

EFFECT OF ENVIRONMENT ON ENERGY
AND PROTEIN UTILIZATION IN RUMINANTS

by

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INTRODUCTION

In establishing the nutrient requirements for various species of livestock (NRC,1970) consideration is not given to the physical environment. These recommendations are valid only under well defined environmental conditions which are difficult to maintain under natural conditions. Cattle in feedlots for example are exposed to various environmental variables such as temperature, humidity, wind, season, rain, barometric pressure and others. In many areas of the United States and Canada, cattle are kept out-of-doors during winter with little or no shelter. During periods of severe cold weather, ruminants must elevate their heat production to maintain homeothermy and thus draw on food energy which could otherwise be used for the production of milk or meat (Webster,1971). On the contrary in tropical countries like Ceylon, Malaya, South Africa and parts of India, stunted growth and poor performance of the indigenous as well as the imported species results due to heat stress (Sharma and Kehar,1961). Climate also affects the body conformation of farm animals, their grazing habits and structural conformation of the digestive tracts (Findlay, 1963). To maximise production efficiency, nutritional programs should be matched to the animal's environment or if feasible, a controlled environment should be used.

The goal of this paper is to review the literature

available for the past 15 years, regarding the effect of environment on the production performance of farm animals and draw some conclusions as to the magnitude of these effects on the animal.

REVIEW OF LITERATURE

Thermal environment:

The thermoneutral zone (TNZ) is some times called the comfort zone and is the environment where the animal is not thermally stressed (Blaxter and Wainman, 1964; Webster, Hicks and Hays, 1969 and Ames, 1974). It depends upon factors such as insulation, radiation, nutritional plane and exercise (Joyce and Blaxter, 1964 and Ames, 1974). Armstrong, et.al., (1959) conducted a series of experiments on sheep at environmental temperatures ranging from 8 to 32 C using 3 levels of feeding. The critical temperature (i.e., lower limit of TNZ) of the closely clipped sheep varied from 24 C at the highest feeding level to 38 C at sub-maintenance feeding level. On the highest feeding level at the critical temperature, the net availability of the metabolizable energy of the ration above maintenance was 58% and at 38 C it was 36% in one sheep, 53% and 12% respectively in the other sheep. The metabolizable energy of the ration increased by 6 kcal /C rise in environmental temperature.

The energy exchange of two Half bred x Down cross wethers was determined at 3 feeding levels and 7 environ-

mental temperatures by Graham, et.al., (1959). Critical temperatures of 39-40 C and 24-27C were observed at low, medium and high feeding levels respectively. Above the critical temperature the heat production increased exponentially with rectal temperature, the coefficient being 0.075 ± 0.014 (Van't Hoff's coefficient) corresponding to a doubling of metabolism for every 9 C increase in rectal temperature. Below the critical temperature, heat production increased at a constant rate per square meter surface area per C, irrespective of feeding level and at 8 C it was more than double the minimal metabolism determined at the medium feeding level. The rate of increase was 115 Kcal/24 hr /C fall in environmental temperature.

The heat emission of two closely clipped sheep was determined using 3 feeding levels and 5 environmental temperatures ranging from 8 to 38 C by Blaxter, et.al., (1959). It was observed that the basal loss of heat of vaporization of water was 316 kcal/m²/24 hr in one sheep and 307 kcal/m²/24 hr in the other. The water vapor loss increased subsequently by 87 kcal/m²/24 hr /C change in environmental temperature in one sheep and 88 kcal/m²/24 hr /C in the other. The rate of body cooling below or warming above the critical temperature was about 10 kcal/m²/24 hr /C change in environmental temperature. The results showed that below the critical temperature the increase in heat production with falling temperatures reflected the increased radiative and convective losses of heat. Calorimetric

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experiments were conducted on 3 sheep having fleece lengths varying from 2.5 cm to 12.0 cm by Blaxter, Graham and Wainman (1959). They observed that the metabolizable energy of the food increased with increasing environmental temperature by 2-3 kcal/24 hr/C. The results showed that sheep with fleece have very wide thermoneutral zones. Rogerson (1960) observed that an increase in environmental temperature in the range of 20-40 C had no effect on the heat production of fasting animals or on animals fed a low plane of nutrition, but a high plane of nutrition increased heat production. Increasing the food intake from 3000 to 6000 g per day resulted in an increased heat production of 25% at 20 C and 40% at 40 C. These studies were made on steers in which the energy lost in faeces increased with improving plane of nutrition and urine energy fell with increasing environmental temperature.

