

Strategies for Managing Livestock under Environmental Stresses in Drylands of India

A.K. Misra*, A.S. Sirohi and B.K. Mathur

Central Arid Zone Research Institute, Jodhpur 342 003, India

Received: December 2012

Abstract: Many factors affect livestock production in drylands. Variability in climate is one of the main limiting factors of production efficiency. The important environmental stressors include (i) heat stress due to direct effects of high temperature and solar radiation on animals, and (ii) nutritional stress due to adverse effects of low rainfall and frequent droughts on crops and rangelands. Heat stress is one of the major causes that can negatively affect both production and reproduction in livestock, especially in animals of high genetic merit. Sustainable development in drylands can only be achieved through optimum utilization of its natural resources. Major advances in management strategies, including improved housing and feeding manipulations, can attenuate the effect of thermal stress on livestock performance. The efficiency of these management strategies depends on several factors related to the animal (species, physiological stage and breed) and the livestock production system (intensive vs. extensive systems). Maximizing the production level and the efficiency of livestock enterprises is important; however, economic considerations largely determine the level of environmental manipulation selected for livestock production systems.

Key words: Drylands, environmental/heat stress, livestock, management strategies.

About 69% of India's total geographical area is under drylands (arid, semi-arid and dry sub-humid). India's drylands contribute 44% of the food grain production and support 40% of the human and 65% of the livestock population (Singh *et al.*, 2004). The farming systems in dryland are quite diverse with a variety of crops and cropping systems, agroforestry and livestock production. Drylands, besides being water deficient, are characterized by high evaporation rates, exceptionally high day temperature during summer, low humidity, high run off and soil erosion. The dryland areas of India suffer from the problems of (i) frequent droughts due to high variability in the quantum and distribution of rainfall, (ii) poor soil health due to continued degradation and inadequate replenishment of nutrient exhaustion, (iii) low animal productivity due to an acute scarcity of fodder and (iv) low risk bearing capacity of farmers due to poor socio-economic base, credit availability and infrastructure. However, the nature has endowed dryland areas with some of the best breeds of cattle (Tharparkar, Kankrej, Rathi, etc.), sheep (Marwari, Chokla, Magra, Malpura, etc.), goats (Sirohi, Marwari, Kutchi, etc.) and other species of livestock. It is

also endowed with nutritious perennial grasses and shrubs (Singh *et al.*, 2004).

Livestock production is an integral part of dryland agriculture in India. Livestock plays multiple roles in drylands livelihood system and economy, and have a strong human dimension, as manifested through socio-cultural link and involvement of women (Rangnekar, 2006). Besides their well-established role in agriculture, livestock have crucial role in food security and as risk aversion mechanism for sustaining family, whenever there is crop failure (Misra *et al.*, 2006). They enable poor and landless farmers to earn income using common-property resources, and provide a constant flow of income and reduce the vulnerability of agricultural production (Holmann *et al.*, 2005). The poor natural resource base of drylands makes the people and livestock vulnerable to environmental stresses and directly impacts livelihoods of people.

Many factors affect livestock production in dryland areas. Climatic environment is one of the main limiting factors of production efficiency in these areas. The extreme climatic conditions will impose various stresses on animals, which will adversely affect their

*E-mail: akmisra@cazri.res.in

performance. The important environmental stresses include (i) heat stress due to direct effects of high temperature and solar radiation on animals, and (ii) nutritional stress due to the negative effect of lower rainfall and more droughts on crops and on pasture growth, reducing quantity and quality of feed. The most important aspect of the temperature effects is heat stress, which is caused by high ambient temperature and aggravated by high relative humidity (Fig. 1). The increasing concerns on production losses because of high ambient temperature (T_a) is justifiable not only for hot arid area but also for cold region in which heat stress is an occasional problem during summer months. According to the modeling result of the Intergovernmental Panel on Climate Change (IPCC, 2007), the likelihood of heat wave events is projected to increase both in number and in intensity. The increase in global average surface temperature by 2100 may be between 1.8°C and 4.0°C. These predictions suggest that the negative effects of heat stress on livestock production will become more apparent in the future, and livestock systems based on grazing (extensive production system) and mixed farming systems (semi-intensive production system) will be more affected by environmental stress than an industrialized system (intensive system).

The present paper reviews the impact of environmental stress particularly heat stress, and effective strategies to minimize the impact

in the context of livestock production in drylands of India. The review is divided into two parts. The first one deals with the effect of hot climate on livestock performance and the second part describes the coping strategies available for reducing the effect of thermal stress in farm animals.

Characterization of Climatic Environment

The animal's climatic environment is complex. T_a alone cannot be a representative measure of thermal environment and relative humidity (RH), solar radiation and wind speed must also be considered. The researchers attempt to define it in an index value representing the influence of sensible and latent heat exchanges between the animal and its environment. Heat exchange could be accessed directly from physiological measurements (rectal and skin temperatures, respiratory rate, panting and heat production) or indirectly from animal performance (growth rate and milk production) that are related to the animal's ability or inability to efficiently cope with acute or chronic hot conditions.

The average annual temperature in most parts of the country is 25°C or higher which is at or above the thermal-comfort zone of cattle and buffaloes for maximum milk yield (Sirohi and Michaelowa, 2007). In India, the upper temperature limit of comfort zone for maximum milk production is 27°C (Dutt *et*

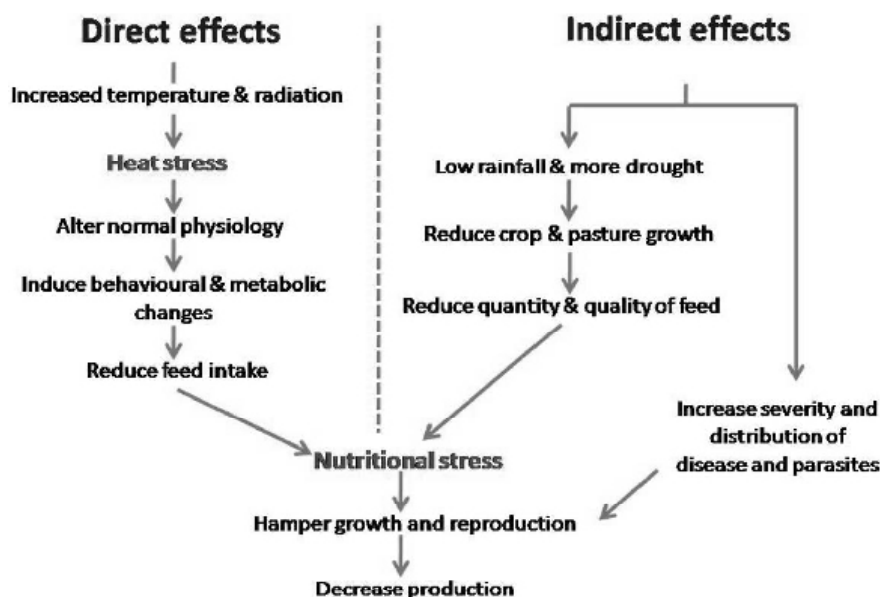


Fig. 1. Effect of environmental stress on livestock productivity (Naqvi and Sejian, 2011).

al., 1992), about two degrees higher than the same reported in temperate countries. This is perhaps, because the crosses of some exotic breed (Brown Swiss, Jersey and Friesian) with native Indian breeds have to some extent, adapted to climatic conditions in the country. However, the average annual temperature is higher than this upper critical limit in several dryland areas of the country. For India, climate change projections with a doubling of carbon dioxide concentration in the atmosphere suggest temperatures are expected to increase between 2.3 and 4.8°C, along with increased precipitation (Lonergan, 1998). Further, the temperatures are expected to rise for all the months of the year. These conditions, especially the more hot-humid climatic conditions and the rise in summer (April to June) temperature (which already ranges from 25 to 45°C maximum daily temperature in most parts of the country), would plausibly aggravate the heat stress in animals and further adversely affect their productive and reproductive performance.

Thermoregulatory Processes

Farm animals are homeotherms as they can keep relatively constant body core temperature within narrow limits despite wide variations in climatic environment. Thermoregulation is the balance between heat production and heat loss mechanisms that occur to maintain a relatively constant body temperature (T_b). Under high thermal conditions, animals reduce heat storage by reducing metabolic heat production and improving heat losses by latent and sensible pathways. Metabolic heat production (HP) is the sum of maintenance requirement and heat generated for production purposes. Maintenance requirement is traditionally considered to be proportional to the metabolic BW and body surface. However, it is also affected by other factors such as T_a , physiological stage (e.g. growing vs. lactating animals) and health status. Except for maintenance, energy is used for the production of meat, milk, eggs, wool and fat tissue. As the efficiency of metabolizable energy (ME) utilization for maintenance and production is not equal to 100%, the ME not retained in the body or in product is lost as heat. The utilization of ME above maintenance depends on the partition of energy into protein and lipid synthesis. Typically, the energetic efficiency for protein deposition is much lower than that for lipids

(van Milgen and Noblet, 2003). Thus, total HP depends on the animal BW, and on the level and the kind of production.

An animal can lose heat by evaporation, conduction, convection and radiation. Although for evaporation the main driving force is the level of humidity in the surrounding air, for convection, radiation and conduction it mainly depends on the thermal gradient between the animal surface area and the surrounding air (radiation and convection) and objects (conductance). In both cases, the body surface area that is in contact with the surrounding environment also plays a crucial role in the efficacy of the heat loss process. When submitted to high temperatures, animals adjust their blood flow to favor heat loss, for instance by increasing blood flow toward skin (Collin *et al.*, 2001). The increase in T_a makes heat transfer by conductive, convective, and radiative exchanges less effective because the reduction of the required minimal thermal gradient between skin and air temperature for exchange (Hillman *et al.*, 1985). In addition, it must be considered that in very humid tropical areas, any evaporation process will be less efficient and mainly sensible heat loss may reduce heat load. However, there is no doubt that heat loss by water evaporation is an efficient means of heat transfer to the hot environment. About 2.4 kJ heat is lost for every gram of water vaporized. Animals can evaporate water from the skin and through the respiratory tract. The early response of an animal is to increase its respiratory rate and thus the respiratory evaporative heat loss. First, a rapid shallow breathing called thermal polypnea leads to an increase in the amount of air passage through the upper region of the respiratory tract. When temperature continues to rise, this thermal polypnea shifts to a slower deeper panting phase (thermal hyperpnea) characterized by an increase of alveolar ventilation rate. This thermal hyperpnea improves the evaporative heat loss increasing the respiratory minute volume, but also results in respiratory alkalosis in the blood and may lead to a moderate-to-severe dehydration. Skin evaporation can occur by both passive and active processes. In passive conditions, water diffuses through the skin with a direction that depends on the vapor pressure gradient and the rate of ventilation. Cattle and sheep have a greater density of

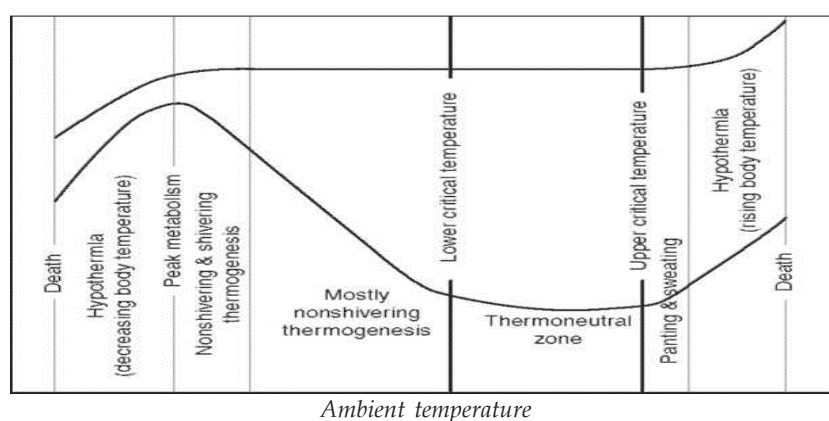


Fig. 2. Effect of ambient temperature on animal metabolism and body temperature (Renaudeau *et al.*, 2012).

sweat glands than pigs (800 to 2000/cm² and 250/cm², respectively; Amakiri and Mordi, 1975) and respond to heat stress by secreting sweat on the skin surface.

