HEAT STRESS AS IT AFFECTS ANIMAL PRODUCTION[1]

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Summary

It is well documented that the stress of hot environments lowers productive and reproductive efficiency in farm animals. Likewise, research information is available to aid in the management of livestock in such adverse conditions. However, practical methods to achieve the desired levels of productive and reproductive performance are lacking. Summer forages that will support a high level of productivity in subtropic and tropic regions are needed for ruminants. More critical information is needed on the total dietary needs of all farm animals in hot environments. Dietary emphasis should be to increase intake or to alter levels of proteins, amino acids or other nutrients to improve the conversion of feed units into production units. Increasing nutrient intake to support a higher level of production will render animals more sensitive, in terms of productive efficiency, to environmental modifications that improve comfort. This should be especially pertinent in the humid Southeast and other regions where production responses to environmental modifications have been variable. There is limited information on the effect of the night cooling cycle on productive efficiency and on the effect of severe heat stress on reproductive phenomena not related to conception.

(**Key Words:** Heat Stress, Milk Production, Reproduction, Forage Quality, Modified Environments, Thermoregulation.)

Introduction

On the basis of reviews written over the last 20 years (Bond *et al.*, 1958; Johnston, 1958; Ulberg, 1958; Warwick, 1958; Yeck and Stewart, 1959; Bianca, 1965; Johnson, 1965; McDowell, 1966; Bond, 1969; Vincent, 1972; Stewart, 1973; Thatcher, 1974) and books written by Brody (1945), Hafez (1968), Esmay (1969) and McDowell (1972), the conclusion that high environmental temperature reduces productive and reproductive efficiency of livestock seems well justified. Also, through studies in controlled-environmental chambers, upper critical temperatures have been established for a number of production traits; these temperatures fall between 24 and 27 C for most traits and most species. Upper critical temperatures will vary depending on several factors, including degree of acclimatization, rate of production (growth or lactation), pregnancy status, air movement around the animals and relative humidity.

Studies in controlled-environment chambers have been valuable in establishing the basic parameters of stress. However, application of such information to field situations is often difficult. With diurnal variation in ambient temperature and relative humidity, with difficulty in controlling other aspects of the animal's environment and with possible intrinsic compensatory mechanisms involved, apparent inconsistent responses to summer stress are not uncommon. The most useful information relating to animals in natural environments has been gained by the application of simple modifications that reduce heat gain and(or) facilitate heat loss.

This paper is not intended as a comprehensive review of all work previously published on the topic at hand. Rather, it is my intent to focus on some specific areas pertaining to the heat-stressed animal in a natural environment that warrant research attention.

Thermoregulation as Affected by Nutrition and Modified Environments

Heat Gain and Heat Loss. Simply defined, thermoregulation is the means by which an animal maintains its body temperature (figure 1). It involves a balance between heat gain and

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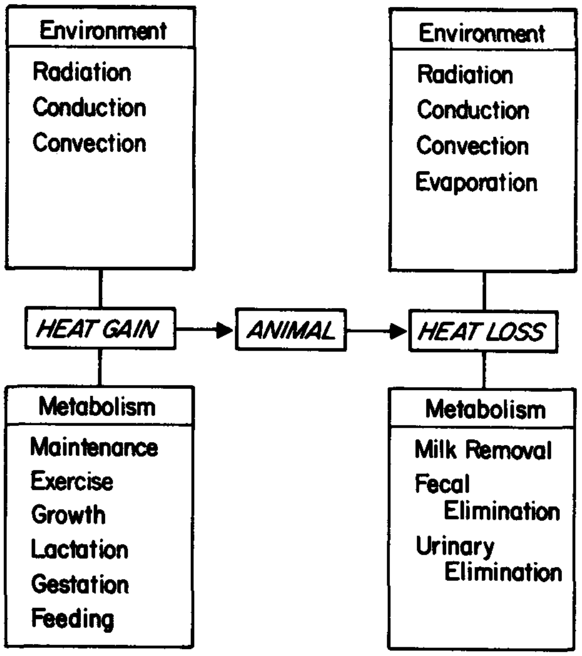

Figure 1. Increments of heat gain and heat loss, which are balanced to constitute thermoregulation in an animal.

heat loss. Metabolic heat includes that necessary for maintenance plus increments for exercise, growth, lactation, gestation and feeding. High rates of these activities will result in more heat gain from metabolism than will low rates. In addition to heat gained from metabolism, heat is gained from the environment. During daylight hours almost all of the heat gained from the environment comes directly or indirectly from solar radiation. Heat is gained from convection or conduction only if air temperature is higher than skin temperature or if the animal is resting against a surface hotter than its skin. Heat loss occurs through both elimination of the by-products of metabolism (feces, urine, milk) and factors of the environment. Radiation is an important avenue of heat loss whenever all or part of the surroundings are cooler than the animal's surface. It is of major importance at night when the animal radiates to the cooler sky. High humidity and clouds impede cooling by radiation. Convective and conductive heat losses are greater at cooler air temperatures and have little impact in hot environments. Evaporative heat loss occurs when the dew point temperature of the air around the animal is lower than the temperature of the evaporative surfaces of the animal (skin and respiratory passages). Increased air velocity around the animal and low humidity facilitate evaporative heat losses. As the ambient temperature rises, evaporative heat loss becomes the major avenue of heat loss because it is not dependent on the thermal gradient, as are conduction and convection.

