Chapter 7
Ameliorative Measures to Counteract Environmental Stresses

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Abstract The severity of heat stress on livestock production can be measured using certain weather parameters, which summate the intensity of heat stress exposure. Temperature-humidity-index (THI) is widely used to predict the severity of heat stress in domestic livestock. Reducing heat stress in livestock requires multidisciplinary approaches which emphasize animal nutrition, housing, and animal health. It is important to understand the livestock responses to environment, analyze them, in order to design modifications of nutritional and environmental management thereby improving animal comfort and performance. Researchers can attempt a variety of approaches to improve reproduction that involve modifying the environment (i.e., attempting to cool cows during reproduction), modifying the genetics of the animal (i.e., breeding of heat tolerant breeds), or intensifying reproductive management during periods of heat stress. Management alternatives, such as the strategic use of wind protection and bedding in the winter or sprinklers and shade in the summer, need to be considered to help livestock cope with adverse conditions. In addition to these changes, manipulation of diet energy density and intake may also be beneficial for livestock challenged by environmental conditions. Additionally, socio-economical status, technological tools, and financial infrastructure have instrumental roles in modifying environment stress. The ameliorative measures, to be incorporated, are therefore driven by socio-economical and environmental factors. This chapter addresses divergent sheltering methodologies that can be used to minimize the effects of multiple stresses, such as heat, nutritional, and health stress that an animal is exposed to.

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7.1 Introduction

The world's climate may be considered to consist of tropical, semitropical, temperate, and arctic zones/types. Each of these climatic zones represents complexes of physical or meteorological and biological factors, which constitute the natural environment. Each climate complex encompasses a multitude of plant and animal species that have evolved successfully by adaptive processes resulting from interactions with the meteorological environment (Kumar 2010). An environmental profile includes such factors as daily, seasonal, maximal and minimal temperatures, humidity, wind, radiation, length of season, and a biological assessment such as quality and quantity of protein and energy available. The physiological profiles are assessments of selected physiological processes, such as thermoregulation, hormonal balance, water balance, and energy balance. The fitting of the physiological or production profile to the environmental profile would be one basis for a 'bioclimatic' index. An animal residing in a region with a suitable bioclimatic index would be an individual with high physiological predictability for production of milk, growth, and reproduction under these environmental conditions. The application of meteorological and physiological principles to animal selection and management practices will increase availability of animal protein, especially in climatic-limiting zones of the world.

Heat stress is defined as the sum of forces external to a homeothermic animal that acts to displace body temperature from the resting state (Yousef 1984). Such stresses can disrupt the physiology and productive performance of an animal (West 2003). The increase in body temperature caused by heat stress has direct, adverse consequences on cellular function (Hansen and Arechiga 1999). Production losses in domestic animals are largely attributed to increases in maintenance requirements associated with sustaining constant body temperature, and altered feed intake (Mader et al. 2002; Davis et al. 2003; Mader and Davis 2004). Depending upon the intensity and duration of environmental stress, voluntary feed intake can average as much as 30% above normal under cold conditions, to as much as 50% below normal under hot conditions.

Increases in air temperature reduce livestock production during the summer seasons which may be partially offset during the winter season (Kadzere et al. 2002). Current management systems for ruminants do not usually provide as much shelter to buffer the effects of adverse weather conditions as for nonruminants. From that perspective, environmental management for ruminants exposed to global warming must consider: (1) general increases in temperature; (2) increases in night time temperatures; and (3) increases in the occurrence of extreme events (e.g., hotter daily maximum temperature and more/longer heat waves) (Nienaber and Hahn 2007).

Adaptation and mitigation strategies should contribute to reduced poverty and at the same time must benefit the most vulnerable communities without harming the environment (Das 2004). Information about climate change impacts, vulnerability patterns, coping, and adaptive capacity as well as facilitating location-specific adaptation and mitigation practices are of central concern.

7.2 Measurement of Severity of Heat Stress

The severity of heat stress on livestock production can be measured using certain weather parameters, which summate the intensity of heat stress exposure. The most noteworthy weather parameters included in such heat stress severity measurements are ambient temperature (including dry and wet bulb temperature) and relative humidity (Nienaber et al. 1999). Mathematical formulae have been developed by a variety of investigators to measure the severity of heat stress. Table 7.1 describes the different temperature-humidity-index (THI) used for evaluating heat stress effect on livestock.

All of these formulae calculate the heat stress severity in terms of scores on a 100 scale and compared on a standard THI chart to asses the stress imposed by the impending climatic condition on livestock over a period of time (Berman 2005). The THI has been used to represent thermal stress due to combined effects of air temperature and humidity and THI is used as a weather safety index to monitor and prevent heat stress-related losses (National Research Council 1971). Different livestock species have different sensitivity to ambient temperature and humidity. The capacity to tolerate heat stress is much higher in native breeds, particularly under higher temperatures at lower humidity than crossbred animals. This is mainly due to the fact that native breeds can dissipate excessive heat more effectively by sweating, whereas crossbreeds have reduced ability to sweat (Nienaber and Hahn 2007). The THI is used as a guide to measure heat stress by combining the effects of temperature and humidity into one value (Marai et al. 2001). There are three stress categories (temperatures given in Fahrenheit): Livestock alert is 75–78 degrees,

Table 7.1 Commonly used indices for evaluating heat stress effect on domestic animals