The relationship between T_a and the balance between heat production and heat loss is schematically illustrated in Fig. 2. The thermoneutral zone (TNZ) is the interval of thermal environment, usually characterized by T_a over which heat production is relatively constant for a given energy intake. The lower and upper limits of the thermoneutral zone are called the lower (LCT) and the upper critical temperature (UCT), respectively. When ambient temperature increases above the UCT, the animal can no longer control its T_b and this severe hyperthermia can be lethal. However, it must be taken into consideration that in domestic animals it is almost impossible to determine the TNZ as a result of their outstanding production, which obviously leads to difficulties to maintain dynamic steady state. The effects of high T_a on T_b depends on the type of exposure: in case of acute heat exposure, T_b will rapidly increase up to critical values (Renaudeau *et al.*, 2012).

Physiological Response to Heat Stress

In drylands, animals are reared under extensive or semi-intensive system of management with a constant exposure to natural climatic conditions. In such conditions, heat stress is caused by a combination of environmental factors (temperature, relative humidity, solar radiation, air movement and precipitation). Stress has been defined by Dobson and Smith (2000), as the inability of an animal to cope with its environment, a phenomenon

which is often reflected in a failure to achieve genetic potential. Rosales (1994) defined stress as the cumulative detrimental effect of various factors on health and performance of animals. The degree to which an animal resists change in body temperature varies in different species because of differences in their heat regulating mechanisms (Salah *et al.*, 1995). Animal responses vary according to the duration and the intensity of the thermal challenge. In cold arid region, short-term changes in physiological, behavioral and immunological functions are required to survive acute stressful events such as summer heat waves. The severity of these short thermal challenges depends on the magnitude (intensity $\times$ duration) of heat wave events and the possibility of recovering during the cool night time period. In contrast, under hot arid conditions, livestock are heat challenged most of the time. The long-term thermoregulatory responses underlying heat acclimation (or acclimatization) increase the physiological strains, which in most cases are accompanied by reduced performance. These responses include a reduction of metabolic rate, changes in the cardiovascular system, efficient alteration in heat loss (vasomotor response: vasodilatation response), changes in behavior response and in the general morphology of the animal (Fig. 3).

Sweating, high respiration rate, vasodilation with increased blood flow to skin surface, elevated rectal temperature, reduced metabolic rate, decreased DM intake, efficiency of feed utilization and altered water metabolism are the physiological responses that are associated with negative impacts of heat stress on production and reproduction in dairy animals

(West, 1999). High metabolic demands during lactation can also impact the oxidative status of dairy cows. Researchers have reported higher oxidative stress in high-producing dairy cows (Lohrke *et al.*, 2005) when compared to average-producing dairy cows. Stage of lactation has also been found to affect the oxidative status of the animal. Buffaloes have poor heat tolerance capacity compared to other domestic ruminants, and are more prone to heat stress due to scarcely distributed sweat glands, dark body color and sparse hair on the body surface (Das *et al.*, 1999). The water buffalo has only 1/10th the number of sweat glands per unit area of skin compared to zebu cattle and must rely on wallowing or wetting to the skin during heat conditions to reduce the heat load. Air temperature (13-18°C), RH (55-65%) and wind velocity (5-8 km h⁻¹) are the optimum conditions for buffaloes (Payne, 1990).

Increasing air temperature above the critical threshold is related with reduced feed intake, decreased activity, milk yield (Umphrey *et al.*, 2001) and a deleterious effect on the physiologic status (West, 2003) of farm animals. Physiological parameters like respiration rate, heart rate, body temperature and skin temperature give an immediate response to the thermal stress and consequently, the level of discomfort/comfort to the animal. These responses have been used as a measure of dairy cow comfort and adaptability to an adverse

environment or as a sensitive physiologic measure of environmental modification. The ability of an animal to withstand the rigors of heat stress under warm conditions has been assessed physiologically by changes in body temperature, respiration rate and pulse rate (Sethi *et al.*, 1994).

Rectal body temperature

Change in rectal temperature has been considered an indicator of heat storage in animal's body and may be used to assess the adversity of thermal environment, which can affect growth, lactation and reproduction of dairy animals (West, 1999). Rectal temperature (RT) and skin temperature have been reported to fluctuate much more in buffaloes than in tropical cattle under increased ambient temperature (Koga *et al.*, 2004). Even a rise of less than 1°C in RT was enough to reduce performance in most livestock species which makes the body a sensitive indicator of physiological response to heat stress because it is nearly constant under normal conditions. Body temperatures beyond 45-47°C are lethal in most species (Shebaita and El Banna, 1982). Joshi and Tripathy (1991) noticed an increase in RT from 102.0°F to 103.8°F when buffalo calves were exposed to 40.5°C for eight hours daily for three months. The RT and respiration rates of buffaloes were significantly higher during direct sun exposure than the values obtained

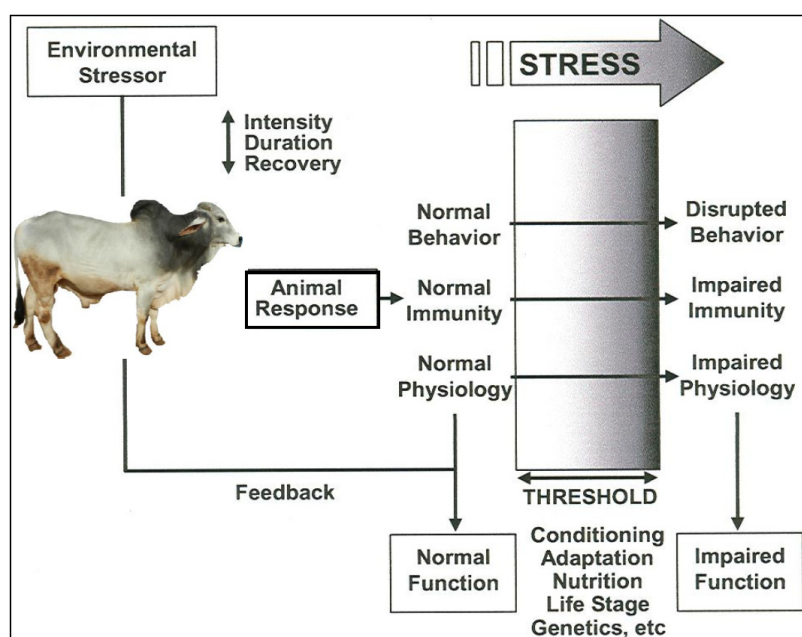


Fig. 3. Response of animals' environmental stressors on performance and health (Hahn, 1999).

when the animals were kept under shade in the barn (Gudev *et al.*, 2007). Therefore, when kept in the barn the buffaloes maintained their RT within the thermoneutral zone at the expense of higher respiratory rate. The RT was higher during summer (39.83°C) than autumn (38.30°C) in lactating cows (Padilla *et al.*, 2006). High relative humidity reduced the effectiveness of the evaporative cooling, and the high relative humidity coupled with high environmental temperature apparently overwhelmed the capacity of the cow to maintain normal body temperature (West *et al.*, 1999). The high RT observed for the heat stressed animals was the indicator of disturbance in the homeothermic status of the animals which was not being effectively countered by the enhanced heat loss by physical and physiological processes of thermolysis (Joshi and Tripathy, 1991).

Respiration rate

Respiration rate (RR) was the indicator of heat stress in the hot environment and gave significant correlations with circulating corticoids concentration (Kumar, 2005). Normal RR is approximately 10-30 breaths/minute. The RR increased when the environmental temperature increased. An evaporative heat loss from the respiratory tract is regarded as one of the primary mechanisms for maintenance of heat balance. This respiratory response arises from direct heat stimulation of peripheral receptors, which transmit nervous impulses to the thermal centre in the hypothalamus. A high RR in most cases did not necessarily indicate that the animal is successful in keeping its body temperature constant, but rather indicated that it is already overheated and trying to restore normal heat balance. A higher RR of 71.5/minute during summer compared to 38.8/minute in winter was recorded in lactating cows (Padilla *et al.*, 2006). RR increased from 29 to 59/minute when male buffalo calves were exposed to 40.5°C (Joshi and Tripathy, 1991). The increase in respiratory frequency was two and half times in heat stressed animals than control animals. Das *et al.* (1999) observed an increase in RR from 14 to 70/minute in the month of June in murrah buffalo calves when exposed to direct sunlight for six hours.

Pulse rate

Pulse rate (PR) did not exhibit consistent and a definite trend with changing environmental

conditions, however, increased moderately during exposure to hot environment in buffaloes (Joshi and Tripathi, 1991). There was a higher PR during summer months and lower during winter months in Indian buffalo bulls. Chikamune and Shimizu (1983) reported an increase in PR with an increase in T_a in swamp buffaloes. This increasing trend in PR continued even when the ambient temperature declined indicating that the physiological responses of animals returned to their normal levels only after a definite period when animals were brought to comfort zone. Environmental temperature has significant relation to the variation in the PR. The result of their studies indicated that average values of PR were higher during summer and lower during winter. Heart rate of calves increased during exposure to severe heat. Upadhyay *et al.* (2008) observed a positive correlation ($r=0.234-0.768$) between T_a and RR and PR in buffaloes. The seemingly contradictory finding that heart rate responds to heat exposure either by a rise or by a fall may be largely explained by the fact that heart rate is positively correlated with metabolic rate.

Measurement of Thermal Stress: Temperature Humidity Index

The temperature humidity index (THI) was developed to measure the combined effects of air temperature and humidity associated with the level of thermal stress on animal (Thom, 1959):

$$\text{THI: } 0.8t_{\text{db}} + \text{RH}(t_{\text{db}} - 14.4) + 46.4$$

where, t_{db} : dry bulb air temperature (°C) and RH: relative humidity in decimal form.

Animal stress level due to temperature rise has been worked out using THI in India (Dutt, *et al.*, 1992; Upadhyay *et al.*, 2008; CAZRI, 2012; Fig. 4). The THI values <72 are considered comfortable (normal), and THI values >72 and <78 are considered as stressful (alert) and THI >78 and <83 are considered very severe (danger), and THI values >84 are considered extreme (lethal) heat stress to the animal. Reactions of homeotherms to moderate climatic changes are compensatory and are directed at restoring thermal balance (West, 1999). However, when the environmental temperature becomes near the animal's body temperature, high ambient relative humidity reduces evaporation, overwhelms the animal's

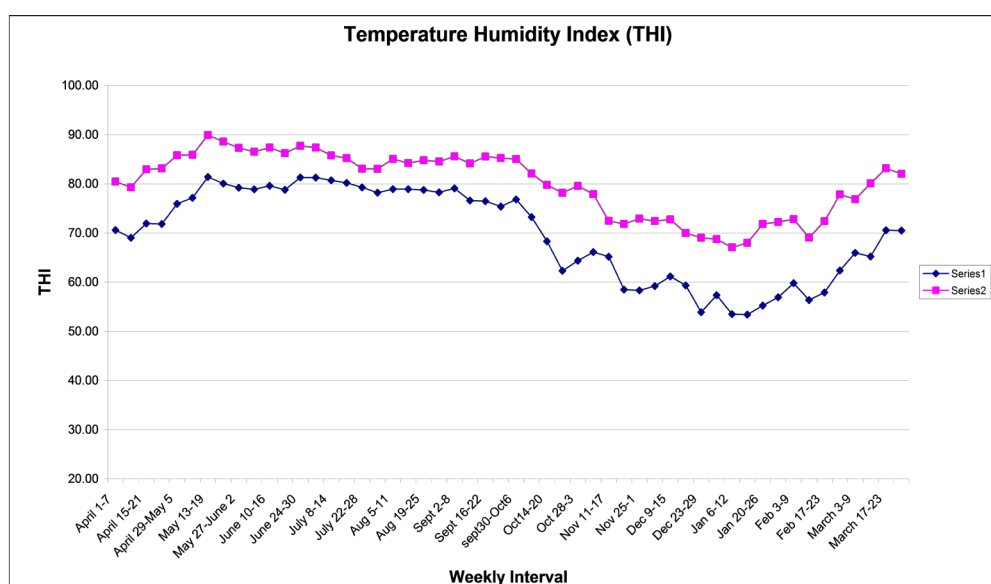


Fig. 4. Weekly THI values recorded at CAZRI, Jodhpur (CAZRI, 2012).

cooling capacity and the body temperature rises.