Maintaining High Production in Hot Environments

Metabolism. Alternatives for reducing metabolic heat production and increasing metabolic heat loss without reducing production are limited. Through management the increment of metabolic heat associated with exercise can be reduced, but the impact on productive efficiency is not proven. One of the greatest challenges to researchers and those associated with animal management is to determine a means of maintaining adequate nutrient intake to support the desired production level, with both the economy and thermogenetic efficiency of the diet to be considered. Animals on a high plane of nutrition react more dramatically to hot conditions than do those on a low plane (Robinson and Lee, 1947; Yeates, 1956a). However, a high plane of nutrition is necessary for high production. Declining feed intake has been identified as a major cause of reduced milk production in dairy cows (Davis and Merilan 1960; Wayman *et al.*, 1962; Johnson and Yeck, 1964). Also, a reduction in the efficiency of converting feed energy units to production energy units during heat stress has been reported in beef heifers (McDowell, 1968) and lactating dairy cows (Wayman *et al.*, 1962; McDowell *et al.*, 1969). In the latter study, milk energy decreased about twice as much as digestible energy intake. Even with forced feeding of stressed dairy cows (32 C) through a rumen fistula, production was 10% below that of controls maintained at 18 C (Wayman *et al.*, 1962). The reduced efficiency is probably due to energy expended in ridding the body of the excess heat load by way of increased respiration and other related activities. Feed digestibility has increased with higher temperatures but is probably due to depressed intake, which results in slower rate of passage (Davis and Merilan, 1960). Improved production should be possible through altered diets that either promote higher intake or improve the biological efficiency of converting feed units into production units.

Leighton and Rupel (1956) reported that cows on a low fiber diet produced more milk and had lower rectal temperatures, respiration rates and pulse rates during midsummer than did cows on a high fiber diet. The diets were essentially equal in energy and protein and produced no differences when fed in mild weather. Stott and Moody (1960) and Breidenstein *et al.* (1960) reported similar results. Reduced milk fat percentage (Stott and Moody, 1960) and increased digestive disturbances (Branding, 1963) may result from the feeding of low fiber diets. This observation offers a seemingly practical way of improving productivity during the summer, provided that the cost of feed energy from low fiber sources can be justified and precautions are taken to prevent digestive problems.

For ruminants dependent on native forages the problem is more complex. Deinum *et al.* (1968) reported a negative relationship between ambient temperature and digestibility of forages native to northern Europe, with summer forage higher in cell walls, higher in crude fiber and lower in soluble carbohydrates than the same forages in early spring. With more rapid maturation, tropical forages tend to be of lower quality than temperate forages (Van Soest *et al.*, 1978). Tropical plants are higher in lignin, silica and cell walls, all contributing to lower digestibility, slower rate of passage and reduced intake (Moore and Mott, 1973). Thus, the higher ratio of structural to soluble components in summer forages, particularly in the tropics, contributes to the heat stress problems of ruminants that must consume them. Factors that retard plant development tend to maintain forage quality for a longer period (Van Soest *et al.*, 1978). Therefore, frequent clipping to allow ruminants to feed on new vegetative growth helps eliminate this problem. Use of rapidly growing summer annuals such as sorghum-sudan hybrids or millet should provide a good quantity of summer forage high in soluble carbohydrates, if managed properly. Digestibility drops markedly and crude fiber rises with stem formation (Deinum *et al.*, 1968). Other alternatives involve the use of stored forage such as corn silage or alfalfa hay. All of these are expensive to maintain. No perennial grasses recommended for tropic and subtropic regions will support a high level of performance during the summer. In addition, the high level of structural components adds to the rumen heat of fermentation compounding heat stress problems.

Management of the feeding of forages must be considered for ruminants. Lactating dairy cows do three-fourths of their grazing at night during the summer (Johnston, 1958). Hutson *et al.* (1971) observed a similar trend for cows given free access to sorghum-sudan greenchop, with a 50% higher dry matter intake at night even though the feeding area was shaded (table 1). Concentrate intake did not differ between morning and evening when concentrate was fed in equal portions to supply 60% of the cows' calculated energy needs. Supplementing night grazing with silage or greenchop has improved performance of cattle, presumably because of reduced exposure to solar radiation (McDowell, 1966). Other factors that could be related to the improved performance observed in the latter report include increased intake, because of accessibility of the greenchop or silage to shaded areas, and the reduced energy requirement compared with that for grazing activity. Reid *et al.* (1958) reported that energy expenditures by grazing cattle resulted in maintenance requirements 40 to 50% higher than those of cows confined to and fed in a barn. Increased heat production from grazing activity would contribute to the total heat load on the animal. However, increases in rectal temperature and respiration rate from forced activity appeared to be short-lived (Graf and Peterson, 1953) and without effect on appetite (Hutson *et al.*, 1971). Thermal load of grazing activity might be offset by the lower fiber intake of cattle selectively grazing the vegetative portion of plants as opposed to greenchop composed of both vegetative and stem portions. It can be concluded that summer forages for ruminants should be of high quality, accessible and abundant enough to ensure free choice intake both day and night.

While much of the previous work on nutritional management during summer stress has emphasized meeting energy needs with

TABLE 1. DIURNAL VARIATION IN DRY MATTER INTAKE PER COW DURING THE SUMMER (KILOGRAMS)[a]

Source	AM feeding	PM feeding
Greenchop	2.9	4.4 ($P<.01$)
Concentrate	4.4	4.3 (NS)

[a]Taken from Hutson *et al.* (1971).

thermogenetically more efficient feeds, other aspects of animal diets need to be considered. Dairy cows have responded with increased milk production to increments of dietary crude protein ranging from 10.7 to 15.5% (Thomas, 1971; Gardner and Park, 1973). If appetite is depressed by high ambient temperature, it seems logical that there would be a milk production response to higher ratios of dietary protein even though the heat increment of protein is comparatively high. There is evidence for increased protein demand during heat stress. Joshi *et al.* (1968) observed an increased loss of nitrogen compounds through skin secretions in cattle. The apparent need for additional dietary protein is further indicated by a reduction in milk protein (Regan and Richardson, 1938; Moody *et al.*, 1967). Kamal and Johnson (1970) reported that acute heat stress for 3 days caused catabolism of body protein in mature Holstein cows, as indicated by decreases in body weight, nitrogen retention and whole body potassium. If similar catabolism occurs in cows in natural environments, this could account for the reported reductions in milk protein, and an increase in dietary protein should be beneficial.

