Chapter 7
Response of Domestic Animals to Climate Challenges

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The climatic niche for an animal is predicted in terms of the temperature extremes it can endure.

Folk 1974, p. 4

Abstract The livestock sector is socially, culturally and politically very significant. It accounts for 40% of the world's agriculture Gross Domestic Product (GDP). It employs 1.3 billion people, and creates livelihoods for one billion of the world's population living in poverty. Climate change is seen as a major threat to the survival of many species, ecosystems and the financial sustainability of livestock production systems in many parts of the world. The potential problems are even greater in developing countries. Economic studies suggest severe losses if current management systems are not modified to reflect the shift in climate. In short, farmers/managers need to adapt to the changes. There has been considerable interest in gaining an understanding how domestic livestock respond to climatic stressors. Studies have for the most part been undertaken in developed countries. These studies have provided a wealth of knowledge on differences between genotypes, the impact of climatic stress on production, reproduction and health. However little is known about adaptation of animals to rapid changes in climatic

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conditions. Furthermore, little is known about the impacts of climatic stressors on many indigenous breeds used throughout Africa, Asia and South America. The uncertainty of climate change, and how changes will impact on animal production on a global scale are largely unknown.

This chapter will discuss: what is understood about animal adaptation; the current knowledge of the impacts of climate stressors on domestic animals, in terms of production, health, and nutrition; housing and management methods which can be used to alleviate heat stress; techniques used to predict animal responses to heat; and, strategies required to ensure continued viability of livestock production.

7.1 Introduction

Climate change is not a new phenomenon. In the past, animals have been subjected to major shifts in the Earths climate. Some species did not survive, while others adapted to the changes and flourished.

- The extinction of Megafauna (mammals >100 kg) around the world was probably due at least in part to environmental and ecological factors.
- The extinction was almost completed by the end of the last ice age.
- It is believed that Megafauna initially came into existence in response to glacial conditions and became extinct with the onset of warmer climates.

What are the implications for animal production today? How will climate change impact modern animal production? How will farmers and domestic animals adapt to these changes?

Climate change is seen as a major threat to the survival of many species, ecosystems (Frankham 2005; Hulme 2005; King 2004), and the viability and sustainability of livestock production systems (Hahn et al. 1990; Sombroek and Gommes 1995; Smit et al. 1996; Frank et al. 2001; Turnpenny et al. 2001). The economic impact of climate changes in relation to livestock production has been considered in several studies (Adams et al. 1990; Ray et al. 1992; Bowes and Crosson 1993; Easterling et al. 1993; Rosenweig and Parry 1994; St-Pierre et al. 2003). Most of the studies predict severe losses if current management systems are not modified to reflect the shift in climate.

7.2 Impact of Climate Change on Animal Agriculture

The livestock sector is socially, culturally and politically very significant. It accounts for 40% of the world's agriculture Gross Domestic Product (GDP). It employs 1.3 billion people, and creates livelihoods for one billion of the world's population living in poverty. Global meat production is expected to more than double from

229 to 465 million tonnes between 1999/2001 and 2050. Milk production is also expected to increase from 580 to 1,043 million tonnes over the same period. In order to achieve these increases, livestock production will intensify. Production of pigs and poultry is expected to account for much of the increase. Grazing occupies 26% of ice-free terrestrial land, and crop production for animal feed accounts for 33% of all arable land. It is estimated that livestock production accounts for 70% of all agricultural land and 30% of the total land surface (Steinfeld et al. 2006). Approximately 3.5 billion hectares are being grazed compared to 1.2–1.5 billion hectares under cropping (Howden et al. 2007).

Climate affects animal agriculture in four ways (Rötter and Van de Geijn 1999) through impacts on livestock: (1) feed-grain availability and price; (2) pastures and forage crop production and quality; (3) health, growth and reproduction; and (4) diseases and pests distributions. Adaptation of practices used by farmers to changing climatic conditions is paramount (ILRI 2006). These changes may result in a redistribution of livestock in a region; changes in the types of animals that are used (e.g., a shift from cattle to buffalo, sheep, goats or camels); genotype changes (e.g., the use of breeds that will handle adverse conditions, such as Brahman cattle); and changes in housing of animals (e.g., protective structures which have allowed the expansion of the dairy industry into areas such as southern USA, Brazil, Israel, Saudi Arabia that would not otherwise be suitable [Darwin et al. 1995]). A lack of thermally-tolerant breeds of cattle is already a major constraint on production in Africa (Voh et al. 2004). Furthermore, it is possible that conflicts over resources may become a problem (Darwin et al. 1995). However, climate change may have a positive impact on livestock production in some areas. For instance, areas that are cooler and wetter may increase forage production and, in turn, livestock production. Warming of areas such as Canada may increase in agricultural production (Arthur and Abizadeh 1988). Increased rainfalls and winter temperatures in India, Pakistan, and Bangladesh may have both positive (e.g., longer growing seasons) and negative (e.g., flooding, increased animal disease risk) effects. Changing conditions in Africa may spread trypanosomosis into previously unaffected areas. Movement of parasites into previously unaffected areas could result in large production and financial losses. Any advantages that may result from climate change could be hampered by an inability (political, social and financial) to change farming practices.

The impact of climate change (higher temperatures) on pastures and rangelands may include deterioration of pasture quality (C_3 grasses) towards lower quality tropical and subtropical C_4 grasses (Barbehenn et al. 2004) in temperate regions as a result of warmer temperatures and fewer frosts (Briske and Heitschmidt 1991; Greer et al. 2000); however, there could also exist potential increases in yield and possible expansion of C_3 grasses if climate change were favorable as a result of an increase in CO_2 (Kimball et al. 1993; McKeon et al. 1993; Idso and Idso 1994; Allen-Diaz 1996; Campbell et al. 1995; Reilly 1996), and if precipitation is favorable. An increase in CO_2 is likely to have a negative effect on C_4 grasses (Collatz et al. 1998; Christin et al. 2008) resulting in declines in pasture productivity and lower carrying capacity.

The impact of climate change on wildlife is deemed to be largely negative (Thuiller et al. 2006). However, in some instances increasing ambient temperature has had little negative impact, at least to date (Johnston and Schmitz 1997; Beaumont et al. 2006), whereas in other cases the impact is largely due to changes in vegetation (Johnston and Schmitz 1997). In some scenarios, a species may be able to extend their current range.

In the animal context, climate change needs to be viewed as more than global warming. As previously mentioned, some areas will become cooler, and this may only have minor impacts on the animals (but could alter feed availability). On the other hand, extreme events such as heat waves can have major impacts on non-adapted animals. Heat waves are recurring events in many current climates, and are projected to increase in number and intensity (Mearns et al. 1984; Gaffen and Ross 1998; IUC 2002). The risk of floods and droughts are also predicted to increase. While there may be little change *per se* in a region, extreme events may increase in both intensity and duration leading to substantial changes in animal management practices. Climatic variables which need to be assessed include: ambient temperature, relative humidity, the day to night and seasonal variations in ambient temperature, rainfall, wind speed, solar and terrestrial radiation, evaporation rates, and atmospheric CO_2 (Folk 1974; Hulme 2005). It is likely that heat and drought will be the major contributing factors to changes in animal production over the next 50 years. Some of the effects will be direct (e.g., heat stress of livestock), and others indirect (e.g., changing pasture composition). In the context of this chapter, we will concentrate on the impact of increasing heat load on livestock, and how animals adapt to increasing heat stress.

Livestock production involves a relatively small group of domesticated animals. Diamond (1999) reported that of the 148 non-carnivorous species weighing more than 45 kg as adults, only 14 have been domesticated. Even fewer bird species (0.001%) have been domesticated (Mignon-Grasteau et al. 2005). However, this does not necessarily make the task any easier.

Mammals are homeothermic endotherms and maintain a core body temperature between 35°C and 40°C depending on the species (Langlois 1994). They are able, through irradiative, conductive, convective, and evaporative exchanges, to generally maintain core body temperature within a fairly narrow range (Langlois 1994; Folk et al. 1998). In many species 5–7°C deviations from core body temperature may cause death, and at least reductions in productive performance. Mammals have a greater capacity for dealing with cold environmental conditions than they do with hot conditions (Folk et al. 1998). The lethal limit of core temperature is about 6°C above normal for healthy animals, and depression of central nervous activity, particularly in the respiratory center, occurs before that (Schmidt-Nielsen 1975). In horses, death may occur if core body temperature decreases by 10°C (27% deviation from normal) or increases by 5°C (13% deviation) (Langlois 1994). In cattle, death has occurred when rectal temperature exceeds 43.5°C (6°C above normal) (J. Gaughan, 2006, personal communication). There is a paucity of information on upper critical body temperature in livestock. Body temperature of some species is more labile, with the capacity to survive large changes in body temperature. For example, the core body temperature of camels can vary between 34.0°C and 42°C (Schmidt-Nielsen et al. 1956; Fowler 1999). Antelope ground squirrels show large fluctuations of core temperature between 37°C to 43°C. These animals will return to burrows or seek shade and rest when core body temperature approaches 43°C. Once body temperature returns to normal (approx 37°C) activity may recommence (Willmer et al. 2000). Animals that hibernate may lower body temperature to only a few degrees above freezing.