S.No.	THI indices	References
1	tdb + 0.36tdp + 41.5	Thom (1958)
2	(0.8 × Amb tem) + {[(RH/100) × (Amb tem − 14.4)} + 46.4	Thom (1959)
3	[0.4 × (Tdb + Twb)] × 1.8 + 32 + 15	Thom (1959)
4	(0.15 × Tdb + 0.85 × Twb) × 1.8 + 32	Bianca (1962)
5	(0.35 × Tdb + 0.65 × Twb) × 1.8 + 3.2	Bianca (1962)
8	0.55DB + 0.2DP + 17.5	Johnson (1965)
9	(Tdb + Twb) × 0.72 + 40.6	National Research Council (1971)
10	(0.55 × Tdb + 0.2 × Tdp) × 1.8 + 32 + 17.5	National Research Council (1971)
11	0.72(Td + Tdp) + 40.6	McDowell (1972)
13	Tdb + (0.36xTdp) + 41.2	Yousef (1985)
14	0.72(Td + Tw) + 40.6	World Mateorological Organization (1989)
15	db°F − {(0.55 − 0.55RH) (db°F − 58)}	LPHSI (1990)
16	(9/5 Temp°C + 32) − (11/2 − 11/2 × Humidity) × (9/5 Temp°C − 26)	Ravagnolo and Misztal (2000)
17	db°C − {(0.31 − 0.31RH) (db°C − 14.4)}	Marai et al. (2001)
18	t − {(0.31 − 0.31RH) (t − 14.4)}	Marai et al. (2002)
19	(0.85 × DBT + 0.15 × WBT) × $V^{-0.058}$	Tao and Xin (2003)
20	t air − [0.55 − (0.55 × RH/100)] × (t air − 58.8)	Oklahoma State University (2003)
21	Temp − (0.55 − (0.55 × (RH/100) × (Temp − 58)	Amundson et al. (2005)
22	BGHI = tbg + 0.36 tdp + 41.5	Buffington et al. (1981)
23	THVI = (0.85 × DBT + 0.15 × WBT) × $V^{-0.058}$	Tao and Xin (2003)
24	WBGTI = (0.7Twb) + (0.2Tbg) + (0.1Tdb)	Al-Tamimi (2005)
25	$HLI_{BG > 25}$ = 8.62 + (0.38 × RH) + (1.55 × BG temp) − (0.5 × wind speed) + ($e^{2.4 - \text{wind speed}}$)	Gaughan et al. (2008)
26	$HLI_{BG < 25}$ = 10.66 + (0.28 × RH) + (1.3 × BG) − wind speed	Gaughan et al. (2008)

Abbreviations: *THI* Temperature-humidity-index; *tdp* Dry bulb temperature; *twb* Wet bulb temperature; *tbg* Black globe temperature; *Tdp* Dew point temperature; *Tw* Wet bulb temperature; *Td* Dry bulb temperature; *RH* Relative humidity; *T air* Air temperature; *HLI* Heat Load index; *BG temp* Black globe temperature; *WBGTI* Wind black globe temperature index; *THVI* Temperature humidity and velocity index; *DBT* Dry bulb temperature; *WBT* Wet bulb temperature; *BGHI* Black globe humidity index

Livestock danger is 79–83 degrees, and Livestock emergency is 84+ degrees. Table 7.2 describes the different THI categories in *Bos taurus* cattle.

The higher the humidity the lower is the temperature for livestock alerts; for danger and emergency levels to occur. The two limitations in THI index are that it does not take into account the wind velocity and solar radiation. These two factors are vital meteorological variables that influence animal performance under semi-arid tropical environmental conditions. However, THI can be a reliable indicator for measurement of quanta of stress in livestock. Modifications to the THI have

Table 7.2 Different THI categories in *Bos taurus* cattle

THI category	Descriptive characteristics			
	Duration	THI[a] − h ≥ 79 (day)	THI[a] − h ≥ 84	Nighttime recovery (h # 72 THI[a])
1. Slight	Limited: 3–4 days	10–25	None	Good: 5–10 h/night
2. Mild	Limited: 3–4 days	18–40	#5/day	Some: 3–8 h/night
3. Moderate	More persistent (4–6 days usually)	25–50	#6/day	Reduced: 1–6 h/night
4. Strong	Increased Persistence (5–7 days)	33–65	#6/day	Limited: 0–4 h/night
5. Severe	Very Persistent (usually 6–8 days)	40–80	3–15/day on 3 or more successive days	Very limited: 0–2 h/night
6. Extreme	Very Persistent (usually 6–10 + days)	50–100	15–30/day on 3 or more successive days	Nil: #1 for 3 or more successive days

[a] Temperature-Humidity-Index (*THI*). Daily THI − h are the summation of the differences between the THI and the base level at each hr of the day. For example, if the THI value at 1,300 is 86.5 and the base level selected is 84, THI − h = 2.5. The accumu-lation for the day is obtained by summing all THI − h ≥ 84, and can exceed 24
Source Hahn et al. (1999)

been proposed to overcome shortcomings related to airflow and radiation heat loads. Based on recent research, Mader et al. (2006) and Eigenberg et al. (2005) have proposed corrections to the THI for use with feedlot cattle, based on measures of wind speed and solar radiation. While differences in the proposed adjustment factors are substantial, there are marked differences in the types and number of animals used in these two studies. Nevertheless, these approaches appear to merit further research to establish acceptable THI corrections, perhaps for a variety of animal parameters. Gaughan et al. (2002) developed a heat load index (HLI) as a guide to management of unshaded *Bos taurus* feedlot cattle during hot weather (>28°C). The HLI was developed following observation of behavioral responses (respiration rate and panting score) and changes in dry matter intake (DMI) during prevailing thermal conditions (Mader et al. 2006). The HLI is based on humidity, wind speed, and predicted black globe temperatures.

As a result of its broadly demonstrated success, the THI is currently the most widely accepted thermal index used for guidance of strategic and tactical decisions in animal management from moderate to hot conditions. Developing climatic indices of summer weather extremes (in particular, heat waves) for specific locations also provide livestock managers with information about how often those extremes (with possible associated death losses) might occur (Hahn et al. 2001). Panting score is one observation method used to monitor heat stress in cattle

(Mader et al. 2006). As temperature increases, cattle pant more to increase evaporative cooling. Respiratory dynamics change as ambient conditions change, and surrounding surfaces warm. This is a relatively easy method for assessing genotype differences and determining breed acclimatization rates to higher temperatures. In addition, shivering score or indices also have potential for use as thermal indicators of cold stress.

7.3 Measurement of Thermal Adaptability

The evaluation of adaptation to heat stress, based upon the lowest rectal temperature, respiratory frequency, and physiological variables as the main parameters under high temperatures, was found to be insufficient. The average relative deviations (ARD) from normal (regardless either positive or negative), due to exposure to hot climates, in thermal, water, and/or nitrogen balances of the animals (or in all traits measured), could be used in the estimation of parameters for detection of adaptability to hot climates (Habeeb et al. 1997; Marai and Habeeb 1998) as follows:

$$\text{Adaptability}\,(\%) = [100 - \text{ARD}] \times 100$$

In males, El-Darawany (1999) and Marai et al. (2006) used tunica dartos indices (TDI) to measure the ability of the male to tolerate increased ambient temperatures. The scrotum actively controls its own temperature through the function of the tunica dartos muscle which is interpreted as the distance between the testes and the abdominal wall. This muscle thus defines the magnitude of vascular heat exchange and is performed by the contraction of the tunica dartos muscle of the scrotum pulling the testes toward the body to increase its warmth, when the environmental temperature is low. During high ambient temperatures, the reverse process occurs in dissipating of the excess heat as much as possible from the testes (Taylor and Bogart 1988). The TDI can be used as an index to measure the ability of male to tolerate increased ambient temperatures, as it reflects the magnitude of vascular heat exchange.