Combs (1965) reported that the requirement for amino acids increased with a rise in ambient temperature in laying hens. Likewise, there has been a tendency for the maintenance protein requirement for lambs to increase during heat stress (Brink and Ames, 1978). Studies of this nature with swine are lacking. Hassan *et al.* (1972) observed both increased feed intake and milk production when comparing Holstein cows in a hot environment on a 21% crude protein diet with others on a 14% diet. Leighton and Rupel (1960) observed no significant difference in milk production between cows fed high and low protein diets, but they noted a trend in favor of the cows on the high protein diet, during a summer study. Additional research is needed on the protein and amino acid requirements of ruminant and monogastric animals during heat stress.

Maximizing water intake should facilitate heat loss to metabolism through increased water turnover. Also, feed intake has been closely linked to water intake among ruminants in arid regions (Macfarlane, 1965). Increased water consumption, water loss through evaporative surfaces, urine volume and decreased fecal water loss are characteristic of cattle encountering heat stress (McDowell *et al.*, 1964, 1969). The increased water consumption may be modulated by declining milk production in lactating cows (Johnson and Yeck, 1964). The provision of cooled water has improved rate of gain in beef cattle (Kelly *et al.*, 1955) and milk production in dairy cows (Ingraham, 1968). The improved productive efficiency is probably due to higher feed intake. Cold water in the rumen has increased intake by 24% as well as lowering both rectal and tympanic membrane temperatures (Bhattacharya and Warner, 1968). Conversely, heating of the rumen with a heating coil has depressed feed intake by 15% (Gengler *et al.*, 1970). The effect of rumen temperature on the appetite of ruminants may be indirect through its influence on the entire organism. It is likely that cold water in the rumen reduces the temperature of the blood passing through the hypothalamus since it reduces both rectal and tympanic membrane temperatures. Therefore, this effect lends support to the concept of a thermostatic mechanism for the regulation of feed intake (Brobeck, 1948, 1960).

Environment. Both heat gain and heat loss occur through radiation, conduction and convection. During the summer there is usually a net heat gain from radiation in the daytime and a net heat loss from radiation at night with the animal radiating to the cooler sky. Summer facilities for animals should be planned to give maximum protection from direct solar radiation during the day, yet to permit maximum cooling by radiation at night. At normal summer temperatures there is little heat gain or loss from either conduction or convection. At high ambient temperatures during the day, most heat loss occurs through evaporative cooling (Yeck and Stewart, 1959).

The basic modification for protecting animals from heat stress during the day is the simple shade (or radiation shield). Studies on the use of shades for beef cattle in southern California, which showed both improved rate of gain and improved feed efficiency (Ittner and Kelly, 1951) and on shades for dairy cows in Louisiana (Guthrie *et al.*, 1967) and Georgia (Johnson *et al.*, 1962), which did not affect milk production, led many to conclude that the use of radiation shields does not help the performance of cattle in the humid Southeast. A more reasonable conclusion would seem to be that response of cattle to shades has been less predictable in regions where high humidity is a factor. Rate of gain in beef cattle was increased by both artificial and natural shades in Louisiana (McDaniel and Roark, 1956), but artificial shades were of no benefit in Georgia (McCormick *et al.,* 1958). Shades did not alter milk production by dairy cows in Texas (Harris *et al.,* 1960) or Oklahoma (Nelson *et al.,* 1961). More recently, in Florida, the use of sheet metal shade that was painted white on top and insulated on the underside with insulation board resulted in a 10.7% increase in milk production by dairy cows over that by controls with no access to shade (Roman-Ponce *et al.,* 1977). The modifications made to this shade structure probably contributed to the more dramatic response in this experiment than in earlier shade studies involving lactating dairy cows in the Southeast. The efficiency of metal roofs as radiation shields has been improved by painting the topside white and underside black (Bond *et al.,* 1958), by insulation (Daniel *et al.,* 1973) and by sprinkling with water (Brown *et al.,* 1973). It is likely that factors other than shade modification also were involved in the milk production response seen in Florida.

Responses to cooled shades have varied. Summer air conditioning has generally been beneficial to the lactating dairy cows (Stewart *et al.,* 1966; Hahn *et al.,* 1969; Thatcher *et al.,* 1974) but the cost makes it impractical. The use of evaporative coolers has improved production in lactating dairy cows and has been economically feasible in Arizona (Stott and Wiersma, 1974). Other responses to evaporatively cooled shades have ranged from no response in Oklahoma (Nelson *et al.,* 1961) to a variable response over three summers in Mississippi (Brown *et al.,* 1974; table 2). The potential of inspired air cooling systems has been demonstrated for lactating cows in pilot studies (Hahn *et al.,* 1965; Roussel and Beatty, 1970). Limited field studies have not demonstrated an improvement in productive efficiency (Fuquay *et al.,* 1979), and present energy costs have dulled interest in the development of improved field models for use with cattle.

TABLE 2. EFFECT OF EVAPORATIVE COOLING ON RECTAL TEMPERATURE AND MILK PRODUCTION[a]

	Rectal temperature, C		Milk production, kg	
Year	Cooled	Control	Cooled	Control
1970	39.8	40.1 (P<.01)	20.5	18.9 (P<.01)
1971	39.0	39.1 (NS)	25.4	24.4 (NS)
1972	38.8	38.9 (NS)	21.4	22.5 (NS)

[a]Taken from Brown *et al.* (1974).

Causes of Variable Response to Modified Environments

The factors related to the less consistent production response of livestock to summer modifications in the Southeast, as compared to hot, arid regions, is important. Without explanations for the cause of these inconsistencies, sound recommendations cannot be made to managers of livestock. The simple answer that radiation shields are needed less in the Southeast because clouds and atmospheric moisture sufficiently reduce solar radiation is not acceptable. Higher radiant heat loads can exist under partly cloudy skies than under clear skies (Hahn *et al.,* 1970). In studies conducted in Mississippi, comparison of simple shade with modified shade has sometimes showed improved milk production, even though the differences in ambient conditions as related to the improved environments have been less pronounced than in the "shades versus no shade" studies in other states. A combination of both animal and environmental factors may be involved in the variable response.