All animals have a range of ambient environmental temperatures termed the thermoneutral zone and temperature below or above this thermoneutral range of the animal creates stress conditions in animals. Analysis of stress level revealed that for 160-165 days during the year average THI was less than 65 in northern India and for about 50 days the THI ranged between 66 and 70. THI remained more than 70 for 40-42 days and THI ranged between 75 and 80 for 95-100 days during the year. The uncomfortable THI (>80) due to high temperature was observed for about 40 days in a year. Climate change scenario constructed for India revealed that temperature rise of about 4°C is likely to increase uncomfortable days (THI >80) from existing 40 days (10.9%) to 104 days (28.5%) for Had CM3-A2 scenario and 89 days for B2 scenario for time slices 2080-2100. This change in THI has a negative impact on the livestock production both directly and indirectly (Srivastava, 2010).

Effects of Environmental Stress on Livestock Productivity

Physiological and metabolic adjustments resulting from the thermoregulatory responses to a thermal stress have negative consequences on animal productivity and health. Under hot arid condition, the reduced animal performance is largely because of both direct

and indirect effects of heat stress on reducing feed intake (Fig. 1). In *ad libitum*-fed animals, the reduction in heat production related to consumption and metabolic utilization of feed is an essential mechanism to maintain T_b within a physiological safe range. The related low energy and nutrient intakes mainly explain the reduction in production under heat stress. However, a portion of the reduced performance is because of a direct effect of high temperature (independent of feed intake) on reproductive physiology, health, energy metabolism and on protein and fat deposition. The decrease in growth rate associated with thermal stress is primarily a result of a decline in feed intake, although a slight increase in feed conversion ratio at very high-temperature level has been reported (Renaudeau *et al.*, 2011; Choubey and Kumar, 2012).

Milk production

A thermal environment is a major factor that can negatively affect milk production in dairy cows, especially in animals of high genetic merit. Because of their very high metabolic rate associated with milk production, high-producing dairy animals (crossbred cows and buffaloes) are more vulnerable to heat stress. According to Kadzere *et al.* (2002), feed intake in lactating cows begins to decline at a threshold T_a of 25°C to 26°C. Johnson (1987) showed a linear reduction of dry matter intake (DMI) and milk yield when THI exceeded 70. The reductions were -0.23 and -0.26 kg day⁻¹ per unit of THI

for DMI and milk yield, respectively. Studies, carried out in climatic chambers, described a decrease in milk yield of 35% in mid-lactating dairy cows (Nardone *et al.*, 1992), and of 14% in early lactating dairy cows (Lacetera *et al.*, 1996) kept under heat stress conditions. Milk yield and TDN intake decline slightly when the THI exceeds 72 and decline sharply when THI exceeds 76 (Pathak and Prasad, 2012). Milk yield declines when body temperature exceeds 38.9°C, and for each 0.55°C increase in rectal temperature, milk yield and TDN intake decline by 1.8 and 1.4 kg, respectively (Pathak and Prasad, 2012).

Studies carried out at NDRI, Karnal, revealed that a temperature rise of 1.0 or 1.2°C with minor change in precipitation during March - August for India (Region 23- HADCM3 A2/B2 scenario) will marginally affect milk production and during other months productivity will remain relatively unaffected (Srivastava, 2010). A sudden change in temperature, either a rise in Tmax during summer i.e. heat wave or a fall in Tmin during winter i.e. cold wave; causes a decline in milk yield. Both increase in Tmax (>4°C above normal) during summer and decline in Tmin (>3°C than normal) during winter negatively impact milk production of crossbred cattle and buffaloes. The decline in yield varies from 10-30% in first lactation and 5-20% in second and third lactations. The extent of decline in milk yield occurs less at mid lactation stage than either late or early stage. The negative impact of cold wave or heat wave on milk yield of buffaloes are not only observed on next day of extreme event, but also on the subsequent day(s), thereby indicating that heat and cold waves cause short to long term cumulative effect on milk yield and production in cattle and buffaloes. Therefore, global warming due to climate change with increased number of stressful days (THI more than 80) and increase in frequency of warm days will impact yield and production of cattle and buffaloes (Upadhyay *et al.*, 2007).

Research has also indicated that the effects of a given temperature on milk production are maximal between 24 and 48 h following heat stress (Collier *et al.*, 1981). It has also been reported that ambient weather conditions two days before milk yield measurement had the greatest correlation to decreases in milk production and dry matter intake (West,

2003). The negative effect of heat stress on milk production is primarily explained by a reduced nutrient intake and a decrease of nutrient uptake by the portal-drained vein (McGuire *et al.*, 1989). Using pair-feeding techniques (Rhoads *et al.*, 2009) showed that the reduced feed intake accounts for only 35% of the milk production decrease under heat stress. The reduced milk production in hot season is accompanied by a decrease in milk protein contents related to a decrease in casein fraction (Bernabucci *et al.*, 2002).

The increase in milk yield increases sensitivity of cattle to thermal stress and reduces the "threshold temperature" at which milk losses occur (Berman, 2005). This is because metabolic heat production increases as the production level of a cow increases (Kadzere *et al.*, 2002). Coppock *et al.* (1982) concluded that high-producing dairy cows are affected more than low-producing cows, because the zone of thermal neutrality shifts to lower temperatures as milk yield, feed intake and metabolic heat production increase. The stage of lactation is an important factor affecting dairy cows' responses to heat. Johnson *et al.* (1988) observed that the mid-lactating dairy cows were the most heat sensitive compared to their early and late lactating counterparts. In fact, mid-lactating dairy cows showed a higher decline in milk production (38%) when the animals were exposed to heat. Calamari *et al.* (1997) observed a decline in milk yield of 11-14%, 22-26% and 15-18% in early (after the 1st month), middle and late-lactating dairy cows, respectively.

Milk production traits in ewes seem to have a higher negative correlation with the direct values of temperature or relative humidity than THI. The values of THI, above which ewes start to suffer from heat stress, seem to be quite different among breeds of sheep (Finocchiaro *et al.*, 2005). Solar radiation seems to have a lesser effect on milk yield, but a greater effect on yield of casein, fat and clot firmness in the milk of ewes (Sevi *et al.*, 2001). Above 72 THI value milk protein content declines, whereas the response of fat yield seems delayed and results are very contradictory. High air temperatures even affect goats, reducing milk yield and the content of milk components. In particular, if lactating goats are deprived of water during the hot season, they activate an efficient mechanism for reducing water loss in

urine, milk and by evaporation, to maintain milk production for a longer time (Olsson and Dahlborn, 1989).

Animal growth and reproduction

The rise in environmental temperature will negatively impact growth and time to attain puberty of livestock species. In addition to this the reproductive efficiency of livestock is also negatively influenced by high ambient temperatures. The negative impact of THI rise on animals growing at higher rates (500 g day⁻¹ or more) will be more than slow growing (300-400 g day⁻¹) cattle. Moreover, heat stress may reduce the fertility of dairy cows in summer by poor expression of oestrus due to a reduced estradiol secretion from the dominant follicle developed in a low luteinizing hormone environment (de Rensis and Scaramuzzi, 2003). A drop of about 20-27% in conception rates can occur in summer (Chebel *et al.*, 2004) or a decrease in 90-day non-return rate to the first service in lactating dairy cows (Al-Katanani *et al.*, 1999). The crossbred cattle have been observed to be more sensitive to rise in temperature and humidity than either Zebu cattle or buffaloes. Time to attain puberty was observed to prolong from 5 to 17 days due to decline in growth rate at high temperatures. The reproductive rhythm of buffaloes may have impacts of temperature rise and variability as number of buffaloes in silent estrus has been

observed to increase with increase in THI, and conception rate declined with an increase in THI above comfortable levels. Buffaloes at high ambient temperatures have been reported to fail in conceiving due to silent heat or poor expression, loss of conception, causing long dry periods and calving intervals. A temperature rise of more than 2°C in unabated buffaloes may cause negative impacts due to low or desynchronized endocrine activities particularly pineal-hypothalamo-hypophyseal-gonadal axis altering respective hormone functions (Upadhyay *et al.*, 2008).

Heat stress compromises oocyte growth in cows by altering progesterone, the secretion of luteinizing hormone and follicle-stimulating hormone and dynamics during the oestrus cycle (Ronchi *et al.*, 2001). Heat stress has also been associated with impairment of embryo development and increased embryo mortality in cattle (Fig. 5: de Rensis and Scaramuzzi, 2003). Heat stress during pregnancy slows down growth of the foetus and can increase foetal loss, although active mechanisms attenuate changes in foetal body temperature when mothers are thermally stressed. Amundson *et al.* (2006) examined the effects of environmental conditions during breeding season on pregnancy rate and reported a reduction in pregnancy rate when the average daily minimum temperature and average daily THI were equal to or exceeded 16.7°C and 72.9, respectively.

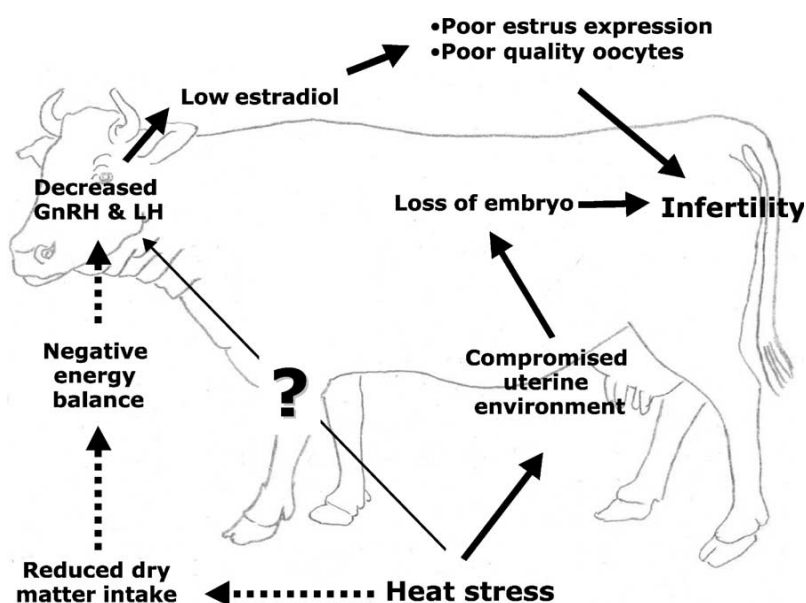


Fig. 5. A schematic description of the possible mechanisms for the effect of heat stress on reproduction in the lactating dairy cow (de Rensis and Scaramuzzi, 2003).

Roy and Prakash (2007) reported a lower plasma progesterone and higher prolactin concentration during oestrus cycle in Murrah buffalo heifers. They concluded that prolactin and progesterone profiles during the summer and winter months were directly correlated with the reproductive performance of buffaloes, and that hyperprolactinaemia might cause acyclicity/infertility in buffaloes during the summer months due to severe heat stress. Semen concentration, number of spermatozoa and motile cells per ejaculate of bulls were lower in summer than in winter and spring (Mathevon *et al.*, 1998). Nichi *et al.* (2006) reported higher percentage of major sperm defects during summer than the winter in Simmental and Nellore bulls.

In contrast to dairy animals, less information about the effects of heat stress on sheep and goats is available in the literature, mainly because of their minor importance with regard to milk production. Sheep and goats appear to be less susceptible to heat stress than other domesticated ruminant species in relation with unique characteristics such as water conservation capability, potential water loss up to 35% of total body water content (Shkolnik and Choshniak, 2006), higher sweating and respiratory rate and lower basal heat production (Kadzere *et al.*, 2002). Whereas cattle are considered stressed above a THI of 72, the threshold for heat stress in sheep is 82 (Marai *et al.*, 2007). Sheep evolving in a semi-arid environment can easily handle high T_a , but have great difficulty with the combination of high T_a and humidity. Sheep are also panting animals and develop respiratory alkalosis under conditions of high T_a and concomitant high respiration rates (Marai *et al.*, 2007).

Livestock diseases

Direct impact of environmental stress includes the temperature related illness, morbidity and mortality of animal during extreme weather condition. Indirect impacts of climate change follow more intrinsic pathways or drivers that influence microbial density and distribution, distribution of vector borne diseases and decrease in the host resistance to infection. High T_a is likely to cause an increase in incidence of animal diseases (bacterial, protozoan and viral diseases) that are spread by insects and vectors due to temperature

and humidity rise in tropical and subtropical climatic conditions. Frequency and incidence of mastitis affecting crossbred cows and other high producing animals may increase due to increase in number of stressful days. Gaughan *et al.* (2009) reported a higher occurrence of mastitis and foot diseases in dairy cows during periods of heat stress and they hypothesized that hot conditions could favor the development of pathogens responsible for mastitis and/or have negative effects on the animals' immune response.