7.3 Economic Impacts of Climate Change on Animal Agriculture

Production losses in livestock enterprises are an expected outcome of climate change. Leva et al. (1997) have determined the present production losses in the major milk producing regions in Argentina, and have projected those losses if the global climate change scenario took place. Estimations based on work by Berry et al. (1964), for cows producing 15, 20 and 25 kg milk/day suggest that, under the global climate change scenario, milk production in Argentina would decline on average by 60% (Leva et al. 1997). The economic effect of heat stress on dairy cows in Australia was estimated to be AUS$11,986 per 100 cows if no heat abatement strategies were implemented (Mayer et al. 1999). A recent investigation of the economic losses due to heat stress for a number of US livestock industries (dairy cattle, beef cattle, pigs, chickens and turkeys) was undertaken by St-Pierre et al. (2003). They concluded that without heat abatement, losses across all livestock industries would average US$2.4 billion/annum. A review by Sackett et al. (2006) estimated that the annual production losses in the Australian feedlot industry due to summer heat stress at A$16.5 million. Clearly, economic losses may be significant.

7.3.1 Effect of Heat Waves on Animals

An aspect of climate change is an increase in severe weather. Significant heat events since the mid 1990s appear to be increasing and have resulted in sizable human and animal mortality. Hahn and Mader (1997), Xin and Puma (2001) and Hahn et al. (2000, 2002) described the impact on livestock from a week long heat wave in the mid-central United States during July 1995: the heat wave also resulted in a significant number of human deaths. That heat wave was estimated to have cost the US cattle industry $28 million in animal deaths and reduced livestock performance. In Iowa over 1.8 million laying hens died during this heat wave. In July 1999, a heat wave in Nebraska was responsible for 3,000 cattle deaths and over $20 million in economic loss (http://hpccsun.unl.edu/nebraska/owh-july31.html). In Australia, a heat wave in 2000 resulted in the death of 24 people and over 2,000 cattle. Poultry losses were estimated to exceed 15,000. Horses and dogs also died during this event. During the heat wave which occurred in Europe during summer 2003, over 35,000 people, thousands of pigs, poultry and rabbits died in the French regions of Brittany and Pays-de-la-Loire (http://lists.envirolink.org/pipermail/ar-news/Week-of-Mon-20030804/004707.html). In 2004 during an Australian heat wave over 900 cattle died. In 2006, a major heat wave moved across the USA and Canada. This heat wave resulted in the death of over 15 pets (not defined), 225 people, 25,000 cattle, and 700,000 poultry in California alone. Heat waves in Europe in 2006 and 2007 resulted in the deaths of more than 2000 people. However the number of animal deaths could not be established. Over 800 peacocks died during a heat wave in India in 2007. It is likely that without some form of intervention, either in terms of management or genetic change (via selection for heat tolerance), significant animal deaths will occur during future heat waves. These losses could be significantly greater if the predicted increase in the intensity and duration of heat waves is realized.

7.4 Impact of Climate Change on Animal Health

The effects of climate changes and, in particular, global warming on health status of livestock have not been considered with the same attention as given to humans (http://www.who.int/globalchange/climate/en/). However, it is assumed that as in the case of humans, climate changes can affect the health of livestock and poultry, both directly and indirectly. Direct impacts include temperature-related illness and death, and the morbidity of animals during extreme weather events. Indirect impacts follow more intricate pathways and include those deriving from the influence of climate on microbial density and distribution, distribution of vector-borne diseases, host resistance to infections, food and water shortages, or food-borne diseases. Some general concepts of livestock environment and health have been presented by Simensen (1984) and these may serve as a guide to management of disease during climate change.

A series of studies carried out in dairy cows indicated a higher occurrence of mastitis during periods of hot weather (Giesecke 1985; Smith et al. 1985; Morse et al. 1988; Waage et al. 1998; Cook et al. 2002; Yeruham et al. 2003). However, the mechanisms responsible for the higher occurrence of mastitis during summer have not been elucidated. The hypothesis to explain these observations include the possibility that high temperatures can facilitate survival and multiplication of pathogens (Hogan et al. 1989) or their vectors (Chirico et al. 1997), or a negative action of heat stress on defensive mechanisms (Giesecke 1985).

During summer, ketosis is more prevalent due to increased maintenance requirements for thermoregulation and lower feed intake (Lacetera et al. 1996), and the incidence of lameness increases as a consequence of metabolic acidosis (Shearer 1999). Furthermore, analysis of metabolic parameters in the blood of dairy cows indicates that high environmental temperatures may be responsible for alteration of liver function, mineral metabolism and oxidative status (Bernabucci et al. 2002) (Table 7.1), which may also lead to animals having clinical or sub-clinical disease.

Results from an epidemiology study carried out in California (Martin et al. 1975) documented higher mortality rates of calves born during summer. Others

Table 7.1 Effects of high environmental temperatures on blood indexes of energy and mineral metabolism, liver function and oxidative balance in dairy cows (Adapted from Lacetera et al. 1996; Ronchi et al. 1999, Bernabucci et al. 2002)

Items	Changes
Energy metabolism	
Body condition score	Loss
Glycemia	Decrease
Non esterified fatty acids	Increase
Ketone bodies	Increase
Urea	Increase/decrease
Liver function	
Albumin	Decrease
Cholesterol	Decrease
Bilirubine	Increase
AST	Decrease/increase
γGT	Decrease/increase
LDH	Decrease/no changes
AlPh	Decrease
Mineral metabolism	
Ca	Decrease/no changes
P	Decrease/no changes
Mg	Decrease
Na	Decrease
K	Decrease
Cl	Increase
CAB (Na + K − Cl)	Decrease
Oxidative balance	
Pro-oxidants (TBARS, ROMs)	Increase
Antioxidants (GSH, Thiols)	Decrease

have reported that heat stress may be responsible for impairment of the protective value of colostrum both in cows (Nardone et al. 1997) and pigs (Machado-Neto et al. 1987), and also for alteration of passive immunization of calves (Donovan et al. 1986; Lacetera 1998). On the other hand, results on the negative influence of heat stress on colostral immunoglobulins may provide an explanation for the higher mortality rate of newborns observed during hot months.

Several studies have assessed the relationships between heat stress and immune responses in cattle, chickens or pigs. However, results of those studies are conflicting. In particular, some authors reported an improvement (Soper et al. 1978; Regnier and Kelley 1981; Beard and Mitchell 1987), others described an impairment (Regnier and Kelley 1981; Elvinger et al. 1991; Kamwanja et al. 1994; Morrow-Tesch et al. 1994), and others indicated no effects (Regnier et al. 1980; Kelley et al. 1982; Bonnette et al. 1990; Donker et al. 1990; Lacetera et al. 2002) of high environmental temperatures on immune function. Recently, in a field study carried out in Italy during the summer 2003 (Lacetera et al. 2005), which was characterized by the occurrence of at

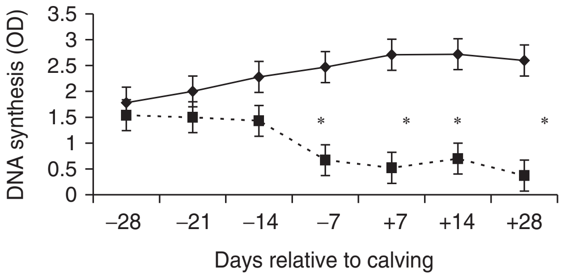

Fig. 7.1 DNA synthesis in peripheral blood mononuclear cells (PBMC) isolated from spring (*solid line*) or summer (*dotted line*) cows. The PBMC were stimulated with concanavalin A. Values are the means ± SEM of the optical density (OD). *Asterisks* indicate significant differences ($P < 0.01$) (Adapted from Lacetera et al. 2005)

least three heat waves, there was a profound impairment of cell-mediated immunity in high yielding dairy cows (Fig. 7.1). Interestingly, such results suggest that immunosuppression during hot periods may be responsible for the failure of vaccine interventions and for reduced reliability of diagnostic tests based on immune system reaction (i.e., tuberculin skin test). The large variety of experimental conditions in terms of species, severity and length of heat stress, recovery opportunities, and also of the specific immune functions taken into consideration are likely to explain the discrepancy among results of different studies. In addition other factors such as photoperiod may impact on immune function (Auchtung et al. 2004).

Global warming will affect the biology and distribution of vector-borne infections. Wittmann et al. (2001) simulated an increase of temperature values by 2°C. Under these conditions, their model indicated the possibility of an extensive spread of *Culicoides imicola*, which represents the major vector of the bluetongue virus. The distribution of ticks and flies is also likely to change.

Another mechanism through which climate changes can impair livestock health is represented by the favorable effects that high temperature and moisture have on growth of mycotoxin-producing fungi. Their growth and the associated toxin production are closely correlated to the degree of moisture to which they are exposed, which itself is dependent on weather conditions at harvest, and techniques for drying and storage (Frank 1991). With regard to alteration of animal health, mycotoxins can cause acute disease episodes when animals consume critical quantities. Specific toxins affect specific organs or tissues such as the liver, kidney, oral and gastric mucosa, brain, or reproductive tract. In acute mycotoxicoses, the signs of disease often are marked and directly referable to the affected target organs. Most frequently, however, concentrations of mycotoxin in feeds are below those that cause acute disease. At lower concentrations, mycotoxins reduce the growth rate of young animals, and some interfere with native mechanisms of resistance and impair immunologic responsiveness, making the animals more susceptible to infection. Studies have shown that some mycotoxins can alter lymphocyte functions in domestic ruminants through alteration of DNA structure and functions (Lacetera et al. 2003, 2006; Vitali et al. 2004).