7.4 Approaches for Alleviating Thermal Stress

Reducing heat stress on livestock requires multidisciplinary approaches which emphasize animal nutrition, housing, and animal health (Collier et al. 2003). Some of the biotechnological options may also be used to reduce thermal stress. It is important to understand the livestock responses to environment, analyze them, in order to design modifications of nutritional and environmental management thereby improving animal comfort and performance.

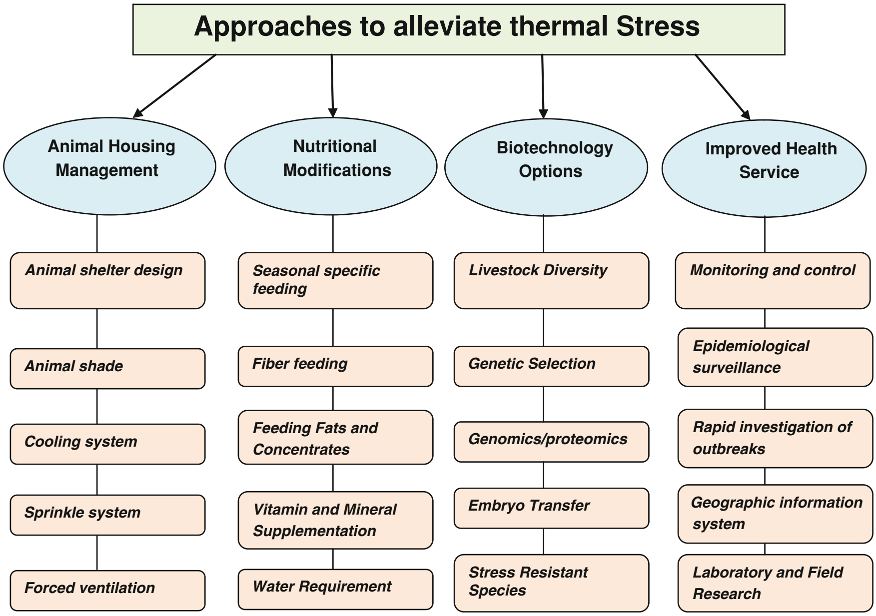

Fig. 7.1 Different approaches for alleviating thermal stress in livestock. The figure describes the various mitigation strategies to reduce the impact of heat stress in livestock. The strategies comprises of animal housing management, nutritional modifications, biotechnology options, and improved health services

So a range of technologies are needed, to match the different economic and other needs of small holders. Figure 7.1 describes the various approaches for ameliorating adverse effects of thermal stress on livestock.

7.4.1 Importance of Livestock Housing

Animal housing has been a matter of concern since livestock were domesticated. Its basic aim is to moderate the range of animal's microclimate and to optimize their production by protecting them from climate extremes. Consequently, animal housing should provide the 5 Freedoms (eating, resting, moving, voiding and respiring, and also comfort) to all types of stresses (climate, social, nutritional, and disease). House cannot be constructed frequently according to climatic needs. Hence, serious consideration of site selection, housing design, and future requirements for the livestock species to be reared at a particular locality are necessary (Sharma and Singh 2008). Loose housing with the provision of easy movement to and from sun in comparison to tie stall barn systems have been found appropriate to specific livestock species. Ambient temperature is the most important climatic variable affecting the design of the housing (Collier et al. 2006). The effects of temperature are observed in the form of radiation and photoperiods. About 50% of radiant energy is obtained by the animal from the sun, sky, and the rest from the earth and surrounding. Their effects are ameliorated by providing shade, shelters, and planting trees for shade. Roofing materials and their painting (outside or inside with black/white) can help in providing desired effects within the house. Roof and walls made of wood, thatch, bamboo, and mud radiate least heat in comparison to stone, concrete, asbestos, tin, and steel (Sharma and Singh 2008). In colder areas, animal houses should be of low height with wide overhanging and roof painted black. An overhanging of sufficient size is helpful in cutting down the effects of strong wind, chill, and rain into the house. Photoperiod directly and indirectly influences well-being of the animal and man. Orientation of the long axis of animal enclosures and paddocks as well as direction and size of main entry (gate) and windows decide the availability of photoperiod to animals. South facing houses receive more sunlight than north facing ones.

Air movement accelerates heat loss from animal's body, especially from the bare skin. Wind is harmful to unsheltered animals at low temperature, particularly when skin is wet. However, it is beneficial to nonsweating animal during hot weather. Serious health problems and production inefficiencies can arise at 30 km/h wind speeds (Sharma and Singh 2008). Therefore, protective measures in the form of shelter in hot, dry hot, and in temperate areas are required (Collier et al. 2006). Wind velocity is affected by local topography. In hill areas, the contours opposed to directional flow provides upward currents on the windward side. On steep slopes, reversed eddy currents over the crest and calm at the base are observed. An area on the base of leeward side is always better in areas of high wind velocity. In valley's, the forces of air are increased in core areas while on ridges the force is more at the peak. Therefore, selection of sites away from the core area and in depressions are useful in valley and ridge areas respectively (Sharma and Singh 2008).

The effects of humidity, both low (rapid evaporation, skin irritation, and general dehydration) and high (heat stagnation in confinement) are harmful to animals. In humid areas, animal housing should be open, having high roofs (spacious), airy and well-ventilated (von Borell 2001). Rainfall has direct and indirect effects on livestock production. Heavy rains increase humidity, reduces forage quality, grazing, and feed intake. Heavy rainfall areas are less suitable for animals possessing heavy coats. In such areas, the stilted, loose, airy, and ventilated and protective (from ecto-parasites) housing should be constructed as raised platforms.

7.4.2 Animal Shelter Design for Comfort

Physical modifications of the environment are based upon two basic concepts-protection of livestock from the factors contributing to heat stress, and enhancing evaporative heat loss by animals.

Differing environmental modification systems are classified according to their impacts on animal production and performance (Hahn 1981). One type are those systems that mitigate heat gain by radiation interception. Among the latter there is a range from forced air ventilation systems and those sprinkling or misting water, each separately, or some combination of these two systems, including evaporative cooling, and air conditioning.The various options are classified as follows:

1. Protective Methods
   - Natural shades
   - Artificial shade
2. Cooling methods

   2.1 Direct (cooling of the animal)

- Wetting the animal
- Forced ventilation
- Combination of ventilation and wetting

   2.2 Indirect (air cooling)

- Nebulizers
- Cross ventilation
- Wind tunnel
- Air conditioning

7.4.2.1 Protective Methods: Using Shades

The most obvious environmental modification to reduce the thermal stress of livestock during hot climate condition is the use of shade (Blackshaw and Blackshaw 1994). Shelter management is one of the key techniques for reduction of heat stress. Shade against direct solar radiation can be provided by trees like the banyan (*Ficus benghalensis)* or shelters made of straw and other locally available materials. Animals kept in or outside during summer are comfortable under tree shades that protect them from direct sunlight during peak hours of the day (Buffington et al. 1983). Tree shades provide an effective shelter to animals and moreover, plantation and forestation are beneficial to animals, humans, and the environment.