Heat-stressed cows generally exhibit altered blood acid-base chemistry as a result of the shift in cooling from sensible heat losses to evaporative cooling. Panting results in a respiratory alkalosis, and is compensated by an increase in urinary bicarbonate excretion leading to decline in blood bicarbonate concentration. This reduced concentration of bicarbonate compromises the buffer capability associated with the bicarbonate system that may cause metabolic acidosis problems, especially during summer when cows are fed diets rich in concentrate in order to compensate the low feed ingestion (West, 2003). In addition, heat-stressed dairy cattle can lose a large amount of K via sweat, whereas feed consumption is reduced and K requirement for milk synthesis is high. This could result in K deficiency with detrimental consequences on health and performance (Beede and Collier, 1986). Helminth infections, particularly of small ruminants will be greatly influenced by changes in temperature and humidity. Climate changes could also influence disease distribution indirectly through changes in the distribution of livestock. Areas becoming more arid would only be suitable for camels and small ruminants. If these species are forced to aggregate around water points, the incidence of parasitic diseases could increase (Thornton *et al.*, 2009).

Feed and fodder resources

A major direct effect of environmental stress on feed resources can have a significant impact on livestock productivity, the carrying capacity of rangelands, grazing management, the buffering ability of ecosystems and their sustainability. The main pathways under such stress can affect the availability of feed resources for livestock are as follows:

Changes in land use pattern

As temperature increases and rainfall increases or decreases (depending on location) and becomes more variable, the niches for different crops and grassland species change. These effects can have substantial effects on animal productivity and on the maintenance of livestock assets. The land-use changes can lead to a different composition of animal diets and to a change in the ability of smallholders to manage feed deficits in the dry season. These two effects can have substantial effects on animal productivity and on the maintenance of livestock assets.

Changes in the primary productivity of crops and rangelands

This is probably the most visible effect of climate change on feed resources for ruminants. However, the effects are different depending on location, production system and on crop and pasture species. In C_4 plants, increases in temperature up to 30-35°C will, in general, increase the productivity of crops, fodders and pastures, as long as the ratio of evaporation to potential evapotranspiration and nutrient availability do not significantly limit plant growth. In C_3 plants, such as rice and wheat, temperature effects have a similar effect but increases in CO_2 levels will also have a significant (positive) impact on the productivity of these types of crops (IPCC, 2007). For food-feed crops, since harvest indexes change with the amount of biomass produced, the end result for livestock production is a change in the quantity of grains and stovers and availability of metabolisable energy for dry season feeding.

Changes in species composition

Species composition in rangelands and some managed grasslands is an important determinant of livestock productivity. As temperature and CO_2 levels change, the optimal growth ranges for different species also change; species alter their competition dynamics, and the composition of mixed grasslands changes. For example, in the temperate regions and subtropics, where grasslands often contain C_3 and C_4 species, some species are more prominent than others in the summer, while the balance of the mix reverts in winter. Small changes in temperature alter this balance significantly and often result in changes in livestock productivity.

The proportion of browse in rangelands may increase in the future as a result of increased growth and competition of browse species due to increased CO_2 levels (Morgan *et al.*, 2007).

Quality of plant material

Higher temperatures increase lignification of plant tissues and therefore reduce the digestibility and the rates of degradation of plant species (Minson, 1990). This leads to reduced nutrient availability for animals and ultimately to a reduction in livestock production, which may have impacts on food security and incomes through reductions in the production of milk and meat for smallholders.

Strategies to Minimize Effects of Heat Stress in Farm Animals

The livestock employ physiological mechanisms to counter the heat stress. The physiological mechanisms are also complemented by the behavioral process, for example buffaloes use wallowing during summer to reduce thermal loads and maintain thermal equilibrium. Goats are more adapted to harsh and drier conditions and have greater resistance to dehydration than temperate animals (Devendra, 2007). The imported exotic animals from temperate climates will be more sensitive to heat stress than tropical animals. An integrated farm approach may be adopted for reducing thermal stress of livestock. There could be three major possible strategies to minimize the effects of thermal stress on livestock production:

- Physical modification of the environment
- Improved nutritional management
- Genetic improvement of heat tolerant breed

Environmental modifications

The management strategies to alleviate heat stress in farm animals are not appropriate if nutrition, disease control and breeding performance are not optimal. The heat can be minimized by adopting simple and basic rules for designing animal shed (shape, orientation, thermo-physical properties of construction materials, ventilation, etc.). Collier and Beede (1985) suggested that physical modification of the environment or genetic selection for more heat-tolerant cattle would be the primary means

of reducing adverse effects of the environment on animal production and profitability. These methods can be divided into two groups, those modifying the environment to prevent or limit the degree of heat stress to which the animals are exposed or those enhancing heat exchange between the animal and the environment.

Reducing heat stress

These environmental modifications attempt to reduce the potential for heat stress by lowering the solar radiation or T_a around the animal. For outdoor animals, the provision of shade (natural or artificial) is one of the simplest and cost-effective methods to minimize heat from solar radiations. Trees are very effective in providing shade to the animals combined with beneficial cooling as moisture evaporates from the leaves. To choose which species is best, several aspects need to be considered, including protection capacity, compatibility with livestock and environment. The best shade was given by *Mangifera indica* (mango tree), with the least radiant heat load. Introduction of silvi-pasture system or plantation of fodder trees in grazing area can be a successful integrated farming type approach that provides feed as well as shelter during summer (Sastry *et al.*, 2012). Artificial shades have been used with success for heat-stressed animals in confinement or in intensive situations. Shade is effective in protecting cows from solar radiation, but does not alter the air temperature or RH around the cows to maximize sensible routes of heat loss (West, 2003). Studies comparing shade vs. no shade have demonstrated improved milk yield and reproduction, as well as reduced respiration rate and rectal temperature in shaded dairy cows (Collier *et al.*, 2006). The beneficial effect of shade on dairy cow performance depends on the breed and coat color. Providing shade is also an effective method of reducing heat stress for stalled animals. Shade ameliorates heat load of cattle (Gaughan *et al.*, 2010) and reduces mortality in extreme weather conditions. However, shade does not remove all the effects of thermal stress (Gaughan *et al.*, 2010). Generally, more consistent advantages of shade were found in hot-arid climates than in humid regions (Ames and Ray, 1983). Major design considerations must be taken into account for shade structures (orientation, space, height and roof construction). East-west orientation is most suitable design of shed under

hot arid condition (CAZRI, 2012). A smaller space increases the risk of occurrence of udder problems, whereas an excessive shade in pen has no additional benefits. Various types of roofing materials can be used for shade structures. The most effective in terms of reducing heat load is a reflective roof such as a white asbestos roof (Sastry *et al.*, 2012).

Various cooling systems have also been evaluated. Air temperature can be lowered by air conditioning, but the expense of such types of mechanical air cooling make it impractical for cooling livestock animals (West, 2003). Evaporative cooling systems use the energy from the air to evaporate water and evaporation of water into warm air reduces the air temperature while increasing RH. Water can be evaporated from atomizing nozzles or from cooling pads. Fogging systems use very fine droplets of water in order to increase the water surface in contact with the air. The water is evaporated into the air causing a reduction in T_a . These systems are most effective in dry areas, but can also be used in high humid regions during day time hours when RH is low. Misting systems generate larger droplets than fogging systems, but cool the air by the same principle. This system was found to be very effective to reduce the T_a during the hottest periods of the day, especially when RH was low. In ruminants, evaporative cooling options have been used mainly in dairy cattle in relationship with their high susceptibility to heat stress. Milk production and reproductive performance of dairy cattle can be improved using an evaporative cooling system (Ryan *et al.*, 1992).

Enhancing animal heat losses

Increased heat exchange generally involves increasing heat loss from the body surface by enhancing heat loss mechanisms. Air movement is an important factor in the relief of heat stress, as it affects both convective and evaporative heat losses. Natural ventilation rate can be maximized using a well-oriented semi-opened building with high and well-isolated roof (Holik, 2009). Additional fans can be installed if natural airflow is not sufficient. A provision of supplemental fresh air directly over the animal can be a very efficient way to improve performance of the heat-stressed animal.

One of the most common and effective methods to promote heat losses involves

the addition of water to the skin with or without supplemental airflow to increase the rate of evaporation of additional water. Water evaporation occurs by absorbing heat directly from the body of the animal and also by absorbing heat from the surrounding air. The water can be provided to the air coat with drippers or sprinkler equipments. Dairy cattle allowed access to sprinklers (with and without forced ventilation) have increased milk production (Turner *et al.*, 1992), improved reproduction and improved conversion of feed to milk (Wolfenson, 2009). The thermal comfort provided by the floor is very important. The reduction in floor temperature improves sensible heat flux between the animal and the floor. Bedded barn facilities appear to be useful for buffering animal against the adverse effects of the environment under hot and cold conditions even though 2 to 4°C higher temperature, as well as THI level is maintained within the barn when compared to outside conditions, possibly by the decreased air flow through the building. The use of bedded barns does not reduce heat stress, as measured by the THI, but act as a shade to decrease the solar heat load on the animal (Sahoo *et al.*, 2013).

Feeding management

Scarcity of feed is the primary constraint to improve livestock production in drylands of India. Livestock diets, currently dominated by crop residues and other low-quality feeds, require more energy-rich feeds to support higher levels of milk and meat production. Better feeding strategies for small holders will come through the application of existing nutritional principles adapted to climate change threats. Several extensive reviews of nutritional strategies for managing heat-stress dairy cows (West, 2003) and small ruminants have been published. Various feeding strategies have been used to alleviate the adverse effect of heat stress with varying degrees of success. They aim to maintain water balance, nutrients and electrolytes intake and/or to satisfy the special needs during heat stress such as vitamins and minerals.

The composition of diet has the effect on the rumen microbial ecosystem so any manipulation in the diet by means of forage, concentrate and their components results in change in the microbial community and may

decrease or inhibit activity of methanogenic bacteria. There are several strategies which can be used to reduce methane production from livestock: supplementation of nutrients to poor quality roughage-based ration, forage processing, feed additives: a large number of inorganic, organic compounds and ionophores are known to modify the microbial activity to reduce to methane production such as carbon tetrachloride, trichloroethyl pivalate, nitrites ionophores, rumensin/monensin etc., feeding of fats, defaunation of ruminants, manipulation of rumen microbes, etc.

In summer feeding studies, restricting feed intake to 85% of *ad libitum* lowers body temperature by approximately 0.5°C, even after the period of feed restriction ended. Development of new nutritional technologies (e.g., protected-fat feeding) under thermoneutral conditions may offer particular advantages to intensively managed animals in warmer environments as well. In intensive management systems where harvested feedstuffs may be fed, reductions in feed intake may be recovered partially by increasing metabolizable energy (ME) and nutrient densities of diets.

Dry matter intake

Increasing milk productivity can be accomplished by improving the intake of feed, nutrient density of the diet (quality) or a combination of both. In the Indian context the option of improving the intake of feed (DMI >3% of body weight) is limited due to the nature of the diet where crop residues are predominant feed resources and greens and concentrates constitute a minor proportion (Ramachandra *et al.*, 2007). Assuming that there would not be any import of feed ingredients, the second option of improving the quality of diets is very limited due to limited availability of concentrate ingredients and preferential use of concentrate ingredients in the poultry sector.

For achieving an average productivity level of 9 L day⁻¹ with a diet of metabolizable energy content of 7.36 ME, the dry matter intake (DMI) should be around 3.6% of the body weight. Achieving a DMI of 3.6% in milch animals with a 7.36 ME would be difficult and the diet quality would need to be improved by increasing the proportion of concentrates. Achieving high DMI is possible with an increase in the proportion of the concentrate in the diet

as in the case of feed blocks where concentrate constitutes around 50% of the diet. The total feed requirement for achieving 9 L day⁻¹ on diets with a ME content of 7.36 and 8.50 MJ works out to be 146 and 126 Mt corresponding to 3.6 and 3.1% DMI of body weight, respectively. While achieving a DMI of 3.1% with better quality diet (8.5 MJ ME) is feasible, the concentrate requirement would work out to be 63 Mt and concentrate availability would be a constraint. Looking into the potential availability of total concentrates at the national level, the available concentrate of 35 Mt (Ramachandra *et al.*, 2007) will not be sufficient to achieve the average productivity level of 9 L day⁻¹. Limited concentrate availability will further constraint options of mitigating CH₄ emissions by shifting from acetate to propionate production.