7.5 Animal Adaptation

Adaptation has the potential to reduce some of the damage caused by climate change (Hulme 2005). However, little work has been undertaken to identify strategies which will allow domestic animals to adapt to climate change (King 2004).

How is adaptation in domestic animals defined? Is it simply the ability of the animals to survive, grow, and reproduce? Or, is it maintenance of productive performance at some predetermined level? Numerous terms are used to describe animal responses to adverse environments (Folk 1974; Yousef 1987).

In its broadest form, adaptation is defined as a change which reduces the physiological strain produced by a stressful component of the total environment. The change may occur within the lifetime of an organism (phenotypic) or be the result of genetic selection in a species or subspecies (genotypic) (Bligh and Johnson 1973).

- Genetic or Biological Adaptation: Adaptation is achieved through genetic change over time (generations), which involves evolutionary processes, and also through environmental stimulation and experiences during an animal's lifetime (Hafez 1968; Price 1984 cited by Mignon-Grasteau et al. 2005). This comes about via natural selection, and selection of animals by humans (Hafez 1968). Identification of heat tolerant phenotypes within existing breeds, or infusion of genes for heat tolerance may be a partial solution. The biological properties of animals are a result of interactions between stress intensity, magnitude of environmental fluctuations, and the energy available from resources (Parsons 1994).
- Phenotypic or Physiological Adaptation: Animals have the ability to respond to acute or sudden environmental change (e.g. shivering when exposed to cold) (Folk 1974; Hafez 1968; Langlois 1994), and with longer exposure to climate change (although this may be somewhat limited).

Other terms commonly used to describe an animal's response to climatic variables include acclimation, acclimatization and habituation. These were defined by Folk (1974) as follows:

- Acclimatization – the functional compensation over a period of days to weeks in response to a complex of environmental factors, as in seasonal or climatic change
- Acclimation – the functional compensation over a period of days to weeks in response to a single environmental factor only, as in controlled experiments
- Habituation – (i) Specific – specific to a particular repeated stimulus and specific to the part of the body which has been repeatedly stimulated, and (ii) General – a change in the physiological set of the organism relevant to the repeated stimulus and the conditions incidental to its application

Animals are regularly exposed to climatic stress (Parsons 1994). The extents to which they are able to adapt are limited by physiological (genetic) constraints (Devendra 1987; Parsons 1994). Selection criteria for livestock and poultry (and possibly domestic animals in general) need to be considered in the context of climate change, and whether the location (habitat) is likely to be favorable or unfavorable to the species of concern. There is a necessity to select livestock, and use livestock systems (e.g. pasture management) on the basis of expected climatic conditions.

Animal performance may be limited where there is climatic adversity. Animals that have evolved to survive in adverse conditions generally have the following characteristics: high resistance to stress, low metabolic rate, low fecundity, long lives, behavioral differences, late maturing, smaller mature size, and slow rate of development (Devendra 1987; Parsons 1994; Hansen 2004). This suggests that selection or use of animals (often indigenous breeds) that are adapted to adverse climates will have lower productivity than those selected for less stressful climates. In general this is true; however, these animals survive, grow and continue to provide food, fibre and fuel under conditions where the animals higher production potential may at the worst die or at best produce at levels at or below the indigenous breeds. In many of the developing countries located in the tropics, the poor reproductive performance of cows (both indigenous and imported), for example, results from a combination of genetics, management, and environmental factors (Agyemang et al. 1991). Depending on location, climate change may improve the local environment or have major negative impacts. In order to take advantage of positive changes or reduce the impact of negative changes, farmers will need to adapt. Improved genetics (including suitability to the environment) and improved management may go a long way to take advantage of changes or minimize the impact. The use of housing, microclimate modification (e.g. shade, sprinklers), improved nutritional management, disease control, and new reproductive technologies are usually needed if animals are to meet their genetic potential (Champak Bhakat et al. 2004; Voh et al. 2004; Magana et al. 2006). However, the cost of implementation of these processes may be too high to be economically viable, especially in developing countries.

Mechanisms of animal adaptation have been defined by Devendra (1987) as: anatomical, morphological, physiological, feeding behavior, metabolism, and performance. Physiological and behavioral adaptations are employed first in response to environmental changes. Animals employ multiple strategies in order to adapt to the environment. For example, Sudanese Desert goats tolerate thermal stress and nutritional shortage (food and water) by their capacity to lose heat via panting and cutaneous evaporation, as well as their ability to concentrate urine to levels above 3,200 mosmols/kg (Ahmed and Elkheir 2004). Additional characteristics of adaptation by goats under different climates are presented in Table 7.2. Camels also use multiple strategies to cope with thermal stress and nutritional shortages. They use sweating to control body temperature in an environment where water loss needs to be minimized. However, they have the ability to increase body temperature during the day (up to 41°C) and then dissipate the heat during the night when desert temperatures may approach or fall below 0°C. Storing heat during the day and dissipating the heat at night is a method of conserving energy and water loss. Camels have an ability to consume large amounts of water when dehydrated. Guerouali and Filali (1995) reported that the water intake of hydrated camels averaged 1.33% of body weight. The camels were then exposed to a 27 day dehydration period. When re-hydrated, water intake increased to 19.12% of body weight within a couple of minutes. Water intakes of up to one third of body weight have been reported. Large water intakes

Table 7.2 Adaptive properties of goats

Climate	Anatomical	Morphological	Physiological	Metabolism	Feeding[a]	Performance
Arid/semi-arid	Large size (30–50 kg), long legs and ears, scrotum shows two distinct sacs	White, black or brown coat color, shiny surface, white colored goats absorb less solar radiation	Panting, sweating	Increased mobilization of fat during periods of feed shortage, low water turnover rate	Browse over long distances, resistance to dehydration, dessication of feces, increased concentration and reduced urine volume, rumen acts as water reservoir, high digestive efficiency of coarse roughages, efficient utilization and retention of nitrogen	Meat/milk/fiber
Sub-tropical	Intermediate size (25–30 kg)	White, black or brown coat, less shiny coat	Panting, sweating	Lower water turnover rate	Intermediate	Meat/milk/fiber
Humid/sub-humid	Small size (10–25 kg), short legs, small ears	Mainly black or brown coat color, shiny coat	Reduced panting, more access to shade	Low metabolic rate	Reduced walking due to increased availability of forages and crop residues	Meat

[a]Feeding behaviour and feed utilization.

may lead to osmotic shock. However, camels are able to store large amounts of water in the stomach. The camel can also dehydrate without affecting blood viscosity and composition. This may be due in part to the shape of camel erythrocytes, which are oval rather than bi-concave as seen in most mammals (Fowler 1999).

Cattle of Indian origin (*Bos indicus*) and those from Europe and parts of Africa (*Bos taurus*) have undergone a separate evolution for several hundred thousand years (Hansen 2004). The Indian or Zebu cattle have during their genetic adaptation acquired genes for thermotolerance (Hansen 2004), and therefore have a higher degree of heat tolerance compared to *Bos taurus* cattle (Allen 1962; Finch 1986;

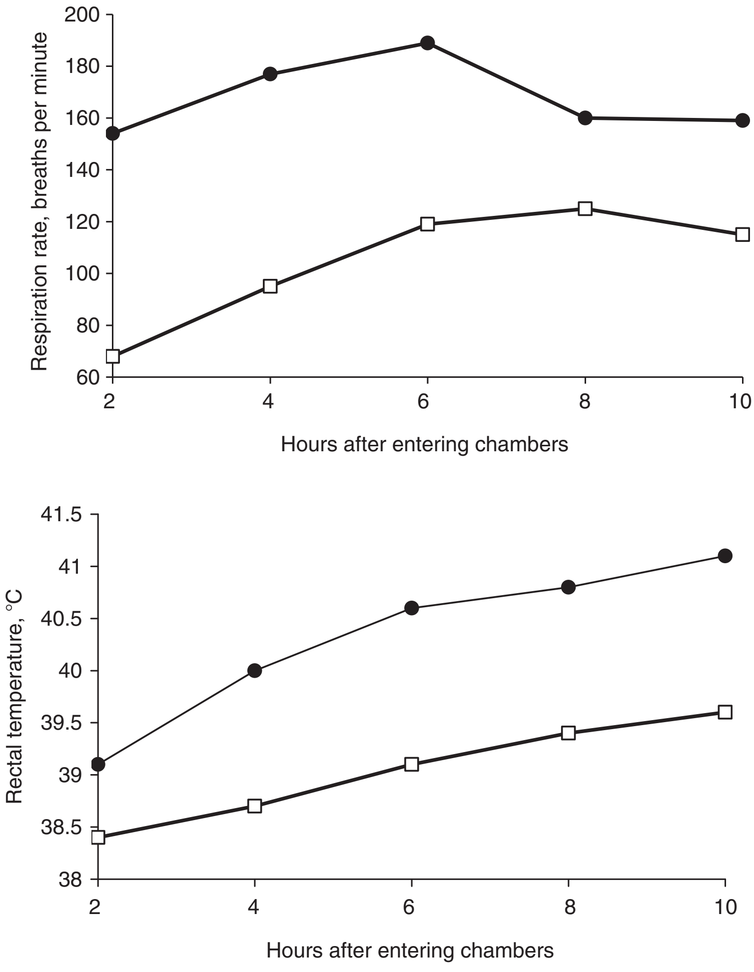

Fig. 7.2 Differences between Hereford (closed circles) and Brahman (open squares) for respiration rate and rectal temperature over 10 h in an environmental chamber when THI > 90 (Adapted from Gaughan et al. 1999)

