RUMINANT COLD STRESS: EFFECT ON PRODUCTION

B. A. Young

University of Alberta, Edmonton, Alberta, T6G 2P5, Canada

Summary

A review is presented of biological issues and practical consequences of the effects of cold stress on ruminant animals. When animals are subjected to extreme cold stress, substantial dietary energy may be diverted from productive functions to the generation of body heat. Failure to produce sufficient heat can result in death. More often, however, cold stress leads to the development of secondary changes and possibly disease. With prolonged exposure to even mildly cold conditions, physiological adaptation occurs in animals resulting in increases in thermal insulation, appetite and basal metabolic intensity, as well as alterations in digestive functions. Much of the reduced productivity, and in particular the reduced nutritional efficiency, observed in ruminant production systems during the colder part of the year, can be accounted for by these adaptive changes.

(Key Words: Ruminant, Cold Stress, Lower Critical Temperature, Adaptation.)

Introduction

While the provision of shelter during inclement weather may reduce disease, animal losses or loss of productivity, the economic advantages are not always evident or appropriately assigned. The optimum type and extent of animal shelter depends upon climatic conditions, construction and operating costs, and potential direct and indirect influences on the animals. Biological issues and some practical consequences are enunciated in this review to provide a basis for rational decision-making in situations relative to potential effect of cold stress on ruminant production systems.

Partition and Utilization of Dietary Energy

Measures of biological energy are the basis of most animal feeding systems and heat energy is the currency of thermal balance. Thus, energy is a convenient common denominator to use when describing the effects of the thermal environment on animals and these effects can be related to animal productivity and efficiency of utilization of feedstuffs. The scheme presented in figure 1 illustrates the partition of dietary energy intake of animal into its various components. Substrate energy released through oxidation appears as heat in the animal and is ultimately disposed to the environment through thermal exchange mechanisms.

In cold environments the heat from maintenance and productive processes may be of considerable value in maintaining body temperature, thus avoiding shivering or other cold-induced thermogenic processes. Conversely, in a hot environment, thermoregulative mechanisms may be needed to eliminate excess body heat. Heat from the so-called maintenance processes of a producing animal may be elevated relative to that of a nonproducing animal because of increased vital functions, activity and overall total requirements (Canas et al., 1982).

From the energy flow scheme (figure 1), it is clear that utilization of dietary energy and productivity by ruminants is largely a function of intake of biologically useful energy (metabolizable energy) and heat production. Consequently, factors climatic or otherwise that influence intake or heat production will influence productivity and the efficiency of use of the feedstuffs. While direct acute effects of
Cold stress can be assigned to the component "combating external stresses," many of the effects of cold on animals result in adaptive changes and are reflected in appetite, digestive and metabolic functions. These latter changes are of substantial practical and economic importance in ruminant production systems.

**Acute Responses To Cold**

Much research has been conducted to estimate physical heat exchanges (thermal balance) in livestock and is based on measurements of heat production, heat loss and body temperature changes in animals exposed for short durations in controlled temperature chambers (see reviews of Monteith and Mount, 1974; Johnson, 1976; Haresign et al., 1977; NRC, 1981). Most of these short-term studies were based on the premise of a zone of thermoneutrality, wherein by definition, an animal's heat production is independent of the ambient temperature (Kleiber, 1961). The lower border of this zone is called the lower critical temperature (LTC) and is the temperature below which an animal must increase its rate of metabolic heat production to maintain homeothermy (figure 2). Below the lower critical temperature, metabolic heat production becomes increasingly dependent upon ambient temperature. However, a point of maximum heat production (summit metabolism) is reached as a consequence of extreme cold, and continual exposure to even lower temperatures results in hypothermia and reduced capacity of the animal to produce metabolic heat and, if the situation is not reversed, death of the animal. The LTC depends on rate of heat production in thermoneutral conditions and the thermal insulation provided by the hair coat and superficial tissues. Estimates of LTC are important guidelines in ruminant production systems involving cold-susceptible animals such as the newborn, animals with reduced thermal insulation or on restricted food intake (Alexander, 1974; Blaxter, 1977). In contrast, cold-adapted adult ruminants on full feed and with substantial thermal insulation are very cold hardy and have generally very low LTC such that in dry, cold, agricultural regions they rarely experience direct cold stress (Webster et al., 1970; Webster, 1974; Young and Christopherson, 1974). Laboratory studies have shown that moisture and wind considerably reduce the effective thermal insulation of an animal's coat (Joyce and Blaxter, 1964; Webster and Park, 1967; Ames et al., 1975). Furthermore, practical experience indicates that high moisture and windy conditions are associated with animal discomfort, but there have been few controlled experiments that have determined the effects of moisture and wind on animal productivity. Researchers in Ireland (McCarrick and Drennan, 1972a,b) showed there to be no advantage in providing wind or overhead shelter to growing cattle. By close confinement animals may be subjected to stress situations that may be as detrimental to the animal as the climatic stress.
for which the housing was provided. Several studies have shown little or no overall economic or production benefits where elaborate housing and climatic modification was provided for over-wintering ruminant animals (ASAE, 1974). While elaborate housing may not be justifiable on the basis of protection of animals from the environment and improved animal performance, animal confinement and housing might be justifiable on other grounds.

