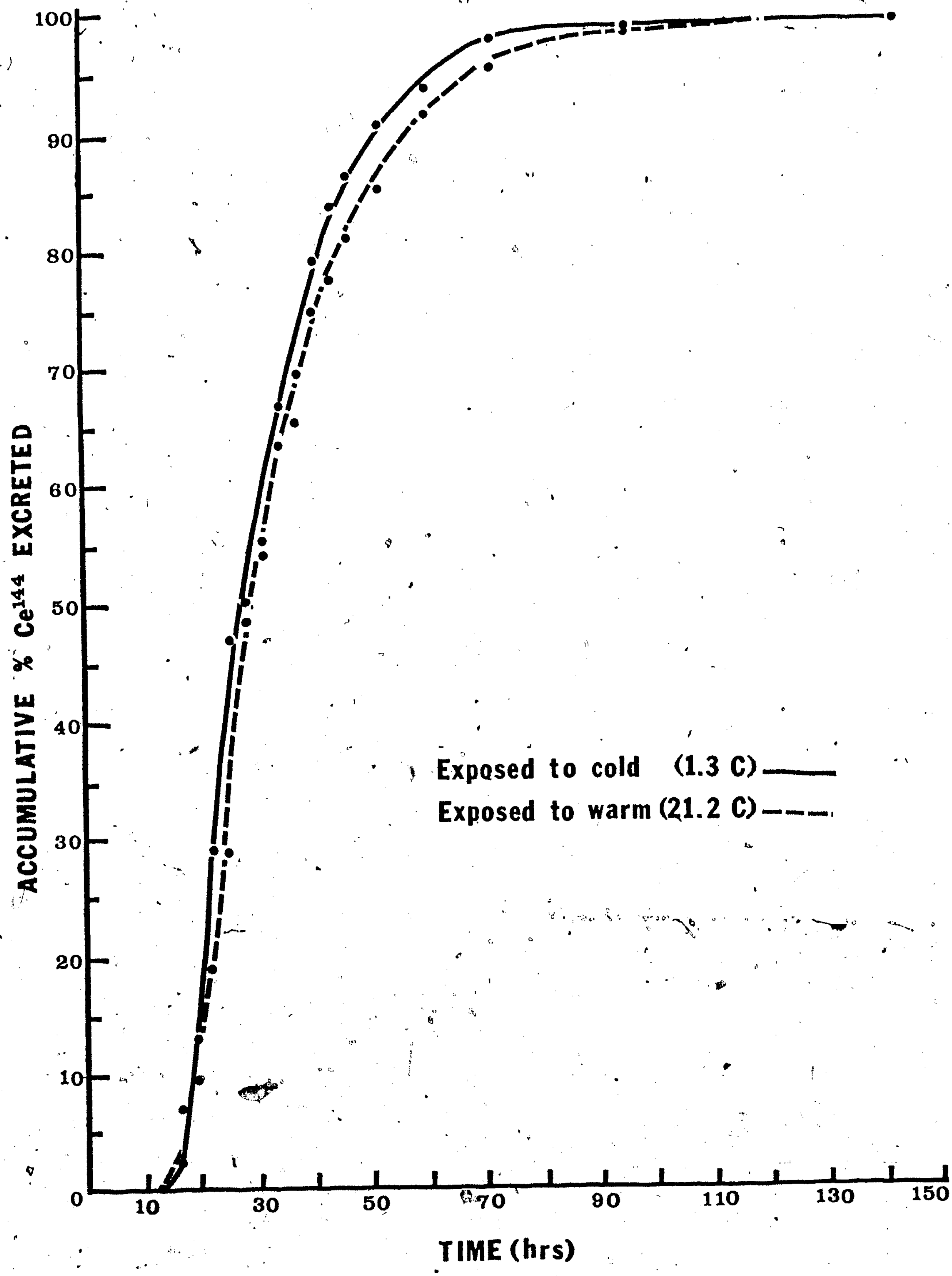
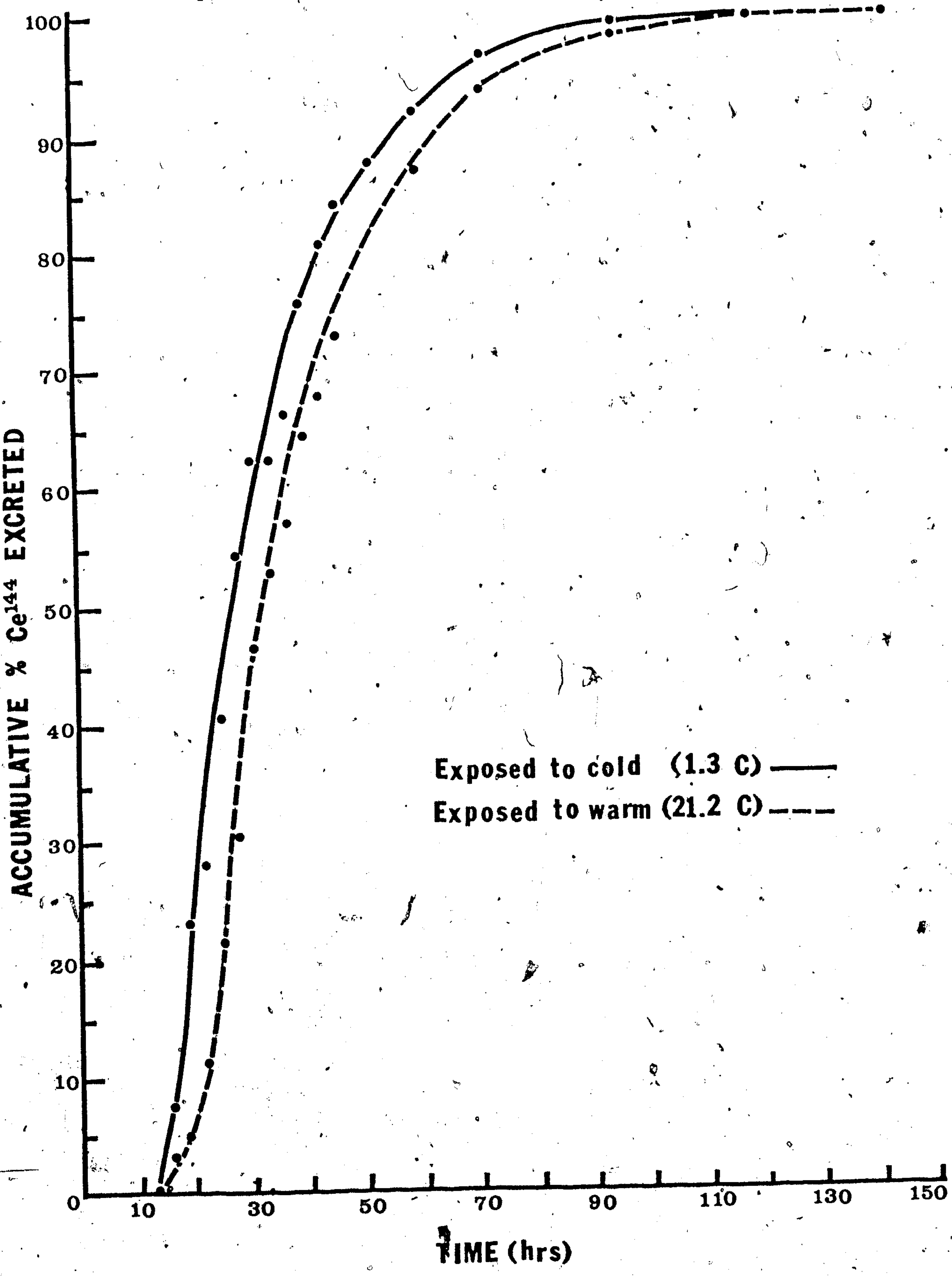


FIGURE 9f. Accumulative excretion curve for Ce^{144} administered into the rumen of sheep 2701.



The multiple regression analysis is presented in appendix table 31a. Analysis of covariance indicated that temperature treatment differences were significant ($P < 0.001$) (shown in appendix table 31b). This means that the sheep within the cold treatment had a significantly greater rate of passage of Ce^{144} through the digestive tract than the same sheep within the warm treatment.

Sheep #2523 and #0513, as shown in figures 9d and 9e respectively, did not show differences in rate of passage between temperature treatments as large as those shown by the other four sheep. Both sheep were within the same SU and were emaciated more than the others. They also had lower BWs (see appendix table 18). Whether poor body condition contributed to the very little change in rate of passage between temperature treatments is, however, uncertain.

Using Balch's (1950) method for estimating mean retention time of Ce^{144} in the digestive tract after the rumen (the number of hours after dosing to 5% accumulative Ce^{144} excreted), the data shown in table 15 was estimated from the six sheep in both temperature treatments read from the excretion curves shown in figures 9a - 9f.

Using Balch's method the calculated mean retention time of Ce^{144} in the digestive tract after the rumen in sheep exposed to the cold was lower although not significantly lower than in sheep exposed to the warm treatments. However, the sheep exposed to cold treatments had a significantly ($P<0.01$) reduced reticulo-rumen mean retention time in contrast to the same sheep exposed to the warm treatments. Calculating the mean retention times by integrating the area beneath the excretion curves (method of Faichney, 1974) the mean retention time of Ce^{144} in the whole tract was significantly ($P<0.05$) reduced from 38.5 in the warm treatment to 32.5 hours in the cold treatment (see table 16).

TABLE 15. Estimation of mean retention time of Ce^{144} in the digestive tract after the rumen (5% excretion time) and in the reticulo-rumen (80 - 5% excretion time) (after Balch, 1950).

	5% excretion time		80-5% excretion time	
	warm	cold	warm	cold
9236	15.0	14.0	37.0	26.0
8229	20.5	15.5	28.5	25.5
2701	17.5	14.0	32.5	27.0
2523	20.5	18.0	29.5	26.0
8236	18.0	16.5	39.0	26.5
0513	16.0	16.0	27.0	23.0
mean	17.9	15.7	32.3	25.7*
S.D.	±2.1	±1.4	±4.4	±1.3

* $P<0.01$-- t-test, Steel and Torie (1960)

Shown in figure 10, mean retention time was significantly ($P<0.005$) reduced by 0.30 hours per degree (C) drop in temperature.

FIGURE 10. The effect of temperature on the retention time of Ce^{144} in the digestive tract of sheep.

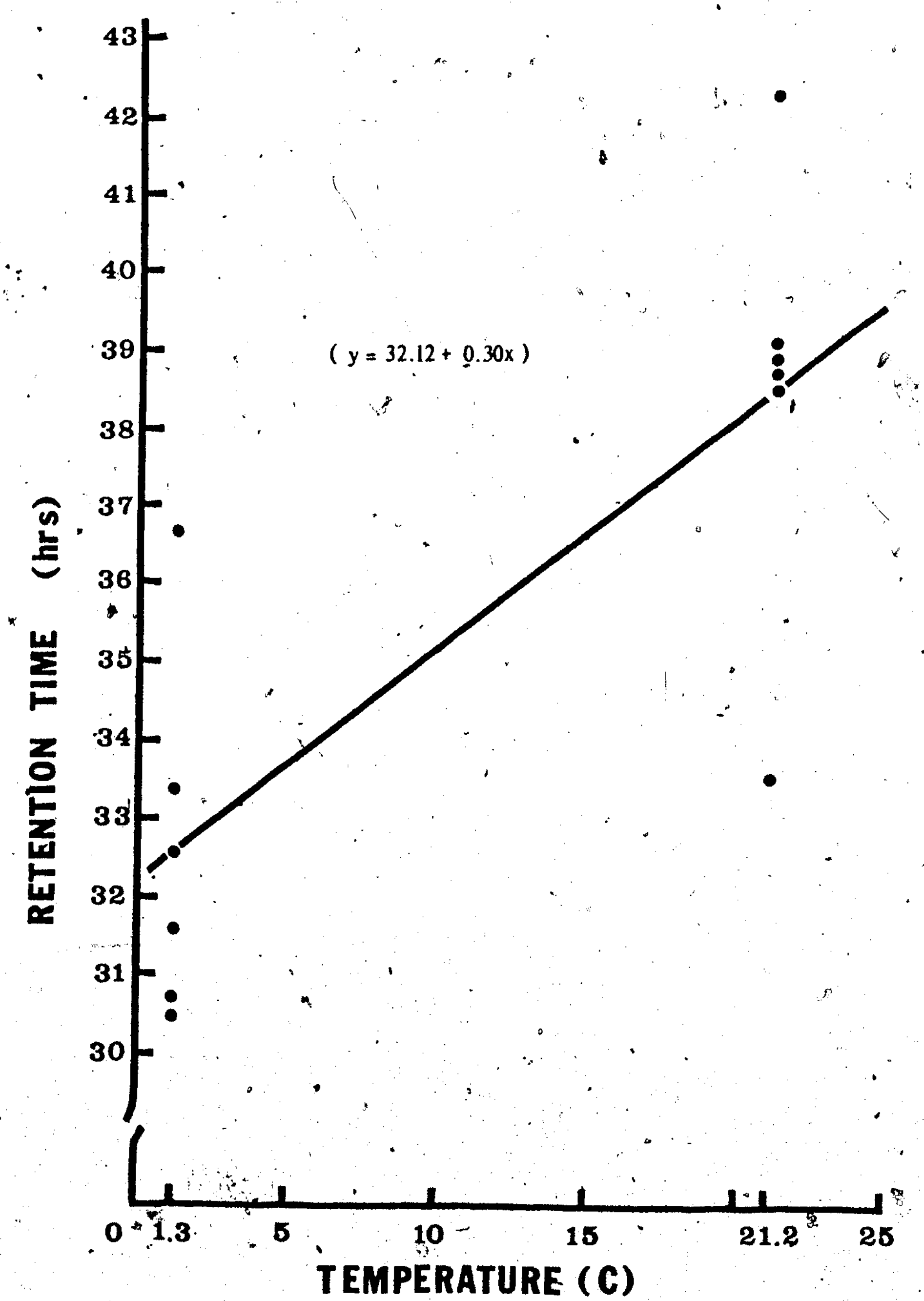


TABLE 16. The effect of temperature on the mean retention time of Ce^{144} in the whole digestive tract and the reticulum motility of sheep.