Spiers et al. 1994; Hammond et al. 1996, 1998; Gaughan et al. 1999; Burrows and Prayaga 2004). However, some *Bos taurus* African breeds such as Tuli, and D'Nama have developed heat tolerance, and appear to be as good as *Bos indicus* cattle in this regard. Under hot climatic conditions, the genetic adaptation of *Bos indicus* cattle allows them to have a lower respiration rate and rectal temperature than *Bos taurus* cattle (Fig. 7.2). An excellent review on the adaptation of zebu cattle to thermal stress was undertaken by Hansen (2004). Adaptation to hot conditions has resulted in animal acquiring specific genes, some of which have been identified (see discussion below).

Sheep and goats are thought to be less susceptible to environmental stress than other domesticated ruminant species (Khalifa et al. 2005). They are widely distributed in regions with diverse climatic conditions and possess unique characteristics such as water conservation capability, higher sweating rate, lower basal heat metabolism, higher respiration rate, higher skin temperature, constant heart rate and constant cardiac output (Borut et al. 1979; D'miel et al. 1979; Shkolnik et al. 1980; Feistkorn et al. 1981).

Differences in physiological responses of sheep adapted to hot conditions (Omani – indigenous breed of Oman) and non-adapted to hot conditions (Merino – Australian) were reported by Srikandakumar et al. (2003). When exposed to hot conditions, the Omani sheep had lower respiration rate than the Merino (65 vs. 128 breaths/min, respectively) (Fig. 7.3). There were no differences in rectal temperature during exposure to hot conditions, but the rectal temperature of the Omani sheep was significantly lower during exposure to cool conditions. The rectal temperature

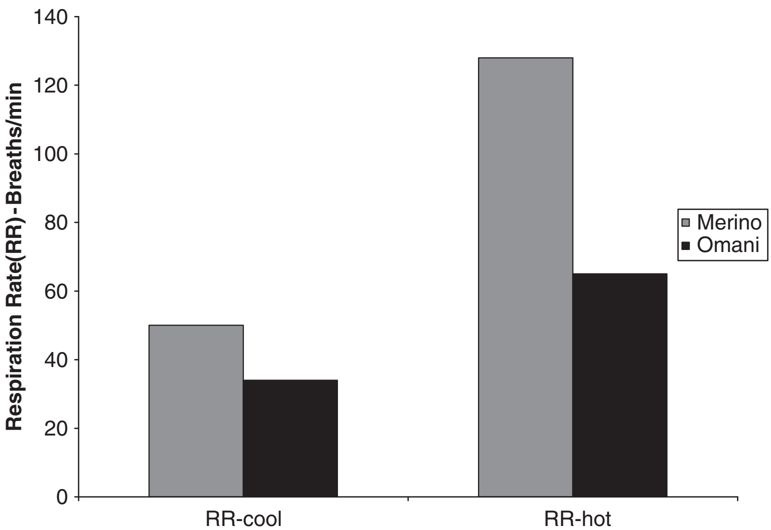

Fig. 7.3 Differences in respiration rate (RR) between Australian merino and Omani sheep when exposed to cool and hot conditions (Adapted from Srikandakumar et al. 2003)

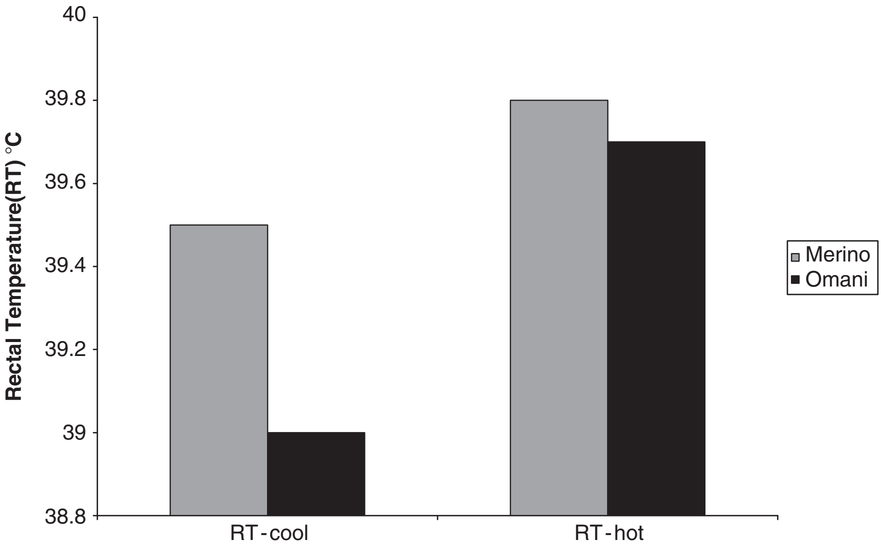

Fig. 7.4 Differences in rectal temperature (RT) between Australian merino and Omani sheep when exposed to cool and hot conditions (Adapted from Srikandakumar et al. 2003)

of the Omani sheep increased by 0.7°C during hot conditions compared to 0.3°C in the Merino sheep (Fig. 7.4).

Goats are a very good example of a domestic animal that is highly adapted to harsh conditions. Silanikove (2000) postulated that goats living in harsh environments represent a climax in the capacity of domestic ruminants to adjust to such areas. Again this ability is multifactorial. While performance in terms of growth rate is greatly reduced, low body mass and low metabolic requirements of goats can be regarded as important assets in minimising their maintenance and water requirements in areas where water sources are widely distributed and food sources are limited by their quantity and quality. An ability to reduce metabolism allows goats to survive even after prolonged periods of severely limited food availability. A skillful grazing behaviour and efficient digestive system enable goats to attain maximal food intake and maximal food utilization in a given condition. There is a positive interaction between the recycling rate of urea and a better digestive capacity of desert goats. The rumen plays an important role in the evolved adaptations by serving as a relatively large fermentation vat and water reservoir. The water stored in the rumen is utilized during dehydration, and the rumen serves as a container which accommodates the ingested water upon re-hydration. The rumen, salivary glands, and kidney coordinate functions in the regulation of water intake and water distribution following acute dehydration and rapid re-hydration.

Animals that have been exposed to non-lethal thermal stress will usually adapt to the conditions. The adaptation may be of short duration (e.g. reduction in feed intake; Mader et al. 2002) or long-term (e.g. reproductive failure). Long-term adaptation has been shown in chickens that were exposed to hot conditions at 4–7 days of age. The exposure reduced the effects (reduced heat production, lower mortality) of heat stress at a later age (May et al. 1987; Wiernusz and Teeter 1996; Yahav and Plavnik 1999; Yalchin et al. 2001).

7.5.1 General Animal Responses

Climate change deals with variations both short- and long-term. Those variations can come in many forms involving both temporal and spatial variations, ranging from the number and severity of acute, dynamic events (such as heat waves) impacting localized microclimates, to long-term chronic (decadal) global changes that may result from changes in atmospheric constituents. This broad perspective is taken here as we consider the impact of thermal environmental challenges associated with climate change on adaptive responses of animals and the management of livestock production systems. Thus, the focus is on how elements of acute and chronic climate change are linked to the ability of the animals to cope with environmental challenges, and the limits of that ability are discussed in the context of sustainable management practices.

Responses of animals vary according to the type of thermal challenge: short-term adaptive changes in behavioral, physiological, and immunological functions (survival-oriented) are the initial responses to acute events, while longer-term challenges impact performance-oriented responses. Within limits delineated by thresholds for disrupted behavior and maladapted physiology and immune functions, domestic animals can cope with many acute thermal challenges through acclimatization to minimize adverse effects and compensation for reduced performance during moderate environmental challenges. These responses to environmental challenges are illustrated in Fig. 7.5 (Hahn 1999, as adapted from Hahn and Morrow-Tesch 1993). The interrelationship between potential environmental challenges and the dynamic response of an animal is apparent. As an aside, it is important to recognize that while management strategies will likely alter some of the biological and adaptive responses, the laws of physics will still apply – heat production and heat losses must balance within the limits of heat storage capacity of the animals.