Major feed nutrients

The depressed feed intake in hot weather is commonly considered as an adaptation to reduce metabolic heat production. Heat increment because of the metabolic utilization of crude proteins (CPs) or fiber is higher than for starch or fat. The higher heat increment of CP is partly related to the desamination of excess of amino acids (AAs) for urea synthesis and a higher protein turnover. The energy losses associated with the metabolic utilization of digestible fiber are mainly related to the losses of combustible gases and heat arising from fermentation and during the production of ATP from the oxidation of short-chain fatty acids, which is less efficient compared with ATP gains from the oxidation of glucose. From that, it has been suggested that low CP or fiber diets should attenuate the depressed intake associated with heat stress. Moreover, the reduction in dietary fiber reduces the bulk density of the diet and then would encourage intake. Practically, two main nutritional strategies are available to minimize the reduction of energy and nutrient intake under heat stress by (1) using energy or protein concentrate diets to overcome the low DM intake, and (2) using low increment diets to improve DM intake. Whatever the species, several authors have shown that increasing the energy content of the diet via fat addition can partially overcome the effect of heat stress. In fact, this practice not only increases the energy intake but also reduces the diet heat increment.

In ruminants, formulating diets with low heat increments can help improve feed intake and performance under heat stress. In hot environments, nutrient requirements are altered during heat stress, which results in a need for reformulation of rations (Collier *et al.*, 2006). In dairy cattle, a portion of the milk production lost (~35% to 50%) as a consequence of heat stress may be potentially recuperated through nutritional management (Rhoads *et al.*, 2010). Some approaches have been successful, such as decreasing fiber intake in order to allow the rumen to function properly, adding fat supplementation mostly because of its high-energy content and low heat increment and implementing increased concentrate diets with caution to avoid metabolic disorders (Morrison, 1983; Beede and Collier, 1986; Knapp and Grummer, 1991).

The most limiting nutrient for cattle during heat stress is usually energy intake, and a common approach to increase energy density is to reduce forage and to increase concentrate content in the ration. Some of the depression of DMI reported during heat stress could be prevented when diets contain 14% to 17% ADF compared with 20% (Cummins, 1992). This effect is explained by a reduction of the bulkiness of the diet, which favors intake by an increase in energy density. Low fiber, high fermentable carbohydrate diets can be used under hot conditions to stimulate energy intake, but the effect must be balanced with the potential for rumen acidosis associated with high-grain diets (West, 2003). To avoid metabolic disorders and maintain proper rumen function, ADF and NDF should not be decreased below 18% and 28% of the ration dry matter, respectively (West, 1994). According to its higher energy density and its lower metabolic heat when compared with fiber or starch, fat supplementation can be used to reduce heat load and to increase net energy intake in heat-stressed dairy cows (Morrison, 1983; Knapp and Grummer, 1991). Several studies investigated the effect of fat supplementation during hot season on milk production and results have varied. Increasing dietary fat content (+5%) enhanced milk production efficiency and yield in the warm season (Skaar *et al.*, 1989). In contrast, another study did not find change in milk production in hot condition when 5% of fat was supplemented in the diet (Knapp and

Grummer, 1991). Strategic supplementation of fatty acids accordingly to physiological stage can selectively benefit immune function, maximize production and improve reproductive responses. Supplementary feeding of lupin grain for 14 days and the 'ram effect' can be combined as a strategy for increasing ovulation rate in sheep. Feeding 500 g lupins/head/day for 14 days commencing 12 days after the introduction of vasectomized rams, increase the number of ovulations from 126 to 146 per 100 ewes exposed to rams.

Reports of feeding excess rumen degradable protein during heat stress have been shown to decrease DMI and milk production (Huber *et al.*, 1994). This reduction is because of the increase in maintenance requirements and decrease in energy being consumed. To metabolize the excess protein, extra energy is required to convert protein into urea for excretion (Huber *et al.*, 1994). An option to prevent this is to improve the quality of the protein being fed so that it may support increased milk levels in cows during heat stress (Huber *et al.*, 1994). Researchers have found that supplementing with lysine led to increase in milk yields by 11% when fed to animals undergoing heat stress (Chen *et al.*, 1993). During periods of heat stress, the effects of decreased DMI and increased maintenance requirements resulted in the animal metabolizing more protein in order to meet energy requirements compared with cows under moderate temperature environments (Beede and Collier, 1986).

Micronutrients

The development of nutritional strategies to cope with heat stress must address metabolic, physiological and immunological disturbances induced by heat strain. As a result of sweating and/or panting, the blood acid-base balance is disturbed in heat-stressed animals (Collier *et al.*, 2006). The alteration in electrolyte status must be corrected by mineral supplementation. In addition, since heat stress could induce oxidative injuries, a supplementation of vitamins could have beneficial effects on performance of heat-stressed animals. More generally, the ability of micronutrients addition to enhance performance under hot conditions depends on species and on the physiological stage within each species. Requirements for specific nutrients appear to differ during thermal stress compared to thermoneutral conditions. It has been

observed that mineral mixture and antioxidant supplementation protected the ewes from the adverse effects of heat stress on feed and water intake, respiration rate and rectal temperature, Hb, packed cell volume, plasma glucose, total protein and endocrine responses (Sejian, 2013). Additionally, there is reduced plasma cortisol level, the principal stress relieving hormone. This could be a short-term and low-cost catalytic micro-nutrient supplementation to check production decline and maintain body condition during heat stress.

Under hot environment, animals reduce their feed intake, and therefore the mineral intake. In addition, thermo-regulatory responses during heat stress may also affect the mineral requirements. The primary avenue for heat loss under heat stress are sweating and panting. Cattle lose a large amount of minerals via sweat (especially potassium and sodium). As reviewed by Beede and Collier (1986) in heat-stressed lactating cows, potassium and sodium supplementation above NRC recommendations resulted in 3% to 11% increase in milk yield. Blood acid-base balance is disturbed by hyper ventilation and results in respiratory alkalosis, which can reduce growth rate and milk production in dairy cattle. Mineral therapy and manipulation appear to be effective means of limiting the detrimental effect of respiratory alkalosis on performance. In heat-stressed cows, reduced concentration of blood bicarbonate as a result of respiratory alkalosis compromises the rumen buffering capacity. The loss of saliva from increased respiratory rate and drooling in severely heat-stressed cows can also accentuate this problem decreasing the salivary HCO_3^- pool for rumen buffering. Reduced feed intake, a preference for concentrates rather than forage and loss of buffering capacities contribute to a greater potential for rumen acidosis during heat stress. Enhanced milk production in heat-stressed lactating cows fed high concentrate diets were generally reported by providing 1.0% dietary sodium bicarbonate (Schneider *et al.*, 1986). The decreased feed consumption at high T_a also has repercussions on the intake of vitamins, which play an important role on performance and immune function. In dairy cattle, injection of vitamin E had no effect on pregnancy rate during heat stress (Alan *et al.*, 1994).

Antioxidants

The use of antioxidants to improve fertility during heat stress is predicated on the idea that free radicals contribute to embryonic mortality. Elevated temperature has been reported to increase free radical production in embryos at Days 0 and 2 relative to insemination (Sakatani *et al.*, 2004). However, experiments using antioxidants to block effects of elevated culture temperature on development of bovine embryos have been largely unsuccessful (Paula-Lopes *et al.*, 2003). Most antioxidant treatments to improve fertility of heat-stressed cows have not been effective. Among the treatments used has been administration of vitamin E at breeding (Ealy *et al.*, 1994), multiple injections of vitamin E and selenium before and after calving (Paula-Lopes *et al.*, 2003) and administration of β -carotene at days 6, 3 and 0 relative to insemination (Arechiga *et al.*, 1998). One explanation for negative results with antioxidants is that the choice of antioxidant or the dosing regimen was inappropriate to block free-radical damage induced by heat stress. There is one study reporting beneficial effects of antioxidant feeding on reproductive function of lactating cows during heat stress (Arechiga *et al.*, 1998). Cows that received supplemental β -carotene (400 mg day^{-1}) for at least 90 days beginning at 15 days postpartum were more likely to be pregnant at 120 days postpartum (35%) than cows not receiving supplemental β -carotene (21%). There was also a non-significant tendency for inseminations required to achieve pregnancy to be lower for cows receiving supplemental β -carotene. Other feed additives such as niacin, fungal culture and conjugated linoleic acid can attenuate the effect of high elevated T_a on the performance in ruminant.

Feeding schedule

Some simple alterations in feeding programs can help the animal to cope with heat stress. Stallfed cattle given access to feed only during the cooler hours of the day enhanced the animal's ability to cope with heat stress during summer time episodes without adversely affecting growth performance (Holt *et al.*, 2004; Mader and Davis, 2004). In fact, these feeding strategies (limiting feed intake and/or feeding duration) prevent the metabolic peak and environmental heat loads from occurring simultaneously. In cattle, provision of fresh feeds through multiple feedings

(especially during night) can also encourage the frequent feeding bouts and increase daily feed consumption under heat stress (West, 1999). In extensive systems, manger and water troughs must be in a shade. Increasing the number of feedings per day may entice animals to take more meals and keep feed fresher, thus increasing total daily consumption. Scheduling feeding strategically with, or right after, other routine events, such as milking, could result in increased daily consumption (Beed and Collier, 1986).

Watering management

Water is an essential nutrient for livestock animals, especially during a thermal stress. Water intake during heat stress is a limiting factor for survival and performance, as water has a fundamental role in the heat exchange system for temperature regulation and maintenance of hydration balance. Whatever the species, water restriction enhances the negative effect of thermal stress on animal performance. The response of increased temperatures on water demand by livestock is well-known. For *Bos indicus*, for example, water intake increases from about 3 kg per kg DM intake at 10°C ambient temperature, to 5 kg at 30°C , and to about 10 kg at 35°C (NRC, 1981). In hot conditions, water losses increase (evaporation by panting and sweating) and water ingested in feed and generated by metabolism is reduced. Consequently, drinking water consumption has to increase to cover the requirements of a heat-stressed animal. Cows acclimatized to 21.1°C and then exposed to 32.2°C for two weeks showed 110% increase in water consumption and water losses from the respiratory tract and from the skin surface increased by 55% and 177%, respectively (Pathak and Prasad, 2012). In warm climate, a key husbandry practice is to provide an abundant and clean source of drinking water close to the feeding area. Studies have demonstrated that a provision of cool water would improve animal performance reducing T_b through absorbed heat energy (Jeon *et al.*, 2006).

Animals exposed to hot environments drinking 2-3 times more water than those in thermo-neutral conditions can run many risks. Indeed, altered water pH may affect metabolism, fertility and digestion; the excess of nitrite content can impair both cardiovascular

and respiratory systems; excess of heavy metals can impair the hygienic and sanitary quality of production, and the excretory, skeletal and nervous systems of animals. In tropical and subtropical regions an increased need of drinking water, as a consequence of prolonged exposure to high environmental temperature, is often coincident with a reduction of water availability and forage water content and quality. Fibrous forages reduce voluntary feed intake and can increase fermentative heat and the thermoregulatory demand for water (Shibata and Mukai, 1979). An additional problem may arise from the quality of water available in hot arid or semi-arid areas. In such climatic areas, water is commonly characterized by high concentration of total dissolved solids. The sheep can be watered on alternate days without any serious effect and rather with some improvement in nutrient digestibility and wool production (Singh *et al.*, 1976). In a comparative study on the effect of water deprivation, it was observed that while Marwari sheep almost ceased taking food on the third day the feed consumption in Barmer goats was reduced only by 40% even after four days of absolute water deprivation under arid conditions of Jodhpur (Ghosh and Khan, 1980).