However, under grazing conditions the use of natural shades is not always appropriate, and is the reason that the use of artificial shades has come into use. Table 7.3 outlines comparative characteristics of natural and artificial shade systems.

Under grazing conditions, the artificial shades have proven effective in improving animal comfort and improving milk production (Valtorta et al. 1996, 1997). In this regard, at INTA Rafaela, Brondino et al. (2008) published a series of recommendations concerning design and construction of temporary housing facilities for animals, which are applicable to the conditions of the central dairy area of Argentina. In the case of permanent confinement systems, such as drylot or

Table 7.3 Some comparative differences between tree and artificial shade (*Adapted from* Valtorta and Gallardo 2004)

Characteristic	Tree shade	Artificial shade[a]
Shadow uniformity	Variable	High
Flooring	Natural soil	Consolidated
Resistance to ponding	Variable according to soil type	Good
Management of availability per animal	Complex	Simple
Availability after planning	Far	Immediate

[a] Considering a structure built following the proper design recommendations

free stall, earth movement to generate slopes is particularly important because of the volume of effluent to be handled routinely (Cook and Nordlund 2004).

Regardless of the management system, an appropriate measure to improve cow comfort is shades for holding pens. It should also be noted that milk production is a crucial period, during which there are a series of hormonal changes that lead to the ejection of milk. Any stressors during this period may alter this process. In the context of providing shade for holding pens, the results of the studies conducted in Argentina demonstrated (1) increased comfort as evidenced by the technical guidance note, which, at the time of maximum air temperature, reached 44°C in sunlight and under nets; (2) lower temperature of concrete floors, which at 1,500 h, reached an average of 52°C without shading and 27°C under shades. Shade is also important during evening milking due to marked increases in solar radiation, in addition to heat emitted by extremely hot floors and crowding of animals in confined areas (Schütz et al. 2010).

Properly designed shade structures provide adequate protection to livestock in the heat of summer and in winter (Armstrong 1994). For tropical climatic conditions, loose housing systems are considered most appropriate (Hahn 1981). The longer sides of the shelter should have an east–west orientation (Schütz et al. 2010). This orientation, reduces encroachment of direct sunlight shining on the side walls or when entering the shelter (Ugurlu and Uzal 2010). However, if mud is an issue, then north to south orientation will increase drying as shade moves across the ground during the day. In such situations animal shelters should be shielded from direct sunlight as much as possible by means of side covers of gunny bags or thatch (Schütz et al. 2010). In addition, the roof can be extended with additional shade material, and vertical shades moved to the outsides of the roof. Such devices result in improved protection from direct solar radiation and sun. The west side of the shed can also be protected similarly and fitted with side covers of gunny bags or curtains. The height of the shed structure should be greater than 2.4 m tall to allow sufficient air movement underneath the shade (Schütz et al. 2010). However, tall structures (more than 30.5 m high) are not economically viable.

Other ways to remove hot air trapped under the roof, inside the shed include outer coverings and shading, perhaps combined with a roof spray, are popular greenhouse technologies which can be applied in the structural design of shed to reduce the height of the shed. There are also a variety of roof systems giving improved natural ventilation by means of roof openings, enhanced solar chimney effect, etc. (Schütz et al. 2010). In addition, painting the roof white increases reflection of sunlight thus reducing the amount of solar energy absorbed. Increasing air flow is another important component for effective ventilation in animal shelters. In an animal shed air movement should be free in all areas of the shed (Bryant et al. 2007). To increase air flow, two main approaches may be used. One is the installation of fans so that air movement is increased, and the second is to provide open sides of the shed. In many cases walls of the shed may be made partially of concrete. In such situation, opening the lower level of the barn to increase air flow is not an option, so the addition of fans is essential to increase air circulation (Bryant et al. 2007). In sheds where sheet metal is used for walls, it may be practical to remove the side and install netting over these areas. The netting can be raised to increase air flow during the summer and lowered during the winter. Increasing the roof venting is yet another option that may be used for animal sheds. Another approach which can be used, similar to housing used for human, is the double wall approach. In this strategy, extra wall layers at either end of shed is constructed and the outer layer is kept 10 cm away from the inside wall, with vertical openings at both ends. The bottom opening allows cold air to enter, and the upper opening allows hot air to exit. The 10 cm of air between the two walls provides a thermal barrier to prevent conductive thermal energy from entering the animal house (Bryant et al. 2007). The double wall approach is an effective and proven technology in structural design for increasing or reducing ambient temperatures.

7.4.2.2 Cooling Methods

In addition to providing adequate shade, use of water as a cooling agent is an effective method for reducing heat stress of livestock particularly under dry heat/ lower humidity and to keep their body temperature as cool as possible. Evaporative cooling can be accomplished by two approaches: (1) direct evaporation from the skin surface of the animal and (2) indirect evaporation involving cooling the microenvironment of the animals with cooling pads and fans in an enclosed shed.

Direct Methods

Wetting the Animal

Some studies report beneficial effects of wetting or misting animals through sprinklers during periods of high temperature. In Mexico, a region of sub-humid tropical climate, there was a 7% increase in milk production in cows sprinkled between 12:00 and 13:00 h under the shade. Also, positive results were reported in few studies conducted in Missouri when animals were sprinkled between 11:00 and 17:30 during moderate summer. In Israel, when cows were sprinkled for 1 h, four times a day, it relieved heat stress as evident from the increased milk production. In Australia when the cows were watered every time the temperature exceeded 26°C, similar effects were observed (Davison et al. 1996).