7.5.2 Animal Responses to Heat Load

Direct effects involve heat exchanges between the animal and the surrounding environment are related to radiation, temperature, humidity, and wind speed (Johnson 1987). Because the thermal environment is more than just heat, the term heat stress is somewhat misleading. The term heat load has been used to highlight the importance of the interactive effects of the fore-mentioned factors. Within breed, animal variation (phenotypes), differences among breeds (genotypes), management factors such as housing and nutrition, physiological status (stage of pregnancy, stage of

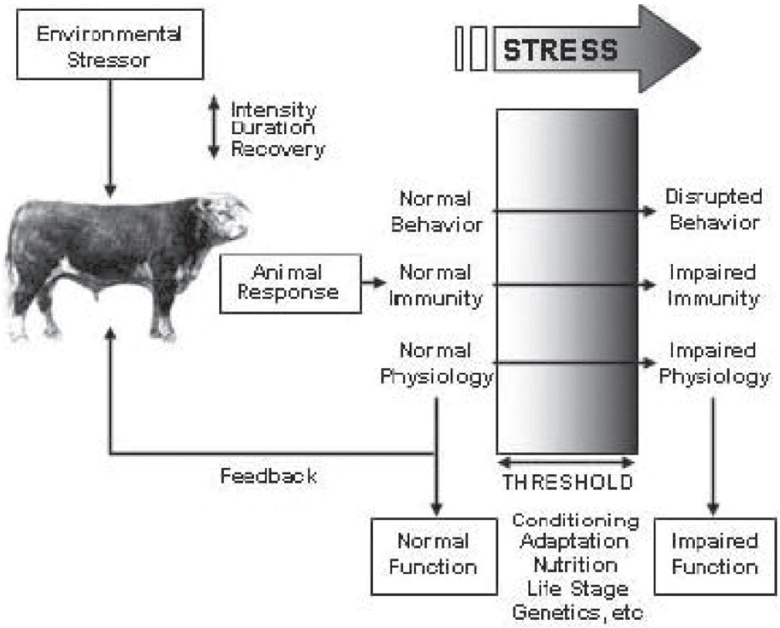

Fig. 7.5 Response model for farm animals with thermal environmental challenges (Hahn 1999)

lactation, growth rate), age and previous exposure to hot conditions may increase or decrease the impact of hot conditions.

High heat load (and environmental stress in general) has the potential for detrimental effects on susceptible animals. The negative effects on health, growth rate, feed intake, feed efficiency, tissue deposition, milk yield, health status, reproduction, and egg production are well documented (Brody 1956; El-Fouley et al. 1976; Biggers et al. 1987; Fuquay 1981; Johnson 1987; Nienaber et al. 1987a, b; Hahn et al. 1990, 1993; Liao and Veum 1994; Valtorta and Maciel 1998; Mader et al. 1999a, b; Nienaber et al. 1999, 2001; West 1999; Hansen et al. 2001; Wolfenson et al. 2001; Yalchin et al. 2001; Valtorta et al. 2002; Kerr et al. 2003; Faurie et al. 2004; Gaughan et al. 2004; Holt et al. 2004; Mader and Davis 2004; Kerr et al. 2005; Huynh et al. 2005; Wettemann and Bazer 1985). However, the actual numerical impacts are unknown. Furthermore genetic change in livestock animals especially in regards to increase productivity has resulted in animals that more likely to be susceptible to the negative impacts of heat stress.

Differences in their ability to withstand environmental stressors should allow selection of animals (within breeds and between breeds/species) better suited to particular environmental conditions (Scott and Slee 1987; Slee et al. 1991; Langlois 1994; Hammond et al. 1996, 1998; Gaughan et al. 1999; Herpin et al. 2002; Abdel Khalek and Khalifa 2004; Koga et al. 2004; Brown-Brandl et al. 2005; Hamadeh et al. 2006). However, as previously discussed, selection of such animals may result in improved welfare and ability to cope at the expense of lower productivity.

Livestock and poultry are remarkable in their ability to mobilize coping mechanisms when challenged by environmental stressors. However, not all coping capabilities are mobilized at the same time. As a general model for bovines, sheep and goats, respiration rate serves as an easily recognized early warning of increasing thermal stress (Khalifa et al. 1997; Butswat et al. 2000; Gaughan et al. 2000; Eigenberg et al. 2005), and increases markedly above a baseline as the animals try to maintain homeothermy by dissipating excess heat through respiratory evaporation. However, Starling et al. (2002) stated that the use of physiological parameters such as rectal temperature and respiration rate for selection is not enough to evaluate the level of adaptive capability. Clearly this is the case as there are many physiological factors which need to be assessed. However, a full assessment (i.e. changes in body temperature, respiration rate, heat shock proteins, hormones etc. – all of which are indicators of heat load status) of animals is difficult, especially under farming conditions. Increased respiration rate and body temperature do not necessarily indicate that an animal is not coping with the environmental conditions to which it is exposed.

7.5.3 Body Heat – Animal x Climate Interactions

There are several components to body heat load which can be divided into two broad categories *viz.* internal or metabolic heat load (ruminal fermentation and nutrient metabolism) and environmental heat load (Armsby and Kriss 1921; Duckworth and Rattray 1946; Shearer and Beede 1990). Metabolic heat load is typically a result of: (i) basal body functions (heart, lungs and liver), (ii) maintenance, (iii) activity, and (iv) performance (e.g., daily gain, milk, eggs) (McDowell 1974).

Basal body functions contribute between 35% and 70% of daily heat production (McDowell 1974), and will tend to the higher levels during non-basal periods of work (e.g., walking, high respiration rate) or high levels of production. Importantly, core body temperature is dynamic even under thermoneutral conditions (Hahn 1989, 1999), and follows a diurnal pattern which is influenced by interactions between animal and environmental factors.

There are a range of thermal conditions within which animals are able to maintain a relatively stable body temperature by behavioral and physiological means (Johnson 1987; Bucklin et al. 1992). This range is defined for a species based on upper critical and lower critical temperatures. Bligh and Johnson (1973) defined the upper critical temperature (UCT) as ‘the ambient temperature above which thermal balance cannot be maintained for a long period and animals become progressively hyperthermic’. This definition was revised in 1987 as ‘the ambient temperature above which the rate of evaporative heat loss of a resting thermoregulating animal must be increased (e.g., by thermal tachypnea or by thermal sweating) in order to maintain thermal balance’ (IUPS Thermal Commission 1987). The lower critical temperature (LCT) is defined by the IUPS Thermal Commission (1987) as ‘the ambient temperature below which the rate of metabolic heat production of a resting thermoregulating tachymetabolic animal must be increased by shivering and/or nonshivering thermogenesis in order to maintain thermal balance’. The thermoneutral zone (TNZ) is defined as the range of ambient temperature at which temperature regulation is achieved only by control of sensible heat loss, i.e. without regulatory changes in metabolic heat production or evaporative heat loss. The TNZ will therefore be different when insulation or basal metabolic rate varies (IUPS Thermal Commission 2001). The UCT, LCT and TNZ of a species are influenced by insulation, nutrition and exercise (Ames 1980; McArthur 1987; Morgan 1997).

Heat stress results from the animal’s inability to dissipate sufficient heat or reduce heat influx to maintain homeothermy (Folk 1974). High ambient temperature, relative humidity and radiant energy, particularly with concurrent low air speed, compromise the ability of animals to dissipate heat. As a result, there is an increase in core body temperature, which in turn initiates compensatory and adaptive mechanisms in an attempt to re-establish homeothermy and homeostasis (El-Nouty et al. 1990; Khalifa et al. 1997; Horowitz 1998, 2002; Lin et al. 2006). These readjustments, generally referred to as adaptations, may be favorable or unfavorable to economic interests of humans, but are essential for survival of domestic animals (Stott 1981). However, it is likely that continued genetic selection for improved levels of production (e.g. growth rate, feed intake and milk production) will result in animals that are generally less heat tolerant (Joubert 1954; Young 1985; Johnson 1987; Yahav et al. 2005; Lin et al. 2006).

When animals are exposed to environmental conditions above their UCT core body temperature begins to increase as a result of the animal’s inability to adequately dissipate the excess heat load. There is a concomitant decrease in feed intake as core body temperature increases, which ultimately results in reduced performance (production, reproduction), health and well-being if adverse conditions persist (Hahn et al. 1993). Thresholds are genotype/phenotype/species dependent, and are affected by many factors, as noted in Fig. 7.5. For shaded *Bos taurus* feeder cattle, Hahn (1999) reported respiration rate typically increases above a threshold of about 21°C air temperature, with a threshold for increasing core body temperature and decreasing feed intake at about 25°C. A recent study (Brown-Brandl et al. 2005) showed the influence of condition, genotype, respiratory pneumonia, and temperament on respiration rate of un-shaded *Bos taurus* heifers). Figure 7.6 illustrates the respiration rate response of different genotypes to hot environmental temperatures.

The lower and upper critical temperatures of both Arabi and Zaraiby goats were 20–25°C and 20–30°C, respectively (El-Sherbiny et al. 1983). Lu (1989) found that the upper critical temperature of goats in maintenance is 25–30°C, and heat stress occurs when they are exposed to ambient temperature above 30°C. He stated that although rectal temperature rose significantly when goats were exposed to 30°C, compared to 20°C, the limit of heat tolerance for goats is between 35°C and 40°C. Dahlanuddin and Thwaites (1993) stated that goats reached the limit of their heat tolerance at 40–45°C ambient temperature. Furthermore, D’miel et al. (1980) stated that goats had a high lower critical temperature of 26°C. Therefore, they must rely mostly on metabolic energy rather than on insulation to keep their body temperature constant during cold weather.