Simplified methods for estimating LTc of ruminant animals (Webster, 1974; Young, 1975a; Blaxter, 1977) express LTc in terms of equivalent dry, still-air, temperature and do not consider the full consequence of wind, moisture, mud and radiation. Furthermore, variations in animal type, feeding level, time after feeding, behavior and prior thermal exposure also should be considered in using LTc values.

Acute cold exposure can be a practical problem with cold-susceptible animals resulting in death losses (Hutchinson, 1968; Blaxter, 1977) or the development of secondary complications that affect later performance. Secondary complications include chronic digestive and respiratory disorders, scouring in young animals and pneumonia (Webster, 1970; ASAE, 1974). Coping with acute cold stress therefore involves minimizing the risk and severity of the immediate effects and pre- or early treatment of animals to reduce the probability of development of secondary complications. Provision of shelters, selection of appropriate calving, lambing or shearing times, and ensuring an adequate supply of feed can reduce the risks (Hutchinson, 1968; ASAE, 1974). Unfortunately, during inclement weather animals tend to temporarily reduce their feed intake and become more cold susceptible (NRC, 1981).

Chronic Responses To Cold

The ability of animals to cope with the cold improves during exposure to mildly cold conditions. Physiological adaptation is well documented in small mammals (Jansky, 1971; Smith et al., 1972) and similar cold-induced adaptive changes apparently occur in ruminant animals (Sykes and Slees, 1969; Webster et al., 1970; Young, 1975b,c). Adaptation to cold in ruminants involves increases in thermal insulation, appetite and basal metabolic intensity (Young, 1980; Young and Degen, 1981) that improve “cold hardiness” and reduce the risks of both acute and chronic cold stress.

Insulation. Increased winter hair coat in cattle is apparently induced and retained by shortening daily photoperiod and mild cold stress, respectively (Yeates and Southcott, 1958; Webster, 1976). Animals that are cold because of low ambient temperatures or because of reduced metabolic heat production, tend to retain hair in situations where animals with higher levels of heat production shed their hair coat (Webster et al., 1970). In addition to the obvious advantages of additional external insulation during winter it has been suggested that tissue insulation also increases as a consequence of prolonged exposure and adaptation to cold (Webster, 1976). Increased thermal insulation, per se, reduces the LTc and the required cold-induced thermogenesis when animals are exposed to temperatures below their LTc.

Metabolic Intensity. An elevated basal metabolic intensity and not simply an acute metabolic response is indicative of metabolic adaptation to cold (Smith et al., 1972). Furthermore, with cold adaptation there is a higher potential summit metabolism (Jansky, 1971). Cold adapted animals therefore survive and apparently suffer less in extreme cold than similar nonadapted animals (Dill, 1964; Jansky, 1971; Smith et al., 1972). The ability of sheep and cattle to withstand increasingly colder temperatures without shivering as winter progresses or during prolonged cold exposure in controlled temperature chambers is evidence of adaptation (Sykes and Sleet, 1969; Webster et al., 1969; Sleet, 1972; Young, 1975b; Gonyou et al., 1979). However, the relative contribution of increased thermal insulation and increased basal metabolic intensity is uncertain in presently available studies showing reduced dependence on shivering thermogenesis.

The idea of a static zone of thermoneutrality (figure 2) comes under question in light of the above evidence of a shift in basal metabolic intensity with an animal’s adaptation to a particular thermal environment. This situation can be resolved by restricting the definition of thermoneutrality to immediately induced metabolic responses of animals to changes in the thermal environment. Thus, two forms of cold-induced metabolic responses by animals are recognized: (1) an acute metabolic response that compensates directly for an increased rate of loss of body heat to the environment and (1) a chronic adaptive basal metabolic response. Measures of the latter are achieved in studies where an
animal is initially exposed to a thermal environment for an extended period and then, during short-term tests, measurements are made of metabolic rate when there is no direct or immediate thermal stress on the animal. This has usually meant conducting the test measurements over a range of temperatures to determine the condition of minimal or no direct or immediate thermal influence. Such studies on ruminants are difficult and time consuming. Consequently, few have been done. In 1967, Slee and Sykes deduced, on the basis of changes in heart rate, an increase in the resting metabolic intensity in sheep as a consequence of prolonged prior exposure to cold. Subsequent calorimetric measurements on sheep (Webster et al., 1969), growing cattle (Webster et al., 1970) and adult cattle (Young, 1975b,c) have confirmed the deduction of Slee and Sykes (1967) and have documented increases in resting, and presumably, basal metabolism of up to 40% after prolonged cold exposure.

From the limited data available Young and Degen (1981) calculated that resting metabolic rates of cattle increased by approximately .69 kcal/kg·°C for each 1 °C decrease in mean ambient temperature. Alternatively the change in metabolic intensity with thermal adaption can be expressed as a .91% increase in maintenance energy requirement for each degree below 20 °C to which cattle have been adapted (NRC, 1981).