Blaxter and Wainman (1961) conducted experiments on the energy metabolism and heat emission of two steers at the maintenance level in an environment of -5, 5, 15, 25 and 35 C at sub-maintenance level in environments of -5 and 19 C. They observed the critical temperature of the steers at the maintenance level of feeding to be 5.7 and 6.8 C. For the sub-maintenance steers the values were 17.8 and 18.4 C. Shivering was observed at temperatures of -5 and 5 C in both animals. The digestibility of the food increased as environmental temperature increased. The thermal

conductance of heat below the critical temperatures were 48.1 ± 0.5 and 50.6 ± 0.7 kcal/m²/24 hr/C and above critical temperature the thermal conductances of heat were 59.1 ± 2.1 and 66.6 ± 2.4 kcal/m²/24 hr/C for the two steers. Rea and Ross (1961) showed that winter has little or no effect on the performance of lambs due to concentrate level but high concentrate level in summer will result in significantly faster gains. Studies were made on the intake and digestibility of growing heifers in a hot and humid climate (Calcutta, India) by Sharma and Kehar (1961). The control group maintained under low temperature and low humidity conditions had higher intakes of dry matter, crude protein, ether extract and total carbohydrates than their counterparts on the same diet in a hot and humid area. Alexander (1961) showed that the heat production of a new born lamb after suckling is about 90 kcal/24 hr/kg in a thermoneutral environment.

Two pregnant ewes were subjected to a range of environmental temperatures and their heat production was measured by Graham (1964a). The results showed that the critical temperature of the shorn sheep was closely related to their heat production per m² surface area in a thermoneutral environment. It was also observed that at sub-critical temperatures, sensible heat loss increased at a rate of 70 kcal/24 hr/m²/C fall of ambient temperature and this increase in heat production was entirely attributed to the oxidation of fat. Under hot

conditions protein degradation accounted for the additional heat in wethers and in pregnant ewes. Total heat production, sensitive heat loss from the limbs and surface and rectal temperature of 4 Cheviot and 4 Suffolk sheep were measured at air temperatures of +5, 0, and -10 C by Webster and Blaxter (1966). The results of the individual exposures showed that at -10 C, heat production fell as fleece depth increased. At temperatures below 0 C cold induced vasodilation (CIVD) was recorded frequently in the ears but rarely in the shanks. At air temperatures above 0 C, CIVD was extremely rare.

Vanes (1967) conducted a series of experiments on growing veal calves to study the influence of environment on energy metabolism. They observed no differences in heat production of young calves with a low feed intake measured at 25, 20 and 15 C, but higher heat production was noted at 12 and 10 C. With rapidly growing animals, a temperature of 27 C and 95% relative humidity or with 30 C and 75% relative humidity caused a 10% increase in heat production. Moose, Ross and Pfander (1969) studied the relationship between concentrate levels (35% and 70%) and environmental effects (cool 0 to 5 C, warm 23-29 C) on feedlot performance, carcass quality and energy utilization in lambs. Live weight gains of lambs fed low concentrate (LC) rations in the cool environment were higher (0.18 kg) than their counter parts which received a high concentrate (HC) ration (0.16 kg). Conversely in warm weather HC

lambs made faster gains (0.2 kg.) than LC lambs (0.16 kg.). Carcasses were 12% heavier for HC lambs but carcass grades were higher for LC group in both environments. On limited feed intake (pair feeding), lambs on LC ate 33% more and gained more. Energy partition showed that heat increment was 31.5% higher in LC group than HC group.

Heat production and thermal insulation were measured in 3 groups of sheep consisting of control (15 C), out door and indoor (in thermostatically controlled refrigerated room) conditions which were exposed to the effect of season, cold climate and cold temperature respectively were studied by Webster, et.al., (1969). They observed that the control, outdoor and indoor groups increased their weight (24 weeks) on an average by 16.2, 10.0 and 14.9 kgs, respectively. The intake of the control group averaged 26.5 g hay per kg body weight per day. The outdoor group had increased intake (23.4 to 28.8 g per kg body weight) throughout the course of the experiment. The indoor group on an average consumed 29.8 g per kg body weight. Results showed an increased resting heat production with coldness. The heat production in control, outdoor and indoor groups were 118, 110 to 128 and 122.5 to 142.6 kcal/kg^{3/4}/24 hr respectively. At the end of the experiment, the sheep were shorn and exposed to -30 C. The mean heat production of the control, outdoor and indoor groups were 294, 206 and 368 kcal/kg^{3/4}/24 hr respectively. Ames, Nellor and Adams (1971) conducted 30 experiments on Suffolk ewes to describe