Animal Factors. The response of lactating cows to hot environments has been related to stage of lactation. Maust *et al.,* (1972) reported that cows in midlactation were most affected and cows in early lactation least affected. Level of milk production would be expected to affect response. For each .45 kg of milk, a 454-kg cow produces 10 kcal of metabolic heat per hour (Brody *et al.,* 1948). However, in a 3-year study comparing modified shade with simple shade in Mississippi, responses could not be related to the level of milk production at the start of each experimental period, over a range of 25.5 to 34 kg (figure 2). The response to modifications did appear to be related to maintenance of milk production at near optimum levels during the experimental period. It can be noted from figure 2 that milk production dropped markedly after the initiation of the experiments in 1973 and 1974, but not in 1975. It was in 1975 only that the use of modified shades resulted in an increase in milk production. Since the modified shades caused similar reductions in rectal temperature and respiration

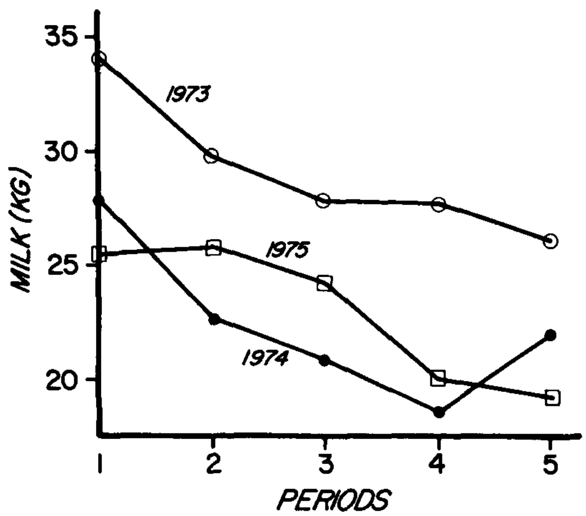

Figure 2. Period changes in milk production during the summer. Each week represents 3 weeks. Cows were confined to a freestall housing area during periods 2, 3 and 4. (From Fuquay *et al.*, 1979.)

rate during the three summers, it was concluded that the milk production response in 1975 was related to the maintenance of a more typical lactation curve (Fuquay *et al.*, 1979).

Maintenance of the more typical lactation curve in 1975 appeared to be related to nutritional management. During that summer, a wet brewers grain product was fed as a topdressing on the greenchop twice daily in the freestall area, whereas in the two earlier summers, a pelleted concentrate was fed twice daily in the milking parlor. Thus, in 1975, cows had greater access to high energy and protein feeds. Feed intakes were not available to validate this point, but it was assumed that the lactation curve in 1975 was maintained because of higher energy and protein intake. It seems likely that lactating dairy cows that are acclimatized and in dynamic equilibrium with the summer environment would be less sensitive to reduced air and black globe temperatures if metabolic heat production dropped because of reductions in milk production and(or) feed intake at the time the environmental modification was employed (Fuquay *et al.*, 1979). Lactating dairy cows on high nutrition have reacted more dramatically to hot conditions than have others on a moderate feeding regimen (Yeates, 1956a).

Environmental Factors. The severity of the daytime conditions can affect animal response to modified environments or, in research situations, the severity of the environment where the controls are maintained. Daytime temperatures are higher in the desert regions of Arizona and California than in Louisiana, Georgia or Florida. In evaporative cooling studies in Mississippi a milk production response to evaporative coolers was observed when the average midafternoon rectal temperature of the controls exceeded 40 C but not when the controls were maintained in a more moderate environment (Brown *et al.*, 1974). In the shade studies in Florida in which a significant milk production response was seen, the rectal temperatures of the controls approached 41 C during midday (Roman-Ponce *et al.*, 1977), but in Oklahoma, where there was no milk production response to shade, the average midafternoon rectal temperature of the controls was 39.1 C (Nelson *et al.*, 1961).

The length of the cooling cycle may affect animal response. This has been demonstrated by studies involving daytime cooling. Evaporative coolers in Mississippi were effective in reducing ambient temperatures only between 1000 and 2000 hr (Brown *et al.*, 1974) and the derived benefit was variable. A similar period of cooling was used in Oklahoma and no milk production response was noted (Nelson *et al.*, 1961). In Arizona, with effective cooling during all daylight hours, improved production has consistently been noted (Stott and Wiersma, 1974). With a 12-hr daytime cooling cycle, air conditioning was beneficial to lactating dairy cows in Florida (Thatcher *et al.*, 1974). Interpretation of these responses is difficult because in the studies with longer daily cooling periods the controls were probably under more severe thermal stress during the day.

The night temperature, the coolest in the diurnal temperature cycle, may affect productivity, also. This would seem to be a particular problem when high humidity reduces heat loss by radiation and evaporation. Higher rectal temperatures have been reported for dairy cows near midnight than during mid-day (Scott *et al.*, 1975; Roman-Ponce *et al.*, 1977). In their study with lactating dairy cows, Thatcher *et al.*, (1974) reported that daytime air conditioning was more beneficial than nighttime air conditioning, but less beneficial than 24-hr air conditioning. A positive response to nighttime cooling (1930 to 0530 hr) was seen.