	Cold	Warm
retention time of Ce^{144} in the digestive tract(hours)	32.5	38.5
reticulum motility(contractions per hour)	72.5	60.0

Balch's calculation, relative to the method used in this study for estimating mean retention time of Ce^{144} in the whole tract, overestimated mean retention time in sheep exposed to the cold treatments by 21.5% and in sheep exposed to the warm treatments by 23.3%. Nevertheless, either method clearly suggested that the mean retention time of digesta was significantly reduced in sheep exposed to cold compared to sheep exposed to warm treatments. In addition, Balch's calculation suggested that the reduced mean retention time of digesta by sheep exposed to cold was due largely to a change in rumen retention time. As shown in figure 11, DM digestibility was significantly ($P < 0.0005$) reduced (appendix table 30) by 0.58% for every one hour reduction in retention time. ($r^2 = 0.67$).

4. The Effect of Temperature on Reticulum Motility.

Sheep exposed to the cold treatments had a very significant ($P < 0.0005$) increase in the number of reticulum contractions per hour compared with the same sheep exposed to the warm treatments (see table 16). Shown in

FIGURE 11. The relationship of dry matter digestibility (DM) and retention time of Ce^{144} in the digestive tract of sheep when acclimated to cold (1.3C) or warm (21.2C) environmental temperatures.

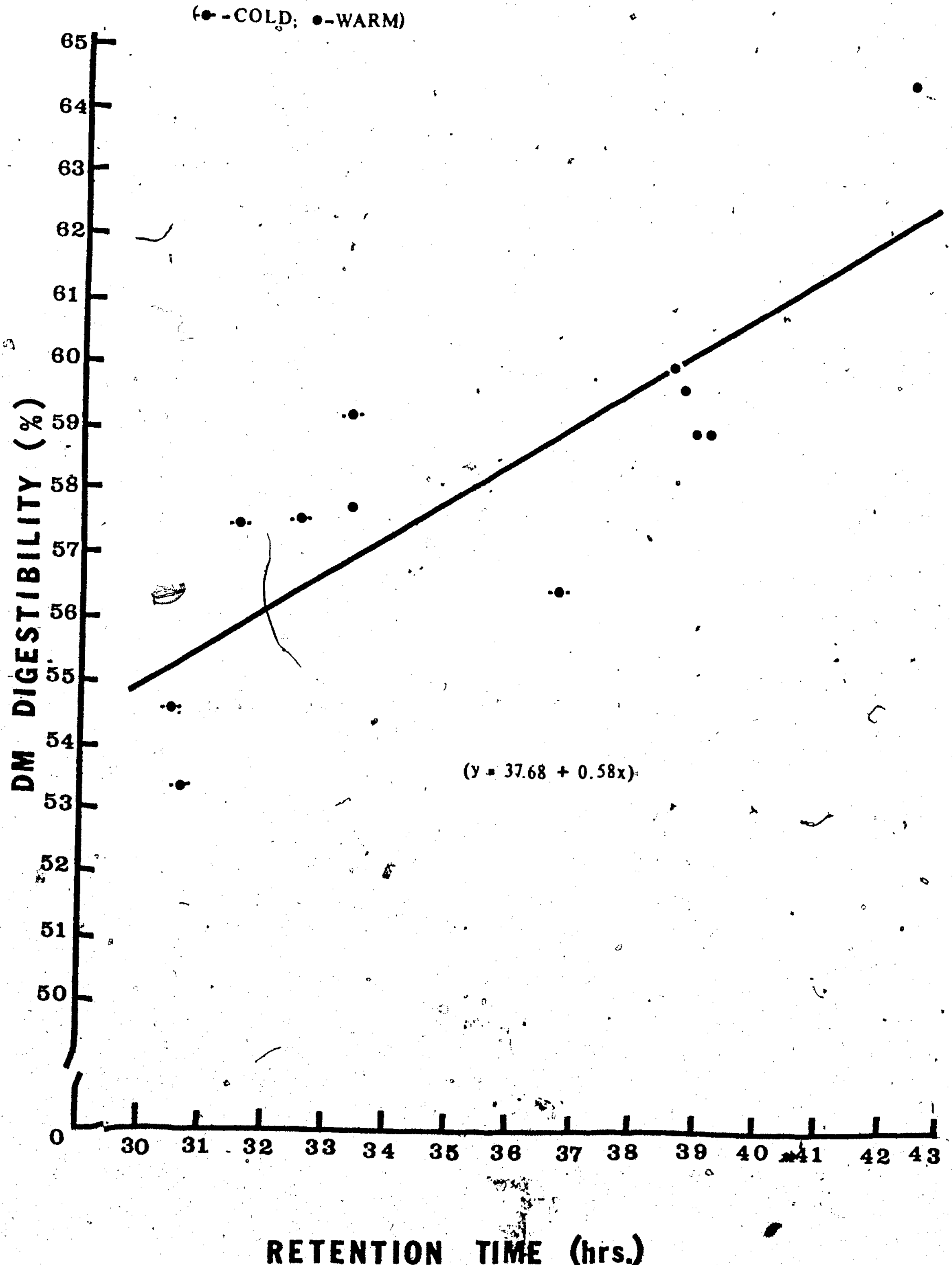


figure 12, the difference in reticulum contraction frequency in sheep between temperature treatments was significantly ($P < 0.02$) maintained throughout the day, except during feeding time (see appendix table 29). These observations suggest that changes in the reticulo-rumen motility may be a major factor in reducing the mean retention time of digesta within the digestive tract, particularly the rumen, and hence reducing the digestibility of feed when sheep are exposed to cold environmental temperatures.

5. The Effect of Temperature on Serum T_4 and T_3 Concentrations

During the cold treatment mean T_4 and T_3 concentrations in the serum were significantly ($P < 0.05$) increased compared to the levels during the warm treatment (table 17), (see also appendix table 32).

TABLE 17. The effect of environmental temperature on the mean serum T_4 and T_3 concentrations in sheep.

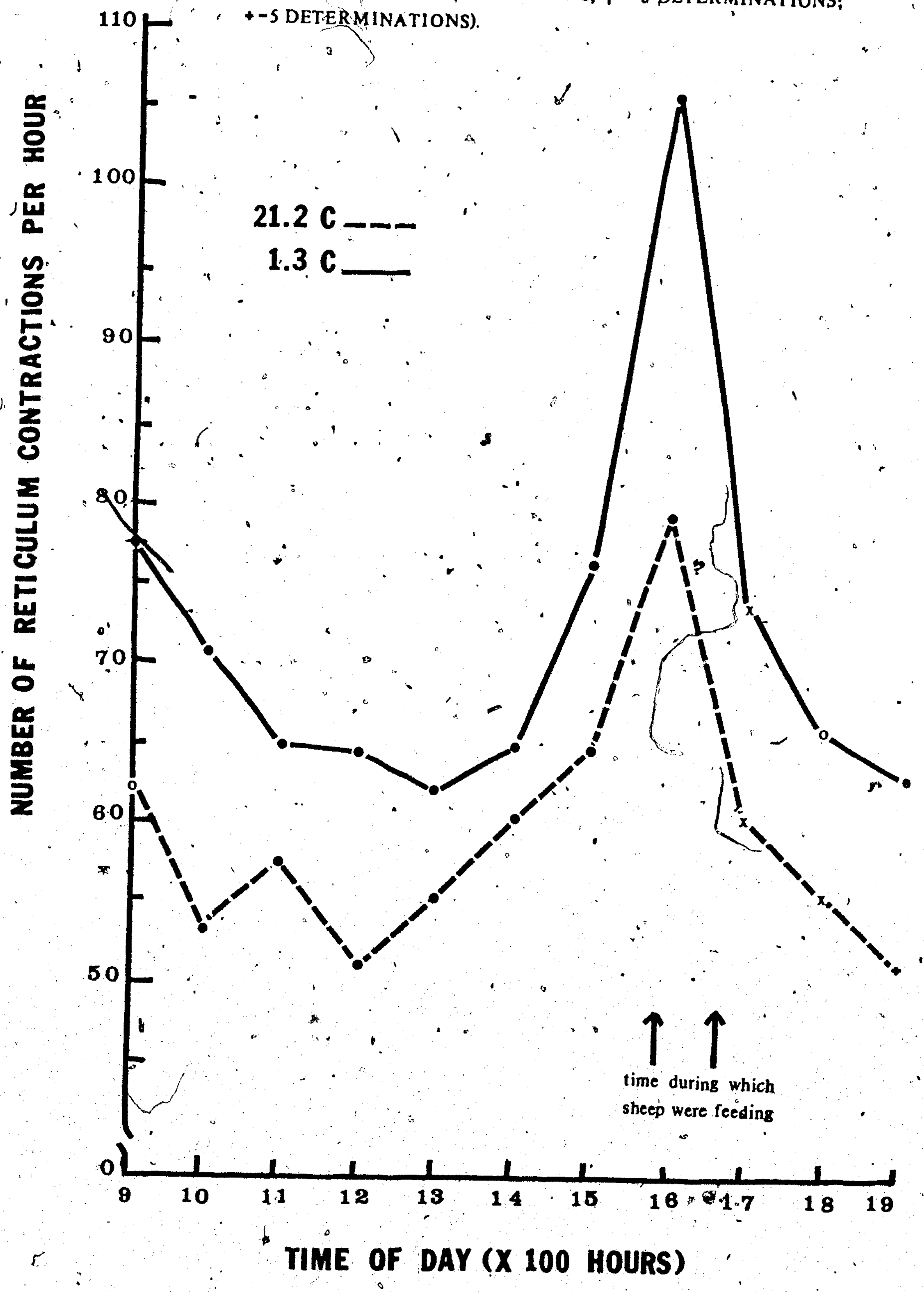
	Cold	Warm
T_4 (ug %)	11.01*	8.62
T_3 (ng %)	156.2 *	94.7

* $P < 0.05$ ANOVA

Thyroxine concentrations were increased by over 25%, while T_3 concentrations were increased by 65% when sheep were acclimated to cold treatments compared to sheep acclimated to warm treatments.

FIGURE 12. The reticulum motility of closely shorn sheep exposed to 21.2 and 1.3 C environmental temperature.

(●–12 DETERMINATIONS; o–10 DETERMINATIONS; x–8 DETERMINATIONS; ●̃–7 DETERMINATIONS; ✦–6 DETERMINATIONS; +–5 DETERMINATIONS).



DISCUSSION

Oxygen consumption (heat production) was 52% higher in the cold (1.3 C) than in the warm (21.2 C) treatment. Similar increases in energy expenditure in sheep exposed to cold treatments were reported by Graham et al (1959). When they exposed sheep to a temperature treatment of 3 C compared to sheep exposed to 23 C a 41% increase in energy expenditure was recorded. (The sheep were fed a controlled ration of 1200 g dried grass cubes). In experiment I, skin temperatures were considerably lower and rectal temperatures were slightly depressed in sheep exposed to the cold treatment. These effects of cold temperature agree with the values reported by Slee and Sykes (1967) and Sykes and Slee (1968). Thus the sheep in experiments I and II were shown to have undergone a substantial degree of cold stress in the cold treatments compared to the same sheep exposed to the warm treatments.

Dry matter digestibilities in both experiments were depressed by 0.18 to 0.21% per degree (C) drop in temperature, slightly less than the values obtained by Graham (1964) and Young and Christopherson (1974), who reported values of -0.47% and -0.25 to -0.40% per degree (C) drop in environmental temperature, respectively. Graham (1964) obtained the % DM regression coefficient from sheep which were closely clipped and on low levels of feeding, and Christopherson and Young (1974) obtained their % DM digestibility measurements on sheep fed either slightly above maintenance or ad lib. The reductions in DM digestibility with decreasing temperature may be influenced by the state of acclimation of sheep. In experiment I the order in which the sheep entered the temperature treatments appeared to affect the degree to which DM and E digestibilities were reduced. Bailey (1964) found no significant reductions in DM digestibility when sheep were moved from a warm (20 C) to a cold temperature treatment (-11 C), but when the sheep returned to the warm temperature treatments after a cold exposure of 1 week a significant increase in DM digestibility resulted. The same was true for ADF digestibilities. Moose et al (1969) in one of his trials with growing lambs observed a reduction in DM digestibility at colder environmental temperatures, but in another trial found no significant reduction. Blaxter and Wainman (19[illegible]) reported a reduction in DM digestibility in steers exposed to cold, but found that DM digestibility tended to increase when environmental temperatures were further reduced. In summary, it appears that DM and E digestibility in sheep may be influenced by the rate at which the environmental temperature decreases or increases and by the length of time the animals are acclimated to a given environmental temperature.

Processing the feed may have influenced the depression in E digestibility in sheep exposed to cold temperatures. Though the hay-fed sheep significantly reduced DM digestibility from 66.6 to 63.3% and ADF digestibility from 63.1

to 58.8% when the temperature was reduced from 17.7 C to 0.8 C, E digestibility was not significantly reduced. On the other hand in the pellet-fed sheep the digestibility of E as well as DM and ADF were significantly reduced. The hay-fed sheep may have compensated for the lower ADF digestibility by increasing the digestion of non-fiber components of the diet when exposed to the cold environmental temperature. Energy and DM digestibilities were significantly greater in the hay-fed sheep than in the pellet-fed sheep. The greater fecal energy losses due to pelleting have previously been reported in the literature and are usually associated with reduced losses of energy as heat, as the work of prehending chewing and cudding (Webster and Hays, 1968; Greenhalgh and Reid, 1973) or as methane (Blaxter and Graham, 1956).

The significant reduction in ADF digestibility in sheep exposed to cold as opposed to warmer environmental temperatures, agrees with the observations made by Bailey (1964) in sheep and Warren et al (1974) in cattle. Since fiber is digested mainly in the rumen, it seems that rumen function was altered by environmental temperature. This might have involved a change in the rate of fermentation and/or a change in the rate of passage of digesta through the digestive tract. Evidence for a shorter retention time of digesta, particularly in the rumen, was provided by experiment II and is discussed below.