the effects of heat stress in terms of metabolic cost at 5 ambient temperatures. They observed that the respiratory rate increased at ambient temperatures above thermoneutral zone (25 C). Respiratory evaporative loss also increased about 65% from 30 to 35 C. Oxygen consumption increased significantly during severe heat stress (45 C). This increase was partitioned into somatic humoral and Q_{10} portions assuming $Q_{10} = 2.0$. The Q_{10} effect accounted for 41% of increased metabolic rate during heat stress. Olbrich, et.al., (1972) conducted studies on 3 Scotch Highland and 3 Zebu heifers at two ambient temperature-humidities, namely 10 C-50% RH and 31 C-50% RH. They observed increased rectal temperature and respiration rates at 31 C. Scotch Highland heifers at 31 C showed signs of heat stress and the rectal temperature and the respiration rates reached 42.4 C and 275 min, respectively.

Insulation:

The homeotherm's physiological responses to cold is to increase the total insulation. Insulation is defined as temperature gradient divided by heat flow per unit time per unit area. The units employed are C/kcal/24 hr/m².

$$\text{Unit Insulation} = \frac{\text{Temperature gradient (C)}}{\text{Heat flow (Kcal) per m}^2 \text{ surface per 24 hr}}$$

(Joyce and Blaxter, 1964). On a maintenance level of feeding, sheep with a fleece length of 0.1 cm, 2.5 cm or 12.0 cm had critical temperatures of 32, 13 and 0 C respectively, (Armstrong et.al., 1959). It was also observed that heavy

fleece not only depresses critical temperature but also reduces the rate of heat loss with falling temperatures under sub-critical conditions. Sensible heat losses above the critical temperatures showed wide variations associated with fleece length (Blaxter,et.al., 1959). It was observed that the total conductance of heat from body to air varied from $100 \text{ kcal/m}^2/24 \text{ hr/C}$ in closely clipped sheep to $28 \text{ kcal/m}^2/24 \text{ hr/C}$ in a sheep having 12 cm fleece. Studies by the same workers on the insulation of the fleece, showed that above the critical temperature most heat was lost from hair covered regions and losses from fleece covered surfaces were reduced to a minimum. The thermal conductivity of the fleece and hair were determined in vivo and found to range from 122 to $149 \text{ kcal/m}^2/24 \text{ hr/C/cm}$.

Blaxter and Wainman (1964) discussed tissue and external insulations in relation to wind speed. During heat, shearing increased tissue insulation but in cold tissue insulation decreased. Maximal tissue insulation was noted in steers having a full coat, kept under cold conditions and exposed to wind. External insulation increased significantly with coat length, the increase in insulation was at a smaller rate when wind velocity was 1.6 mph than at 0.4 mph. Joyce and Blaxter (1964) observed that following vasoconstriction tissue insulation was unaffected by wind velocity or environmental temperature. External insulation increased linearly with fleece length over a range of

5 to 50 mm. External insulation decreased with increasing wind velocities, the decrease being numerically greater when the fleece was long than when it was short. It was observed that a 42% reduction of coat insulation is caused by a wind speed of 9.6 mph. Webster and Blaxter (1966) showed the relationship of heat production and tissue insulation, fleece growth and external insulation in 4 Cheviot and 4 Suffolk sheep at environmental temperatures of +5, 0, -5 and -10 C. Tissue insulation fell from 5.7 units at 5 C to 4.6 units at -10 C. The lower tissue insulation at -10 C was independent of the magnitude of metabolic response of the animals to cold. It was observed that in still air, fleece type had relatively little effect on the insulation provided by the fleece. It was also shown that at 0.6 mph wind velocity, the increase in fleece insulation per mm depth was $0.55 \pm 0.02 \text{ kcal/m}^2/24 \text{ hr/C}$.

Webster (1966) in a series of 193 experiments using well trained sheep (eight) showed that the amount of insulation provided by the fleece has considerable effect on establishment of a new thermal equilibrium in a cold environment. With a fleece depth of less than 15 mm or 15 to 25 mm the increase in oxygen consumption during the first 10 min. was 71% and 13%, respectively. A very slow rise was observed when the fleece length was greater than 25 mm. The time necessary for establishment of a new thermal equilibrium was also related to fleece depth.