Breeding management

There are clear genetic differences in resistance to heat stress, with tropically-adapted breeds experiencing lower body temperatures during heat stress than non-adapted breeds. Even in non-adapted breeds, it is probably possible to perform genetic selection for resistance to heat stress. In tropical areas, the process of natural selection has favored the emergence of breeds with a high ability to cope with thermal stress. Considerable variation exists for heat tolerance between individual species/breeds and even between individuals within a species/breed. In dryland areas, the process of natural selection has favored the emergence of breeds with a high ability to cope with thermal stress (Renaudeau *et al.*, 2012). However, their adaptation includes not only heat tolerance, but also their ability to survive, to grow and to reproduce in the presence of poor seasonal nutrition, high parasite and disease pressure. The high heat tolerance of tropical local breeds is generally correlated with their small size, their low-production level and some special morphological traits (properties of the skin or

hair, sweating capacity, tissue insulation, special appendages) compared with mainstream breeds and commercial lines (Hansen, 2004). The cattle breeds of drylands of India (Tharparkar, Red Sindhi, etc.) has the higher number of sweat gland per unit area and larger sweat gland perimeter resulting in higher sweating response compared to crossbred/exotic breeds (Govindaiah *et al.*, 1980). The Tharparkar cow, a local breed of the Thar Desert is adapted to the environmental conditions of the area including rugged terrain grazing.

Improving animal adaptation to climatic stress can be achieved either by selection in stressed conditions or by introgressing 'heat adaptation' genes from a local breed into a commercial breed. In addition, animal breeding will need to account for higher indigenous cattle, breed temperatures, lower quality diets, greater disease challenges, that is better suited to survive the mitigation strategies and food demand. The rectal temperature reflects the animals' ability to maintain thermal equilibrium. It is the only parameter for which heritability has been ascertained with a rather good accuracy. The heritability estimates for rectal temperature have been found to be moderate, between 0.11 and 0.37 (Renaudeau *et al.*, 2004). Cattle with slick hair coats experience lower body temperature during heat stress conditions (Dikmen *et al.*, 2008). Finocchiaro *et al.* (2005) proposed the use of heat-resistant individuals in a sheep breeding programme as a main strategy to improve animal comfort and productivity in hot climates. Studies conducted on genetic variation of adaptation to heat at CSWRI, Avikanagar, have revealed that the exotic fine wool breeds arising from temperate/sub-temperate environments are less suitable to hot semi-arid zone of the country as they showed higher increases in cardinal physiological responses, greater decline in food intake per unit body weight and poor survival. On the other hand, the natives were better adapted since they exhibited smaller increase in physiological responses and had higher food and water consumption per unit body weight.

In terms of breeding objectives, different choices can be envisaged: either the breeders will be able to select animals adapted to each production environment or the breeders will choose to breed for robust animals, that is, animals able to maintain a high level of pro-

duction in most conditions of production. Hayes *et al.* (2013) proposed to select sires whose daughters will cope better with low feeding levels and higher heat stress. They identified markers associated with sensitivity of milk production to feeding level and sensitivity of milk production to THI in Jersey and Holstein. Because feed efficient animals are also more cost effective and productive, need to be included as an integral part in breeding programme. With the availability of animal genome sequences, a new area of genome-enabled technologies is foretelling the feasibility of rapidly identifying genetic markers associated with production traits using emerging high-throughput novel technologies. Good examples are high-density single-nucleotide polymorphism (SNP) panels. These genetic markers are now a tool of choice to further dissect complex traits for heat tolerance. These markers are essential for two main purposes: the first is localizing *Quantitative Trait Locus* (QTL)/genes related to heat tolerance and the second is selecting chromosomal regions involved in heat tolerance. Protocols to map QTL for heat tolerance traits in livestock species are often complex and costly to implement. Currently, functional genomics research via the identification of genes that are up-regulated or down-regulated during thermal stress can provide new knowledge about how stress impacts productive functions. These new genetic tools will facilitate the selection of livestock animals with high production level under warm environment.

Restoration of community grazing resources

Community grazing resources (CPR) in most parts of the country have either drastically been reduced or have almost disappeared. Restoration is most important not only for providing regulated grazing, but also for protecting valuable resource. One option is restoration of such lands to village panchayat for their improvement and proper management for providing forage and grazing for the village livestock besides some fuel wood from the silvipasture blocks. First step in improvement of the CPR is the adoption of necessary soil and water conservation measures. This is done by dividing the whole area into five equal compartments. Every year one such compartment is taken up for development and closed for grazing, half taken under silvi pastoral development and the other half for

grassland/pasture development (Pathak and Roy, 1994). In the second year, the second half the development area is open to grazing and the next compartment is taken up for development. First half, i.e. silvi-pasture area closed for grazing in the first year, may be open to grazing at the end of the third year. The process is repeated every year so that in the fifth year, the whole area is developed. Once the lands are developed, they should be managed properly for sustained forage production.

In order to maintain the vigor of the grass and legumes, and also to meet the needs of the livestock, CPR may be subjected to one of the grazing systems namely (i) continuous grazing, (ii) deferred grazing, (iii) rotational grazing and (iv) deferred rotational grazing for a given site at a specific period as per requirement. In *Sehima* dominated semi-arid grasslands at Jhansi (India), deferred rotational grazing was found much superior to continuous grazing. In the arid grazing land situation, Das and Paroda (1980) observed a 22% increase in dry matter yield of *Cenchrus* under deferred rotational grazing compared to only 6.3% under continuous grazing. In *Lasiurus* dominated grassland in western Rajasthan, deferred rotational grazing gave higher body weight gains of heifers over continuous system. Calving of animals was also higher in the former compared to latter system (Shankarnarayan *et al.*, 1981). For fixing stocking rate in the grazing land, information on grazing height/animal weight relationships would be of much use to make adjustment to the traditional carrying capacity during the growing season, or year round, as the case may be.

Alternate feed resources

Inclusion of alternate feed resources in the animals' diet could be a useful strategy to minimize the nutritional stress during lean months. It has been demonstrated that feeding cactus to livestock reduced water requirement and increased nutrients digestibility without affecting health of the calves (Mathur and Misra, 2014). Similarly, feeding of *Blepharis indica*, *Anabaena azollae* may also hold promise to provide feed as well as water to animals during summer feed scarcity, particularly in semi-arid and arid regions of the country (Sahoo *et al.*, 2013). Inclusion of *Prosopis juliflora* pods in concentrate

mixture or feed blocks improved the production, reproduction of animals during summer without any adverse effect on health.

Crop and livestock integration

Successful integration involves intentionally creating synergies among crops, livestock, trees that result in enhanced social, economic and environmental sustainability. The added value of integrating crops and livestock has been understood and practised by the dryland farmers of western Rajasthan for thousands of years and yet these systems can hold a key for climate resilient agriculture in the future. Integration can be on farm as well as an area wise. The integration that reflects a synergetic relationship among the components (the whole is greater than the sum of the parts) of crops, livestock and trees and that this synergetic relationship results in enhanced social, economic/productive and environmental sustainability of the systems and improves the livelihoods of those farmers who manage them.

Livestock species diversification

The use of multi-species and multi-breed herds is one strategy that many traditional livestock farmers use to maintain high diversity in on-farm and to buffer against climatic and economic adversities (Hoffmann, 2010). Such traditional diversification practices are useful for adaptation to climate change. Seo and Mendelsohn (2008) modelled that small farms in developing countries were more climate change resilient because of their more diverse species portfolios, the ease with which they can shift between species and diversify, and their reliance on goats and sheep. On the contrary, commercial dairy were more vulnerable than small farms, because their specialized nature makes it difficult for them to switch to other species. Goats for example, are more adapted to harsh and drier conditions and have greater resistance to dehydration than temperate animals (Devendra, 2007).

Pastoral systems: Livestock migration

In the arid and semi-arid regions of India where low rainfall and very high temperatures are the norm, an important traditional survival strategy that has been developed by the people to cope with the seasonal changes through nomadic and transhumance systems and

sheer resilience. These nomads migrate with their cattle, goats, sheep and camels in search of water and forage. Many migratory routes exist, and with the herds passing through, water supplies and plant cover are often used up well before the end of the long dry season. With the environment becoming drier by the year and density of livestock continuing to grow, the shortfall especially of feeds and water is turning into a serious problem for the people. Although these systems provide less production than the other one, they are of high social and economical importance for local inhabitants and, in several zones, of very relevant interest for cultural inheritance.

In India, it is estimated that between 30% and 40% of the total small ruminant population is on the move annually. These movements are spectacular, are a way of life, and involve whole households along well defined routes with several men accompanying the large flocks. Kids are often placed in baskets and are carried by camels/donkeys along with kitchen utensils. With the onset of the rains and increased feed availability, grazing becomes more localized. During the height of summer and very high temperatures (35°C-40°C), these result in 4-6 months of animal movement of between 10 km -15 km per day, motivated by the search for grazing as well as wage labor opportunities. Quite often signs of environmental degradation are apparent in areas around sources of drinking water, which are extremely localized. Streams and ponds are quickly drained after the rains, leaving livestock and people alike to rely on a variety of specialized manmade water sources. The most widely used are bore holes, either man made or mechanically created.

The way forward

The Inter-governmental Panel on Climate Change (IPCC) has forecasted global warming leading to rise in average temperature by 1.8 to 4.0°C by the year 2100 with rise in sea levels. The annual mean temperature of India has risen by 0.51°C during the period 1901-2005. The annual mean temperature has been consistently above normal (normal based on period, 1961-1990) since 1993. This warming is primarily due to rise in maximum temperature across India. However, since 1990, minimum temperature is steadily rising and rate of rise is slightly more than that of maximum

temperature. Season-wise, maximum rise in mean temperature has been observed during the post-monsoon season (0.7°C) followed by winter season (0.67°C), pre-monsoon season (0.50°C) and monsoon season (0.30°C). During the winter season, since 1991, rise in minimum temperature is appreciably higher than that of maximum temperature over northern plains (Srivastava, 2010).

Environmental factors such as ambient temperature, solar radiation and humidity have both direct and indirect effects on animals. Thermoregulation is the means by which an animal maintains its body temperature. It involves a balance between heat gain and heat loss. Under heat stress, a number of physiological and behavioural responses vary in intensity and duration in relation to the animal genetic make-up and environmental factors. The general homeostatic responses to thermal stress in livestock include reduction in faecal and urinary water losses, reduction in feed intake and production and increased sweating, respiratory rates and heart rates. Adaptation to heat stress requires the physiological integration of many organs and systems, namely, endocrine, cardiorespiratory and immune system. Direct effects involve heat exchanges between the animal and the surrounding environment that are related to radiation, temperature, humidity and wind speed. Dairy cattle show signs of heat stress when THI is higher than 72. The comfort limit depends on level of production.

Three basic management options for reducing the effect of environmental stress have been suggested: (a) physical modification of the environment, (b) genetic development of less sensitive breeds, and (c) improved nutritional management strategies. Physical protection with artificial or natural shade presently offers the most immediate and cost-effective approach for sustainable livestock production. Introduction of silvi-pasture system or plantation of fodder trees in grazing area can be a successful integrated-farming approach that provides feed as well as shelter to livestock during summer. The identification of heat-stressed livestock and understanding the biological mechanism by which heat stress reduces milk production and reproductive functions is critical for developing novel approaches to maintain production or to minimize the

reduction in productivity during hot summer months. A greater understanding is required on mechanisms associated with immune suppression and hormonal changes in animals having high productivity. The supplementation of antioxidants in feed (micronutrients and vitamin E) to high-producing, especially during periparturient period, may help in improving the productivity by reducing the stress and risk of mastitis. Knowledge on feeding and eating rhythm and postprandial intake patterns will enable predicting diurnal patterns in rumen, post-rumen, and peripheral nutrient assimilation.