Sprinkling maximizes the amount of heat removed from the animal through evaporative cooling at reduced water costs (Gaughan et al. 2008). In addition, the ambient air temperature is lowered in the area immediately surrounding the animal, increasing the heat gradient and increasing the effectiveness of non-evaporative cooling mechanism (Morrison et al. 1981). To achieve adequate heat loss when sprinkling, droplets must wet the hides of the animal as accumulation of water in the hair may increase the humidity around the animal and reduce effective heat loss (Means et al. 1992). High pressure irrigation-type sprinklers can improve inexpensive wetting of animals, especially when coupled with fans, to increase air movement (Nienaber and Hahn 2007). However, cooled animals have limited ability to adapt to warm condition and may become reliant on sprinkling to keep cool even in milder conditions (Gaughan et al. 2008). Cessation of sprinkling during the day on hot days may increase the heat load in cattle, even though ambient temperature and humidity may decrease (Gaughan et al. 2008). Altering the microclimate of the sprinkled area helps in improving the well-being of feedlot cattle under extreme environment condition by reducing body temperature. Therefore, one point which should be kept in mind while using evaporative cooling system in hot and humid subtropical region is that cooling requires the use of forced ventilation.

Forced Ventilation

When there is no sufficient natural ventilation, the layer of air closest to the animal, warms. This reduces the rate of heat dissipation from the surface of the animal to the environment. The role of fans is to increase heat loss by convection. Therefore, ventilation is effective when the air temperature is lower than body temperature.

Fans should be located mainly in:

- The holding pen
- The milking parlor
- The resting pen (if any)
- The feeding area, the flow being directed toward the back of the animals.

Fans can reduce the body temperature by 0.3–0.4°C, provided that the temperature of the provided air is lower than the surface temperature of the animal. However, fans are not sufficient to reduce conditions of heat stress in high producing dairy cows in hot weather (Mader et al. 2007).

However, when working in high humidity environments, consideration should be given to any system introducing water into the environment as it may produce negative effects because water will evaporate, further increasing the humidity and saturating the air. It is for this reason that evaporative systems are designed to combine forced ventilation with wetting.

Combination of Forced Ventilation and Wetting

This system is based on the most important route of heat loss, which is evaporation from the surface of the skin under high temperature conditions.

It is important to consider how heat loss is enhanced on combining sprinkling and forced ventilation. Each gram of water evaporated from the skin of the animal represents a loss of 56 calories. However, there are large differences in the amount of water that evaporates through differing mechanisms:

- Passive diffusion, or perspiration, evaporating about 30 g/h, representing 16.8 kcal/h
- Active transpiration evaporates 170 g/h, equivalent to 95.2 kcal/h
- Wetting + forced ventilation evaporates 1,000 g/h, which means a loss of 560 kcal/h

This system is effective in all types of weather (dry and humid), since the forced high speed of the air allows drying of cows and prevents air saturation.

The combination of sprinklers and fans are suitable for both confined and grazing animals. In the latter case it can be implemented in holding pens.

Indirect Cooling Methods

Nebulizers

Nebulizers are a low-cost evaporative cooling system, characteristic of poultry houses. This process is based upon producing mists of fine droplets that must evaporate before reaching the ground, so as to cool the air in contact with animals. Some of these droplets may be deposited on the surface of the animal coat, which could alter insulative properties (Hahn 1985). However, if nebulization ensures substantial air movement, the system could lead to improvements in the environment for milk production in cows (Armstrong 1994).

Cross Ventilation

In this system, one of the side walls of the barn consists of a large refrigerated water panel, while on the opposite wall there are large pumps, as those used in poultry barns. These pumps expel the stale indoor air and force it to enter through the chilled panel, thus air-conditioning the barn.

Wind Tunnel

Wind tunnels are characterized by air inlets in one end of the barn and exhaust at the other end (Smith et al. 2006). This technology is based on the principle of increasing evaporative heat loss by removing excess heat and humidity of the air directly in contact with animals. It can provide adequate cooling in temperate climates (Stowell et al. 2001), but should be combined with other methods of cooling in warmer environments. Significant effects of the combination of evaporative cooling through the wind tunnel effect in swine and poultry facilities have been reported. Brouk et al. (2003) used the combination of wind tunnel with evaporative cells to cool dairy cows and reported significant reductions in rectal temperature and breathing rates during the afternoon and evening. Smith et al. (2006) also observed an increase of 2.4 kg milk/cow/day with this cooling system in the southeastern United States, where both temperature and humidity are high.

Air Conditioning

The use of this cooling system, for 24 h, produced a 10% increase in milk production in subtropical environments (Collier et al. 2006; West 2003). However, the costs associated with air-conditioning, together with the facilities necessary to provide a closed environment, or the conditioning ducts for zonal cooling, have made this technology a failure.

Order of Priorities for the Cooling of Cows

According to Catalá (2010), when different categories of animals are handled separately, the order of priority for cooling is the following:

1. Fresh cows (first 3 weeks postpartum)
2. Close pre-partum cows (3 weeks prepartum)
3. High producing cows (first 100 days)
4. Cows in mid lactation (100–200 days)
5. Dry cows (from dry to 3 weeks before delivery)
6. Late lactation cows (over 200 days)

An important aspect to consider is how long it takes to amortize the investment made in cooling systems. In intensive systems (free-stalls or dry-lot) this aspect has been very well-studied. In the U.S. and Israel, they believe that if the annual production increases 5–10%, the return on investment is between 2 and 3 years. If the increase is 20% the return on investment is 1 year (Catalá 2010). In pastoral or mixed systems, the analysis must consider that the cooling systems will not have permanent use. In many cases, this makes it difficult to determine the incidence of the costs involved in the cooling system.

A majority of livestock are kept by the smallholder farmers. Hence the above-mentioned protective measures may be unaffordable under most of the small and marginal farming conditions. Then alternative cost-effective systems can also be used like water application or sprinkling before milking, wallowing in case of buffaloes and low cost, renewable energy operated evaporative cooling systems can be used. So combinations of fans, wetting, shed, and well-designed housing can help alleviate the negative impact of high temperatures on animals in the tropics.

7.4.3 Nutritional Modification to Combat Heat Stress

7.4.3.1 Feed Requirement

During hot dry summer there is decrease in dietary feed intake which is responsible for reduced productivity. In these situations, the efficient practical approaches like frequent feeding, improved forage quality, use of palatable feeds, good nutritient balance, and greater nutrient density are required (Beede and Shearer. 1996). However, feeding excessive quantities of nutrients, like crude protein, can contribute to reduced efficiency of energy utilization, potentially adding to stress levels. Likewise if less forage is consumed, and the forage is high in quality, the cows' rumination activity may decrease. So, a through understating of dietary modification to minimize heat stress is necessary (NRC 2001).

Heat production from feed intake peaks 4–6 h after feeding. Therefore heat production in animal feed in the morning will peak in the middle of the day when environmental temperature is also elevated (Brosh et al. 1998). Consequently, it has been suggested that feeding animals later in the day prevents the coincidence of peak metabolic and environmental heat loads (Reinhardt and Brandt 1994; Brosh et al. 1998). Furthermore, limiting energy intake can effectively decrease basal metabolic heat production (Carstens et al. 1989) and therefore decrease total metabolic heat load of animals subjected to high environmental temperature.