Times of 60, 80 and 180 min. was required with fleece depths of less than 15 mm, 15 to 25 mm and greater than 25 mm, respectively. The rectal temperature of the sheep in a constant thermoneutral environment was shown to increase by 0.49 ± 0.07 C/cm increase in fleece depth. Joyce, Blaxter and Park (1966) studied the effect of infrared radiation environment on the heat loss of sheep in two respiration chambers having different emissivities. It was found that the radiative conductance was $109 \text{ kcal/m}^2/24\text{hr/C}$ for one sheep and $99 \text{ kcal/m}^2/24\text{hr/C}$ for another. The convective conductances were 113 and 114 $\text{kcal/m}^2/24\text{hr/C}$. These results were used in a prediction equation for external insulation.

Blaxter (1967) discussed the insulatory value for the animals. He showed that the thermal insulation of the interface between the surrounding air and the surface of animals differing in size, shape and fur cover was reasonably constant between 6.0 and 7.5 $\text{C/kcal/m}^2/24\text{hr}$. Observations showed that the convective heat transfer does not increase linearly with wind velocity. The thermal insulation of air decreased by a factor of four when the wind speed increased by a factor of twenty. In still air, the cooling resistance of a sheep with 10 mm wool was $19.8 \text{ C/Mcal/m}^2/24 \text{ hr}$. This includes a term of $7.2 \text{ C/Mcal/m}^2/24 \text{ hr}$ for the insulation of the air interface. It was shown that in a wind speed of 10 mph, insulation of air interface would reduce to 1.8 and the cooling resistance to $14.4 \text{ C/Mcal/m}^2/24 \text{ hr}$. Then the

critical temperature of the sheep will shift from 22 C to 27 C dry bulb temperature.

Wind and humidity:

Wind significantly lowers effective temperature during cold weather, by altering the insulatory barriers of the animal. The heat lost through the animal's natural insulation must be measured to determine the combinations of temperature and wind that cause the greatest degree of heat loss due to destruction of insulatory barriers (Insley, 1973). Blaxter and Wainman (1964) determined the effects of air velocities ranging from 0.4 to 1.6 mph in a respiration chamber on four steers. The results showed that the highest heat production occurred when the animals were clipped and exposed to wind and cold. For a mean value of three steers at 0 C with 0.4 mph and with full coat, the mean heat production was 8987 kcal/24 hr and at 1.6 mph the value was 9490 kcal/24 hr. When the steers were clipped the mean heat production for 24 hr was 13.2 Mcal and 13.6 Mcal at 0.4 and 1.6 mph, respectively. It was also shown that wind alone increased metabolism irrespective of environmental temperature. At 1 C with 0.4 mph wind, the 24 hr heat production was 12.4 Mcal and at 0.9 C with 1.6 mph it was 12.9 Mcal. Joyce and Blaxter (1964) conducted a series of experiments on four tracheotomized sheep to determine the effects of changes in air velocity and air temperature on heat emission. With an air temperature of 5 C and fleece

length of 39 to 50 mm, no change in the metabolism was observed until the wind velocity exceeded 4.2 mph. With a fleece length of 19 mm, the metabolism was elevated even without the wind. Sheep having a 6 mm fleece and kept at -3 C produced 6371 kcal in 24 hr, when subjected to a wind velocity of 4.2 mph. This increased heat production was approximately 3 times greater than that observed in the thermoneutral environment.

Observations by Webster, Chlumecky and Young (1970) were made on 12 heifers to measure the effects of cold and wind on the energy exchange when exposed to different environments. The control, sheltered and exposed groups gained an average 102, 101 and 90 kg, respectively during a three month experimental period. The exposed group showed the effect of winter and wind on live gain. A decrease in external insulation with increasing wind speeds was noted. For the control group when the wind velocity changed from 10 m/ min to 320 m/ min, the external insulation dropped from 10.74 to 4.93, likewise for the sheltered and exposed groups the values were :3.1 to 7.8 and 12.33 to 7.52, respectively. Webster (1971) studied the effects of wind, air temperature and radiation exchanges on cattle heat losses by using a model ox MOOCOW. The power consumption necessary to maintain a constant temperature (39 C) was used to estimate the heat losses from the model. The results of this study

indicated that wind was related to heat loss by the equation

$$H = \frac{39.0 - T_A}{18.56 - 0.44 \times \text{sq.root of } V}$$

where

H = heat loss (kcal /m²/24 hr)