Environmental temperature did not have a significant effect on N digestibility in either the hay-fed or pellet-fed sheep, although the mean N digestibilities tended to be slightly depressed in the cold. These results are in agreement with those of Bailey (1964). Sharma and Kehar (1961) found a significantly higher apparent digestibility of crude protein in cows exposed to cooler temperatures than in cows exposed to hot, humid climates. However, the significantly higher feed intakes in the cows exposed to the cooler temperatures could have contributed to these differences. Nitrogen losses in the feces and, therefore, nitrogen digestibility, are probably determined largely by enzymatic and absorptive activities in the small intestine. A possible explanation for the small but insignificant effect of temperature on nitrogen digestibility in the present study ~~may~~ be that temperature had very little influence on retention time of digesta in the intestinal tract. This suggestion is supported by the results of experiment II which also showed a small but insignificant difference between temperature treatments in the 5% excretion times of Ce^{144}. Thus the effect of temperature on both the 5% excretion times of Ce^{144} and the mean N digestibilities appear to be positively and directly related. Michael and Hodges (1973) have suggested that in certain circumstances such as protein malnutrition, semistarvation, starvation, or high bulk feeding the cell turnover rate decreases in the small intestine allowing the epithelial cells in the villi more time to mature and develop a full compliment of digestive enzymes. The result would be an increased digestive and absorptive capacity of the small intestine, thus decreasing losses of N and possibly other substances in the feces. It is conceivable that the intestine could have an increased digestive capacity even at times when digestibility in the rumen is depressed. Whether such intestinal changes as described by Michael and Hodges (1973) occur in sheep in the cold is not known but might be a process worth considering in future studies.

Water consumption, calculated as water intake per kg BW per day, varied significantly between temperature or ration treatments, except there was a tendency for the sheep exposed to the cold treatments to consume less than the same sheep exposed to the warm treatments. Similar observations were reported by other investigators for sheep (Bailey et al, 1962; Bailey 1964; Butcher, 1974) and for cattle (Sherman and Kehar, 1961; Gengler et al, 1970; Winchester and Morris, 1956).

In the second experiment of this study, sheep that were exposed to a cold environmental temperature were shown to have a significant reduction in mean retention time of particulate matter in the digestive tract, using Ce^{144} as a flow marker. The mean retention time for sheep in the warm treatments was 38.5 hours, and for the same sheep in the cold treatments was 32.5 hours--a reduction of 15.6%. Warren et al (1974) reported similar results in Holstein steers. When the steers were exposed to two temperature treatments of 18 C and 32 C, the mean retention times were 36.6 hours and 43.2 hours--a reduction of 15.3% when exposed to the colder temperature treatment.

Castle (1956) reported mean retention times for goats ranging from 32.2 to 44.8 hours. She calculated mean retention time by taking the time required for every 10% of the residues from 5 to 95% to be excreted. Blaxter et al (1956) in calculating retention times by integrating the area beneath the excretion curve, obtained values of 34 to 53 hours for sheep receiving finely ground cubes at daily feed intake levels of 1500 and 600 gm respectively. Church (1969) in reviewing the work of several investigators reported that decreasing the size of the feed particles decreased both mean retention time and DM digestibility. A similar reaction occurred as feed intakes were increased. Blaxter et al (1956) further reported that as DM digestibility increased, mean retention time increased with DM digestibility reaching a plateau at about 80%. However, in the experiments of this study, both feed intake and the level of processing were held constant across temperature treatments and therefore, did not contribute to the observed changes in DM digestibility and mean retention times associated with the changes in environmental temperature.

Using Balch's (1950) method for calculating mean retention times of Ce^{144} in the reticulo-rumen and the digestive tract after the reticulo-rumen, it was shown that the reticulo-rumen was mainly responsible for the difference in mean retention time between temperature treatments. Sheep exposed to the cold treatments had a significantly reduced mean retention time for Ce^{144} in the reticulo-rumen compared to the same sheep exposed to the warm treatments, but no significant differences in mean retention times were obtained in the digestive tract after the reticulo-rumen. This information suggested that the rumen is mainly responsible for the observed changes in mean retention time and DM digestibility between temperature treatments.

When mean retention time was regressed on the DM digestibility of each sheep across temperature treatments, it was shown that these parameters were significantly ($P < 0.0005$) related ($r^2 = 0.67$). DM digestibility was reduced 0.58% for every one hour reduction in mean retention time.

In Experiment II, the mean reticulum motilities in sheep exposed to warm and cold treatments were 60.0 and 72.5 contractions per hour, respectively. There was a diurnal variation in reticulum motility from average values of about 62 to 106 contractions per hour in sheep exposed to the cold treatment and from values about 51 to 80 contractions per hour in sheep exposed to the warm treatments (see figure 11). The highest levels of motility were recorded while the sheep were eating and the low levels while the sheep were resting. These values agree with those reported by Dziuk et al (1963) who determined rumen motility in deer. Dziuk and McCauley (1965) reported values of 60 to 120 cycles per hour in sheep, cattle and goats at rest and feeding. Similar reticulum motility values were obtained by Balch (1952) and by Balch et al (1951) in cattle. These authors did not study the effects of environmental temperature on reticulo-rumen motility. The effects of temperature on reticular contraction frequency observed in the present study support the results of Attebery and Johnson (1969) who reported an effect of temperature on the frequency and amplitude of rumen contractions in cattle.

In experiment II, methane production rates in sheep did not differ significantly between temperature treatments. Methane production, according to Blaxter and Graham (1956), is a by-product of rumen fermentation, and increases as retention time increases and as the digestion of cell-wall constituents increases. Methane production would therefore be expected to be depressed in sheep exposed to cold temperature treatments. However, Graham et al (1959) in agreement with the results of this study found methane production in sheep exposed to cold or warm environmental temperatures to remain at relatively stable levels.

Methane production rates within the two SUs were directly opposed to one another. In SU 1 which included sheep 8229, 9236 and 2701, methane production was 24.6 x 10^{-3} l/hr/kg in the cold treatment and 17.0 x 10^{-3} l/hr/kg in the warm treatment, while in SU 2, which included sheep 2523, 8236 and 0513, methane production was 18.3 x 10^{-3} l/hr/kg in the cold treatment, and 22.7 x 10^{-3} l/hr/kg in the warm treatment (the averages were calculated from appendix table 21).

The observed changes with environmental temperature in reticulo-rumen motility may have been due either to a neural or humoral mechanism or both, activated, presumably, by peripheral or deep body temperature receptors. There is presently very little evidence concerning the physiological properties and mechanisms of the various reticulo-rumen receptors, except for the tension receptors (Iggo & Leek, 1969). Rawson and Quick (1972) were able to demonstrate that, by heating the intra-abdominal regions of a ewe, thermoreceptors appeared to be located in the walls of the rumen and intestine. They were able to further demonstrate by denervation techniques, that the splanchnic nerves were the major afferent pathways for the receptors. Similar conclusions were drawn by Riedel _et al_ (1973) in the rabbit. However, Ingram and Legge (1972) could not obtain thermoregulatory responses in the pig by intra-abdominal heating.

Riedel _et al_ (1973) and Rawson and Quick (1972) did not obtain any thermoregulatory responses nor were they able to activate the splanchnic afferent fibers by intra-abdominal cooling below normal core temperatures. Riedel et al were able to demonstrate, however that the abdominal area required 4-times more heat than that supplied to the vertebral canal to evoke similar responses and suggested that the vertebral canal may have 3 to 4 times more thermoreceptors than the abdominal regions. This may offer an explanation as to why no changes in DM digestibility occurred when low temperature water was consumed, as demonstrated by Cunningham et al (1964), because the cold water is constantly being warmed to near body core temperature each time it is ingested and does not provide a chronic cold stress on the intra-abdominal region for a sufficiently long period of time.

Since skin temperatures tended to be considerably lower and rectal temperatures tended to be slightly depressed in the cold treatment compared to the warm treatment (experiment I), it is possible, as suggested by Slee (1973), that the skin temperatures might have influenced the superficial cold receptors whereas the deep body temperature may have influenced both intra-abdominal and spinal cord thermoreceptors. The possibility that cold activation of thermoreceptors in sheep may result in increased vagal activity has not been studied, although it has been shown by Le Blanc and Cote (1967) that cold-adapted rats do experience increased vagal activity as compared to warm adapted rats. Tsuchiya et al (1974) demonstrated that increasing vagal activity by cooling the spinal cord increased gastrointestinal motility in dogs. Though the cold temperatures necessary to illicit increased gastrointestinal motility were physiologically abnormal, the work of Tsuchiya et al may point to an explanation for the increased reticulo-rumen motility in the cold exposed sheep. It has been established that the reticulo-rumen is innervated by the postganglionic parasympathetic system via the vagus nerves and that medullary neuron and efferent vagal fiber activities are closely associated with reticulum contractions (Titchen, 1968). It is therefore conceivable that either peripheral or deep body temperature receptors could lead to an increased vagal activity.

In both experiment I and II, T_4 and T_3 serum concentrations in sheep were higher in the cold than in the warm treatments. These results agree with the findings of Gale (1973), for sheep and Yousef et al (1968) for cattle. The increased serum T_4 and T_3 concentrations were associated with increased metabolic activity, as indicated by the increased oxygen consumption and are consistent with the results of Yousef et al (1967). Increased T_4 and T_3 serum concentrations as a result of decreased temperature may augment reticulo-rumen motility and thereby decrease DM digestibility.

Kirton and Barton (1958) demonstrated that thyroxine implanted ewes, had highly significant reductions in the weights of empty gastric tracts but no reduction in the weights of the empty intestinal tracts. There was also a reduction in the weight of gastrointestinal contents. Miller et al (1974) demonstrated that hypothyroid cows not only had a significant increase in retention time of digesta in the digestive tract, but had 90% more wet ingesta and 76% more dry matter in the rumen than cows with intact thyroids. Abomasal contents had 50% more wet material and 40% more dry matter and the distal large intestine contained 127% more wet material and 100% more dry matter in the thyroid damaged cows than in the normal cows. But the contents in the omasum and remaining digestive tract differed very little between hypothyroid and normal cows. Although the changes in gut-fill in the above study might have been due to changes in feed intake, there may also be direct effects of thyroid hormones on the gut (Balch et al, 1952). These investigations support the suggestion that increased serum thyroid hormone concentrations may have augmented rumen motility and thus decreased DM digestibility in sheep exposed to cold treatments.

However, the thyroid hormones may have a different effect on the small intestine. Levin (1969), in reviewing the work from several investigators, concluded that thyroxine appears to have a mitogenic effect on the intestinal crypts and an overall hypertrophic effect on the small intestine. This may help to explain why N and possibly E digestibilities did not always differ significantly between temperature treatments in experiment I. A possible hypertrophy of the small intestine, as a result of the increase in thyroid hormones, may have increased the digestive and absorptive capacity of the small intestine. This was discussed earlier.

Although the sheep in this study were on a controlled intake, the daily excretion of DM in the feces was greater in the sheep exposed to the cold treatments (decreased digestibility). It has been shown (Gale, 1973) that a rise in thyroid hormone is related to the enhanced enterohepatic clearance of unmetabolized hormone. Rats exposed to the cold increase their uptake of food and therefore excrete more thyroid hormone in the greater fecal bulk. This may have occurred in the sheep of experiments I and II, however this possibility has not been studied in ruminants.

Although most of the PBI values fell within the usual range of 3.0 to 7.0 mcg % (Falconer and Draper, 1967) they did not significantly differ between temperature treatments. Halliday et al (1969) found PBI concentrations to be significantly higher in the cold-acclimated than in the warm-acclimated sheep. However, Heroux and Brauer (1965) found that cold-acclimated rats could dispose of a much greater amount of thyroxine than the warm-acclimated rats and were able to maintain a normal PBI level. They suggested that this greater tolerance of thyroxine by the cold-acclimated rats could be due either to increased elimination or to increased metabolism of thyroid hormones. The lack of effect of temperature on PBI levels, in spite of increase in serum T_3 and T_4 levels in the cold, suggests that PBI concentration is not always a reliable indicator of circulating levels of thyroid hormone.

SUMMARY AND CONCLUSIONS

1. Experiment I

a. In the first of two experiments, 12 closely shorn yearling wethers receiving hay either in the long form (hay-fed sheep), or in the pelleted form (pellet-fed sheep), and maintained at the same intake throughout the experiment, were acclimated to temperatures of 0.8, 10.0 and 17.7 C. The apparent digestibilities of DM, E, and ADF within each ration were positively correlated with environmental temperature. In the hay-fed sheep ADF digestibility was significantly ($P<0.05$) reduced by 0.25% and DM was reduced but not significantly ($P>0.05$) by 0.19% per degree drop in temperature. Dry matter, E and ADF digestibilities in the pellet-fed sheep were significantly ($P<0.05$) reduced by 0.21, 0.19 and 0.23% respectively, per degree drop in temperature.

b. Neither environmental temperature nor ration had a significant effect on the apparent digestibilitiy of N in sheep. N retention tended to be higher in the sheep exposed to the warm treatments than in the sheep exposed to the cold treatments.

c. Environmental temperature had no significant effect on water intake in sheep although there was a trend for water intake to decrease with decreasing environmental temperature.

d. Thyroxine (T_4) and triiodothyronine (T_3) plasma concentrations were significantly ($P<0.05$) increased from 7.30 to 10.56 μg% and 73.0 to 119.7 ng% respectively in the hay-fed sheep as temperature was decreased from 17.7 to 0.8 C. Plasma T_4 and T_3 concentrations were increased significantly ($P<0.05$) from 8.70 to 12.76 μg% and 123.2 to 241.7 ng% respectively, in the pellet-fed sheep as temperature was decreased from 17.7 to 0.8 C.

2. Experiment II

a. In this experiment, six rumen fistulated and closely shorn sheep receiving a constant intake of a pelleted hay ration, were acclimated to temperatures of 1.3 and 21.2 C. The apparent digestibility of DM was significantly ($P<0.05$) reduced by 0.18% per degree (C) decrease in temperature.

b. The mean retention time of digesta, determined from fecal excretion patterns of Ce^{144} was significantly ($P<0.05$) reduced to 32.5 hours in the cold treatment from 38.5 hours in sheep exposed to the warm treatment.

c. Reticulum motility was significantly ($P<0.005$) increased from 60 contractions per hour in the warm treatment to 72.5 contractions per hour in the cold treatment.

d. Oxygen consumption was significantly ($P<0.05$)

increased in the cold treatment compared to the warm treatment. Environmental temperature had no significant effect on methane production.

e. T_4 and T_3 serum concentrations increased from 8.62 to 11.01 µg% and from 94.7 to 156.2 ng% respectively ($P < 0.05$) as temperature was decreased from 21.2 to 1.3 C.