7.4.3.2 Concept of Cold Diets

A cold diet is one that generates a high proportion of net nutrients for the synthesis and decreases heat generated during fermentation and metabolism. The salient features of a cold diet are:

1. Higher energy content per unit volume
2. More digestible fiber
3. Effective fiber (NDFef)
4. Lower protein degradability
5. More bypass nutrients.

In contrast, hot diets are characterized by marked imbalances between the basic nutrients: energy and protein. In general terms, hot diets may have a high proportion of undigestible fiber, accompanied in some cases with low protein concentration and/or energy. Also, they may be characterized by low NDFef with highly degradable protein, in relation to the amount of carbohydrates available in rumen.

In other cases, there are hot diets with a high proportion of rapidly degradable carbohydrates (starch and soluble sugars) in relation to the available nitrogen in rumen. These diets, in which lack of synchronization between nutrients, lead inevitably to lower conversion efficiency. Table 7.4 describes the differences between the two types of diet discussed.

During hot weather, declining DMI and high locational demand requires increased dietary mineral concentrations and further minerals are more easily depleted during hot summer months (Collier and Beede 1985). The increase in respiration will cause excessive water losses, thereby reducing mineral concentrations. As a result, mineral should be made available, 24 h a day during the summer. Potassium, sodium, magnesium, copper, selenium, zinc, and phosphorus levels should be supplied in the feed. Nutritional tools, such as antioxidant feeding (Vit-A, selenium, zinc etc.) and ruminant specific live yeast cultures can help in

Table 7.4 Characteristics of cold and hot diets

Diet characteristics	Cold	Hot
Digestibility	High	Low
Fiber	Low	High
Proteins	Low degradability	High Degradability
Minerals	High Na^+ and K^+	Low Na^+ and K^+
Examples	Tender pastures, high grain silages, high fat concentrates	Mature Pasture, Fibrous hays and silages, High fiber concentrates

protecting the animals against heat stress (Nayyar and Jindal 2010). Studies showing the addition of antioxidants in the diets of cows are able to reduce heat stress apart from limiting mastitis, optimizing feed intake, and reducing the negative impact of heat stress on milk production. Moreover, the use of antioxidants, such as Vit-E, Vit-A, selenium, and selenium enriched yeast help reduce the impact of heat stress on the redox balance, resulting in improved milk quality and cow health. A recent study in cattle showed that the supplementation of Vit-E helps in reducing the heat stress and improves the antioxidant status and lowers the incidence of mastitis, metritis, and retention of placenta (Sathya et al. 2007). During periods of heat stress, the incidence of rumen acidosis is increased particularly in high producing cows maintained on high concentrate diets (West 2003). Factors contributing to rumen acidosis problems in cow are related to DMI decreases, particularly lower forage intake and higher levels of fermentable carbohydrates (Patra 2007). Decreased rumination and decreased salivary activity reduces the buffering capacity of the rumen. Lowered rumen pH associated with subacute neous rumen acidosis (SARA) impairs fiber digestion efficiency due to pH effects on rumen fibrolytic bacteria (Krause et al. 2009). Table 7.5 describes the general feeding management practices to be followed for ruminants in hot climate.

7.4.3.3 Fiber Feeding

Because there is greater heat production associated with metabolism of acetate compared with propionate, there is a logical rationale for the practice of feeding low fiber rations during hot weather. Feeding more concentrate at the expense of fibrous ingredients increases ration energy density and reduces heat increment (Magdub et al. 1982). Altered proportions of ruminal volatile fatty acids (VFA) may explain a part of the differences in heat increment with fiber feeding during heat stress (Beatty 2005). VFA constitute a large proportion of the energy available to the cow, and declining intakes during heat stress reduces the quantity of VFA in the rumen because fermentable carbohydrate is reduced. Increased feeding of concentrates is a common practice during conditions conducive to heat stress, but maximal benefit from concentrates appears to be approximately 60–65% of the diet (Coppock 1985). Excessive concentrate feeding leads to acidosis and the

Table 7.5 General feeding management of ruminants in hot climate

Increase number of feeding
Feed will be fresh
Stimulate cows to come to manger
Select suitable time of feeding
Having fresh feed after milking
Feeding more feed during night time
Feeding a total maintenance ration (*TMR*)
Well-balanced combination for heat stress cows
Fiber is limited
Only good quality roughage is used
Provide good condition for fermentation
Under shade managers are preferable

associated production, health, and metabolic difficulties. The large amount of highly fermentable carbohydrate fed in typical high-concentrate diets should minimize the heat production observed in the very high fiber diets, which were used in research settings (Mader et al. 2002). Although high fiber diets contribute to heat stress, the level of intake is far more critical to the total amount of metabolic heat produced. Growing heifers fed pelleted rations containing 75% alfalfa or 25% alfalfa produced 48.8 and 45.5 MJ/d of heat (Reynolds et al. 1991). However, when the low and high intake (4.2 and 7.1 kg/d DMI) heifers were compared, heat production was 38.2 and 56.1 MJ/d. Therefore, intake effects have a substantial effect on heat production and must be considered in designing an effective nutritional and environmental management program. Research suggests that lower fiber, high grain diets may indeed reduce metabolic heat production and contribute to lower heat load in the animal (Holt et al. 2004). Further, low fiber, high grain diets provide more efficiently used end products, which contribute to lower dietary heat increments (Mader et al. 2002). However, low fiber, high grain diets must be balanced with the need for adequate fiber to promote chewing and rumination to maintain ruminal pH and cow health (Beatty 2005).

7.4.3.4 The Role of Effective Fiber

One of the main components of the dairy cow diet is fiber. The importance of fiber is that it is necessary for:

1. Adequate rumination activity (through the flow of adequate saliva)
2. Appropriate relationships between the main products of rumen fermentation, volatile fatty acids
3. Regulatory capacity of the ruminal acidity (ability to buffer or buffer capacity)
4. Modulation of the rate of passage and digestion of small particles in the ration.

The fiber in forage represents the plant cell wall and is determined in the laboratory as the component called neutral detergent fiber (NDF) (Holt et al. 2004).