T_A = ambient temperature (°C)

V = wind velocity (m/min)

Source of heat production:

Using milk fed lambs Kielanowski (1965) estimated the cost per gram of protein and fat synthesis to be 7.50 and 14.97 kcal metabolizable energy, respectively. Orskov and McDonald (1970) conducted experiments on the efficiency of conversion of dietary energy into body fat and protein using comparative slaughter techniques on 99 early weaned lambs. The partition of energy between maintenance and protein and fat deposition was assessed with protein levels by multiple regression analysis and the following equations were derived.

Gross energy intake = 0.147 MWD+4.3 PRR+1.99 FTR+11.8

Digestible energy intake = 0.116 MWD+3.47 PRR+1.48 FTR+8.7

where digestible and gross energies are the total intakes in Mcal. Mwd is the mean metabolic weight (kg^{3/4}) multiplied by the days on experiment. PRR and FTR are the energy values in Mcal. for the total deposition of protein and fat respectively. Assuming the metabolizability of digestible

energy as 86%, the requirement of metabolizable energy was 3.04 kcal per kcal protein or 16.25 kcal per gram protein. Corresponding values for fat were 1.26 kcal per kcal fat or 11.44 kcal per gram fat. Armstrong et al (1959) showed that cold does not accelerate protein catabolism but utilizes body fat to keep the body warm. Results indicated that at any feeding level as the environmental temperature was reduced, the amount of energy arising from the dissimilation of fat increased. In one sheep at the higher feeding level and at low environmental temperature the rate of combustion of fat, carbohydrate and protein was 947, 234 and 87 kcal/24 hr, respectively. For the same animal at the higher environmental temperature the rates of combustion were 95, 156 and 177 kcal/24 hr, respectively. Over 50% of the increased catabolism at high environmental temperature was accounted for by protein catabolism.

Pregnant Merino ewes were exposed to ambient temperatures of 10 and 35 C and their serum free fatty acid levels, glucose and urinary nitrogen loss were measured by Graham (1964b). He observed an increase of $75 \text{ kcal/m}^2/24 \text{ hr/C}$ in sensible heat loss with falling temperatures. The increased heat production was due to the oxidation of fat as shown by the calculated respiratory quotient. At 10 C an elevation of blood glucose level was shown. Free fatty acid levels were highest at the lowest temperature indicating the

mobilization of body fat. In the non pregnant ewe the urinary nitrogen was increased by 2 to 3 g per day at 35 C but no such increase was observed in the pregnant ewe. Blaxter and Wainman (1961) showed that the additional heat production in cold weather was due to the oxidation of fat alone. Experiments on two steers showed no change in the nitrogen retention at low environmental temperature and the decrease in energy retention was due to the increased loss of carbon from the body. The amount of carbohydrates dissimilated, calculated from the corrected respiratory quotients remained constant and the sole source of additional carbon was body fat. This shows that oxidation of body fat was the source of additional heat. Slee and Halliday (1968) studied the effect of acute cold exposure on serum free fatty acid levels in eight Scottish Blackface and four Merino Cheviot ewes during pregnancy. The sheep were shorn and exposed in a climatic chamber to 18 C temperature with an air movement of 4 mph. Cold treatment was continued until the rectal temperature fell by 4.5 C or for a maximum period of 10 hours. Sheep at the thermoneutral temperature showed a free fatty acid level of 100 to 200 micro equiv./litre of serum. The severe cold treatment resulted in free fatty acid levels of 2000 micro equiv./litre. Halliday, Slee and Sykes (1969) observed the effects of acute cold on serum free fatty acids, protein

bound iodine, glucose, acetone and serum protein levels. It was observed that concentration of free fatty acids were higher at 8 C (chronic cold) than at 30 C (thermoneutral). The higher acetone concentrations during cold exposure (-20 C and 4 mph wind) in cold acclimatized sheep suggested that they had been oxidising more free fatty acids than the non acclimatized group. Glucose levels increased initially but fell towards the end of the exposure, suggesting that relatively less carbohydrates and more fat was utilized for energy metabolism during this period.