Indirect evidence of a more dominant effect of nighttime temperature than daytime temperature on lactating dairy cows has been observed in Mississippi (Fuquay *et al.*, 1974, 1975, 1979; Clemmer, 1977). Because of the interest of some groups in the use of blood plasma profiles for determining the health and nutritional status of dairy herds, blood samples were drawn at 3-week intervals during the freestall modifications experiments mentioned previously to assess the effects of altered environments on the constituents. Five samples were drawn during each of three summers, at 1500 hr during the first summer and at 0800 hr the last two. Whether drawn at 1500 hr or 0800 hr, many blood constituents varied significantly among sampling days. To identify causes of this variation, correlations were run between maximum ambient temperature on the day of sampling (approximately 1400 hr) with specific blood constituents and minimum ambient temperature (at approximately 0600 hr) with these constituents. It should be noted that similar temperatures were usually found for the 2- to 3-day period before sampling. During all three summers, varying levels of calcium and inorganic phosphorus were correlated with minimum temperature, but not maximum temperature, on the day of sampling. During some summers protein, cholesterol, sodium and potassium were more highly correlated with varying minimum temperature than with maximum temperature. Similar responses were seen for both 0800– hr sampling and 1500–hr sampling. This does not explain the physiology involved, but does suggest a more dominant effect for minimum than maximum ambient temperature on those physiological systems related to plasma levels of these constituents. Additonal research on the effect of the nighttime cooling cycle on animal productivity is needed.

Air movement around the cows must be considered. Seath and Miller (1948) reported that cows that had been stressed for 2 hr in direct sunlight cooled more rapidly with a combination of shade and a gentle breeze produced by a fan than with shade alone. In Mississippi natural cross ventilation in a freestall shelter as compared to no cross ventilation, resulted in significantly lower rectal temperatures and respiration rates, with a nonsignificant trend toward higher milk production (Fuquay *et al.*, 1979). While not partitioned, part of the response from evaporative coolers in Arizona was probably due to increased air movement around the cooled cows. Fans offer a potentially practical method for increasing animal cooling during the night by increasing heat loss at the animal surface through evaporative and convective means.

Reproduction

Most research on the effects of heat stress on reproduction has focused on its relationship to conception rate, which would include both fertilization and early embryonic mortality. McDowell (1972) stated that conception in cattle was essentially zero when the rectal temperature of the cow was 39 C. This point was presumably based on psychrometric studies. Fallon (1962) reported a lower conception rate for cows with above normal body temperatures at time of insemination than for cows with normal temperatures. Similar observations have been made for ewes (Dutt *et al.*, 1959; Ulberg and Burfening, 1967). In shade and modified shade studies in which the rectal temperature of the control cows exceeded 40 C during midafternoon, shades have improved conception rate (Roman-Ponce *et al.*, 1977; Stott and Wiersma, 1974). The most critical time appeared to be the period from insemination to a few days afterward, with less of an effect of severe heat noted after the cleaving zygote had reached the uterus in cows and sheep (Ulberg, 1958; Stott *et al.*, 1974). In a statistical study that included 21 climatological measurements, Gwazdauskas *et al.* (1975) ranked the five most important to conception as: "(1) maximum temperature day after insemination (2) rainfall day of insemination (3) minimum temperature day of insemination (4) solar radiation day of insemination and (5) minimum temperature day after insemination." As with milk production, this would seem to support a hypothesis that both reduction of heat gain during the day and facilitation of heat loss at night are important to the maintenance of optimum reproductive performance in the humid Southeast, where atmospheric mosture hinders both evaporative and radiational cooling. Reductions in semen quality of cattle that occur during the summer (Vincent, 1972) can seemingly be managed through artificial insemination. However, as indicated by studies with rabbits, short incubation at 40 C of spermatozoa, or of zygotes soon after fertilization, was detrimental to embryo survival (Alliston *et al.*, 1965; Burfening and Ulberg, 1968). In the dairy herd at Mississippi State University, there has been little difference in services per conception across seasons (Fuquay *et al.*, 1970). However, more open days were prevalent for cows bred during the summer season, apparently because of irregular or missed estrus periods. The summer herd lot at Mississippi State is a 10-ha soil area shaded with large oak trees, and it is probably less stressful than those that would be found with the large herd settings in Florida and Arizona.

Heat stress has reduced the duration and intensity of expression of estrus. Researchers in Louisiana reported that the average length of estrus was 11.9 hr, about 5 hr shorter than in temperate regions (Hall *et al.*, 1959). In a later study, duration of estrus averaged 20 hr for cows maintained in cool conditions, but 11 and 14 hr for "hot" cows in a psychrometric chamber and natural summer environment, respectively (Gangwar *et al.*, 1965). Intensity of estrus was greater under cool than under hot conditions, and anestrus was a problem under hot but not under cool conditions. In a survey of reproductive records of the dairy herd at Mississippi State University, more short estrous cycles (<15 days) and long estrous cycles (>30 days) were noted during the summer than during other seasons (Fuquay *et al.*, 1970). Both intensity of estrus and endocrine dysfunction could have been involved in the observed phenomena. However, intensity of estrus resulting in missed estrus appeared to be the more serious problem.

While most researchers have concentrated on the effect of heat stress on factors related to conception, the summer season is not the major breeding season for most classes of livestock, some breeds of sheep being the exception. Stott *et al.* (1972) reported that the effects of heat stress on cattle carried over into the fall months. However, the effect of heat stress on stages of the gestation other than conception should be of more concern to livestock producers. In that animals become acclimatized to the summer environment, short periods of severe heat stress, as would occur during "heat waves," might be particularly critical. Research information on this topic is limited. When two Holstein cows in midgestation were exposed to 38 C for 27 hr, they aborted (Ragsdale *et al.*, 1948). The stress in this case was probably more severe than would occur in a natural environment. Calves born in summer have been reported to be lighter than winter born calves (Bonsma, 1949). Also, lambs from heat-stressed ewes have been reported to be smaller than lambs from control ewes maintained in a cool environment (Yeates, 1956b; Brown *et al.*, 1977). Reproductive efficiency was not affected when dairy cows were stressed by high ambient temperature for the first 10 days postpartum (Chapin *et al.*, 1976). Stress did cause a reduction in peak progesterone concentrations between 30 and 50 days postpartum and decreased the number of days to involution of the uterus. Carry-over effects of severe heat stress during late gestation on the next gestation have not been reported.