References

- Alan, D.E., Carlos, F.A.C., David, R.B., Carlos, A.R. and Peter, J.H. 1994. Effectiveness of short-term cooling and vitamin E for alleviation of infertility induced by heat stress in dairy cow. *Journal of Dairy Science* 75: 3601-3607.
- Al-Katanani, Y.M., Webb, D.W. and Hansen, P.J. 1999. Factors affecting seasonal variation in non-return rate to first service in lactating Holstein cow in a hot climate. *Journal of Dairy Science* 82: 2611-2616.
- Amakiri, S.F. and Mordi, R. 1975. The rate of cutaneous evaporation in some tropical and temperate breeds of cattle in Nigeria. *Animal Production* 20: 63-68.
- Ames, D.R. and Ray, D.E. 1983. Environmental manipulation to improve animal productivity. *Journal of Animal Science* 57: 209-220.
- Amundson, J.L., Mader, T.L., Rasby, R.J. and Hu, Q.S. 2006. Environmental effects on pregnancy rate in beef cattle. *Journal of Animal Science* 84: 3415-3420.
- Arechiga, C.F., Vazquez-Flores, S., Ortiz, O., Hernandez-Ceron, J., Porras, A., McDowell, L.R. and Hansen, P.J. 1998. Effect of injection of b-carotene or vitamin E and selenium on fertility of lactating dairy cows. *Theriogenology* 50: 6576.
- Beede, D.K. and Collier, R.J. 1986. Potential nutritional strategies for intensively managed cattle during thermal stress. *Journal of Animal Science* 62: 543-554.
- Berman, A.J. 2005. Estimates of heat stress relief needs for Holstein dairy cows. *Journal of Animal Science* 83: 1377-1384.
- Bernabucci, U., Lacetera, N., Ronchi, B. and Nardone, A. 2002. Effects of the hot season on milk protein fractions in Holstein cows. *Animal Research* 51: 25-33.
- Calamari, L., Maianti, M.G., Calegari, F., Abeni, F. and Stefanini, L. 1997. Variazioni dei parametri lattodinamografici nel periodo estivo in bovine

- in fasi diverse di lattazione. *Atti Congresso Nazionale S.I.S.Vet* 51: 203-204.
- CAZRI 2012. *Annual Report 2011-12*. Central Arid Zone Research Institute, Jodhpur, India, 132 p.
- Chebel, R.C., Santos, J.E.P., Reynolds, J.P., Cerri, R.L.A., Juchem, S.O. and Overton, M. 2004. Factor affecting conception rate after artificial insemination and pregnancy loss in lactating dairy cows. *Animal Reproductive Science* 84: 239-255.
- Chen, K.H., Huber, J.T., Theurer, C.B., Armstrong, D.V., Wanderley, R.C., Simas, J.M., Chan, S.C. and Sullivan, J.L. 1993. Effect of protein quality and evaporative cooling on lactational performance of Holstein cows in hot weather. *Journal of Dairy Science* 76: 819-825.
- Chikamune, T. and Shimizu, H. 1983. Comparison of physiological response to climate condition in swamp buffaloes and cattle. *Indian Journal of Animal Science* 53: 595-599.
- Choubey, M. and Kumar, A. 2012. Nutritional interventional to combat heat stress in dairy animals. *Vetscan* 7: 19-27.
- Collier, R.J. and Beede, D.K. 1985. Thermal stress as a factor associated with nutrient requirements and interrelationships. In *Nutrition of Grazing Ruminants in Warm Climates* (Ed. L.R. McDowell), pp. 59-71. Academic Press, Inc., Orlando, FL, USA.
- Collier, R.J., Dahl, G.E. and VanBaale, M.J. 2006. Major advances associated with environmental effects on dairy cattle. *Journal of Dairy Science* 89: 1244-1253.
- Collier, R.J., Eley, R.M., Sharma, A.K., Pereira, R.M. and Buffington, D.E. 1981. Shade management in subtropical environment for milk yield and composition in Holstein and Jersey cows. *Journal of Dairy Science* 64: 844-849.
- Collin, A., Lebreton, Y., Fillaut, F., Vincent, A., Thomas, F. and Herpin, P. 2001. Effects of exposure to high temperature and feeding level on regional blood flow and oxidative capacities of tissues in piglets. *Experimental Physiology* 86: 83-91.
- Coppock, C.E., Grant, P.A., Portzer, S.J., Charles, D.A. and Escobosa, A. 1982. Lactating dairy cow responses to dietary sodium, chloride, and bicarbonate during hot weather. *Journal of Dairy Science* 65: 566-576.
- Cummins, K.A. 1992. Effect of dietary acid detergent fiber on responses to high environmental temperature. *Journal of Dairy Science* 75: 1465-1471.
- Das, K., Upadhyaya, R.C. and Madan, M.L. 1999. Heat stress in Murrah buffalo calves. *Livestock Production Science* 61: 71-78.
- Das, R.B. and Paroda, R.S. 1980. Rational utilization of grazing resources for sustained primary and secondary productivity in arid zone of western Rajasthan. *Annals of Arid Zone* 19: 96-100.
- de Rensis, F. and Scaramuzzi, R.J. 2003. Heat stress and seasonal effects on reproduction in the dairy cow a review. *Theriogenology* 60: 1139-1151.
- Devendra, C. 2007. Perspectives on animal production systems in Asia. *Livestock Science* 106: 1-18.
- Dikmen, S., Alava, E., Pontes, E., Fear, J.M., Dikmen, B.Y., Olson, T.A. and Hansen, P.J. 2008. Difference in thermoregulatory ability between slick-haired and wild type lactating Holstein cows in response to acute heat stress. *Journal of Dairy Science* 91: 395-402.
- Dobson, H. and Smith, R.F. 2000. What is stress and how does it affect reproduction? *Animal Reproduction Science* 60: 743-752.
- Dutt, T., Taneja, V.K., Singh, A. and Singh, A. 1992. Comfort zone for maximal milk production in crossbred cattle. *Indian Journal of Dairy Science* 45(3): 119-122.
- Ealy, A.D., Arechiga, C.F., Bray, D.R., Risco, C.A. and Hansen, P.J. 1994. Effectiveness of short-term cooling and vitamin E for alleviation of infertility induced by heat stress in dairy cows. *Journal of Dairy Science* 77: 3601-3607.
- Finocchiaro, R., van Kaam, J.B.C.H., Portolano, B. and Misztal, I. 2005. Effect of heat stress on production of mediterranean dairy sheep. *Journal of Dairy Science* 88: 1855-1864.
- Gaughan, J.B., Bonner, S., Loxton, I., Mader, T.L., Lisle, A. and Lawrence, R. 2010. Effect of shade on body temperature and performance of feedlot steers. *Journal of Animal Science* 88: 4056-4067.
- Gaughan, J., Lacetera, N., Valtora, E., Khalifah, H.H., Hahn, L. and Mader, T. 2009. Response of domestic animals to climate challenges. In *Biometeorology for Adaptation to Climate Variability and Change* (Eds. K.L. Ebi, I. Burton and G.R. McGregor), pp. 131-170. Springer, Auckland, New Zealand.
- Ghosh, P.K. and Khan, M.S. 1980. *The Goat in the Desert Environment*. Central Arid Zone Research Institute, Division of Animal Studies, Research Bulletin. 26 p.
- Govindaiah, M.G., Sharma, K.N.S. and Nagarcenkar, R. 1980. Density of sweat glands in *Bos Taurus* x *Bos indicus* cross breed dairy cattle. *Indian Journal of Animal Genetics and Breeding* 2: 25-30.
- Gudev, D., Popova, R.S., Moneva, P., Aleksiev, Y., Peeva, T., Penchev, P. and Ilievai. 2007. Physiological indices in buffaloes exposed to sun. *Arciva Zootech* 10: 1-7.
- Hahn, G.L. 1999. Dynamic response of cattle to thermal heat loads. *Journal of Animal Science* 77: 10-20.

- Hansen, P.J. 2004. Physiological and cellular adaptations of zebu cattle to thermal stress. *Animal Reproduction Science* 82-83: 349-360.
- Hayes, B.J., Lewin, H.A. and Goddard, M.E. 2013. The future of livestock breeding: genomic selection for efficiency, reduced emissions intensity, and adaptation. *Trends in Genetics* 29(4): 206-214.
- Hillman, P.E., Scott, N.R. and Van Tienhoven, A. 1985. Physiology response and adaptation to hot and cold environment. In *Stress Physiology in Livestock* (Ed. M.K. Yousef), pp. 27-71, CRC Press, Boca Raton, F.L., USA.
- Hoffmann, I. 2010. Climate change and the characterization, breeding and conservation of animal genetic resources. *Animal Genetics* 41(Suppl-1): 32-46.
- Holik, V. 2009. Management of laying hens to minimize heat stress. *Lohmann Information* 44: 16-29.
- Holmann, F., Rivas, L., Urbina, N., Rivera, B., Giraldo, L.A., Guzman, S., Martinez, M., Medina, A. and Ramirez, G. 2005. The role of livestock in poverty alleviation: An analysis of Colombia. *Livestock Research for Rural Development* 17(1): 1-7.
- Holt, S.M., Gaughan, J.B. and Mader, T.L. 2004. Feeding strategies for grain-fed cattle in a hot environment. *Australian Journal of Agricultural Research* 55: 719-725.
- Huber, J.T., Higginbotham, G., Gomez-Alarcon, R.A., Taylor, R.B., Chen, K.H., Chan, S.C. and Wu, Z. 1994. Heat stress interactions with protein, supplemental fat, and fungal cultures. *Journal of Dairy Science* 77: 2080-2090.
- IPCC (Intergovernmental Panel on Climate Change) 2007. *Climate Change 2007: Impacts, Adaptation and Vulnerability*. Summary for policy makers. Online at <http://www.ipcc.cg/SPM13apr07.pdf>
- Jeon, J.H., Yeon, S.C., Choi, Y.H., Min, W., Kim, S., Kim, P.J. and Chang H.H. 2006. Effects of chilled drinking water on the performance of lactating sows and their litters during high ambient temperature under farm condition. *Livestock Science* 105: 86-93.
- Johnson, H.D. 1987. Bioclimate effects on growth, reproduction and milk production. *Bioclimatology and the Adaptation on Livestock* (Ed. H.D. Johnson), pp. 35-57. Elsevier, Amsterdam, Netherlands.
- Johnson, H.D., Shanklin, M.D. and Hahn, L. 1988. Productive adaptability of Holstein cows to environmental heat. *Research Bulletin No. 1060*, University, Missouri Coll. Agr., Agr. Exp. Station, USA.
- Joshi, B.C. and Tripathy K.C. 1991. Heat stress effect on weight gain and related physiological responses of buffalo calves. *Journal of Veterinary Physiology and Allied Science* 10: 43-48.
- Kadzere, C.T., Murphy, M.R., Silanikove, N. and Maltz, E. 2002. Heat stress in lactating dairy cows: A review. *Livestock Production Science* 77: 59-91.
- Knapp, D.M. and Grummer, R.R. 1991. Response of lactating dairy cows to fat supplementation dry matter intake, metabolism, and lactation in heat stress. *Journal of Dairy Science* 74: 2573-2579.
- Koga, Kuhara T. and Kanai, Y. 2004. Comparison of body water retention during water deprivation between swamp buffaloes and fresian cattle. *Journal of Agricultural Science* 138: 435-440.
- Kumar 2005. Status of oxidative stress markers in erythrocytes of heat exposed cattle and buffaloes. *M.Sc. Thesis*. NDRI, Deemed University of Karnal, India.
- Lacetera, N., Bernabucci, U., Ronchi, B. and Nardone, A. 1996. Body condition score, metabolic status and milk production of early lactating dairy cows exposed to warm environment. *Revista Agriculture Sub Tropical* 90: 43-55.
- Lohrke, B., Viergutz, T., Kanitz, W., Losand, B., Weiss, D.G. and Simko, M. 2005. Short communication: hydroperoxides in circulating lipids from dairy cows: implications for bioactivity of endogenous-oxidized lipids. *Journal of Dairy Science* 88: 1708-1710.
- Lonergan, S. 1998. Climate warming in India. In *Measuring the Impact of Climate Change on Indian Agriculture* (Eds. A. Dinar *et al.*), pp. 33-67. World Bank Technical Paper No. 402, Washington, DC.
- Mader, T.L. and Davis, M.S. 2004. Effect of management strategies on reducing heat stress of feedlot cattle: Feed and water intake. *Journal of Animal Science* 80: 3077-3087.
- Marai, I.F.M., El-Darawany, A.A., Fadiel, A. and Abdel-Hafez, M.A.M. 2007. Physiological traits as affected by heat stress in sheep: A review. *Small Ruminant Research* 71: 112. <http://dx.doi.org/10.1016/j.smallrumres.2006.10.003>
- Mathevon, M., Buhr, M.M. and Dekkers, J.C.M. 1998. Environmental, management, and genetic factors affecting semen production in Holstein Bulls. *Journal of Dairy Science* 81(12): 3321-3333.
- Mathur, B.K. and Misra, A.K. 2014. Feeding of thornless cactus (*Opuntia ficus indica*) to livestock in arid regions. *National Workshop on Cactus Pear*, CAZRI, Jodhpur, 21st March 2014.
- McGuire, M.A., Beede, D.K., Delorenzo, M.A., Wilcox, C.J., Huntington, G.B., Reynolds, C.K. and Collier, R.J. 1989. Effect of thermal stress and level of feed intake on portal plasma flow and net fluxes of metabolites in lactating Holstein cows. *Journal of Animal Science* 67: 1050-1060.
- Minson, D.J. 1990. *Forage in Ruminant Nutrition*. Academic Press, San Diego.