DISCUSSION

Thermoneutral zone (TNZ) is the environment in which minimal heat production occurs and the animal is not thermally stressed. Metabolism will increase within a small range of temperature at both higher and lower levels of thermoneutral zone. Animals must dissipate heat from the body at higher temperatures and conserve heat at lower temperatures to be most efficient and to maintain homeothermy. Heat dissipation occurs mainly by the following two methods: (1) Sensible heat loss due to radiation, conduction and convection. (2) Evaporative heat loss resulting from vaporization of water from the skin and respiratory passages. The amount of sensible heat lost by the animal is determined by the physical attributes of the environment, air temperature, incoming radiation from the surroundings and the amount of air movement. Animals have limited ability to control sensible heat loss by changing insulation between body parts in which heat is produced and the environment. Evaporative heat loss can be controlled to a greater extent by the animal, although vapor pressure gradient afforded by the environment is central to rate of vaporization.

Heat stress:

Heat stress is defined as any ambient temperature above the thermoneutral zone (TNZ). Animals exposed to heat must dissipate heat to maintain homeothermy. The initial response to heat stress is increased

respiratory rate and oxygen consumption, as well as sweating and/or panting. During heat stress blood circulation will be increased to the extremities (vasodilation) in order to loose more heat to the environment. It appears that sheep are able to loose more heat by vasodilation than are cattle. This is probably due to the efficient utilization of regional body cooling in heat dissipation by shunting blood to limbs, head and ears which are poorly insulated (Blaxter et.al., 1959). On this basis sheep would be expected to withstand warm conditions better than the cattle. Increased oxygen consumption will result in an elevated NE_m and consequently reduces NE_p . This increase in metabolic rate is attributed to the somatic humoral factors such as panting, heart rate and sweat gland activity. Another factor which plays a major role for the increased metabolism is the Q_{10} effect. The Q_{10} effect (Ames, Nellor and Adams, 1971) accounted for 23% of the increased metabolic rate at 35 C and 41% at 45 C. It was observed (Graham, et.al., 1959) that above the critical temperature, heat production increased exponentially with rectal temperature, the coefficient being 0.075 ± 0.014 (Van't Hoff's coefficient) corresponding to a doubling of metabolism for every 9 C raise in rectal temperature.

As the temperature gradient between the environment and the body surface decreases, sensible heat losses decreases. Thus the animal must rely on evaporative heat losses. Respiratory evaporation increases with ambient temperatures up to a certain level. In sheep, maximum respiratory heat

loss occurs when the respiratory rate is approximately 240/min. This is due to a non linear relationship of the respiratory rate to respiratory evaporative water loss. However, in severe heat stress, panting does not become a thermal liability (Ames, et.al., 1971). In cattle and sheep cutaneous evaporative water loss is an important avenue of heat loss at higher temperatures. Measurements made by (Blaxter, 1967) the mask technique in cattle showed that heat of vaporization is largely due to evaporation from the skin. It appears that in sheep and cattle about 30% of water vapor loss occurs from the respiratory apparatus and the remainder being evaporated from the skin. Since in severe heat stress, increases in respiratory heat loss is less corresponding to heat production, the animal must sweat to maintain a thermal balance. Ames, et.al., (1971) showed that during severe heat stress sweating is the most important avenue of heat loss in sheep.

Cold stress:

The critical temperature is referred as lower limit of the thermoneutral zone and signifies the beginning of cold stress. Major avenues of heat loss during cold are conduction, convection and radiation. Water evaporation is minimal in cold conditions and the animal has limited control over it. Variables affecting the sensible heat loss are temperature gradient, air velocity and thermal conductance. A combination of these variables reflects the cooling power of the environment. The cooling power of the environment must account for the animal's ability to adjust to cold by reducing the conductance (its reciprocal being increased in-

sulation). Total insulation consists of 3 components:

a) Tissue insulation (I_t) controlled by vasomotion, subcutaneous fat and other tissues; b) external insulation (I_e) is provided by hair or wool and c) air interface insulation (I_a) is provided by the air over the surface of the animal. These 3 components are additive with the destruction of any one resulting in less total insulation.