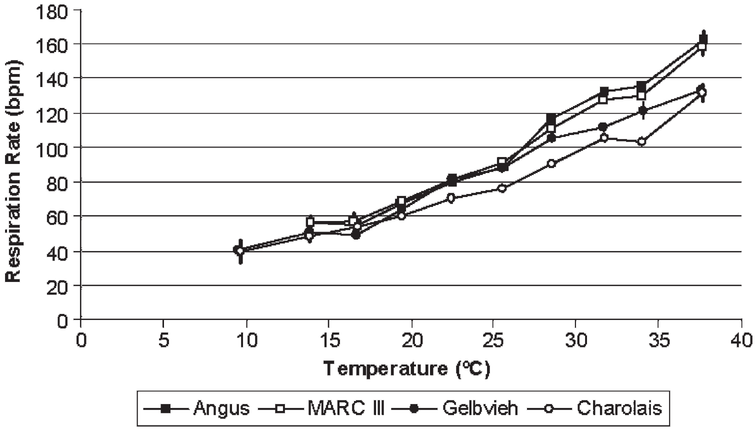

Fig. 7.6 Respiration rates as a function of ambient temperature for unshaded cattle of four genotypes (Brown-Brandl et al. 2005)

There also appears to be a time-dependency aspect of responses in some species. For example, Hahn et al. (1997) reported that for beef cattle with access to shade, respiration rate lags behind changes in dry bulb temperature, with the highest correlations obtained for a lag of 2 h between respiration rate and dry bulb temperature. For un-shaded beef cattle, respiration rate closely tracks solar radiation; increasing or decreasing with solar radiation. There is also a delay in acute body temperature responses (during the first 3–4 days of exposure) to a heat challenge, with an increasing mean and amplitude, along with a phase shift reflecting entrainment by the ambient conditions (Hahn et al. 1997; Hahn and Mader 1997; Hahn 1999). Even though feed intake reduction usually occurs on the first day of exposure to hot conditions, the endogenous metabolic heat load from existing rumen contents adds to the increased exogenous environmental heat load. Nighttime recovery also has been shown to be an essential element of survival for cattle when severe heat challenges occur (Hahn and Mader 1997). After 3 days, the animal enters the chronic response stage, with mean body temperature declining slightly and feed intake reduced in line with heat dissipation capabilities. Diurnal body temperature amplitude and phase remain altered. These typical thermoregulatory responses (discussed more fully in Hahn 1999), when left unchecked during a severe heat wave with excessive heat loads, can lead to a pathological state resulting in impaired performance or death (Hahn and Mader 1997). The intensity and duration of exposure to a given thermal stress will also determine animal responses (Hahn and Mader 1997; Gaughan and Holt 2004; Beatty et al. 2006). Further studies are required to determine species and breed responses.

Thus, an increase in air temperature, such as that expected in different scenarios of climate change, would directly affect animal performance by affecting animal heat balance. The thermal environment influences animal performance primarily through the net effects of energy exchanges between the animal and its surroundings

(Folk 1974; Hahn 1989; Yahav et al. 2005). There are four modes of energy transfer: radiation (gain or loss of heat from the animal), convection (gain or loss), conduction (gain or loss), evaporation (loss only), all of which are governed by physical laws. Several physical parameters control heat transfer by each mode. Air temperature affects energy exchanges through convective, conductive, and radiative exchanges (not evaporation) (Hahn 1976). In hot conditions, evaporation becomes the most important method of heat loss, as it is not dependent on a temperature gradient (Ingram and Mount 1975). Therefore, the combination of temperature and humidity acquire more relevance, since humidity increases the magnitude of the thermal strain especially at high ambient temperatures.

The temperature humidity index (THI; Thom 1959) is commonly used as an indicator of the intensity of climatic stress on animals, where a THI of 72 and below is considered as no heat stress, 73–77 as mild heat stress, 78–89 as moderate, and above 90 as severe (Fuquay 1981). On the other hand, the Livestock Weather Safety Index (LCI 1970) categories associated with THI are normal (THI ≤ 74), Alert (75–78 THI), danger (79–83 THI) and emergency (THI ≥ 84). Davis et al. (2003) suggest that there is no heat stress for beef cattle when average THI < 70, mild heat stress when 70 ≤ THI < 74, moderate heat stress when 74 ≤ THI < 77, and severe heat stress when THI ≥ 77. Khalifa et al. (2005) indicated that for sheep and goats, there is no heat stress when average THI < 70, mild heat stress when 70 ≤ THI < 74 in sheep and 70 ≤ THI < 78 in goats, moderate heat stress when 74 ≤ THI < 88 in sheep and 78 ≤ THI < 84 in goats and severe heat stress when THI ≥ 84 in goats. It is worth noting that these data were obtained on crossbred sheep and goats which are acclimatized to Egyptian conditions but not well adapted to the subtropical environment like native breeds. Dairy cattle show signs of heat stress when THI is higher than 72 (Johnson 1987; Armstrong 1994); however the actual threshold will be associated with a decline in milk production (Berry et al. 1964; Kadzere et al. 2002), and whether or not heat abatement strategies are implemented (Mayer et al. 1999). Cows with higher levels of milk production are more sensitive to heat load (Johnson 1987; Hahn 1989). Amundson et al. (2006) indicated that a THI threshold of 73 pregnancy rates of beef cattle became negatively affected. Conception rate of dairy cows was affected by just 1 day exposure to THI between 65 and 70 (Ingraham et al. 1974; and Du Preez et al. 1990). The conception rate of water buffalo was significantly lower when THI > 79 (Pagthinathan et al. 2003). Whether these beef cattle, dairy, or buffalo could adapt to a greater THI is not known. A review of heat stress in lactating dairy cows has been published by Kadzere et al. (2002).

Although THI is widely-accepted for evaluating the climatic environment, it is limited because it does not take into account the effects of thermal radiation (solar and long-wave) or wind speed. Modifications to the existing THI to account for wind speed and solar load (Mader et al. 2006) and the development of new indices (Eigenberg et al. 2000, 2005; Khalifa et al. 2005; Gaughan 2008) have been reported. A review of thermal indices used with livestock was undertaken by Hahn et al. (2003). A new heat load index (HLI) which incorporates the effects of solar radiation and wind speed on the heat load status of feedlot cattle has been established (Gaughan et al. 2008a). This index is based on the establishment of thresholds above which cattle gain heat and below which heat is dissipated. The thresholds are adjusted based on genotype, health status, nutritional management, pen management and the provision of shade.

Current indices do not account for cumulative effects of heat load, and/or natural cooling. Cattle may ‘accumulate’ heat during the day (body temperature rises) and dissipate the heat at night. If there is insufficient night cooling, cattle may enter the following day with an ‘accumulated’ heat load (Hahn and Mader 1997). The THI-hours model was developed to account for the impact of intensity x duration on thermal status (Hahn and Mader 1997). This concept was further developed for feedlot cattle as the accumulated heat load model (Gaughan et al. 2008a). This model is able to account for genotype differences, management factors and housing factors (e.g. provision of shade).

It is not only the intensity and duration of the thermal challenge, but also the amount of time animals have to recover from the challenge that determines their response (Mendel et al. 1971; Hahn et al. 2001; Gaughan et al. 2008a). In the central Santa Fe region, a major dairy area in Argentina, THI > 72 for 13 h a day is common in January (Valtorta and Leva 1998). These conditions result in poor reproductive performance and milk yield; de la Casa and Ravelo (2003) have estimated the impacts on milk production in Argentina. When considering a global climate change scenario, determined by paleoclimatological studies (Budyko et al. 1994), the hours when THI > 72 would increase to approximately 16 h by 2025 (Valtorta et al. 1996a). The implications of such a change are that the already compromised summer dairy performance measured in terms of reduced milk production (Valtorta et al. 1996b, 1997) and lower conception rates (Valtorta and Maciel 1998), could be further impaired.

7.6 Animal Management Adaptations

7.6.1 Genetic Modifications

The use of genomics may hold the key to improving heat tolerance in a number of species. How do we identify cattle with superior heat tolerance? Basically there are three broad genetic options for improving heat tolerance: (i) select phenotypes within the breed types preferred that have high heat tolerance e.g. identify heat tolerant Angus within the Angus breed, (ii) identify phenotypes within the heat tolerant breeds (e.g. Brahman) that will meet current and future market specifications, and (iii) identify breeds that currently meet market requirements and are heat tolerant. The focus of many researchers has been to identify genes, biological markers, or molecular markers that can be used to assess heat tolerance in animals (Collier et al. 2002; Mariasegaram et al. 2007; Regitono et al. 2006). An example is the “slick” gene in cattle. Cattle which have shorter hair, have hair of greater diameter and are of lighter color are more adapted to heat than those with longer hair coats and darker colors. The cattle with the shorter hair carry the “slick coat” gene. The slick coat phenotype has been observed in tropical *Bos taurus* breeds (e.g. Senepol and Carona) in the Americas. The adaptation is manifested in the shorter haired cattle by lower rectal temperatures, lower respiration rates, increased sweating rate (Olson et al. 2006) and better fertility (Bertipaglia et al. 2005) compared to long haired cattle under high heat load. The slick gene appears to be a simple dominant gene. Therefore, as long as a crossbred animal carries the dominant allele they will be heat tolerant. In a recent study, Angus x Senepol and Charolais x Senepol were shown to be as heat tolerant as Brahmans (Mariasegaram et al. 2007). However, there was no mention of carcass attributes. Selection of cattle for this gene may be a useful mechanism for improving heat tolerance provided carcass and other performance attributes are not compromised.