Conclusions

In reviewing heat stress affects on animal production, one must consider the entire scope of factors affecting thermoregulation in the animal. The goal is to help the animal maintain those increments of metabolic heat associated with growth, lactation and gestation. This can be accomplished to some degree through modified diets and modified environments. For optimum productivity both diet and environment must be considered. Future research needs include: (1) development of improved summer forages for ruminants that can be utilized in tropic and subtropic regions, particularly perennial grasses; (2) reassessment of diets for ruminant and monogastric animals to achieve maximum productivity during heat stress – protein and amino acid requirements and diet palatability may be fruitful; (3) determination of the effect of nighttime cooling cycle on animal productivity, particularly in humid regions; (4) evaluation of the effect of severe heat stress during middle and late gestation on fetal survival and on the next gestation; (5) development of improved models for predicting animal response to modifications employed in natural environments. Such models need to include level of production and diet as well as pertinent climatic factors. Contributions from plant breeders, nutritionists, physiologists and engineers are needed.

Literature Cited

Alliston, C. W., B. Howarth and L. C. Ulberg. 1965. Embryonic mortality following culture *in vitro* of one and two-cell rabbit eggs at elevated temperatures. J. Reprod. Fertil. 9:337.

Bhattacharya, A. N. and R. G. Warner. 1968. Influence of rumen temperature on central cooling or warming and on the regulation of voluntary feed intake in dairy cattle. J. Dairy Sci. 51:1481.

Bianca, W. 1965. Reviews of the progress of dairy science. Section A. Physiology. Cattle in a hot environment. J. Dairy Res. 32:291.

Bond, T. E. 1969. Livestock environment research review. Annu. Meet. of the ASAE, Pacific Coast Region, Phoenix, AR.

Bond, T. E., C. F. Kelly and H. Heitman, Jr. 1958. Improved livestock environment in high temperature areas. J. Hered. 49:75.

Bonsma, J. C. 1949. Breeding cattle for increased adaptability to tropical and subtropical environments. J. Agr. Sci. (Camb.) 39:204.

Branding, A. E. 1963. Physiological effects of low levels of fiber in the diet of lactating cows on a high plane of nutrition. M. S. Thesis. The Pennsylvania State Univ., University Park.

Breidenstein, C. P., J. E. Johnston, G. A. Hindrey and L. L. Rusoff. 1960. Effect of fiber content of the ration on the performance of dairy cows under hot and cool conditions. J. Dairy Sci. 43:443. (Abstr).

Brink, D. R. and D. R. Ames. 1978. Effect of thermal stress on protein for maintenance. J. Anim. Sci. 47 (Suppl. 1):407.

Brobeck, J. R. 1948. Food intake as a mechanism of temperature regulation. Yale J. Biol. Med. 20:545.

Brobeck, J. R. 1960. Food and temperature. Recent Progr. in Horm. Res. 16:439.

Brody, S. 1945. Bioenergetics and Growth. Reinhold Publishing Corp., New York.

Brody, S., D. M. Worstell, A. C. Ragsdale and H. H. Kibler. 1948. Growth and development with special reference to domestic animals. LXV. Heat production and cardiorespiratory activities during gestation and lactation in Holstein cattle. Missouri Agr. Exp. Sta. Res. Bull. 424.

Brown, D. E., P. C. Harrison, F. C. Hinds, J. A. Lewis and M. H. Wallace. 1977. Heat stress affects on fetal development during late gestation in the ewe. J. Anim. Sci. 44:442.

Brown, W. H., J. W. Fuquay, W. H. McGee and S. S. Iyengar. 1974. Evaporative cooling for Mississippi dairy cows. Trans. ASAE 17:513.

Brown, W. H., S. S. Iyengar and J. W. Fuquay. 1973. Air and radiant temperature reduction by roof sprinkling in animal shelters. Proc. 70th Annu. Conv., Soc. Agr. Workers, Inc., p. 33 (Abstr.).

Burfening, P. J. and L. C. Ulberg. 1968. Embryonic survival subsequent to culture of rabbit spermatozoa at 38 and 40°C. J. Reprod. Fertil. 15:87.

Chapin, L. T., J. W. Fuquay and W. H. Brown. 1976. Effect of short term chronic heat stress on progesterone and early postpartum events in dairy cows. Proc. 71st Annu. Meet. ADSA, p. 143 (Abstr.).

Clemmer, R. M. 1977. Effect of modified summer environment on the physiological response of lactating dairy cows. III. Blood minerals. M.S. Thesis. Mississippi State Univ., Mississippi State.

Combs, G. F. 1965. Studies of protein and amino acid needs of poultry. Proc. 18th Annu. North Carolina Anim. Nutr. Conf., p. 7.

Daniel, J. W., J. W. Fuquay, W. H. McGee, W. H. Brown and J. T. Cardwell. 1973. Roof insulation in a freestall barn for lactating cows during the summer. J. Dairy Sci. 56:306 (Abstr.).

Davis, A. V. and C. P. Merilan. 1960. Effect of constant environmental temperature and relative humidity on feed digestion by lactating Holstein cows. J. Dairy Sci. 43:871.

Deinum, B., A.J.H. van Es and P. J. Van Soest. 1968. Climate, nitrogen and grass. II. The influence of light intensity, temperature and nitrogen on *in vivo* digestibility of grass and the prediction of these effects from some chemical procedures. Netherlands J. Agr. Sci. 16:217.

Dutt, R. H., E. F. Ellington and W. W. Carlton. 1959. Fertilization rate and early embryo survival in sheared and unsheared ewes following exposure to elevated air temperatures. J. Anim. Sci. 18:1308.

Esmay, M. L. 1969. Principals of Animal Environment. AVI Pub. Co., Inc., Westport, CT.

Fallon, G. R. 1962. Body temperature and fertilization in the cow. J. Reprod. Fertil. 3:116.

Fuquay, J. W., W. H. McGee and F. M. Hutson. 1970. Seasonal effect on reproductive performance in dairy cattle. Mississippi Farm Res. 33:8.