The rate of heat flow from the animal to the environment is partially dependant on these insulatory barriers. These are extremely important in minimizing heat loss in cold weather. Air movement over the hair, wool or surface decreases I_a resulting in a reduction of total insulation. Fleece length has an effect on external insulation. Tissue insulation is controlled by the rate of blood flow to the extremities and by subcutaneous fat. The critical temperature can be estimated by the equation given by Blaxter, et.al., (1959).

$$T_c = 39.0 - \frac{H - (H_{v(B)} + H_w)}{A \cdot C_A}$$

where

T_c = Critical temperature

H/A = Heat production per unit area

$H_{v(B)}/A$ = Loss of heat by vaporization

H_w/A = Heat loss in warming food and water to body temperature.

C_A = Conductance below critical temperature.

The variable components that can effect critical temperature are 1) insulation provided by the tissue, skin and fleece,

2) level of heat production and 3) heat needed to warm food and water to body temperature.

Heat production:

The nature and level of food intake can influence the heat production of an animal at a particular temperature. It has been shown that animals on a high plane of nutrition showed a decrease in energy retention due to the accelerated passage of food through the gut resulting in lowered digestibility (Blaxter, Graham and Wainman, 1956). Another factor which affects heat production is the fill in the digestive tract. When expressed on a surface area basis, at low temperatures heat production is constant irrespective of feeding level. Heat production is determined by the losses of heat from the surface. The surface area of the animal is increased on a larger ration because of the "fill" resulting in increased heat losses; Based on this theory a highly metabolizable ration with low bulk has been recommended (Graham et.al., 1959). However, rations composed largely of forages have a higher heat increment. This heat increment can be used effectively at cold temperatures to reduce NE_m and thus increase NE_p (Moose, et.al., 1969). Propionic and acetic acids results in higher heat increment losses. These losses amounted to 41% and 68% respectively in isocaloric diets in sheep (Armstrong, et.al., 1958). As the environmental temperatures increases above thermoneutral zone, the animal decreases its intake in order to reduce heat production. It was shown that the metabolizable energy of the ration increased by 6 kcal/C rise in environmental temperature (Armstrong,

et.al., 1959). This was largely due to a decline in fecal energy.

Wind velocity:

Of the environmental variables, the wind factor directly alters the insulatory barriers of the animals. Past research had shown that cold weather in combination with wind resulted in increased maintenance requirements and less efficient gains. Webster (1971) studied the effect of wind velocity on animal energetics using "MOOCOW" (model ox observing cold outdoor weather), as a model system. A quadratic relationship between rate of heat loss and cold and wind combinations was observed. However, the model ox that was used in this study did not possess external insulation in the form of hair or wool and therefore may not be relevant for animals having such insulation. Results of Insley (1973) with animal hides showed a cubic relationship between the heat loss and wind velocities.

During still air conditions, the rate of heat loss is minimized by 3 insulatory factors. 1) I_t is altered only during vasomotion and is not directly affected by wind velocity, 2) I_e is provided by hair or wool and in most farm animals cannot be changed physiologically in a short period of time and 3) I_a is present on all surfaces and is the first insulation that is destroyed by air movements, resulting in increased heat lossess. Partial destruction of hair or wool occurs during high wind velocities. Partial regression analysis results of Webster (1970) showed that external insulation decreased as a linear function of square

root of the velocity. The relationship between the wind velocity, cold temperature and rate of heat flow in animals such as sheep and cattle assume a cubic rather than quadratic relationship that was predicted for bare skinned animals. Tissue insulation decreased at air temperatures below freezing point. This occurs because the animal prevents tissue damage to its extremities by maintaining its surface temperature at or about 0 C. Webster and Blaxter (1966) measured regional losses of heat from air temperatures of -12 C and showed that the extremities are kept close to 8 C by periodic vasodilation. The temperatures of extremities is maintained in the animals by several distinct mechanisms: (a) Hunting reaction (CIVD) in the ears due to sharp and precise increase in ear temperatures at regular intervals, (b) a single sharp increase in the surface temperature of the ears and legs quite distinctly from the Hunting reaction and (c) control of blood flow in the hind legs in proportion to the heat loss (Webster and Blaxter, 1966).