3. The direct relationship between environmental temperature and apparent digestibility of DM, E and ADF in sheep was confirmed, although in sheep receiving long hay, the apparent digestibility of E was not significantly affected by environmental temperature. In experiment II apparent digestibility of DM, was positively ($P < 0.05$) correlated with mean retention time of digesta in the digestive tract. The possible involvement of thyroid hormones and vagal activity as mediators of the increased reticulo-rumen motility were discussed. It is concluded that cold environmental temperatures increase the motility and reduce the mean retention time of digesta in the digestive tract resulting in depressed apparent digestibilities of DM and ADF in cold exposed sheep.

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APPENDIX FIGURES

APPENDIX

Figure 1. Abbreviations used within the text and appendices.

a	the Y-intercept
ADF	acid detergent fiber
Am't	amount
ANOVA	analysis of variance
$b_{o,1,2,3}$	regression coefficient
BW	body weight
C	degrees centigrade
cm	centimeter
cpm	counts per minute
d	day
d.f.	degrees of freedom
DM	dry matter
E	gross energy
g or gm	gram
H	hay-fed sheep
Hp	heat production
hr or h	hour
I.D.	identification
kcal	kilocalories
kg or kgm	kilogram
l	liter
μci	microcurie
mcg, μg or μgm	microgram
min	minute
ml	milliliter
M.S.	mean square
N	nitrogen
ng	nanogram
P	pellet-fed sheep
PBI	protein bound iodine
$Pd_{1,2 \text{ or } 3}$	trial period 1,2 or 3
P.L.	probability level

APPENDIX

Figure 1. Continued.

R	ration
r^2	correlation coefficient squared
S.S.	sum of squares
SU	sheep unit
$S_{y.x}$	standard deviation of Y for fixed X
$T_{1,2 \text{ or } 3}$ .... (as used in appendix tables 1-7; experiment I)	exposure temperature 1 = 0.8 C exposure temperature 2 = 10.0 C exposure temperature 3 = 17.7 C
T_3	triiodothyronine
T_4	thyroxine
Temp	temperature
$T_{p4 \text{ or } 5}$ (experiment II)	exposure temperature 4 = 1.3 C exposure temperature 5 = 21.2 C
Vol	volume

APPENDIX

Figure 2. Retention Time Calculation. (Data from Appendix Table 23k).

$$\Theta = \sum_{i=1}^{n} t_i M_i \qquad \text{(Faichney, 1975)}$$

t_i = ½ x 12 hours (midpoint of the i^{th} time interval)

= 6 hours

Therefore, Θ = 6 h x 0.066 % ÷ 100 = 0.0039 hours

The next time interval is: 12 h + (½ x 3 h) = 13.5 hours

Therefore, Θ = 13.5 h x 0.33 % ÷ 100 = 0.019 hours

and the next time interval is:

15 h = (½ x 3h) = 16.5 hours

then Θ = 16.5 h x 3.16 % ÷ 100 = 0.29 hours

Total retention time of Ce^{144} in the digestive tract of sheep 2523 is then:

0.004 + 0.019 + 0.29 + ... + 1.6 = 39.13 hours

APPENDIX TABLES

APPENDIX

TABLE 1. The effect of temperature and ration on feed intake in sheep.

SU	R	Sheep I.D.	DM (gm) intake/kg $BW^{3/4}$/d			DM consumed/d (gm)			ADF (gm) intake/kg $BW^{3/4}$/d		
			Pd_1	Pd_2	Pd_3	Pd_1	Pd_2	Pd_3	Pd_1	Pd_2	Pd_3
			T_1	T_3	T_2	T_1	T_3	T_2	T_1	T_3	T_2
1	P	9494	69.7	71.6	75.5	1108.5	1181.7	1201.2	23.45	23.94	26.05
		9490	80.8	75.8	78.4	1285.2	1272.6	1293.6	27.19	25.33	27.04
	H	9488	87.1	76.7	81.4	1360.0	1220.5	1307.4	27.73	26.89	26.54
		9495	76.6	75.2	83.8	1252.9	1241.1	1383.0	24.81	26.42	27.64
			T_2	T_1	T_3	T_2	T_1	T_3	T_2	T_1	T_3
2	P	9497	72.3	71.6	73.6	1193.4	1181.7	1203.8	24.34	23.94	25.39
		9498	71.4	76.5	75.7	1188.8	1181.7	1203.8	24.03	25.56	26.10
	H	9493	76.0	77.8	75.8	1162.5	1166.8	1183.4	24.56	27.34	24.57
		9499	67.3	87.0	76.6	1020.4	1224.9	1172.8	20.70	30.50	24.39
			T_3	T_2	T_1	T_3	T_2	T_1	T_3	T_2	T_1
3	P	9492	72.3	72.9	77.7	1193.4	1181.7	1201.2	24.34	24.38	26.80
		9496	70.5	71.0	77.0	1193.4	1181.7	1201.2	23.71	23.73	26.55
	H	9491	74.4	69.0	69.0	1092.8	1067.1	1078.3	23.30	23.75	23.07
		9489	73.5	72.2	82.4	1234.9	1243.7	1371.0	23.73	26.36	27.11

APPENDIX

TABLE 2. The effect of temperature and ration on fecal excretion in sheep.

SU	R	Sheep I.D.	% DM in feces $\frac{Pd_1}{T_1}$	$\frac{Pd_2}{T_3}$	$\frac{Pd_3}{T_2}$	DM in feces (gm)/d $\frac{Pd_1}{T_1}$	$\frac{Pd_2}{T_3}$	$\frac{Pd_3}{T_2}$
1	P	9494	43.5	37.3	48.9	515.6	547.6	517.2
		9490	37.0	36.3	36.1	602.2	565.9	576.6
	H	9488	41.9	45.4	40.1	448.2	469.3	463.4
		9495	39.4	47.8	43.5	443.6	419.2	477.5
			T_2	T_1	T_3	T_2	T_1	T_3
2	P	9497	42.3	35.9	37.8	538.6	591.0	499.4
		9498	39.4	35.6	35.3	553.4	549.8	486.5
	H	9493	56.5	45.4	40.7	373.5	487.1	379.6
		9499	52.2	43.1	38.5	324.2	503.1	330.2
			T_3	T_2	T_1	T_3	T_2	T_1
3	P	9492	34.2	24.3	42.8	514.4	538.4	541.3
		9496	30.5	41.5	45.2	521.5	487.3	552.2
	H	9491	27.0	49.9	51.3	376.7	366.7	355.6
		9489	36.1	39.4	37.3	413.0	501.6	492.6

APPENDIX

TABLE 3. The effect of temperature and ration on N intake, N output, and N retention in sheep.

SU	R	Sheep I.D.	gm N in urine and feces/d			N (gm) intake/kg $BW^{3/4}$/d			N in urine/d (gm)			Apparent N retained (%) of intake		
			pd_1 T_1	pd_2 T_3	pd_3 T_2	pd_1 T_1	pd_2 T_3	pd_3 T_2	pd_1 T_1	pd_2 T_3	pd_3 T_2	pd_1 T_1	pd_2 T_3	pd_3 T_2
1	P	9494	19.40	19.42	20.39	1.41	1.29	1.54	11.19	10.09	12.26	13.62	8.69	16.98
		9490	20.24	22.22	21.24	1.64	1.36	1.60	10.34	12.44	10.86	22.27	2.99	19.86
	H	9488	19.18	19.65	16.68	1.90	1.61	1.60	11.38	11.19	8.86	35.46	23.27	35.24
		9495	21.62	19.79	19.75	1.74	1.56	1.62	13.73	12.61	12.09	24.21	23.31	26.12
			T_2	T_1	T_3	T_2	T_1	T_3	T_2	T_1	T_3	T_2	T_1	T_3
2	P	9497	19.04	18.92	18.82	1.47	1.29	1.45	9.90	8.02	10.61	21.25	11.70	20.83
		9498	19.78	22.09	18.22	1.45	1.38	1.49	9.99	12.43	10.09	17.88	0.82	23.36
	H	9493	14.46	19.05	21.12	1.73	1.61	1.76	7.53	10.96	13.59	45.53	21.16	23.09
		9499	13.69	21.64	20.53	1.71	1.82	1.84	7.41	11.72	13.73	47.22	15.66	27.16
			T_3	T_2	T_1	T_3	T_2	T_1	T_3	T_2	T_1	T_3	T_2	T_1
3	P	9492	18.20	20.15	24.86	1.47	1.31	1.59	8.43	10.23	16.04	24.72	13.07	0.30
		9496	18.93	20.95	23.67	1.43	1.28	1.57	8.76	12.68	14.34	21.72	1.53	3.61
	H	9491	16.29	17.15	22.20	1.82	1.57	1.61	8.39	10.06	15.48	39.06	33.23	4.88
		9489	19.15	19.65	20.65	1.69	1.52	1.62	10.73	11.02	12.05	32.38	25.13	22.31

APPENDIX

TABLE 4. The effect of temperature and ration on water intake, water output, and water retention in sheep.

EU	R	I.D.	Total water intake (g/d) pd$_1$	pd$_2$	pd$_3$	Water in feces (g)/d pd$_1$	pd$_2$	pd$_3$	Urine excreted/d (ml) pd$_1$	pd$_2$	pd$_3$	Apparent water retention (%/d) pd$_1$	pd$_2$	pd$_3$
			T_1	T_3	T_2	T_1	T_3	T_2	T_1	T_3	T_2	T_1	T_3	T_2
1	F	9494	1624	3851	2496	669.8	610.2	540.5	915.6	1167.8	1134.5	2.4	53.8	32.9
		9490	2037	3976	2633	1160.3	993.1	1020.6	773.9	1309.1	845.2	5.1	42.1	29.1
	H	9488	1826	2880	2197	621.6	564.4	692.1	717.2	659.7	681.2	26.7	57.5	37.5
		9495	2074	2906	1876	682.3	457.8	620.2	781.3	966.6	760.2	29.4	51.0	26.4
			T_2	T_1	T_3	T_2	T_1	T_3	T_2	T_1	T_3	T_2	T_1	T_3
2	F	9497	2452	2464	3242	734.6	1055.4	821.7	875.3	532.6	1703.0	34.3	35.6	22.1
		9498	2499	2443	2887	851.3	994.6	891.7	644.7	849.5	1111.1	40.1	25.5	30.6
	H	9493	1916	1894	2873	287.6	585.9	644.4	524.5	745.6	896.9	57.6	29.7	46.4
		9499	1610	1989	2208	296.9	664.3	527.5	506.7	750.1	741.7	50.1	28.9	42.5
			T_3	T_2	T_1	T_3	T_2	T_1	T_3	T_2	T_1	T_3	T_2	T_1
3	F	9492	2433	4035	2279	990.1	1677.3	732.4	686.2	1193.3	1167.2	31.1	28.9	16.6
		9496	2893	2108	2056	1188.5	686.9	669.5	584.7	929.9	1001.0	38.7	23.3	18.8
	H	9491	2626	1668	1694	1018.6	368.3	337.6	523.1	675.1	831.2	41.3	37.4	31.0
		9489	2477	2337	2190	731.2	771.6	828.0	795.2	784.0	858.7	38.4	33.4	23.0

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TABLE 5. The effect of temperature and ration on the body weight of sheep.

SU	R	I.D.	Feb 8	Feb 21	Mar 8	Mar 15	Mar 22	Apr 3	Apr 16	Apr 24	Apr 30	May 11	May 27	May 31	Jun 7	Jun 17	Average Body Weight (kg) Pd_1	Pd_2	Pd_3
					Pd_1				Pd_2				Pd_3						
					T_1				T_3				T_2				T_1	T_3	T_2
1	P	9494	46	43	39	40	40	40	40	41	41	43	43	43	40	40	40.0	42.0	40.0
		9490	51	47	39	39	40	40	42	42	41	45	44	45	42	42	40.0	43.0	42.0
	H	9488	46	41	38	38	38	40	41	40	38	42	40	41	40	41	39.0	40.0	40.5
		9495	51	48	42	43	41	42	41	42	40	44	42	44	41	43	41.5	42.0	42.0
					T_2				T_1				T_3						
2	P	9497	50	45	42	44	44	40	43	42	41	43	43	42	41	42	42.0	42.0	41.5
		9498	51	45	42	42	43	42	39	40	38	39	40	41	39	41	42.5	38.5	40.0
	H	9493	45	41	37	38	38	38	36	36	38	36	39	39	39	39	38.0	37.0	39.0
		9499	43	38	36	38	38	37	36	35	34	34	36	37	38	38	37.5	34.0	38.0
					T_3				T_2				T_1						
	P	9492	46	41	40	41	40	44	42	44	40	42	42	40	40	37	42.0	41.0	38.5
		9496	45	43	41	42	43	44	43	44	42	43	42	41	40	38	43.5	42.5	39.0
	H	9491	46	41	36	37	35	37	37	45	38	39	38	37	36	35	36.0	38.5	35.5
		9489	48	44	41	44	42	44	42	44	43	46	44	41	43	42	43.0	44.5	42.5

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TABLE 6. The effect of temperature and ration on the apparent digestibility of DM, E, N, and ADF in sheep.