Fuquay, J. W., W. E. Poe and W. H. Brown. 1974. Effect of summer confinement on blood plasma in lactating Holstein cows. J. Dairy Sci. 57:609 (Abstr.).

Fuquay, J. W., A. B. Zook, J. W. Daniel, W. H. Brown and W. E. Poe. 1979. Modifications in freestall housing for dairy cows during the summer. J. Dairy Sci. 62:577.

Fuquay, J. W., A. B. Zook, W. E. Poe, W. H. Brown and L. T. Chapin. 1975. Summer fluctuation in bovine plasma constituents. J. Anim. Sci. 41:268 (Abstr.).

Gangwar, P. C., C. Branton and D. L. Evans. 1965. Reproductive and physiological response of Holstein heifers to controlled and natural climatic conditions. J. Dairy Sci. 48:222.

Gardner, R. W. and R. L. Park. 1973. Protein requirements of cows fed high concentrate rations. J. Dairy Sci. 56:390.

Gengler, W. R., F. A. Martz and H. D. Johnson. 1970. Effect of temperature on food and water intake and rumen fermentation. J. Dairy Sci. 53:434.

Graf, G. C. and W. E. Peterson. 1953. Changes in respiration and heart rates, body temperature, lactic acid levels and plasma creatinine levels caused by stress in dairy cows. J. Dairy Sci. 36:1036.

Guthrie, L. D., J. E. Johnston, J. Rainey and J. A. Lee. 1967. Effects of solar radiation and levels of fiber on production and composition of Holstein cows milk. J. Dairy Sci. 50:608 (Abstr.).

Gwazdauskas, F. C., C. J. Wilcox and W. W. Thatcher. 1975. Environmental and managemental factors affecting conception rate in a subtropical climate. J. Dairy Sci. 58:88.

Hafez, E.S.E. 1968. Adaptation of Domestic Animals. Lea & Febiger, Philadelphia, PA.

Hahn, G. L., H. D. Johnson, M. D. Shanklin and H. H. Kibler. 1965. Inspired air cooling for lactating cows in a hot environment. Trans. ASAE 8:332.

Hahn, G. L., J. D. McQuigg and W. L. Decker. 1970. Cloud cover implications for animal and plant shelter design. Trans. ASAE, Paper No. 70–826, ASAE Winter Meeting, December 1970.

Hahn, G. L., J. D. Sikes, M. D. Shanklin and H. D.

Johnson. 1969. Dairy cow responses to summer air conditioning as evaluated by switchback experimental design. Trans. ASAE 12:202.

Hall, J. G., C. Branton and E. J. Stone. 1959. Estrus, estrous cycles, ovulation time, time of service and fertility of dairy cattle in Louisiana. J. Dairy Sci. 42:1086.

Harris, D. L., R. R. Shrode, I. W. Rupel and R. E. Leighton. 1960. A study of solar radiation as related to physiological and production responses of lactating Holstein and Jersey cows. J. Dairy Sci. 43:1255.

Hassan, A. A., J. D. Roussel and L. F. Gomila. 1972. Effect of protein on the productivity of dairy cattle in hot environments. J. Dairy Sci. 55:396 (Abstr.).

Hutson, F. M., J. W. Fuquay, J. T. Cardwell and W. H. Brown. 1971. Influence of activity on the comfort and performance of lactating cows during hot, humid weather. J. Dairy Sci. 54:459 (Abstr.).

Ingraham, R. H. 1968. Milk production and rectal temperature response of Holstein cattle to cooled drinking water in a subtropical climate. M. S. Thesis. Iowa State Univ., Ames.

Ittner, N. R. and C. F. Kelly. 1951. Cattle shades. J. Anim. Sci. 10:184.

Johnson, H. D. 1965. Environmental temperature and lactation. International J. Biom. 9:103.

Johnson, H. D. and R. G. Yeck. 1964. Environmental physiology and shelter engineering. LXVIII. Age temperature effects on TDN, water consumption and balance of dairy calves and heifers exposed to environmental temperatures of 35 to 95 F. Missouri Agr. Exp. Sta. Res. Bull. 865.

Johnson, J. C., B. L. Southwell, R. L. Givens and R. E. McDowell. 1962. Interrelationships of certain climatic conditions and productive responses of lactating dairy cows. J. Dairy Sci. 45:695 (Abstr.).

Johnston, J. E. 1958. The effects of high temperatures on milk production. J. Hered. 49:65.

Joshi, B. C., H. B. Joshi, R. E. McDowell and D. P. Sadhu. 1968. Composition of skin secretions of three Indian breeds of cattle under thermal stress. J. Dairy Sci. 51:917.

Kamal, T. H. and H. D. Johnson. 1970. Whole body ^{40}K loss as a predictor of heat tolerance in cattle. J. Dairy Sci. 53:1734.

Kelly, C. F., T. E. Bond and N. R. Ittner. 1955. Water cooling for livestock in hot climates. Agr. Eng. 36:173.

Leighton, R. E. and I. W. Rupel. 1956. Effects of fiber content of the ration on milk production and hot weather discomfort of producing dairy cows. J. Dairy Sci. 39:937. (Abstr.)

Leighton, R. E. and I. W. Rupel. 1960. Effects of protein content of the ration on hot weather performance of producing dairy cows. J. Dairy Sci. 43:443 (Abstr.).

Macfarlane, W. V. 1965. Water metabolism of desert ruminants. *In* Studies in Physiology. Springer Verlag, New York.

Maust, L. E., R. E. McDowell and N. W. Hooven. 1972. Effect of summer weather on performance of Holstein cows in three stages of lactation. J. Dairy Sci. 55:1133.

McCormick, W. C., R. L. Givens and B.L. Southwell. 1958. Proc. Soc. Agr. Workers. (As reported by Warwick, 1958.).

McDaniel, A. H. and C. B. Roark. 1956. Performance and grazing habits of Hereford and Aberdeen-Angus cows and calves on improved pastures as related to types of shades. J. Anim. Sci. 15:59.