7.6.2 Environmental Modifications

Global climate change models predict an increase of heat stress events, as well as general warming in some areas. Therefore, methods that will alleviate the impact of these events should be considered, especially if alternative land use or species/breed use is not an option. Beede and Collier (1986) suggest three management options for reducing the effect of thermal stress in cattle which have application for all livestock and poultry. The options are: (1) physical modification of the environment; (2) genetic development of breeds with greater heat tolerance and (3) improved nutritional management during periods of high heat load.

Numerous methods of environmental modifications to ameliorate heat stress in livestock and poultry are found in the literature, ranging from provision of shade through environmental control using mechanical air conditioning (e.g., Hahn and McQuigg 1970; Hahn 1989; Bucklin et al. 1991; Bull et al. 1997; Mader et al. 1999a; Valtorta and Gallardo 1998; Mitlöhner et al. 2001; Spiers et al. 2001; Pagthinathan et al. 2003; Champak Bhakat et al. 2004; Correa-Calderon et al. 2004; Mader and Davis 2004; Lin et al. 2006). However, while all are technologically feasible, not all are economically viable or acceptable from a management perspective.

Shade: In many cases, the most economical solution to high heat load is the provision of shade. Shade is a simple method of reducing the impact of high solar radiation (Bond et al. 1967; Fuquay 1981; Curtis 1983), but has little impact on air temperature. Black globe temperatures under shade structures can be as much as 12°C lower than the black globe temperature in the sun (36°C vs. 49°C) (J. Gaughan, 2007, personal communication). Shade can be either natural or artificial. It has been suggested that shade from trees is more effective (Hahn 1985) and is preferred by cattle (Shearer et al. 1991). However, Gaughan et al. (1998) reported that dairy cows preferred the shade from a solid iron roof even when they had access to shade trees. This result may have been a result of differing shade density, leading to a greater reduction in radiation heat load under the roof. Aspects concerning design and orientation of shades have been widely published (Buffington et al. 1983; Hahn 1989; Bucklin et al. 1991; Valtorta and Gallardo 1998). Many species, even those deemed to be heat tolerant will seek shade under hot conditions if it is an option. Shades are effective in reducing heat stress and the effects of heat stress in cattle (Davison et al. 1988). Valtorta et al. (1996b) found that cattle with access to shade had lower rectal temperature and respiration rate in the afternoon, and yielded more milk and greater milk protein compared to unshaded cows. Khalifa et al. (2000) reported that exposure to solar radiation (46°C black globe temperature) and 27% RH, significantly increased rectal temperature, skin temperature, ear temperature, respiration rate and pulse rate of goats without access to shade compared to those in shade. However, exposure to solar radiation significantly decreased temperature gradients from the skin to air and from rectal to ear temperatures.

Air movement: Air movement is an important factor in the relief of heat stress, since it affects convective and evaporative heat losses (Armsby and Kriss 1921; Mader et al. 1997; Yahav et al. 2005). Air movement whether outside or in buildings is critical if cooling is to be effective. The use of natural ventilation in animal buildings should be maximized by the construction of open-sided sheds (Ferguson 1970; Bucklin et al. 1991), sheds with ridge top ventilation (Baxter 1984) and good separation distance between buildings (Ferguson 1970). Forced or mechanical ventilation, provided by fans, is an effective method for enhancing air flow, if properly designed and maintained (Baxter 1984; Xin and Puma 2001). Numerous methods of increasing air movement in animal buildings ranging from simple overhead fans, mechanically driven curtains which open or close depending on ambient temperature, tunnel ventilation systems to fully controlled computer operated systems can be found in the literature. Shelters, shade and wind breaks, if not designed correctly, can lead to micro-climate conditions that may induce severe heat stress in animals.

Using water for cooling livestock: Direct access to water such as in dams, ponds and rivers is effective in cooling animals in grazing situations. It is not unusual to see cattle standing belly deep in water. Intensively housed dairy cattle, feedlot cattle and pigs will also use water troughs for similar purposes if they can gain access. Where access is limited water splashing and dunking the head in the trough is a common practice. Pigs will use nipple drinkers to spray water over their bodies in an effort to keep cool. Where animals are housed there are several methods which are commonly used, including misting, fogging, and sprinkling systems. A large number of studies have investigated the efficacy of these systems in reducing the incidence of heat stress in domestic animals (Berman et al. 1985; Hahn 1985; Armstrong and Wiersma 1986; Schultz 1988; Turner et al. 1989; Strickland et al. 1989; Bucklin et al. 1991; Armstrong 1994; Armstrong et al. 1999; Brouk et al. 2001, 2003a; Pagthinathan et al. 2003; Gaughan et al. 2004; Marcillac et al. 2004; Barbari and Sorbetti Guerri 2005; Calegari et al. 2005; Gaughan and Tait 2005).

Evaporative coolers may be effective in reducing air temperature especially when relative humidity is low and there is adequate ventilation and air movement. Evaporative coolers are effectively used to cool the air in cattle, pig, sheep and poultry buildings in areas characterized by a hot dry environment. Misting is routinely used in the dairy industry and is especially effective in dry climates (e.g. Israel, Saudi Arabia, and Arizona) (Armstrong et al. 1993), and is also used for cooling the ventilation air entering poultry and swine buildings (Xin and Puma 2001; Brouk et al. 2003b). However, misting systems can be effective even when relative humidity is high e.g. Hawaii (dairy cattle) (Armstrong et al. 1993), Florida (dairy cattle) (Taylor et al. 1986; Beede 1993; Mearns et al. 1992), Missouri (dairy cattle, swine and poultry) (Brouk et al. 2003b) and Iowa (poultry) (Xin and Puma 2001) provided that there is sufficient air movement. Misting or fogger systems are not generally recommended in hot humid environments (Bucklin et al. 1991; Bottcher et al. 1993; Turner et al. 1993). However, misters do have the advantage of low water usage (Lin et al. 1998).

Direct water application: Direct application of water to the skin is an effective method of cooling buffalo, cattle, pigs, and poultry. Adding water to the body surface increases the latent heat loss from an animal. It is the evaporation of the water from the surface that results in the cooling of the animal. Under the right conditions, water application will reduce heat load on animals (Fig. 7.7). However, the use of water for cooling livestock may lead to an increase in relative humidity, especially where there is limited air movement, and this reduces the ability of the animal to dissipate heat via evaporation (Frazzi et al. 1997; Xin and Puma 2001; Correa-Calderon et al. 2004). Gaughan et al. (2003) demonstrated that wetting cattle exposed to high temperature and humidity had only minor short term effects

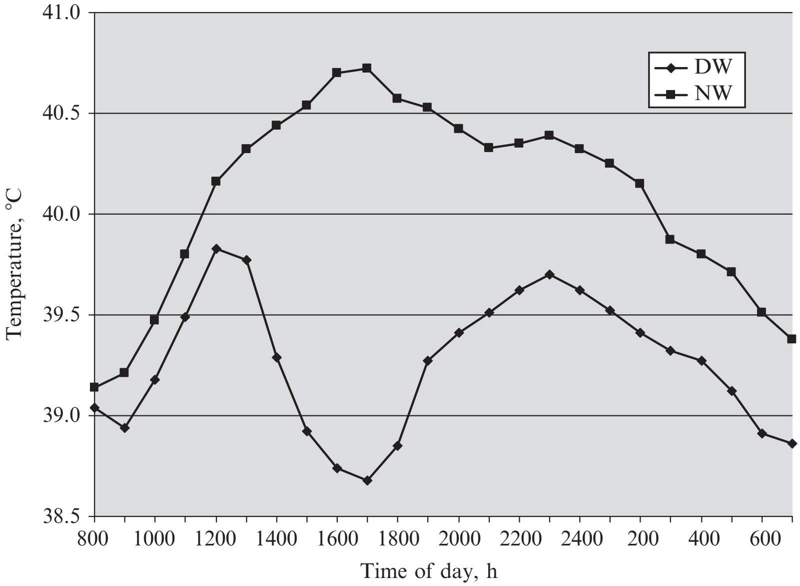

Fig. 7.7 The effect on rectal temperature when cattle have been sprinkled (DW) between 1,200 and 1,600 h or not sprinkled (NW) (Adapted from Gaughan et al. 2004)

on relative humidity, provided that ventilation was adequate. The negative impacts of high relative humidity and/or limited air movement on the animals ability to dissipate heat may be magnified when insufficient water is used e.g. foggers or misters or there is insufficient ventilation to remove the moisture laden air. In these circumstances water particles may form a cover over the hair or pelage of the animal trapping heat and thereby increasing the level of heat stress (Hahn 1985).