SU	R	Sheep I.D.	DM digestibility			E digestibility			N digestibility			ADF digestibility		
			Pd_1	Pd_2	Pd_3	Pd_1	Pd_2	Pd_3	Pd_1	Pd_2	Pd_3	Pd_1	Pd_2	Pd_3
			T_1	T_3	T_2	T_1	T_3	T_2	T_1	T_3	T_2	T_1	T_3	T_2
1	P	9494	53.5	53.6	56.9	52.48	51.73	55.96	63.44	56.12	66.91	43.9	45.6	50.4
		9490	53.1	55.5	55.4	51.80	54.17	54.60	61.97	57.28	60.76	43.7	47.7	50.4
	H	9488	67.0	61.5	64.6	65.08	58.57	62.80	73.77	66.94	69.66	61.2	58.4	59.4
		9495	64.5	66.2	65.5	63.24	63.94	63.76	72.34	72.18	71.36	60.6	63.2	60.5
			T_2	T_1	T_3	T_2	T_1	T_3	T_2	T_1	T_3	T_2	T_1	T_3
2	P	9497	54.9	50.0	58.5	53.18	49.03	58.43	62.20	49.39	65.47	46.2	39.9	48.3
		9498	53.4	53.5	59.6	52.35	52.16	59.10	59.37	54.55	65.81	45.9	48.2	50.8
	H	9493	67.9	58.2	67.8	65.79	55.87	65.00	73.81	66.52	72.51	63.0	54.0	64.6
		9499	68.2	58.9	71.8	66.34	57.00	70.04	75.81	61.32	75.86	62.2	55.4	69.0
			T_3	T_2	T_1	T_3	T_2	T_1	T_3	T_2	T_1	T_3	T_2	T_1
3	P	9492	56.9	54.4	54.9	55.91	53.71	54.51	59.59	53.57	64.07	51.6	48.1	49.0
		9496	56.3	58.8	54.0	55.27	56.44	53.52	57.79	61.11	62.02	51.9	52.4	48.1
	H	9491	65.5	65.6	67.0	63.30	62.93	65.38	70.42	70.68	71.19	60.7	63.7	62.9
		9489	66.5	59.7	64.1	56.25	58.02	62.50	70.26	67.11	67.65	62.6	58.9	58.7

APPENDIX

TABLE 7. The effect of temperature and ration on some blood components in sheep.

			protein-bound iodine (mcg %)			thyroxine (mcg %)			triiodo-thyronine (ng %)			hematocrit		
			Pd_1	Pd_2	Pd_3	Pd_1	Pd_2	Pd_3	Pd_1	Pd_2	Pd_3	Pd_1	Pd_2	Pd_3
SU	R	sheep I.D.	T_1	T_3	T_2	T_1	T_3	T_2	T_1	T_3	T_2	T_1	T_3	T_2
	P	9494	2.22	2.04	5.69	9.72	6.67	11.96	295	140	210	37.5	33.0	40.5
1		9490	2.86	3.32	5.07	14.05	8.59	13.52	315	69	225	39.0	31.5	29.5
	H	9488	3.18	3.34	6.60	8.64	6.84	10.60	79	67	185	40.0	37.0	36.0
		9495	4.01	2.67	2.86	16.69	8.15	13.89	195	63	170	37.5	18.5	34.0
			T_2	T_1	T_3	T_2	T_1	T_3	T_2	T_1	T_3	T_2	T_1	T_3
	P	9497	2.61	2.78	6.58	10.65	11.85	8.55	255	225	110	37.0	30.5	30.0
2		9498	2.71	2.86	3.46	10.63	12.46	11.09	112	245	110	32.0	32.0	29.5
	H	9493	1.85	2.90	2.06	9.82	11.43	7.99	98	69	120	39.0	42.0	39.5
		9499	2.06	3.09	0.70	9.01	12.47	6.73	175	205	47	39.5	36.5	33.0
			T_3	T_2	T_1	T_3	T_2	T_1	T_3	T_2	T_1	T_3	T_2	T_1
	P	9492	2.94	2.90	6.32	7.48	9.07	12.80	150	110	145	33.5	39.0	43.0
3		9496	4.29	5.37	5.30	9.84	15.25	15.69	160	240	225	32.5	33.0	34.5
	H	9491	2.99	1.93	1.47	9.77	8.69	8.49	43	105	80	30.5	25.0	15.0
		9489	4.97	1.72	2.06	4.33	8.32	5.64	98	235	90	35.5	25.0	29.0

APPENDIX

TABLE 8. ANOVA of the Effects of Temperature and Ration on Feed and Water Intake Data

Source of Error		gm DM/kg $BW^{3/4}$/day		gm N/kg $BW^{3/4}$ per day		gm ADF/kg $BW^{3/4}$/day		gm total water/kg BW/day	
Between Sheep	d.f.	M.S.	P.L.	M.S.	P.L.	M.S.	P.L.	M.S.	P.L.
Rations (R)	1	76.8	N.S.	0.518	<0.0002	1.58	N.S.	876	<0.014
Sheep Units (U)	2	45.2	<0.07	0.007	N.S.	5.81	N.S.	16.2	N.S.
RU	2	13.0	N.S.	0.016	N.S.	1.78	N.S.	1.69	N.S.
Sheep/RU	6	16.5		0.008		2.78		73.59	
Within Sheep									
Periods (P)	2	39.5	N.S.	0.088	<0.005	9.01	N.S.	455	<0.10
Temperature (T)	2	61.0	N.S.	0.012	N.S.	6.64	N.S.	1243	<0.005
PT'	2	15.5	N.S	0	N.S.	2.29	N.S.	33.3	N.S.
RP	2	0.12	N.S.	0.027	N.S.	8.92	N.S.	189	N.S.
RT	2	13.0	N.S.	0.010	N.S.	1.30	N.S.	142	N.S.
PTR'	2	16.4	N.S.	0.009	N.S.	2.44	N.S.	48.4	N.S.
Residual	12	22.7		0.007		3.30		144	

d.f. = degrees of freedom
M.S. = mean square
P.L. = probability level
N.S. = not significant

APPENDIX

TABLE 9. ANOVA on the effect of temperature and ration on the apparent digestibility of DM, E, N and ADF.

Source of Error		DM digestibility		E digestibility		N digestibility		ADF digestibility	
Between Sheep	d.f.	M.S.	P.L.	M.S.	P.L.	M.S.	P.L.	M.S.	P.L.
Rations (R)	1	873	<0.00001	637	<0.0001	983	<0.00001	1558	<0.00001
Sheep Units (U)	2	0.99	N.S.	2.25	N.S.	12.5	N.S.	14.0	N.S.
RU	2	2.30	N.S.	16.5	N.S.	5.28	N.S.	11.0	N.S.
Sheep/RU	6	3.15		8.22		4.05		6.42	
Within Sheep									
Periods (P)	2	43.3	<0.005	56.5	<0.005	140	<0.005	27.9	<0.025
Temperature (T)	2	36.1	<0.005	19.8	<0.025	15.0	N.S.	53.0	<0.005
PT'	2	14.2	N.S.	24.8	N.S.	44.1	<0.025	8.99	N.S.
RP	[illegible]	15.8	<0.05	8.78	N.S.	23.7	N.S.	4.99	N.S.
RT	2	0.19	N.S.	4.09	N.S.	1.86	N.S.	1.50	N.S.
PTR'	2	7.08	N.S.	15.4	<0.025	0.96	N.S.	22.5	<0.05
Residual	12	3.93		2.99		7.96		4.70	

d.f. = degrees of freedom

M.S. = mean square

P.L. = probability level

N.S. = not significant

APPENDIX

TABLE 10. ANOVA of the effect of temperature and ration on N metabolism

Source of Error	d.f.	Average daily N(gm) in urine/d		Average daily N(gm) in feces and urine		Apparent N retention %		Water excreted in urine(ml)	
		M.S.	P.L.	M.S.	P.L.	M.S.	P.L.	M.S.	P.L.
Between Sheep									
Rations(R)	1	0.407	N.S.	16.4	<0.025	1899	<0.0001	495990	<0.006
Sheep Units(U)	2	3.79	N.S.	5.06	<0.034	58.3	N.S.	16359	N.S.
RU	2	1.05	N.S.		N.S.	2.00	N.S.	[illegible].7	N.S.
Sheep/RU	6	1.85		2.20		20.7		28316	
Within Sheep									
Periods(P)	2	21.7	<0.005	[illegible]	<0.01	619	<0.00[illegible]	[illegible]	[illegible]5
Temperature(T)	2	13.4	<0.025	[illegible].5	<0.01	377	<0.01	[illegible]	[illegible]
PT'	2	6.55	N.S.	1.09	N.S.	50.7	N.S.	1193[illegible]	<0.025
RP	2	0.032	N.S.	0.61	N.S.	66.9	N.S.	50684	N.S.
RT	2	7.51	N.S.	9.75	N.S.	76.7	N.S.	47180	N.S.
PTR'	2	4.66	N.S.	8.40	N.S.	39.9	N.S.	67408	N.S.
Residual	12	2.14		2.53		46.7		25453	

d.f. = degrees of freedom

M.S. = mean square

P.L. = probability level

N.S. = not significant

APPENDIX

TABLE 11. ANOVA of the effects of temperature and ration on water excretion data

Source of Error		Urine Excreted (ml)		% DM in feces		Average daily total water excreted (gm)/kg BW	
Between Sheep	d.f.	M.S.	P.L.	M.S.	P.L.	M.S.	P.L.
Rations (R)	1	1214	<0.0032	187	<0.08	1270	<0.0031
Sheep Units (U)	2	16.46	N.S.	58.5	N.S.	20.9	N.S.
RU	2	1.49	N.S.	37.1	N.S.	1.95	N.S.
Sheep/RU	6	53.9		42.6		55.5	
Within Sheep							
Periods (P)	2	92.3	N.S.	6.22	N.S.	118	N.S.
Temperature (T)	2	111	N.S.	73.3	N.S.	90.0	N.S.
PT'	2	105	N.S.	184	<0.01	103	N.S.
RP	2	20.3	N.S.	41.0	N.S.	25.9	N.S.
RT	2	46.6	N.S.	29.9	N.S.	52.3	N.S.
PTR'	2	112	N.S.	12.1	N.S.	115	N.S.
Residual	12	228		24.4		72.7	

d.f. = degrees of freedom

M.S. = mean square

P.L. = probability level

N.S. = not significant

APPENDIX

TABLE 12. ANOVA of the effect of temperature and ration on some water metabolic components

Source of Error		DM in feed/ total water + DM in feed (%)		Apparent water retention %	
Between Sheep	d.f.	M.S.	P.L.	M.S.	P.L.
Rations (R)	1	175	<0.0012	872	<0.0007
Sheep Units (U)	2	1.81	N.S.	141	<0.033
RU	2	1.59	N.S.	9.27	N.S.
Sheep/RU	6	5.26		22.0	
Within Sheep					
Periods (P)	2	4.97	N.S.	171	<0.01
Temperatures (T)	2	205	<0.001	1096	<0.001
PT'	2	5.52	N.S.	457	<0.005
RP	2	13.0	N.S.	83.3	N.S.
RT	2	13.4	N.S.	2.56	N.S.
PTR'	2	0.78	N.S.	187	<0.01
Residual	12	10.7		22.1	

d.f. = degrees of freedom

M.S. = mean square

P.L. = probability level

N.S. = not significant

APPENDIX

... the effect of temperature and ration on some blood components

[illegible]	d.f.	Thyroxine (mcg%) M.S.	Thyroxine (mcg%) P.L.	Triiodo-thyronine (mcg%) M.S.	Triiodo-thyronine (mcg%) P.L.	Protein Bound Iodine (mcg%) M.S.	Protein Bound Iodine (mcg%) P.L.	Hematocrit (%) M.S.	Hematocrit (%) P.L.
[illegible]	1	29.1	N.S.	41141	<0.015	9.88	<0.02	17.4	N.S.
[illegible]	2	4.06	N.S.	2456	N.S.	2.51	N.S.	13.4	N.S.
[illegible]	2	13.8	N.S.	525	N.S.	4.03	N.S.	50.0	N.S.
[illegible]	6	12.2		3663		1.04		12.8	
[illegible]									
[illegible]	2	1.28	N.S.	1535	N.S.	4.31	N.S.	59.2	N.S.
[illegible]	2	45.2	<0.025	26023	<0.025	0.13	N.S.	24.4	N.S.
[illegible]	2	6.10	N.S.	5737	N.S.	3.20	N.S.	13.4	N.S.
[illegible]	2	5.93	N.S.	2384	N.S.	7.27	N.S.	22.8	N.S.
[illegible]	2	0.48	N.S.	6941	N.S.	0.07	N.S.	9.84	N.S.
[illegible]	2	3.24	N.S.	111	N.S.	2.32	N.S.	50.0	N.S.
[illegible]	12	8.43		4724		1.25		18.4	

...rees of freedom
...n square
...bability level
...t significant

APPENDIX

TABLE 14. The effect of temperature and ration on rectal temperature in sheep.

Room Temp. (C)		0.8				10.0				17.7			
Ration		P		H		P		H		P		H	
Sheep ID		9498	9497	9499	9493	9496	9492	9491	9489	9490	9494	9495	9488
Date	Time(h)												
May 2	900	38.2	38.8	37.8	37.4	39.4	39.1	38.8	38.8	39.2	39.4	38.9	39.4
May 3	900	38.4	39.0	38.4	39.0	39.6	39.4	39.3	40.5	39.6	39.4	39.0	38.8
4	1300	38.6	39.2	39.2	38.5	39.3	38.5	39.0	39.3	38.9	39.1	38.9	39.6
5	1300	39.0	39.4	39.4	38.1	39.4	38.9	39.0	39.6	39.4	39.2	39.3	39.1
6	1000	38.8	38.8	39.6	38.9	39.0	38.8	39.8	40.5	39.5	39.4	39.4	39.2
7	900	39.2	39.2	38.5	38.8	39.2	38.6	38.8	39.7	39.6	39.4	39.0	39.4
8	900	39.2	39.4	38.2	39.0	39.4	38.8	38.6	39.6	39.5	39.1	38.7	39.1
9	900	39.8	39.0	38.5	38.8	39.0	38.2	38.8	40.0	39.2	38.9	38.7	38.9
Average		38.9	39.0	38.7	38.6	39.3	38.8	39.0	39.8	39.4	39.2	39.0	39.2
S.D.		(0.51)	(0.24)	(0.63)	(0.56)	(0.21)	(0.37)	(0.38)	(0.58)	(0.24)	(0.19)	(0.25)	(0.27)

TABLE 15. ANOVA on the effect of temperature and ration on rectal temperature in sheep.

Source of Error	d.f.	S.S.	M.S.	F_1	F_2
Temperature(T)	2	3.18	1.59	2.62 (N.S.)	9.94 ($P < 0.005$)
Ration(R)	1	0.15	0.15	N.S.	N.S.
TR	2	2.24	1.12	1.85 (N.S.)	7.01 ($P < 0.005$)
Sheep(S)/RT	6	3.63	0.61		3.79 ($P < 0.005$)
Determinations(D)/S/RT	84	13.44	0.16		
Total	95				

d.f. = degrees of freedom
S.S. = sum of squares
M.S. = mean square

F_1 = tested against S/RT
F_2 = tested against D/S/RT

APPENDIX

TABLE 16. The effect of temperature and ration on water intake and the relationship of water temperature to the time of day it is consumed by sheep.