Appetite and Feed Value. The influence of thermal environment on the appetite of animals is well recognized (Baile and Forbes, 1974; NRC, 1981). Cold usually stimulates appetite and the increase has been assumed to reflect the increase in the metabolic demands of the animal. Recent research indicates that when ruminants are exposed to cold there is also an increase in rumination activity, reticulorumen motility and rate of passage of digesta as well as a reduction in the volume of the reticulorumen (Westra and Christopherson, 1976; Kennedy et al., 1976, 1977; Gonyou et al., 1979). A consequence of these digestive changes is a reduction in digestion in the reticulorumen, particularly with roughage feeds (Young and Degen, 1981; NRC 1981), associated with an increased rate of passage of digesta (Kennedy et al., 1982). However, tests with concentrate diets have indicated little or no decrease in digestibility presumably because they are not markedly influenced by rate of passage (Young and Degen, 1981; Kennedy et al., 1982).

Adjustments for the effect of thermal environment on the digestibility of roughage feeds has been suggested by NRC (1981). For example, for the energy components of roughages given to cattle the following formula can be utilized:

\[ A = B + B \cdot 0.0010 (T-20) \]

where A is the adjusted energy value, B is the unadjusted value and T is the average effective ambient temperature (°C) to which the animal is exposed. The thermal influence on diet digestibility may be slightly greater for sheep than for cattle (NRC, 1981; Young and Degen, 1981).

While an increase in rate of passage may decrease the biological value of feedstuffs because of reduced digestibility, there is an associated increased appetite. In situations of abundant food supply, an animal may benefit more from the increase in appetite than the loss from the reduced ability to digest feed.

Practical Consequences

Ruminant animals may be subjected to cold stress because of their geographic location, season or fluctuations in weather conditions. The cold stress may have a direct influence requiring an immediate response or cause adaptive changes. The practical importance of the cold-induced changes are illustrated in two examples.

Pregnant Beef Cow. Beef cows are usually fed over winter to maintain live weight or fed at slightly submaintenance levels resulting in a slight loss in live weight. Consequently they are more susceptible to cold stress than if they were fed at a higher level. Canadian researchers reported that feed requirements for overwintering beef cows are elevated by 30 to 70% due to adverse winter conditions (Jordan et al., 1968; Hironaka and Peters, 1969; Young and Berg, 1970; Lister et al., 1972). Estimates of the components causing the increased nutrient requirement in relation to the effective ambient temperature based on NRC (1981) guidelines, produce similar conclusions to those observed under field conditions. Of course, any increased requirement can be met by the cow either ingesting greater amounts of feed as the conditions become colder or, if feed is not available, drawing on body reserves.

The increased winter requirement for the
beef cow can be assigned primarily to decreased digestion and increased maintenance functions. Pregnancy, development of the conceptus and subsequently the calf, are not detrimentally affected by cold stress (Wiltbank et al., 1962; Jordan et al., 1968; Hironaka and Peters, 1969). If, however, too much reliance is placed on using body energy reserves where feeding level is insufficient or protein is deficient, complications such as the weak calf syndrome (Bull et al., 1978) may arise. Furthermore, if reduced severely in body condition, cows may have reduced lactation potential and may experience delays in rebreeding (Wiltbank et al., 1962).

Feedlot Steer. Data from research institute feedlots in Canada and the U.S. showed satisfactory feedlot gains and feed-to-gain conversion ratios over a wide range in climatic conditions (Young, 1980). However, within feedlots there were differences between winter and summer performance. Elam (1971) reported a 14 to 20% lower feed-to-gain ratio by feedlot cattle during winter than during summer in large commercial feedlots in Southern California and in the Midwestern states. Similarly, data from Milligan and Christison (1974) from the University of Saskatchewan and Knox and Handley (1973) and D. E. Johnson (personal communication; figure 3) from Northern Colorado feedlots showed marked seasonal fluctuation in the performance of grain-fed cattle. Regression equations relating thermal-stress indices to performance of cattle in commercial and semicommercial feedlots indicate that much of the variation can be accounted for by climatic variables (Handley, 1971; Petritz, 1972; Knox and Handley, 1973; Milligan and Christison, 1974; Johnson and Crowner, 1975; Ames et al., 1975). These data illustrate the substantial influence of the thermal environment on feedlot cattle at effective ambient temperatures well above their estimated $LT_c$ (Webster et al., 1970; Young and Christopherson, 1974; NRC, 1981) and support the argument of the importance of reduced digestive function and increased basal metabolic intensity as factors influencing the efficiency of ruminant production systems.

Conclusions

The animal's adaptive responses to protect itself from the unpleasantness of cold exposure and the farmer's desire for a nutritional efficient production system are not consistent. The cold-adapted animal with its improved thermal insulation, increased appetite, elevated basal metabolic intensity and reduced capacity to digest feed, is at an advantage in unpredictable cold climates. Advantage, however, does not come without cost because there is an increase in the maintenance feed requirement. The increased requirement is present while the animal remains in a cold adapted state even if the weather conditions are temporarily mild and may be looked upon as insurance premium paid for the protection against the risk of calamitous weather situations.

Literature Cited