Fleece:

The amount of insulation provided by the fleece has considerable effect on the establishment of a new thermal equilibrium in response to cold. Studies have shown that the time lag necessary for establishing a new thermal equilibrium increases as the fleece depth increases. Heat production and critical temperatures drop sharply as fleece depth increases. Heat production and critical temperatures

drop sharply as fleece length increases above nominal lengths. The results of Armstrong et.al., (1959) showed that a 2.5 cm fleece had a critical temperature of 13 C and the critical temperature was reduced to 0 C with a 12 cm fleece. Above the critical temperature, the protection provided by the fleece depends on adequate heat production by the animal which in turn depends on the type and amount of food given. The loss of production which occurs below the critical temperature however, is a direct function of fleece length. At a given level of feeding, a heavy fleece thus results not only in a lowered critical temperature but also in a smaller loss of production per C fall of environmental temperature below critical temperature. Wind velocity has a considerable effect on external insulation provided by wool or hair. External insulation decreased with increased wind velocities. Partial destruction of external insulation occur at high wind velocities in animals having long staples as compared to a short, thick coat. It was observed that the partial destruction of coat insulation by a wind speed of 9.6 mph was 42%.

Contradicting views were recorded as to the effect of temperature on the wool or hair growth. Yeates and Southcott (1958) have shown that cold has a direct effect on hair growth of cattle, but Morris (1961) observed no significant effect of cold on wool growth in sheep. In the light of above results, Webster et.al., (1970) stated that hair growth

is governed by photoperiod alone and further concluded that cold exposure influenced hair shedding and thereby coat cover.

Source of heat production:

In conditions like pregnancy, starvation and acute cold exposure, the energy expenditure exceeds intake of energy and the animal must produce more heat to keep itself warm. This is initially accomplished by shivering. However, shivering is not an efficient process for maintaining body temperature. A more efficient process would be an increase in metabolism of the more deep seated tissues. Experiments have shown that oxidation of fatty acids increases during cold exposure (Blaxter and Wainman, 1961; Graham, 1964a and Slee and Halliday, 1968). Concentration of free fatty acid levels in blood serum is an index of breakdown of body fat. Free fatty acid levels of 5 to 6 times were observed in acute cold conditions (Halliday, Sykes and Slee, 1969). Acclimatization of the animal to cold exposure, results in increased breakdown of body fat due to the action of noradrenaline.

Glucose levels increase to a certain extent during cold exposures but rapidly decline due to depletion of liver glycogen. Cold does not accelerate protein catabolism and thus does not lead to an increased protein requirement since the body solely draws upon body fat (Blaxter and Wainman, 1961). However, increased protein

degradation was observed in wethers subjected to heat stress (Graham, et.al., 1959 and Graham, 1964a).

SUMMARY

The literature available on the effect of environment on energy and protein utilization in ruminants is reviewed. Increased metabolic rate during severe heat stress is attributed to the somatic humoral factors and the Q_{10} effect. Sensible heat losses decrease to a minimum at high ambient temperatures and the animal depends on cutaneous and respiratory evaporative heat losses to dissipate heat. During cold weather conditions fleece length, wind velocity and total heat production determines the critical temperature of the animal.

The source of energy for heat production during cold weather is due to the oxidation of fat, as indicated by serum free fatty acid levels and calculated respiratory quotient. Protein catabolism increases during severe heat stress. Carbohydrates play a minor role as a source of heat production because of the limited reserves of glycogen in the muscle and liver.

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EFFECT OF ENVIRONMENT ON ENERGY
AND PROTEIN UTILIZATION IN RUMINANTS
by

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AN ABSTRACT OF A MASTER'S REPORT

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ABSTRACT

The production performance of animals depends on the level of nutrition and also on environmental factors such as ambient temperature, wind velocity, external coat length etc. The effect of environment on energy and protein utilization in ruminants is the subject of this report. The literature available for the past 15 years has been reviewed and in the light of information available at present, the significance of these environmental factors has been discussed.

The maintenance requirement of the animal is lowest in the thermoneutral zone and increases during both cold and heat stress. During cold stress, the heat production increases 4 to 5 times in order to keep the body warm. The body fat reserves serve as a major source of energy in cold weather. The critical temperature of the animal is significantly influenced by the insulation provided by the tissue, skin and external coat, level of heat production and heat needs to warm food and water to body temperature.

During heat stress, an increase in metabolic activity results, in association with heat dissipation. This increase in metabolic activity is attributed to the somatic humoral factors such as sweating, panting and respiratory rate and the Q_{10} effect. In an effort to reduce heat production, the animal lowers food intake. In cattle and sheep 30% of the evaporative heat loss occurs through the respiratory passage, the major portion being evaporated from the skin.

The value of heat increment should be considered in formulating rations during thermal stress. Nutrient requirements must be matched to the animal's environment. Rations should be formulated at frequent intervals according to environmental conditions existing on the feedlots for an efficient production performance.