Ration	Pellets		Hay		Pellets		Hay		Pellets		Hay	
Sheep I.D.	9496		9489		9494		9488		9498		9499	
Room Temp(C)	0.8		0.8		10.0		10.0		17.7		17.7	
Time	Vol(ml)	Temp(C)	Vol(ml)	Temp(C)	Vol(ml)	Temp(C)	Vol(ml)	Temp(C)	Vol(ml)	Temp(C)	Vol(ml)	Temp(C)
830 (fed)										12.5		13.5
900		15.0		13.0		18.0		19.5		13.0		13.5
930					1550	17.0	950	19.0	200	13.5		14.0
1000	550	13.0	400	11.0	300	15.5		18.0	150	14.0	550	14.5
1030	300	11.0	550	9.0	500	15.0	100	17.5	1100	14.5		14.8
1100	50	10.0	250	9.0	700	14.5		17.0		15.0		15.5
1130		9.5	50	8.5						15.5		15.5
1200						14.0		16.0				
1230		8.0		8.0								
1300												
1330						12.5		14.5				
1400		6.5		7.0								
1430						12.5		13.5		16.5		17.0
1500												
1530										18.0		18.0
1600(fed)	100	4.0		5.0		11.5		13.0				
1630												
1700		5.0		4.5		11.5		13.0		18.5		18.0
1800	300	3.5		4.0		11.5		12.5		18.5	750	18.5
1900	250	3.0		3.5		11.0	100	12.5		18.5	100	18.5
2000	50					11.0		12.0		19.0	50	19.0
2100	50	2.5		3.0		11.0		12.0		19.0	450	19.0
800(next day)		1.5	150	2.0		11.0		11.0		19.0		19.0

APPENDIX

TABLE 17. The effect of temperature and ration on the temperature of the various body sites in *sheep from period 2, taken between 1100 and 1300 h daily.

Temp	Sheep	Hay or Pellets	Room	Ear	Shoulder	Front leg	Front leg below knee	Mid back	Belly	Rump	Hind foot	Hind leg	Rectal
0.8	9489	H	1	8	18.5	23.5	27	22.5	27.5	24	24	26.5	37.5
	9492	P	0	5	21	21.5	16.5	19	20.5	17	18	20	37
10.0	9488	H	8.5	26.5	24.5	26.0	20.0	25	25.5	27.5	26	26.5	37.5
	9490	P	10	12.5	26.0	24.5	21.0	22	24	23.5	25	22	38.0
17.7	9493	H	19	32.0	31.0	30.0	30.0	31.5	28.5	31	29	32.5	38
	9497	P	19	23.0	29.5	31.0	28.0	29.5	32	29.5	27.5	32	37.5

* see figure 1 for location of sites on body of sheep.

TABLE 18. The effect of temperature on body weights (BW) of sheep.

		Period 1					Period 2				
		Temperature exposure = 1.3 C					Temperature exposure = 21.2C				
Sheep No.	Date 1974	Sept 16	Oct 1	Oct 15	Oct 21	Nov 2	Nov 9	Nov 25	Dec 2	Dec 10	Dec 21
9236		82	76	75	69	70	72	74	75	75	75
8229		59	55	54	51	49	46	53	52	54	54
2701			55	48	47	44	46	49	49	50	46
		Temperature exposure = 21.2C					Temperature exposure = 1.3 C				
2523		47	49	46	47	48	49	47	46	45	44
8236		66	72	72	74	73	73	68	68	66	66
0513			42	43	43	43	44	42	42	41	39

APPENDIX

TABLE 19. The effect of temperature on feed intake and feces output.

	Trial Period I					
Sheep I.D.	2701	9236	8229	2523	8236	0513
	T_{p4}	T_{p4}	T_{p4}	T_{p5}	T_{p5}	T_{p5}
Gm of Daily feed intake (wet)	1400	1900	1500	1300	1600	1200
Gm of Daily feed intake (dry)	1268.4	1721.1	1359.0	1177.8	1449.6	1087.2
Gm of Average daily feces (dry)	540.9	782.6	577.3	438.8	515.4	459.5
Average % DM in feces	43.7	40.5	42.5	53.4	52.6	48.0
DM digestibility (%)	57.4	54.5	57.5	58.9	64.4	57.7
	Trial Period II					
	T_{p5}	T_{p5}	T_{p5}	T_{p4}	T_{p4}	T_{p4}
Gm of Daily feed intake (wet)	1400	1900	1500	1300	1600	1200
Gm of Daily feed intake (dry)	1285.2	1744.2	1377.0	1193.4	1468.8	1100
Gm of Average daily feces (dry)	518.2	716.9	551.7	520.9	599.0	520.9
Average % DM in feces	46.1	37.5	45.5	48.2	46.5	48.2
DM digestibility (%)	59.6	58.9	59.9	56.4	59.2	56.4

APPENDIX

TABLE 20. The effect of temperature on oxygen consumption in sheep.

Trial Period 1

Sheep No.	8229	9236	2701	2523	8236	0513
	T_{p4}	T_{p4}	T_{p4}	T_{p5}	T_{p5}	T_{p5}
Time (x100Hrs)	*l/hr/kg (x10^{-2})	l/hr/kg (x10^{-2})	l/hr/kg (x10^{-2})	l/hr/kg (x10^{-2})	l/hr/kg (x10^{-2})	l/hr/kg (x10^{-2})
10 - 11	48.79	27.72	38.21	27.85	17.34	21.19
11 - 12	41.33	29.64	31.85	32.08	17.82	19.54
12 - 13	46.26	27.18	27.03	26.13	15.90	18.70
13 - 14	33.53	26.70	28.61	13.10	15.90	21.16
14 - 15	30.65	38.58	30.26	2.91	17.34	21.18
15 - 16	37.09	33.60	34.26	23.29	23.16	30.96
	**(49kg)	(70kg)	(44kg)	(40kg)	(73kg)	(43kg)

Trial Period 2

	T_{p5}	T_{p5}	T_{p5}	T_{p4}	T_{p4}	T_{p4}
10 - 11	19.77	22.07	30.36	35.98	32.70	45.23
11 - 12	19.75	14.86	25.58	31.80	30.50	33.92
12 - 13	18.40	12.43	36.80	37.65	27.78	41.52
13 - 14	19.09	13.86	40.77	31.80	25.06	51.86
14 - 15	19.75	12.44	43.21	41.01	25.06	59.44
15 - 16	49.71	31.63	41.60	44.31	27.24	53.80
	(54kg)	(75kg)	(46kg)	(44kg)	(66kg)	(39kg)

* l/hr/kg = liters per hour per kg body weight

** values in brackets are the body weights of the sheep during the trial period when the oxygen consumption determinations were being made.

APPENDIX

TABLE 21. The effect of temperature on methane production in sheep.

	Trial Period 1					
Sheep No.	8229	9236	2701	2523	8236	0513
Time (x100hrs)	T_{p4} *1/hr/kg ($x10^{-3}$)	T_{p4} 1/hr/kg ($x10^{-3}$)	T_{p4} 1/hr/kg ($x10^{-3}$)	T_{p5} 1/hr/kg ($x10^{-3}$)	T_{p5} 1/hr/kg ($x10^{-3}$)	T_{p5} 1/hr/kg ($x10^{-3}$)
10-11	42.39	25.20	30.77	11.13	33.90	25.70
11-12	36.34	25.32	25.27	10.27	27.18	24.19
12-13	18.74	23.04	26.34	10.58	23.94	24.23
13-14	22.67	23.22	17.02	8.50	23.10	18.81
14-15	11.16	38.40	17.36	25.17	22.68	13.26
15-16	12.84	29.52	20.00	19.33	48.54	39.72
	**(49kg)	(70kg)	(44kg)	(40kg)	(73kg)	(43kg)
	Trial Period 2					
	T_{p5}	T_{p5}	T_{p5}	T_{p4}	T_{p4}	T_{p4}
10-11	8.08	27.10	8.31	8.58	31.34	7.19
11-12	9.51	23.97	6.12	9.08	25.23	6.68
12-13	10.37	21.05	13.40	7.99	27.24	29.48
13-14	21.47	21.87	14.05	26.05	28.17	10.25
14-15	5.96	22.02	7.36	25.73	24.41	20.06
15-16	28.51	45.78	10.94	4.15	21.03	17.43
	**(54kg)	(75kg)	(46kg)	(44kg)	(66kg)	(39kg)

* - liters per hour per kilogram

** - the values in brackets refer to the average body weight of each sheep during the experimental period.

APPENDIX

TABLE 22a. The effect of temperature on retention time of digesta in sheep.

SHEEP # 8229 DATE: Dec.11-16, 1974 ROOM TEMPERATURE: 21.2 C

sample	hours after admini- stration	average cpm/gm	cpm	accumu- lative cpm	percent of total cpm(%)	accum. cpm as % of infusate	t_i hrs	retention time of Ce^{144} (hrs)
1	12	-19	0	0	0	0	6	0
2	15	664	36,463	36,463	0.35	0.47	13.5	0.05
3	18	3,514	133,534	169,997	1.63	2.19	16.5	0.21
4	21	6,909	459,462	629,459	6.05	8.11	19.5	0.86
5	24	13,400	1,373,505	2,002,964	19.24	25.81	22.5	2.97
6	27	17,008	690,527	2,693,491	25.87	34.71	25.5	1.69
7	30	15,720	2,126,968	4,820,459	46.30	62.11	28.5	5.82
8	33	12,941	328,693	5,149,152	49.46	66.35	31.5	0.99
9	36	12,416	351,380	5,500,532	52.84	70.87	34.5	1.64
10	39	10,881	1,032,577	6,533,109	62.76	84.18	37.5	3.72
11	42	7,931	499,666	7,032,775	67.56	90.62	40.5	1.94
12	45	6,576	676,667	7,709,442	74.06	99.33	43.5	2.83
13	51	5,294	637,930	8,347,372	80.18	107.6	48	2.94
14	59	4,274	877,873	9,225,245	88.62	119.9	55	4.64
15	71	2,030	614,378	9,839,623	94.52	126.8	65	3.84
16	95	823	458,121	10,297,744	98.92	132.7	83	3.65
17	119	153	96,840	10,394,584	99.85	133.9	107	0.99
18	143	24	15,655	10,410,239	100.0	134.1	131	0.20
							total	38.51

infusate = 7,761,100 cpm

APPENDIX

TABLE 22b. The effect of temperature on retention time of digesta in sheep.

SHEEP # 8229 DATE: Oct.29-Nov.2, 1974 ROOM TEMPERATURE: 1.3 C

sample	hours after administration	average cpm/gm	cpm	accumulative cpm	percent of total cpm(%)	accum. cpm as % of infusate	t_i hrs	retention time of Ce^{144} (hrs)
1	12	18	4,942	4,942	0.07	0.10	6	0.004
2	15	3,087	293,908	298,850	4.12	6.52	13.5	0.55
3	18	7,522	536,325	835,175	11.50	18.22	16.5	1.22
4	21	10,646	440,748	1,275,923	17.57	27.84	19.5	1.18
5	24	12,334	1,087,864	2,363,787	32.55	51.59	22.5	3.37
6	27	13,377	963,160	3,326,947	45.82	72.61	25.5	3.38
7	30	11,236	629,220	3,956,167	54.49	86.35	28.5	2.47
8	33	8,765	699,456	4,655,623	64.12	101.6	31.5	3.03
9	36	6,425	609,136	5,264,759	72.51	114.9	34.5	2.89
10	39	5,203	288,228	5,559,987	76.48	121.2	37.5	1.49
11	42	3,233	367,259	5,920,246	81.53	129.2	40.5	2.05
12	45	2,056	91,337	6,011,583	82.79	131.2	43.5	0.55
13	51	2,714	467,318	6,478,901	89.23	141.4	48	3.09
14	59	3,098	335,320	6,814,221	93.85	148.7	55	2.54
15	71	828	234,794	7,049,015	97.08	153.9	65	2.10
16	95	297	168,092	7,217,107	99.39	157.6	83	1.92
17	119	68	43,908	7,261,015	100.0	158.5	107	0.65
18	143						total	32.49

infusate = 4,581,490 cpm

APPENDIX

TABLE 22c. The effect of temperature on retention time of digesta in sheep.

SHEEP # 8236 DATE: Dec.11-16, 1974 ROOM TEMPERATURE: 1.3 C

sample	hours after administration	average cpm/gm	cpm	accumulative cpm	percent of total cpm(%)	accum. cpm as % of infusate	t_i hrs	retention time of Ce^{144} (hrs)
1	12	15	6,237	6,237	0.61	0.08	6	0.004
2	15	2,745	129,548	135,785	1.33	1.74	13.5	0.171
3	18	7,269	616,379	752,164	7.37	9.69	16.5	0.996
4	21	11,975	598,731	1,350,895	13.23	17.4	17.5	1.144
5	24	14,634	1,448,734	2,799,629	27.42	36.07	22.5	3.193
6	27	15,676	1,791,779	4,591,408	44.98	59.15	25.5	4.476
7	30	13,280	1,132,753	5,723,861	56.07	73.75	28.5	3.162
8	33	10,107	1,292,727	7,016,588	68.73	90.41	31.5	3.989
9	36	8,502	223,603	7,240,191	70.92	93.29	34.5	0.756
10	39	7,071	395,294	7,635,485	74.80	98.38	37.5	1.452
11	42	5,795	461,901	8,097,386	79.32	104.3	40.5	1.832
12	45	4,770	182,687	8,280,073	81.11	106.7	43.5	0.778
13	51	4,454	553,156	8,833,229	86.53	113.8	48	2.601
14	59	2,696	664,343	9,497,572	93.04	122.4	55	3.579
15	71	1,426	402,540	9,900,112	96.98	127.6	65	2.563
16	95	441	272,678	10,172,790	99.65	131.1	83	2.217
17	119	54	33,173	10,205,963	99.98	131.5	107	0.348
18	143	5	2,541	10,208,504	100.0	131.5	131	0.033
							total	33.29

infusate = 7,761,100 cpm

APPENDIX

TABLE 22d The effect of temperature on retention time of digesta in sheep.