Continuous application of water is not required to achieve heat stress alleviation. Morrison et al. (1973) used a 30 min cycle where cattle were wetted for 30 s and then exposed to forced air ventilation for 4.5 min. The 30 min cycle was repeated nine times a day. The dairy cows which were exposed to the cooling strategy had a lower (0.5–0.9°C) rectal temperatures than those not cooled. In a later study Morrison et al. (1981) using feed conversion efficiency and rate of gain as indicators did not find any benefit from wetting cattle. However, feed intake was greater in the cooled cattle. Flamenbaum et al. (1986) wetted dairy cows for either 10, 20 or 30 s followed by forced ventilation (1.5 m/s at cow height) for either 15, 30 or 45 min. They found that the 20 and 30 s wetting followed by the 30 and 45 min forced ventilation reduced rectal temperature by 0.7°C and 1.0°C respectively. Igono et al. (1987) reported effective cooling when where sprinklers were used for were used for 20 minutes on and were then off for 10 min. Using beef cattle in Florida, Garner et al. (1989) used a 3 min on 30 min off when temperature was greater than 26.7°C. Fans were also used in this study however air speed at animal height was not mentioned. Lin et al. (1989) used 3 min on and 15 min off. Two and a half minutes on and 7 min off was used by Turner et al. (1992). Beede (1993) recommended approximately 1–2 mm per dairy cow per 15 min wetting cycle, or just enough water to wet the back. In a study by Brouk et al. (2001) used a cycle of 3 min on and 12 min off, while Gaughan et al. (2008b) used 5 min on and 15 min off.

Brouk et al. (2001) suggests that the coat of dairy cows should be allowed to dry between water applications, however Gaughan et al. (2008b) reported that beef cattle which were completely dry within 10–15 min of water application had an increase in respiration rate. It is likely that these animals were under some degree of heat stress, albeit for short periods of time, because water was evaporating from the skin but not removing sufficient body heat (Frazzi et al. 2000). This suggests that the 15 min interval between wettings was too long given the ambient conditions to which the cattle were exposed or that the duration of water application was too short or that the amount of water supplied was insufficient.

Before considering water application, a number of factors need to be considered. These include: infrastructure and running cost, water availability, how will water be removed from the site, provision of sufficient air movement, and micro-climate effects.

Livestock managers need to be especially vigilant when applying water to animals. Changes in micro-climate (e.g., an increase in relative humidity) may reduce evaporative cooling from the animal's surface. Therefore increased wetting frequency may be required. Furthermore, consistency in application is important. Once started, wetting needs to continue until high heat load has abated (Gaughan et al. 2004, 2008b).

7.6.3 Nutritional Modification

Excellent reviews of nutritional strategies for managing heat-stressed dairy cows (West 1999), and poultry (Lin et al. 2006) have been published. Dietary manipulation has been shown to be beneficial for reducing the effects of heat stress in cattle (Beede and Collier 1986; Schneider et al. 1986; West et al. 1991; Mader et al. 1999b; Granzin and Gaughan 2002). A 'cold' dairy cow diet generates a high net nutrient proportion for milk production and lower heat increment (Gallardo 1998). The author indicates that some outstanding characteristics of 'cold' diets are: (1) higher energy contents per unit volume; (2) highly fermentable fiber; (3) lower protein degradability; and (4) high by-pass nutrients contents. These recommendations are useful when feeding totally mixed rations. However, diet manipulation may be useful even under grazing systems. Gallardo et al. (2001) found that hydrogenated fish fat could be a good ingredient to sustain high yields and elevated maintenance requirements in a grazing system during hot conditions. These are in reality, however, only short-term solutions. In many areas of the world, feeding grains and other high energy ingredients will not be financially sustainable. In many areas, animal production is based on grazing, foraging or browsing. A changing climate will impact on grasses, shrubs, and trees. If these effects are negative, then there will be significant changes in livestock production in the affected areas (see previous discussion).

Water is the most critical nutrient for animals. Climate change may have a number of impacts on water availability. In addition, water requirements are higher during periods of heat load (Winchester and Morris 1956; Beede and Collier 1986; Beatty et al. 2006). High production animals have a greater need for water compared to low production animals. Classical studies have demonstrated that water losses from animals increase with increasing air temperature (Kibler and Brody 1950; McDowell and Weldy 1960). Drinking behaviour is complex and is influenced by a number of factors such as diet, live weight, health status, and physiological status. Normally, it would be expected that water intake will increase when animals are exposed to hot conditions. Beatty et al. (2006) reported that water intake of *Bos taurus* heifers (331 kg) increased from approximately 19.8 L/head/day under cool conditions (wet bulb <25°C) to 31.4 L/head/day when exposed to a wet bulb temperature between 25°C and 33°C (Fig. 7.8). Water intakes reported by Gaughan and Tait (2005) for Angus steers (550 kg) exposed to hot conditions (36°C) were 41.1 L/head/day, up from 19.8 L/head/day under thermoneutral conditions (26°C). Concurrent feed intake fell from approximately 1.5% of body weight to almost zero (Beatty et al. 2006), and from approximately 2.4% of body weight to 1.8% of body weight (Gaughan and Tait 2005). For camels, feed intake was not affected when exposed to high heat load (40°C) provided they had access to water (Guerouali and Filali 1995). However, water intake increased by 300%. Other studies have shown that water intake decreases when feed intake is reduced (Chaiyabutr et al. 1980; Kadzere et al. 2002; Mader and Davis 2004). Goats (and other species) respond to water restrictions by reducing feed intake and concentrating their urine (Ahmed and

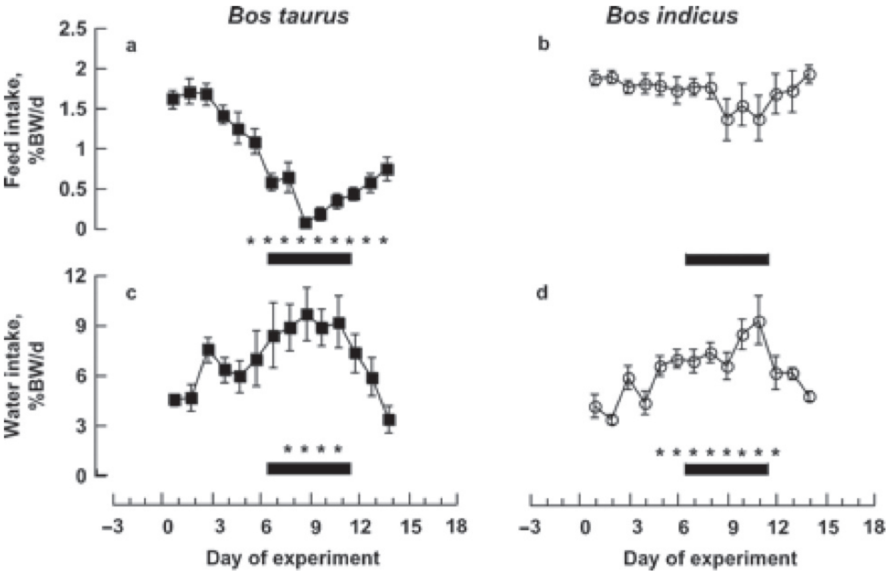

Fig. 7.8 Mean daily feed intake (**a** and **b**) and water intake (**c** and **d**) for *Bos taurus* and *Bos indicus* heifers. Points show the mean ± SEM for each of six animals. The horizontal bar under each figure indicates the hottest 5 days of the experiment. Asterisks under the data denote $P < 0.05$ for the day marked vs. the control days (days 1 and 2) (Beatty et al. 2006)

El Kheir, 2004). Offering warm rather than cool water has improved water intake of heat stressed animals in some cases (Lanham et al. 1986; Olsson and Hydbring 1996; Olsson et al. 1997). It is generally agreed that provision of good quality water is an important factor to manage nutrition during periods of high heat load.

7.7 Conclusions

The adaptive capabilities of animals and livestock production systems have been emphasized in this report. Biometeorology has a key role in rational management to meet the challenges of thermal environments for livestock production systems, whether in current or altered climates.

Understanding the responses of animals to environmental challenges is paramount to successful implementation of strategies to ameliorate negative impacts of climate change. Livestock managers have routinely dealt with intra- and inter-annual climate variability. The challenge will be dealing with on-going change and possible major climatic shifts. Livestock managers will need to consider both climatic conditions and resource availability (e.g. feed, water, veterinary care, financial, animals, people) when determining the best strategies to adopt. Animal managers need to be proactive, as we cannot wait for changes to occur – there is a need to act now to reduce the risk of longer-term changes to livestock industries around the world.

Summarizing, the most important element of proactive environmental management to reduce risk is preparation: (1) be informed – governments may need to fund training programs in regions where current livestock practices will no longer be viable; (2) develop a strategic plan – both short-term and long-term; (3) observe and recognize animal responses to climatic/nutritional conditions; (4) adopt farming practices to the changing conditions; and, (5) select animals (be prepared to change breeds/species) that are suited to the environmental and nutritional conditions. Livestock managers who adopt such a proactive approach will be better prepared for both current and future climates.

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