McDowell, R. E. 1966. The role of physiology in animal production for tropical and sub-tropical areas. World Rev. Anim. Prod. 1:39.

McDowell, R. E. 1968. Climate *versus* man and his animals. Nature 218:614.

McDowell, R. E. 1972. Improvement of Livestock Production in Warm Climates. W. H. Freeman and Co., San Francisco, CA.

McDowell, R. E., G. L. Ford, E. G. Moody and P. J. Van Soest. 1964. Physiological response of lactating cows fed dietary fats at high temperatures. J. Dairy Sci. 47:692.

McDowell, R. E., E. G. Moody, P. J. Van Soest, R. P. Lehman and G. L. Ford. 1969. Effect of heat stress on energy and water utilization of lactating cows. J. Dairy Sci. 52:188.

Moody, E. G., P. J. Van Soest, R. E. McDowell and G. L. Ford. 1967. Effect of high temperature and dietary fat on performance of lactating cows. J. Dairy Sci. 50:1909.

Moore, J. E. and G. O. Mott. 1973. Structural inhibitors of quality in tropical grasses. *In* Anti-Quality Components of Forages. Crop Sci. Soc. Amer., Spec. Publ. No. 4, Chapt. 4.

Nelson, G. L., G. W.A. Mahoney and E. R. Berouseh. 1961. Hot weather shelter for lactating dairy cattle. Oklahoma State Univ. Tech. Bull. T-87.

Ragsdale, A. C., S. Brody, H. J. Thompson and D. M. Worstell. 1948. Environmental physiology with special reference to domestic animals. II. Influence of temperature 50 to 105°F on milk production and feed consumption in dairy cattle. Missouri Agr. Exp. Sta. Res. Bull. 425.

Regan, W. M. and G. A. Richardson. 1938. Reactions of the dairy cow to changes in environmental temperature. J. Dairy Sci. 21:73.

Reid, J. T., A. M. Smith and M. J. Anderson. 1958. Differences in the requirements for maintenance of dairy cattle between pasture and barn feeding conditions. Proc. Cornell Nutr. Conf., p. 88.

Robinson, K. W. and D.H.K. Lee. 1947. The effect of nutritional plane upon reactions of animals to heat. J. Anim. Sci. 6:182.

Roman-Ponce, H., W. W. Thatcher, D. E. Buffington, C. J. Wilcox and H. H. Van Horn. 1977. Physiological and production responses of dairy cattle to a shade structure in a tropical environment. J. Dairy Sci. 60:424.

Roussel, J. D. and J. F. Beatty. 1970. Influence of zone cooling on performance of cows lactating during stressful summer conditions. J. Dairy Sci. 53:1085.

Scott, I. M., H. D. Johnson and L. Hahn. 1975. Physiological response of Holstein cows to patterns of diurnally-imposed heat stress. J. Dairy Sci. 58:777 (Abstr.).

Seath, D. M. and Miller, G. D. 1948. Effect of water sprinkling with and without air movement on cooling dairy cows. J. Dairy Sci. 31:361.

Stewart, R. E. 1973. Environmental research in cattle since 1968. Proc. 1973 Annu. Meet. of the ASAE, Univ. of Kentucky, Lexington, Proc. No. 73–415.

Stewart, R. E., J. C. Notestine, D. L. Pfost and W. R. Schnug. 1966. Field test of summer air conditioning for dairy cattle in Ohio. ASHRAE Trans. 7:271.

Stott, G. H. and E. G. Moody. 1960. Tolerance of dairy cows on low roughage ration. J. Dairy Sci. 43:871 (Abstr).

Stott, G. H. and F. Wiersma. 1974. Response of dairy cattle to an evaporative cooled environment. Proc. Internat'l Livestock Environment Symp., ASAE SP-0174:88.

Stott, G. H., F. Wiersma and J. M. Woods. 1972. Reproductive health program for cattle subjected to high environmental temperatures. J. Amer. Vet. Med. Assoc. 161:1339.

Thatcher, W. W. 1974. Effects of season, climate and temperature on reproduction and lactation. J. Dairy Sci. 57:360.

Thatcher, W. W., F. C. Gwazdauskas, C. J. Wilcox, J. Toms, H. H. Head, D. E. Buffington and W. B. Fredriksson. 1974. Milk performance and reproductive efficiency of dairy cows in environmentally controlled structure. J. Dairy Sci. 57:304.

Thomas, J. W. 1971. Protein requirements of milking cows. J. Dairy Sci. 54:1629.

Ulberg, L. C. 1958. The influence of high temperature on reproduction. J. Hered. 49:62.

Ulberg, L. C. and P. J. Burfening. 1967. Embryo death resulting from adverse environment on spermatozoa or ova. J. Anim. Sci. 26:571.

Van Soest, P. J., D. R. Mertens and B. Deinum. 1978. Preharvest factors influencing quality of conserved forage. J. Anim. Sci. 47:712.

Vincent, C. K. 1972. Effect of season and high environmental temperature on fertility in cattle. J. Amer. Vet. Med. Assoc. 161: 1333.

Warwick, E. J. 1958. Effects of high temperatures on growth and fattening in beef cattle, hogs and sheep. J. Hered. 49:69.

Wayman, O., H. D. Johnson, C. P. Merilan and I. L. Berry. 1962. Effect of *ad libitum* or force feeding of two rations on lactating dairy cows subject to temperature stress. J. Dairy Sci. 45:1472.

Yeates, N.T.M. 1956a. The influence of nutritional state on heat tolerance of cattle. Nature: 178:702.

Yeates, N.T.M. 1956b. The effect of high ambient temperature on pregnancy and birth weight in merino sheep. Australian J. Agr. Res. 7:435.

Yeck, R. G. and R. E. Stewart. 1959. A ten year summary of psychro-energetic laboratory dairy cattle research at the University of Missouri. Trans. ASAE 2:71.