SHEEP # 8236 DATE: Oct. 29–Nov. 2, 1974 ROOM TEMPERATURE: 21.2 C

sample	hours after admini-stration	average cpm/gm	cpm	accumu-lative cpm	percent of total cpm(%)	accum. cpm as % of infusate	t_i hrs	retention time of Ce^{144} (hrs)
1	12	19	4,339	4,339	0.06	0.09	6	0.004
2	15	423	20,639	24,978	0.34	0.54	13.5	0.04
3	18	2,858	293,840	318,818	4.36	6.95	16.5	0.66
4	21	6,652	559,464	878,282	12.01	19.17	19.5	1.49
5	24	9,546	713,076	1,591,358	21.77	34.73	22.5	2.19
6	27	9,434	735,823	2,327,181	31.83	50.79	25.5	2.57
7	30	8,952	598,863	2,926,044	40.02	63.86	28.5	2.33
8	33	7,860	390,645	3,316,689	45.37	72.39	31.5	1.68
9	36	6,447	515,102	3,831,791	52.41	83.63	34.5	2.43
10	39	5,951	475,497	4,307,288	58.92	94.01	37.5	2.44
11	42	5,311	118,426	4,425,714	60.54	96.59	40.5	0.66
12	45	4,961	338,853	4,764,567	65.17	104.0	43.5	2.02
13	51	4,329	351,536	5,116,103	69.98	111.7	48	2.31
14	59	3,644	796,942	5,913,045	80.88	129.1	55	5.99
15	71	1,960	484,500	6,397,545	87.51	157.1	65	4.31
16	95	1,096	675,041	7,072,586	96.74	154.4	83	7.66
17	119	474	238,108	7,310,694	100.0	159.6	107	3.48
18	143						total	42.28

infusate = 4,581,490 cpm

APPENDIX

ABLE 23a. The effect of temperature on retention time of digesta in sheep.

SHEEP # 2701 DATE: Dec.11-16, 1974 ROOM TEMPERATURE: 21.2° C

sample	hours after admini-stration	average cpm/gm	cpm	accumu-lative cpm	percent of total cpm(%)	accum. cpm as % of infusate	t_i hrs	retention time of Ce^{144} (hrs)
1	12	-31	0	0	0	0	6	0
2	15	3,256	307,371	307,371	2.94	3.96	13.5	0.40
3	18	8,110	158,136	465,136	4.46	6.00	16.5	0.74
4	21	11,212	674,948	1,140,455	11.92	14.69	19.5	1.26
5	24	16,243	1,067,196	2,207,651	21.14	28.45	22.5	2.30
6	27	17,071	954,284	3,161,935	30.27	40.74	25.5	2.33
7	30	15,703	1,661,408	4,823,343	46.18	62 15	28.5	4.53
8	33	11,845	692,911	5,516,254	52.81	71.08	31.5	2.09
9	36	8,822	428,737	5,944,991	56.92	76.60	34.5	1.42
10	39	7,900	778,952	6,723,943	64.37	86.64	37.5	2.80
11	42	5,901	363,473	7,087,416	67.85	91.32	40.5	1.41
12	45	5,641	535,873	7,623,289	72.98	98.22	43.5	2.23
13	51	5,078	715,011	8,338,300	79.83	107.44	48	3.29
14	59	4,358	763,124	9,101,424	87.13	117.3	55	4.02
15	71	2,009	705,253	9,806,677	93.89	126.4	65	4.39
16	95	822	477,827	10,284,504	98.46	132.5	83	3.80
17	119	277	130,636	10,415,140	99.71	134.2	107	1.34
18	143	57	30,188	10,445,328	100.0	134.6	131	0.38
							total	38.70

infusate = 7,761,100 cpm

APPENDIX

TABLE 22f. The effect of temperature on retention time of digesta in sheep.

SHEEP # 2701 DATE: Oct.29-Nov.2,1974 ROOM TEMPERATURE: 1.3 C

sample	hours after administration	average cpm/gm	cpm	accumulative cpm	percent of total cpm(%)	accum. cpm as % of infusate	t_i hrs	retention time of Ce^{144} (hrs)
1	12	23	6,920	6,920	0.08	0.12	6	0.005
2	15	4,763	601,984	608,904	7.07	11.23	13.5	0.94
3	18	11,552	1,363,098	1,972,002	22.86	36.38	16.5	2.61
4	21	13,274	434,064	2,406,066	27.92	44.39	19.5	0.98
5	24	14,704	1,060,143	3,466,209	40.23	63.95	22.5	2.77
6	27	12,518	1,212,951	4,679,160	54.30	86.33	25.5	3.59
7	30	9,229	685,744	5,364,904	62.26	98.98	28.5	2.27
8	33	0	0	5,364,904	62.26	98.98	31.5	0
9	36	8,347	342,238	5,707,142	66.23	105.3	34.5	1.37
10	39	6,554	834,952	6,542,094	75.92	120.7	37.5	3.63
11	42	5,302	419,383	6,961,477	80.79	130.4	40.5	1.97
12	45	3,929	296,613	7,258,090	84.23	133.9	43.5	1.50
13	51	3,198	314,006	7,572,096	87.87	139.7	48	1.75
14	59	2,660	366,257	7,938,353	92.12	146.5	55	2.34
15	71	1,151	413,835	8,352,188	96.93	154.1	65	3.12
16	95	399	218,001	8,570,189	99.46	158.1	83	2.10
17	119	88	46,771	8,616,960	100.0	159.0	107	0.58
18	143						total	31.53

infusate = 5,419,664 cpm

APPENDIX

TABLE 22g. The effect of temperature on retention time of digesta in sheep.

SHEEP # 9236 DATE: Dec. 11-16, 1974 ROOM TEMPERATURE: 21.2 C

sample	hours after administration	average cpm/gm	cpm	accumulative cpm	percent of total cpm(%)	accum. cpm as % of infusate	t_i hrs	retention time of Ce^{144} (hrs)
1	12	26	9,090	9,090	0.09	0.12	6	0.005
2	15	3437	495,631	504,721	4.90	6.50	13.5	0.65
3	18	6871	561,372	1,066,093	10.35	13.74	16.5	0.90
4	21	8591	670,961	1,737,054	16.86	22.38	19.5	1.27
5	24	10263	588,736	2,625,790	25.49	33.83	22.5	1.94
6	27	10586	1,237,450	3,863,240	37.50	49.78	25.5	3.06
7	30	8832	620,905	4,484,145	43.53	57.78	28.5	1.71
8	33	7885	613,476	5,097,621	49.48	65.68	31.5	1.88
9	36	7426	539,106	5,636,727	54.72	72.63	34.5	1.81
10	39	5845	562,916	6,199,643	60.18	79.88	37.5	2.50
11	42	4969	708,135	6,907,778	67.05	89.01	40.5	2.78
12	45	4532	288,222	7,196,000	69.85	92.72	43.5	1.22
13	51	4361	753,593	7,949,593	77.17	102.4	48	3.51
14	59	3141	781,164	8,730,757	84.75	112.5	55	4.17
15	71	1873	756,679	9,487,436	92.09	122.2	65	4.77
16	95	811	587,874	10,075,310	97.80	129.8	83	4.74
17	119	240	197,746	10,273,056	99.72	132.4	107	2.05
18	143	41	28,769	10,301,825	100	132.7	131	0.37
							total	38.89

infusate = 7,761,100 cpm

APPENDIX

Table 13h. The effect of temperature on retention time of digesta in sheep.

SHEEP # 9236 DATE: Oct. 29-Nov. 2,1974 ROOM TEMPERATURE: 1.3 C

sample	hours after admini-stration	average cpm/gm	cpm	accumu-lative cpm	percent of total cpm(%)	accum. cpm as %-of infusate	t_1 hrs	retention time of Ce^{144} (hrs)
1	12	124	53,150	53,150	0.60	0.98	6	0.04
2	15	4,819	693,935	747,085	8.37	13.78	13.5	1.05
3	18	8,105	714,014	1,461,099	16.36	26.95	16.5	1.32
4	21	9,758	975,818	2,436,917	27.29	44.96	19.5	2.13
5	24	11,471	1,566,896	4,003,813	44.84	73.87	22.5	3.95
6	27	8,082	969,844	4,973,657	55.70	91.77	25.5	2.77
7	30	6,648	663,515	5,637,172	63.13	104.0	28.5	2.12
8	33	5,832	447,297	6,084,469	68.14	112.3	31.5	1.58
9	36	4,652	397,301	6,481,770	72.59	119.6	34.5	1.53
10	39	3,820	583,671	7,065,441	79.12	130.4	37.5	2.45
11	42	3,722	279,894	7,345,335	82.26	135.5	40.5	1.27
12	45	2,597	206,197	7,551,532	84.57	139.3	43.5	1.00
13	51	2,282	497,015	8,048,547	90.13	148.5	48	2.67
14	59	1,787	397,573	8,446,120	94.58	155.8	55	2.45
15	71	675	282,241	8,728,361	97.74	161.0	65	2.05
16	95	199	150,006	8,878,367	99.42	163.8	83	1.39
17	119	65	51,408	8,929,775	100.0	164.8	107	0.62
18	143						total	30.39

infusate = 5,419,664 cpm

APPENDIX

[illegible]21. The effect of temperature on retention time of digesta in sheep.

SHEEP # 0513 DATE: Dec.11-16, 1974 ROOM TEMPERATURE: 1.3 C

sample	hours after admini-stration	average cpm/gm	cpm	accumu-lative cpm	percent of total cpm(%)	accum. cpm as % of infusate	t_i hrs	retention time of Ce^{144} (hrs)
1	12	-32	0	0	0	0	6	0
2	15	1,300	254,721	254,721	2.49	3.28	13.5	0.34
3	18	12,243	1,089,666	1,344,387	13.13	17.32	16.5	1.76
4	21	19,981	1,659,220	3,003,607	29.34	38.70	19.5	3.16
5	24	19,055	1,842,609	4,846,216	47.33	62.44	22.5	4.05
6	27	17,026	131,779	4,977,995	48.62	64.14	25.5	0.33
7	30	16,544	607,163	5,585,158	54.55	71.96	28.5	1.69
8	33	13,556	1,316,304	6,901,462	67.41	88.92	31.5	4.05
9	36	12,307	262,138	7,163,600	69.97	92.30	34.5	0.88
10	39	9,[illegible]	991,613	8,155,213	79.65	105.1	37.5	3.63
11	42	6,[illegible]	481,439	8,636,652	84.35	111.3	40.5	1.90
12	45	4,645	266,160	8,902,812	86.95	114.7	43.5	1.13
13	51	3,672	454,949	9,357,761	91.40	120.6	48	2.13
14	59	2,434	318,325	9,676,086	94.51	124.7	55	1.71
15	71	1,161	434,301	10,110,387	98.75	130.3	65	2.76
16	95	220	104,689	10,215,076	99.77	131.6	83	0.85
17	119	46	21,269	10,236,345	99.98	131.9	107	0.22
18	143	4	2,225	10,238,570	100.0	131.9	131	0.03
							total	30.62

infusate = 7,761,100 cpm

APPENDIX

22j. The effect of temperature on retention time of digesta in sheep.

SHEEP # D513 DATE: Oct.29–Nov.2, 1974 ROOM TEMPERATURE: 21.2 C

sample	hours after administration	average cpm/gm	cpm	accumulative cpm	percent of total cpm(%)	accum. cpm as % of infusate	t_1 hrs	retention time of Ce^{144} (hrs)
1	12	30	7,083	7,083	0.10	0.15	6	0.006
2	15	4,692	497,324	504,407	7.14	11.00	13.5	0.95
3	18	9,044	176,352	680,759	9.63	14.85	16.5	0.41
4	21	11,057	659,012	1,339,771	18.96	29.24	19.5	1.82
5	24	13,175	710,135	2,049,906	29.01	44.74	22.5	2.26
6	27	13,208	1,518,901	3,568,807	50.51	77.89	25.5	5.48
7	30	10,040	358,443	3,927,250	55.58	85.71	28.5	1.45
8	33	8,466	596,017	4,523,267	64.02	98.72	31.5	2.66
9	36	7,407	157,780	4,681,047	66.25	102.2	34.5	0.77
10	39	6,258	649,006	5,330,053	75.44	116.3	37.5	3.44
11	42	4,756	120,796	5,450,849	77.15	119.0	40.5	0.69
12	45	4,524	313,523	5,764,372	81.58	125.8	43.5	1.93
13	51	3,454	297,760	6,062,132	85.80	131.9	48	2.02
14	59	2,685	467,456	6,529,588	92.41	142.1	55	3.64
15	71	1,211	272,824	6,802,412	96.27	148.1	65	2.51
16	95	443	199,767	7,002,179	99.10	152.4	83	2.35
17	119	128	63,439	7,065,618	100.0	153.8	107	0.96
18	143						total	33.35

infusate = 4,581,490 cpm

APPENDIX

TABLE 22k. The effect of temperature on retention time of digesta in sheep.

SHEEP # 2523 DATE: Dec. 11-16, 1974 ROOM TEMPERATURE: 1.3 C

sample	hours after admini-stration	average cpm/gm	cpm	accumu-lative cpm	percent of total cpm(%)	accum. cpm as % of infusate	t_i hrs	retention time of Ce^{144} (hrs)
1	12						6	0
2	15	-3					13.5	0
3	18	4830	515,325	515,325	5.14	6.64	16.5	0.85
4	21	13982	496,373	1,011,698	10.08	13.04	19.5	0.96
5	24	17022	636,605	1,648,303	16.43	21.24	22.5	1.43
6	27	17996	622,673	2,270,976	22.63	29.26	25.5	1.58
7	30	18592	689,770	2,960,746	29.51	38.15	28.5	1.96
8	33	20113	1,938,939	4,899,685	48.83	63.13	31.5	6.09
9	36	14311	1,006,033	5,905,718	58.86	76.09	34.5	3.46
10	39	11323	1,194,567	7,100,285	70.76	91.49	37.5	4.46
11	42	7674	615,486	7,715,771	76.90	99.42	40.5	2.48
12	45	7505	172,615	7,888,386	78.62	101.6	43.5	0.75
13	51	5240	852,548	8,740,934	87.11	112.6	48	4.08
14	59	3901	369,406	9,110,340	90.80	117.4	55	2.02
15	71	1954	634,738	9,745,078	97.12	125.6	65	4.11
16	95	458	244,848	9,989,926	99.56	128.7	83	2.03
17	119	82	43,973	10,033,899	100.0	129.3	107	0.47
18	143	-8		10,033,899			131	0
							Total	36.73

infusate = 7,761,100 cpm

APPENDIX

TABLE 22 1. The effect of temperature on retention time of digesta in sheep.