- Misra, A.K., Subrahmanyam, K.V., Shivarudrappa, B. and Ramakrishna, Y.S. 2006. Experiences on participatory action research for enhancing productivity of dairy animals in rainfed agro-ecosystem of India. *Journal of SAT Agricultural Research* 2: 1-14. <http://www.icrisat.org/Journal/aesrpaper.htm>
- Morgan, J.A., Milchunas, D.G., LeCain, D.R., West, M. and Mosier, A.R. 2007. Carbon dioxide enrichment alters plant community structure and accelerates shrub growth in the shortgrass steppe. *PNAS* 104: 14724-14729.
- Morrison, S.R. 1983. Ruminant heat stress effect on production and means of alleviation. *Journal of Animal Science* 57: 1594-1600.
- Naqvi, S.M.K. and Sejian, V. 2011. Global climate change: Role of livestock. *Asian Journal of Agricultural Science* 3(1): 19-25.
- Nardone, A., Lacetera, N.G., Ronchi, B. and Bernabucci, U. 1992. Effetti del caldo ambientale sulla produzione di latte e sui consumi alimentari di vacche Frisone. *Produzioni Animali* 5(1): 1-15 (III Serie).
- Nichi, M., Bols, P.E.J., Zuge, R.M., Barnabe, V.H., Goovaerts, I.G.F., Barnabe, R.C. and Cordata, C.N.M. 2006. Seasonal variation in semen quality in *Bos indicus* and *Bos Taurus* bulls raised under tropical conditions. *Theriogenology* 66: 822-828.
- NRC 1981. *Effect of Environment on Nutrient Requirements of Domestic Animals*. National Academy Press, Washington, DC.
- Olsson, K. and Dahlborn, K. 1989. Fluid balance during heat stress in lactating goats. *Quarterly Journal of Experimental Physiology* 74: 645-659.
- Padilla, Matsui T., Kamiya, Y., Tanaka, M. and Yano, H. 2006. Heat stress decreases plasma vitamin C concentration in lactating cows. *Livestock Science* 101: 300-304.
- Pathak, K.M.L. and Prasad, C.S. 2012. Adaptation and Mitigation Strategies for Addressing Climate Change Issues in Livestock. www.niam.res.in/pdfs/DDG%20AS.pdf
- Pathak, P.S. and M.M. Roy, 1994. *Silvipastoral System of Production*. A Research Bulletin. IGFRI, Jhansi, 55 p.
- Paula-Lopes, F.F., Al-Katanani, Y.M., Majewski, A.C., McDowell, L.R. and Hansen, P.J. 2003. Manipulation of antioxidant status fails to improve fertility of lactating cows or survival of heat-shocked embryos. *Journal of Dairy Science* 86: 2343-2351.
- Payne, W.J.A. 1990. *An Introduction to Animal Husbandry in the Tropics*. Longman Scientific and Technical, England.
- Ramachandra, K.S., Taneja, R.P., Sampath, K.T., Angadi, U.B. and Anandan, S. 2007. *Availability and Requirement of Feeds and Fodders in India*. Published by National Institute of Animal Nutrition and Physiology, Bangalore.
- Rangnekar, D.V. 2006. *Livestock and Livelihoods of the Underprivileged Communities in India: A Review*. International Livestock Research Institute, Nairobi, Kenya, 72 p.
- Renaudeau, D., Collin, A., Yahav, S., de Basilio, Gourdine, J.L. and Collier R.J. 2012. Adaptation to hot climate and strategies to alleviate heat stress in livestock production. *Animal* 6(5): 707-728.
- Renaudeau, D., Gourdine, J.L. and St-Pierre, N.R. 2011. A meta-analysis of the effect of high ambient temperature on growing-finishing pigs. *Journal of Animal Science* 89: 2220-2230.
- Renaudeau, D., Mondonnet, N., Tixier-Boichard, M., Noblet, J. and Bidanel, J.P. 2004. Attenuer les effets de la chaleur sur les performances des porcs: la voie genetique [Attenuate the effects of high ambient temperature on pig performance: the genetic selection]. *INRA Productions Animales* 17: 93-108.
- Rhoads, M.L., Kim, J.W., Collier, R.J., Crooker, B.A., Boisclair, Y.R., Baumgard, L.H. and Rhoads, R.P. 2010. Effects of heat stress and nutrition on lactating Holstein cows: II. Aspects of hepatic growth hormone responsiveness. *Journal of Dairy Science* 93: 170-179.
- Rhoads, M.L., Rhoads, R.P., Van Baale, M.J., Collier, R.J., Sanders, S.R., Weber, W.J., Crooker, B.A. and Baumgard, L.H. 2009. Effects of heat stress and plane of nutrition on lactating Holstein cows: I. Production, metabolism, and aspects of circulating somatotropin. *Journal of Dairy Science* 92: 1986-1997.
- Rosales, A.G. 1994. Stress syndrome in birds. *Journal of Applied Poultry Research* 3: 199-203.
- Ronchi, B., Stradioli, G., Verini Supplizi, A., Bernabucci, U., Lacetera, N., Accorsi, P.A., Nardone, A. and Seren, E. 2001. Influence of heat stress and feed restriction on plasma progesterone, estradiol-17b, LH, FSH, prolactin and cortisol in Holstein heifers. *Livestock Production Science* 68: 231-241.
- Roy, K.S. and Prakash, B.S. 2007. Seasonal variation and circadian rhythmicity of the prolactin profile during the summer months in repeat-breeding Murrah buffalo heifers. *Reproduction, Fertility and Development* 19: 569-575.
- Ryan, D.P., Boland, M.P., Kopel, E., Armstrong, D., Munyakazi, L., Godke, R.A. and Ingraham, R.H. 1992. Evaluating two different evaporative cooling management systems for dairy cows in a hot, dry climate. *Journal of Dairy Science* 75: 1052-1059.
- Sahoo, A., Kumar, D. and Naqvi, S.M.K. (Eds.) 2013. *Climate Resilient Small Ruminant Production*. NICRA, CSWRI, Avikanagar, India, 106 p.

- Sakatani, M., Kobayashi, S. and Takahashi, M. 2004. Effects of heat shock on in vitro development and intracellular oxidative state of bovine preimplantation embryos. *Molecular Reproduction Development* 67: 77-82.
- Salah, M.S., Al Shaikh, M.A., Al Saiadi, M.Y. and Mogawer, H.H. 1995. Effect of prolactin inhibition on thermoregulation, water and food intake in heat stressed fat-tailed male lambs. *Animal Science* 60: 87-91.
- Sastry, N.S.R., Thomas, C.K. and Singh, R.A. 2012. *Livestock Production Management*. Kalyani Publishers, Lucknow.
- Schneider, P.L., Beede, D.K. and Wilcox, C.J. 1986. Responses of lactating cows to dietary sodium source and quantity and potassium quantity during heat stress. *Journal of Dairy Science* 69: 99-110.
- Sejian, V. 2013. Climate change: Impact on production and reproduction: Adaptation mechanisms and mitigation strategies in small ruminants: A review. *The Indian Journal of Small Ruminants* 19(1): 1-21.
- Seo, S.N. and Mendelsohn, R. 2008. Measuring impacts and adaptations to climate change: A structural Ricardian model of African livestock management. *Agricultural Economics* 38: 151-165.
- Sethi, R.K., Bharadwaj, A. and Chopra, S.C. 1994. Effect of heat stress on buffaloes under different shelter strategies. *Indian Journal of Animal Science* 64: 1282-1285.
- Sevi, A., Annicchiarico, G., Albenzio, M., Taibi, L., Muscio, A. and Dell Aquila, S. 2001. Effect of solar radiation and feeding time on behavior, immune response and production of lactating ewes under high ambient temperature. *Journal of Dairy Science* 84: 629-640.
- Shankarnarayan, K.A., Kakkar, N.L. and Mertia, R.S. 1981. *Productivity of Large Herbivorous Cattle and Sheep Productivity of Arid Grazing Land Ecosystem*. Monograph No. 10 CAZRI, Jodhpur.
- Shebaita, M.K. and El Banna, I.M. 1982. Heat load and heat dissipation in sheep and goats under environmental heat stress. In *Proceedings of 6th International Conference on Animal and Poultry Production*, pp. 459-469. University of Zagazig, Zagazig, Egypt.
- Shibata, M. and Mukai, A. 1979. Effect of heat stress and hay concentrate rations on milk production, heat production and some physiological responses to lactating cows. *Japanese Journal of Zootechnical Science* 50: 630-644.
- Shkolnik, A. and Choshniak, I. 2006. The special physiology and history of the black Bedouin goat. In *Adaptation to Live in the Desert* (Ed. T. Shkolnik). A.R.A. Ganter Verlag K.-G., Ruggell.
- Singh, H.P., Sharma, K.D., Reddy, G.S. and Sharma K.L. 2004. Dryland agriculture in India. In *Challenges and Strategies for Dryland Agriculture*, pp. 67-92. CSSA Special Publication No. 32. Madison, USA
- Singh, N.P., More, T. and Sahni, K.L. 1976. Effect of water deprivation on feed intake, nutrient digestibility and nitrogen retention in sheep. *The Journal of Agricultural Science* 86(2): 431-433.
- Sirohi, S. and Michaelowa, A. 2007. Sufferer and cause: Indian livestock and climate change. *Climate Change* 85: 285-298.
- Skaar, T.C., Grummer, R.R., Dentine, M.R. and Stauffacher, R.H. 1989. Seasonal effects of prepartum and postpartum fat and niacin feeding on lactation performance and lipid metabolism. *Journal of Dairy Science* 72: 2028-2038.
- Srivastava, A.K. 2010. Climate change impacts on livestock and dairy sector: Issues and strategies. In *National Symposium on Climate Change and Rainfed Agriculture* (Eds. B. Venkateswarlu *et al.*) February 18-20, 2010. Indian Society of Dryland Agriculture, Central Research Institute for Dryland Agriculture, Hyderabad, India. Pages 192.
- Thom, E.C. 1959. The discomfort index. *Weather Wise* 12: 57-59.
- Thornton, P.K., Steeg, J.V., Notenbaert, A. and Herrero, M. 2009. The impacts of climate change on livestock and livestock systems in developing countries: A review of what we know and what we need to know. *Agricultural Systems* 101(3): 113-127.
- Turner, L.W., Chastain, J.P., Hemken, R.W., Gates, R.S. and Crist, W.L. 1992. Reducing heat stress in dairy cows through sprinklers and fan cooling. *Applied Engineering in Agriculture* 8: 251-256.
- Umphrey, J.E., Moss, B.R., Wilcox, C.J. and van Horn, H.H. 2001. Interrelationship in lactating holsteins of rectal and skin temperature, milk yield and composition, dry matter intake, body weight, and feed efficiency in summer in Alabama. *Journal of Dairy Science* 84: 2680-2685.
- Upadhyay, R.C., Singh, S.V., Kumar, A., Gupta, S.K. and Ashutosh 2007. Impact of climate change on milk production of Murrah buffalos. *Italian Journal of Animal Science* 6: 1329-1332.
- Upadhyay, R.C., Singh, S.V. and Ashutosh 2008. Impact of climate change on livestock. *Indian Dairyman* 60(3): 98-102.
- van Milgen, J. and Noblet, J. 2003. Partitioning energy intake to heat, protein, and fat in growing pigs. *Journal of Animal Science* 81: E86-E93.
- West, J.W. 1994. Interactions of energy and bovine somatotropin with heat stress. *Journal of Dairy Science* 77: 2091-2102.

- West, J.W. 1999. Nutritional strategies for managing the heat-stressed dairy cow. *Journal of Animal Science* 77: 21-35.
- West, J.W. 2003. Effects of heat-stress on production in dairy cattle. *Journal of Dairy Science* 86: 2131-2144.
- Wolfenson, D. 2009. Impact of heat stress on production and fertility of dairy cattle. In *Proceedings of the 18th Annual Tri-State Dairy Nutrition Conference*, pp. 55-59. Fort Wayne, IN, USA, 21-22 April 2009.