Veterinary Research Communications, 30(Suppl. 1) (2006) 75–81
DOI: 10.1007/s11259-006-0016-x

Climatic Effects on Productive Traits in Livestock

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Nardone, A., Ronchi, B., Lacetera, N. and Bernabucci, U., 2006. Climatic effects on productive traits in livestock. *Veterinary Research Communications*, **30(Suppl. 1)**, 75–81

Keywords: climate, farm animals, production, reproduction

Abbreviations: HS, heat stress; RH, relative humidity; THI, temperature humidity index

INTRODUCTION

Each species, breed or animal category, correlated with its physiological state, has a comfort zone, in which the energy expenditure of the animal is minimal, constant and independent of environmental temperature. Outside of this zone, the animal experiences stress to maintain homeothermy. This requires extra energy to thermoregulate, so that less energy is available for production processes (Bianca, 1976). The animal modifies its behaviour, especially feeding, physiological and metabolic functions and the quantity and quality of its production. When an animal is for a medium/long period outside of its zone of thermoneutrality it activates mechanisms of acclimatization, whereas population of animals experiencing significant climatic changes can adopt, by genetic adaptation, modifying genetic and phenotypic features over generations. The more the impact of the climatic conditions on the animal varies in magnitude and length, the more difficulties the organism has to maintain homeothermy. Outside the extreme limits of this zone, the organism experiences hypothermy or hyperthermy until it dies from cold or heat. The difference between normal and lethal body temperature is in the order of 15–25°C in the cold and of only around 3–6°C in the heat. This explains why cold represents less of a problem than heat (Bianca, 1976; Collier *et al.*, 1982) and why high selected productive animals, with high endogenous heat production, show high tolerance to cold and low tolerance to heat. Consistently, the limits of the thermal comfort zone for these selected animals becoming lower and the animals are becoming more and more sensitive to heat stress (HS). Animals have two means by which to exchange heat with the environment: via evaporative or latent (sweating and painting) or non-evaporative or sensible (conduction, convection, radiation) systems (Yousef, 1987). Because air temperature alone is an imperfect measure of the thermal environment, many attempts have been made to combine the effects of two or more thermal environmental factors to better represent the influence of sensible and latent heat exchange between an organism and its environment. The Temperature Humidity Index (THI) (Johnson, 1980) is the most extensively employed index for moderate to hot conditions, even though some limitations exist related to air speed and radiation heat loads (Hahn *et al.*, 2003). Heat and draught frequently destroy pasture and crops in arid tropical and subtropical zones of developing countries, where whole herds die of starvation. Negative climatic effects on pasture and crop production, diffusion of animal diseases and livestock production occur even in developed countries where appropriate cooling techniques (sprinkler systems, air-conditioning, fans, shade, etc.) and management strategies to alleviate extreme climatic effects are adopted. St-Pierre *et al.* (2003) estimated a total economic animal loss incurred by the US farm animals due to HS at between 1.69 and 2.36 billion US dollars. About 58% of this occurs in the dairy industry, 20% in the beef industry, 15% in pigs and the remaining 7% in the poultry industry. The aim of this paper is to review the effects of climate, primarily of those conditions capable of causing heat stress, on the reproduction and production of farm animals.

REPRODUCTION

High ambient temperatures compromise reproductive efficiency of farm animals in both sexes and hence affect milk and meat production and the results of animal selection.

Cattle

Heat stress compromises oocyte growth in cows by altering progesterone, luteinizing hormone, and follicle-stimulating hormone secretions during the oestrus cycle (Ronchi *et al.*, 2001), as well as impairing embryo development and increasing embryo mortality (Wolfenson *et al.*, 2000). Moreover, HS may reduce the fertility of dairy cows in summer by poor expression of oestrus due to a reduced estradiol secretion from a dominant follicle developed in a low luteinizing hormone environment (De Rensis and Scaramuzzi, 2003). About a 20% drop in conception rates (Lucy, 2002) or decrease in 90-day nonreturn rate to the first service in lactating dairy cows (Al-Katanani *et al.*, 1999) can occur in summer. In these situations the calving interval is longer, the birth rate is lower and farm milk yield per year can be reduced. Heat stress during pregnancy slows down growth of the fetus, although active mechanisms attenuate excursions in fetal body temperatures when mothers are thermally stressed. Semen concentration, number of spermatozoa and motile cells per ejaculate of bulls are lower in summer than in winter and spring (Mathevon *et al.*, 1998). Conversely, Karagiannidis *et al.* (2000) refer an improvement of semen characteristics of goat bucks reared in Greece during summer and autumn.