SHEEP # 2523 DATE: Oct.29–Nov.2/74 ROOM TEMPERATURE: 21.2 C

sample	hours after admini- stration	average cpm/g	cpm	accumu- lative cpm	percent of total cpm(%)	accum. cpm as % of infusate	t_i hrs	retention time of Ce^{144} (hrs)
1	12	17	4,854	4,854	0.06	0.10	6	0.004
2	15	1[illegible]	10,185	15,039	0.20	0.33	13.5	0.019
3	18	2,077	128,139	143,178	1.94	3.16	16.5	0.29
4	21	7,267	597,372	740,550	10.02	16.37	19.5	1.58
5	24	9,935	603,051	1,343,601	18.18	29.70	22.5	1.84
6	27	10,513	622,356	1,965,957	26.60	43.46	25.5	2.15
7	30	12,037	730,616	2,696,573	36.49	59.61	28.5	2.82
8	33	9,586	695,918	3,392,491	45.91	75.00	31.5	2.97
9	36	7,758	1,023,288	4,415,779	59.76	97.63	34.5	4.78
10	39	6,419	247,786	4,663,565	63.11	103.11	37.5	1.26
11	42	5,065	166,633	4,830,198	65.37	106.79	40.5	0.91
12	45	5,173	440,765	5,270,963	71.33	116.54	43.5	2.59
13	51	4,453	605,646	5,876,609	79.53	129.93	48	3.93
14	59	3,157	663,630	6,540,239	88.51	144.6	55	4.94
15	71	1,636	345,182	6,885,421	93.18	152.2	65	3.04
16	95	817	391,320	7,276,741	98.47	160.9	83	4.39
17	119	254	112,760	7,389,501	100.0	163.4	107	1.63
18	143						total	39.13

infusate = 4,581,490 cpm

APPENDIX

TABLE 23. The effect of temperature on the reticulum contraction frequency.

Period 1 - Contractions/Hr.

Sheep No.	8229		2701		9236		2523		0513		8236	
Temperature (C)	1.3		1.3		1.3		21.2		21.2		21.2	
Time (x100 hrs.)	Day 1	Day 2	Day 1	Day 2	Day 1	Day 2	Day 1	Day 2	Day 1	Day 2	Day 1	Day 2
9 - 10		78		68	82		66	60		58		
10 - 11	68	64	70	64	73		57	57	51	54	48	
11 - 12	55	61	62	55	66		56	56	52	53	51	
12 - 13	58	60	62	58	66		57	56	47	50	44	
13 - 14	55	63	59	61	69		63	58	47	56	48	
14 - 15	59	61	64	66	65		67	57	50	72	46	
15 - 16	73	81	79	69	79		75	68	48	70	45	
16 - 17 (fed)	84	116	76	120	103		84	83	48	94	47	
17 - 18		75		63	76		54	65		57		
18 - 19	72	65	64	58	69		56	62		51		
19 - 20	70	61	58	55	70		58	56		48		
20 - 21	63	62	55					59				

Period 2 - Contractions/Hr.

Temperature (C)	21.2		21.2		21.2		1.3		1.3		1.3	
9 - 10	63	61		67	62	61	74	78		79	88	76
10 - 11	54	57	48	47	58	60	69	71	79	65	74	71
11 - 12	56	56	45	62	50	58	73	71	73	59	69	68
12 - 13	62	56	46	54	58	57	73	73	68	59	65	67
13 - 14	65	54	52	58	59	58	68	69	65	58	54	63
14 - 15	75	60	56	61	75	59	71	70	72	65	56	63
15 - 16	81	70	60	67	82	60	72	70	82	86	68	78
16 - 17 (fed)	74	88	82	111	109	100	76	103	122	111	128	110
17 - 18	54	56		51	67	90	67	71		72	72	101
18 - 19	64	46		51	62	65	64	64		63	72	67
19 - 20	54			46			62			61		
20 - 21				54						59		

APPENDIX

TABLE 24. The effect of mixing Ce^{144} with non-radioactive feces and then drying, grinding and counting in a gamma counter.

*Trial	Total mixture of dried feces and Ce^{144} infusate	Ce^{144} infusate added to feces (gm)	Ground dried feces and Ce^{144} in counting vial (gm)	1st count (cpm)	2nd count (cpm)	cpm/gm of infusate administered
	4.3528	0.3985	1.5935	25916	25737	174,750
	4.1642	0.7522	1.5378	46521	46718	167,829
2	4.4126	1.1236	1.5587	65362	65630	165,019
	4.3607	1.5245	1.559	92156	91449	168,437
	4.3341	1.9726	1.5191	116162	100084	168,362
		empty vial - background --		793	730	168,879**
		empty vial - background ---		586	560	
	4.7434	0.4142	1.4829	12025	12084	93,093
	4.7184	0.8044	1.4718	22305	22035	88,357
1	4.4507	1.2002	1.504	40556	40276	99,651
	4.3996	1.6306	1.4296	45934	45751	86,521
	4.2954	2.0019	1.4204	61142	60853	92,143
						91,953**

*Trial - Ce^{144} infusate administered into the rumen of sheep in experimental period 1 is designated as Trial 1 and Ce^{144} infusate administered into the rumen of sheep in experimental period 2 is designated as Trial 2.

** - This figure is the average cpm/gm for the five determinations above it.

APPENDIX

TABLE 25. The effect of water temperature on the time of day it was consumed in some representative sheep exposed to a cold environment (1.3C).

Time (x100hrs)	Date	Sheep 2701 Temp (C)	Sheep 2701 Am't (ml)	Sheep 8229 Temp (C)	Sheep 8229 Am't (ml)	Date	Sheep 2523 Temp (C)	Sheep 2523 Am't (ml)	Sheep 0513 Temp (C)	Sheep 0513 Am't (ml)
8-9	Oct 29	10.5	1300	10.5	150	Dec 12	13.0	50	12.0	100
9-10	"	9.0	1350	9.0	1700	"	10.0	1350	9.0	3650
10-11	"	6.5	100	6.5	50	"	8.5	50	7.0	50
11-12	"	–	0		0	"		0	5.0	900
12-17	"		0		0	"		0		0
17-18	"	4.0	0			"	3.5	0	2.0	950
18-19	"	4.0	250	4.0	0	"				
19-20										
20-21	"	2.5	600	3.0	700	"	1.0	750	0	2300
21-9	Oct 30	2.5	0	3.0	0	Dec 13	0.0	0	0.0	0
8-9	Oct 30	–	–	14.5	0	Dec 13	16.0	50	15.5	50
9-10	"	12.0	1800	12.0	1250	"	12.0	1000	12.0	800
10-11	"	8.0	0	9.0	0	"	6.0	100		
11-12	"	–	0		0	"		0	6	2250
12-17	"		0		0	"		0		0
17-18	"	3.0	0	4.0	0	"	5.0	750	4	2300
18-19	"					"	4.0	200	3	100
19-20	"					"				
20-21	"	2.0	50	3.0	850	"				
21-9	Oct 31	1.0	0	2.0	0	Dec 14	0.0	0	0.0	0

APPENDIX

TABLE 26. The ANOVA of the effect of temperature on oxygen consumption and methane production of sheep.

Source of error	d.f.	Methane Production M.S. $(x10^{-5})$	Methane Production P.L.	Oxygen Consumption M.S. $(x10^{-3})$	Oxygen Consumption P.L.
Sheep (S)	5	39.4	N.S.	30.44	N.S.
Temperature (T)	1	4.77	N.S.	282.3	<0.031
Period (P)	1	65.3	N.S.	41.28	N.S.
Residual	4	9.53		26.67	
Hours (H)	5	5.77	N.S.	13.74	<0.032
HS	25	6.07	N.S.	3.05	N.S.
HT	5	19.5	N.S.	5.70	N.S.
HP	5	8.74	<0.006	8.90	N.S.
Residual	20	4.24		4.47	

TABLE 27. The ANOVA on the effect of temperature on DM digestibility, % DM in feces, retention time of digesta, thyroxine(T_4) and triiodothyronine(T_3) concentrations.

	d.f.	Retention Time(hrs) M.S.	Retention Time(hrs) P.L.	% DM Digestibility M.S.	% DM Digestibility P.L.	% DM in Feces M.S.	% DM in Feces P.L.
Sheep	5	9.747		9.248	70.025	35.709	70.025
Temperature	1	106.86	0.0062	37.101	0.0027	29.453	0.0317
Period	1	4.7754	0.32	0.801	0.38	16.33	0.0733
Residual	4	3.8319		0.8508		2.8058	

	d.f.	mcg T_4/100 ml M.S.	mcg T_4/100 ml P.L.	ng % T_3 M.S.	ng % T_3 P.L.
Sheep	5	2.2957		1189.89	
Temperature	1	17.184	0.0339	11347	0.0313
Period	1	0.0800	0.84	2054.1	0.238
Residual	4	1.7101		1072.2	

APPENDIX

TABLE 28. The ANOVA on the effect of temperature on the reticulum contraction frequency in sheep.

	d.f.	M.S.	P.L.[1]	P.L.[2]
Sheep (S)	5	356.348		
Temperature (T)	1	6537.5	<<0.0005	<<0.0005
Period (P)	1	1597.2		<<0.025
Residual[1]	4	281.88		
Residual[2] (D/TSU)	*10	188.8		
Hours (H)	6	3581.4	0.0000	<<.0000
HS	30	55.024		
HT	6	240.91	<0.05	<0.0025
HP	6	161.39		<0.05
Residual[1] (HTS/U)	24	95.645		
Residual[2] (HD/TSU)	**62	63.419		

* lost 2 degrees of freedom since 2 sets of determinations were estimated to be the same as the second 2 sets of determinations

** lost 10 degrees of freedom since 10 determinations were lost

P.L.[1] - probability level tested against residuals[1]

P.L.[2] - probability level tested against residuals[2]

APPENDIX

TABLE 29. The effect of temperature on the hourly mean reticulum contraction frequency (contractions per hour) in sheep.

Time of Day (hours)	No. of determinations	Contractions/hr	No. of determinations	Contractions/hr	P.L. (t-test)
900 - 1000	6	77.88 ± 5.44	6	62.25 ± 2.82	<0.001
1000 - 1100	12	70.08 ± 4.27	12	53.25 ± 4.45	<0.001
1100 - 1200	12	66.5 ± 7.15	12	53.83 ± 4.24	<0.001
1200 - 1300	12	64.6 ± 5.07	12	52.58 ± 5.85	<0.001
1300 - 1400	12	62.75 ± 5.21	12	55.5 ± 5.61	<0.01
1400 - 1500	12	64.75 ± 4.55	12	60.33 ± 9.83	<0.25
1500 - 1600	12	76.33 ± 5.51	12	64.25 ± 12.38	<0.02
1600 - 1700	12	104.33 ± 16.72	12	80.58 ± 21.84	<0.02
1700 - 1800	8	74.63 ± 10.71	8	61.75 ± 11.87	<0.10
1800 - 1900	10	65.8 ± 4.09	8	57.13 ± 6.68	<0.02
1900 - 2000	7	62.43 ± 5.26	5	52.4 ± 4.63	<0.01

APPENDIX

TABLE 30. Regression analysis on DM digestibility, retention time of Ce^{144}, T_3, T_4 and % DM in feces with environmental temperature; and DM digestibility with retention time of Ce^{144}.

Dependant Variable	Independant Variable	Slope (b)	Intercept (a)	P.L.	$S_{y.x}$	r^2
DM digestibility	environmental temperature	0.18	56.2	<0.025	2.25	0.42
% DM in feces	"	0.16	43.8	N.S.	4.54	0.13
Retention time	"	0.30	32.1	<0.005	2.62	0.61
T_4	"	-0.12	11.2	<0.025	1.36	0.48
T_3	"	-3.16	160	<0.025	35.4	0.49
DM digestibility	Retention Time	0.58	37.7	<0.005	1.56	0.67

$S_{y.x}$ - standard error of the estimate (Steel & Torie, 1960)

APPENDIX

TABLE 31a. Multiple regression analysis of the % accumulative Ce^{144} excreted on time after administration of Ce^{144} in each sheep exposed to cold (1.3C) and warm (21.2C) temperature treatments.

Temperature Treatment(C)	Sheep I.D.	b_o	b_1	b_2	b_3	Multiple Correlation Coefficient Squared
	9236	-66.21	6.14	-0.070	0.00029	0.991
	8229	-70.81	5.98	-0.068	0.00025	0.986
	2701	-60.05	5.65	-0.066	0.00025	0.992
1.3	2523	-63.44	4.61	-0.040	0.0001	0.961
	8236	-73.66	6.03	-0.069	0.00025	0.975
	0513	-70.17	6.21	-0.074	0.00028	0.989
	9236	-48.30	4.05	-0.037	0.0001	0.995
	8229	-59.35	4.38	-0.038	0.0001	0.977
	2701	-57.50	4.47	-0.042	0.0001	0.984
21.2	2523	-57.25	4.23	-0.036	0.0001	0.980
	8236	-49.39	3.86	-0.034	0.0001	0.991
	0513	-65.90	5.66	-0.064	0.0024	0.984

TABLE 31b. An Analysis of covariance on the data making up the accumulative excretion curves, by removing temperature treatments.

variable	Regression coefficient	Std. error of regression coeff.	Partial F-test
x	5.038	0.191	695
x^2	-0.052	0.004	214
temperature	-7.704	0.936	68
x^3	0.00018	0.00002	89
intercept	-57.04		

Analysis of variance for the regression

Source of variation	d.f.	S.S.	M.S.	Overall F
attributable to regression	4	228632	57158	1280
deviation from regression	199	8889	45	
Total	203	237521		

APPENDIX

TABLE 32. The effect of temperature on total serum thyroxine (T_4) and total serum triiodothyronine (T_3).

Sheep I.D.	T_4 (μg%)		T_3 (ng%)	
	cold	warm	cold	warm
9236	12.08	9.51	155	78
2701	9.32	7.57	92	103
8229	12.58	9.23	170	130
0513	10.24	10.51	210	91
8236	10.85	8.60	195	75
2523	10.99	6.28	115	83