Research pertaining to fiber requirement for animals must take into account not only its chemical function, such as nutrient precursor of VFA, but also its mechanical action (Mader et al. 2002). The NDFef is the fraction of NDF that affects chewing, rumination, insalivation, rumen pH, and movements (mixing cycle) (Holt et al. 2004). Because of the important functions of the effective fiber and the negative effects of heat on rumen function, cows are more likely to have subclinical ruminal acidosis during summer, especially when receiving rations with low forage: concentrate ratio. With less NDFef in the diet, reduced rumination activity and reduced saliva buffer capacity lead to lower rumen pH and often decrease the concentration of milk fat (West et al. 1999). Although forages are the main source of fiber, when they are ground and/or pelletized, NDFef can be seriously limiting, due to the small size of the particles (Beatty 2005). Furthermore, ground and pelletized feeds stimulate less salivation and cud chewing (Patra 2007).

On the other hand, if dietary fiber exceeds 40% NDF, consumption and rates of passage and digestion will be altered, because of the rumen fill effect, thus depressing appetite. This effect also depends on the nature of the fiber, being higher for those from mature forages or megatherm grasses (van Soest 1994). Exceptions are maize and sorghum due to their high grain content.

The NDFef can be measured indirectly by measuring the size and homogeneity of the particles. For the TMR diets, methods to make these measurements have been developed in the United States. One is the Penn State particles separation system, a shaker box, which has set of four screens, three of which have holes of different sizes and fourth collector or bottom pan (Heinrichs and Kononoff 2002).

When operating the system, the particles of the TMR are separated into four groups:

1. Top screen: retains particles larger than 2 cm
2. Screen 2: retains particles between 0.8 and 2 cm
3. Screen 3: retains particles between 0.2 and 0.8 cm
4. Bottom pan: retains particles smaller than 0.2 cm

The proportions of particles that are retained in each screen indirectly represent the mechanism of ruminal digestion. The particles retained in the top plate identify the coarse particles floating in the rumen, which contribute to chewing and insalivation. Middle screens include moderately digestible particles and the bottom pan collects the particles that are easily digestible or removable from the rumen.

According to the Penn State separation system guide (Heinrichs and Kononoff 2002), if a sample of an adequate corn silage-based TMR was separated, the proportion of the particles, on a moist basis, retained in each plate would be: upper screen 7–10%; second screen 40–50%; third screen less than 35% and bottom pan less than 20%. However, these recommendations are only guides and, these recommendations should be determined for different agro-ecological regions since the characteristics of the components of the diets vary from region to region.

Under grazing conditions, it is a common practice to provide small quantities (1.5–2 kg/cow/day) hay along with silage and concentrate mixes for high producing cows to substantially improve their performance. In summer, this management is particularly recommended because the pattern of grazing imposes a strong selectivity of the animal to consumption of leaves, which do not represent a source of NDFef (Heinrichs and Kononoff 2002).

7.4.3.5 Feeding Fats and Concentrates

The addition of fat to the diet of lactating dairy cows is common practice, and the higher energy density and the potential to reduce heat increment of high-fat diets may be particularly beneficial during hot weather (Beatty 2005). There are studies demonstrating that dietary fat can be added to the ration at up to 3–5% without any adverse effects to ruminal microflora (Collier et al. 2005). Improved efficiency and lower heat increments should make fat especially beneficial during hot weather. Ruminally protected fats allow the inclusion of a substantial quantity of fat in the diet, which could lower heat increment significantly.

7.4.4 Water Balance and Water Requirements

Water is the most essential element for the survival of animals. Water requirements for livestock can be met in three ways:

1. Metabolic water, derived from the oxidation of organic substrates and tissue
2. Water contained in food
3. Drinking water.

In any event the first route is the most important in quantitative terms and in summer it is by far the largest source. During the summer, any factor that limits access to water, directly affects the production of milk, which will fall sharply, mainly in high producing cows. Cows with water restrictions manifest higher body temperature, with a degree of heat stress higher than normal. Furthermore, water consumption and dry matter intake are closely related (NRC 2001). Under intense heat, ingestion of large volumes of water provides comfort to the animals by reducing the temperature of the rumen reticulum.

Dairy cows normally drink large amounts of water, but with intense heat they could take more than 120 L/day (NRC 2001). In a landmark study conducted in climatic chambers, it was recorded that water consumption of lactating cows increased by 29% when the temperature rose from 18 to 30°C. Concomitantly, fecal water loss decreased 33%, but losses via urine, skin, and respiratory tract increased by 15, 59, and 50%, respectively.

Regarding minerals, heat-stressed cows increase their need for Na^+ and K^+, due to the electrolyte imbalance generated at the cellular level. The higher needs of Na^+ are attributed to increased production of urine that, as explained above, reduces the plasma concentration of aldosterone (Sanchez et al. 1994). Instead, the increased demands for K^+ are attributable to an increased removal of this element with sweat.

In lactating cows fed a diet based on corn silage, hay, and concentrates, typical of many production models, it was found that the main factors that determined water intake were: dry matter consumed; the level of milk production, temperature and Na^+ intake. The following equation (NRC 2001) shows these relationships:

$$\begin{aligned} \mathrm{WI} &= 16 + [(1.58 \pm 0.271) \times (\mathrm{DMI})] + [(0.9 \pm 0.157) \times (\mathrm{MP})] \\ &\quad + [(0.05 \pm 0.023) \times (\mathrm{Na}^{+})] + [(1.20 \pm 0.106) \times (\mathrm{T_{md}})], \end{aligned}$$

where

WI	Water intake (kg/day)
DMI	Dry matter intake (kg/day)
MP	Milk production (kg/day)
Na^+	sodium (g/day)
T_{md}	daily minimum temperature (°C)

The quality of drinking water is often one of the causes limiting its intake. Water quality is measured in chemical, bacteriological, and physical terms, through laboratory tests. To avoid significant production losses, each of these aspects must be carefully and regularly evaluated. Regarding chemical composition, the concentration of total dissolved solids (TDS) and the prevalent salts represent the quality factors that can seriously limit milk production in many regions. Ingestion of water with high levels of TDS is bad for dairy cattle, with a pronounced effect during hot weather (THI > 72); (NRC 2001). There is a controversy regarding the maximum levels of salts that affect the performance of dairy cows. For high producing cows (>35 l/day) water with TDS > 7,000 mg/l would not be suitable, but would have little effect on low producing animals (<25 l/day) (Bahman et al. 1993; NRC 2001). Experiments conducted in Israel (Solomon et al. 1998) showed that water with TDS above 4,000 mg/l produced negative effects on cows producing an average 35 l/day, when temperature was above 30°C.

The information available in Argentina (Taverna et al. 2001) indicates that under grazing conditions, water with 7,000–10,000 mg/l TDS, with 20–30% of sulfate, had little effect on productivity, for cows producing below 30 l/d.

All sulfate salts (Ca++, Na+, Mg++), when exceeding 1,500 mg/l, can decrease productivity because they have a laxative effect, the most potent being sodium sulfate. However, livestock, drinking water high in sulfates, (1,000–2,500 mg/l) initially suffer diarrhea, but then a process of habituation begins.

Moreover, ingestion of "light" water, i.e., very low in TDS, is also detrimental to productivity, especially when levels of sodium chloride are very low.

The temperature of drinking water could be another factor limiting intake. For example, in an experiment conducted in Texas, (Wilks et al. 1990) it was observed that cows drinking water cooled to 10°C presented lower respiration rates (70 vs. 81 rpm), lower rectal temperatures in the afternoon (39,8 vs. 40.2°C), and higher milk production (26.0 vs. 24.7 l/cow/day), as compared to animals drinking water at 27°C.

7.4.5 Biotechnology Options

The adverse effect of heat stress on livestock production had further increased in the recent years due to global warming. The desirable proposition in the present scenario is thus to develop thermotolerant animal breeds utilizing recent technology advances.

7.4.5.1 Livestock Diversity

In spite of livestock being reared in tropical environment, there are local indigenous breeds of livestock which can effectively perform countering environmental extremes. These local breeds can perform well in adverse climatic condition like high temperature, drought, and feed scarcity. Therefore, even under the changed climate scenario, the rich animal germplasm available may help to sustain the livestock productivity. In addition, there is a need to take up breeding programmes to develop climate change ready breed which performs better under stress caused due to climatic variability by using available rich germplasm.

7.4.5.2 Embryo Transfer

The reproductive efficiency of livestock is negatively influenced by high ambient temperatures resulting into silent; short estrus and hence low conception rate (Rutledge 2001). In this situation, we can use the embryo transfer technology in which in vitro produced embryo or embryo derived from donors, not exposed to high ambient temperature was used. With this technology, encouraging results have been obtained as a means to reduce adverse effect of heat stress on fertility (Al-Katanani et al. 2002). Caution should however be exercised as transfer of an embryo with non-compromised quality to a recipient subjected to the effects of the heat stress does not eliminate negative effect on endocrine axis and uterine environment. Moreover, embryo transfer is often not an economically or technically viable option for many countries in high temperature zones.

7.4.5.3 Genomics/Proteomics

Genomic and proteomic study play an important role to understand mechanism of thermoregulation and delineation of genes conferring superior thermotolerant capability in different livestock species. Earlier, attempts were made to evaluate histological response of skin to heat stress, association analysis of hair length and heat stress, embryonic resistance to heat stock, identification and characterization of heat stress response-related genes in cattle. Among the various proteins, the expression of heat shock protein (HSP) 70 is strictly stress inducible and can only be detected following a significant stress upon the cell and organisms (Satio et al. 2004; Khoei et al. 2004). The HSP70 helps in conferring the thermo adaptability and high level of thermotolerance. A recent study has shown that intracellular HSP70 expression in buffaloes is similar to the other livestock species. Higher intensity and duration of thermal exposure cause the higher HSP70 induction in buffalo lymphocytes to maintain cellular homeostasis with a threshold of thermal dose for maximum HSP70 expression (Patir and Upadhyay 2010). A few isolated studies have been carried out on heat stress-associated genes/transcripts (Lacetera et al. 2006; Moran et al. 2006; Collier et al. 2008).

The recent advancement in global expression technologies (whole genome arrays, RNA sequencing) is poised to be effectively utilized to identify those genes that are involved in key regulatory/metabolic pathway for thermal resistance and thermal sensitivity. Gene knockout technology will also allow better delineation of cellular metabolic mechanism required for acclimatization to thermal stress in dairy animals. By knowing the various genes responsible for thermotolerance we can change the genetic structure of animal and drift toward superior thermotolerant ability.

7.4.6 Improved Health Service

Increase in temperature and humidity due to climate change is strongly associated with emerging and re-emerging animal diseases by (1) increasing the numbers and geographic movement of insects (Culicoides imicola) that are major vectors of several arboviruses (e.g., bluetongue and African sickness); (2) increasing the survival of viruses from one year to the next; (3) improving conditions for new insect vectors that are now limited by colder temperatures (Mellor and Wittmann 2002; Colebrook and Wall 2004; Gould et al. 2006). These factors lead to production losses. Thus, improved disease control strategies and health services at larger scale are required.

As human, animal, and environmental health is interrelated therefore, strengthened communication and cooperation among professionals in these areas would be particularly valuable as we seek to predict, recognize, and mitigate the impact of global climate change on infectious diseases. For prevention, monitoring, and control of livestock diseases good data exchange mechanism are required at both state and national level. These should cover the distribution of animal diseases, ecological conditions including climate, and associated drugs and chemotherapeutants. In this contest, epidemiological surveillance is a critical component and it not only involves the early identification of emerging diseases and trends but also for resource planning and measuring the impact of control strategies. A global approach to epidemiological surveillance should be taken and should involve collaboration between professionals involved in human, animal, and environmental health. Of particular importance is the rapid investigation of unusual outbreaks. Such surveillance programmes are essential in allowing us to recognize and respond to emerging risk to climate change. It allows us to know what to expect and to be prepared with the right strategy in place and this might be a case of isolating the diseases and enforcing restriction zones.

We can also use the geographic information system (GIS) by which we can both monitor the level of stress and how our climate is changing and monitor the spread of diseases. We can use it to look for periods of heavy rainfall using a spatial analyst and illustrate it using GIS. This system tells us which pathogens will flourish, under their preferred condition. This tool can also help to pinpoint period of continually high minimum temperature. For example, in Israel 2000, the minimum temperatures were a key factor in the west Nile Virus outbreak and high night time temperatures were a feature of the 2003 heat wave in Europe. Likewise predictive modeling system can also be used to predict the probability of an outcome. It has potential to predict the probability of global climate change on ecological system and emerging hazards. Furthermore, laboratory and field research will also help in illuminating how climate changes influence pathogen characteristics, and models will help researchers and producers predict and plan for pathogen threats.

7.5 Conclusions

This chapter elaborates on ameliorative strategies that should be given consideration to prevent economic losses incurred due to environmental stresses on livestock productivity. Further, this chapter details the issues of imperfect information about the impact of climate and vulnerabilities, and the need for informed decisions on "resilient adaptation" by merging adaptation, mitigation, and prevention strategies. It offers new perspectives for policy-makers, institutions, societies, and individuals on improved ways of identifying most at risk communities and "best practices" of coping with current climate variability and extreme climate events.

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