Pigs

Pigs, due to their low sweating capacity, suffer from serious impairment of reproductive efficiency when thermally stressed. A sudden increase in air temperature has a tremendous effect on periparturient sows. D'Allaire *et al.* (1996) discovered a 5–6 times higher death-rate in sows exposed to temperatures over 33°C at delivery. Sows and gilts that experience high air temperature in the mating period manifest a delayed return to oestrus or an increase in the number of non-pregnant animals. Heat stress impairs embryonic development and affects reproductive efficiency until 5–6 weeks after exposure to hot conditions. Kunavongkrita *et al.* (2005) refer to lower sperm concentration (174 × 106 sperm per ml in summer compared to 266 × 106 sperm per ml in winter) and volume (128 ml in summer and 145 in winter, respectively), for boars reared in Thailand, where the air temperature in summer reaches on average 30°C and the length of the photoperiod shows little change during different seasons.

Poultry

Exposure to elevated ambient temperature decreases fertility even in poultry. Male birds appear to contribute more than females to HS infertility, and high temperatures have a greater impact on semen quality and fertility in those males with a better sperm quality index (Karaca *et al.*, 2002).

MILK PRODUCTION

Dairy Cattle

The higher the milk yield of a cow the higher her feed intake. This basic principle conflicts with the fundamental behaviour of heat-stressed animal, which reduces feed intake to reduce heat gain. Among farm animals, a high yielding dairy cow represents one of the extreme cases of this difficult situation. At the peak of lactation a cow of 700 kg body weight (BW) with a milk yield of 60 kg/day, produces about 44171 kcal/day (25782 kcal/day at the end of lactation, with a milk yield of 20 kg/day). Exposure to a hot environment may negatively affect growth of young calves. We found lower wither height, oblique trunk length, hip width (−35, −26, −29% respectively) and body condition score (0.0 *vs* +0.4 points) in six 5-month-old female Holstein Friesian calves exposed to hot conditions as compared with a control group (the corresponding six sisters of six pairs of twins), kept under thermoneutrality conditions (Lacetera *et al.*, 1994). Decrease in body growth and body reserves between birth and puberty, especially during the first few months, can be detrimental for milk production of the future cow and can increase the replacement rate later (Chillard, 1991). High temperatures during late pregnancy and the early post partum period markedly modify colostrum composition. Holstein Friesian heifers kept in a climatic chamber and exposed during late pregnancy and the early post partum period to 82 THI daytime and to 76 THI night-time, when compared to a counterpart maintained under thermoneutrality conditions (65 THI), showed lower colostrum net energy due to a reduction in lactose, fat and protein content. In addition, the analysis of protein fractions showed a reduction in percentages of casein, lactoalbumin, IgG and IgA (Nardone *et al.*, 1997). This can explain why summer calves have a lower concentration of circulating Ig (Stott *et al.*, 1976). According to Ravagnolo *et al.* (2000), HS in lactating cow starts at 72 THI, which corresponds to 22°C at 100% RH (or 25°C at 50% RH or other combinations of the two parameters). Above this THI value milk production and protein content decline, whereas the response of fat yield seems delayed. The mean THI two days earlier has the greatest effect on cow milk yield, while dry matter intake is most sensitive to the mean air temperatures two days earlier (West *et al.* 2003). The fall in milk yield in a hot environment is higher for older and more productive animals when they are at the peak of lactation. An investigation on Israelian Holstein cows in their third and fourth lactation periods showed the antagonistic effect of heat (−0.38 kg of milk/1°C) and photoperiod (+1.157 kg of milk/per 1 h more of light) (Barash *et al.*, 2001). On comparing milk production during summer and spring in a dairy herd located in central Italy we found a lower milk yield (−10%), and also lower casein percentages and casein number in summer (2.18 *vs* 2.58% and 72.4 *vs* 77.7% respectively) (Bernabucci *et al.*, 2002). The fall in casein was due to the reduction in α_s-casein and β-casein percentages. No differences were found between the two seasons for κ-casein, α-lactoalbumin and β-lactoglobulin, whereas serum protein contents were higher in summer than in spring. The strict relationship between casein content and fraction and milk behaviour during technical processes can explain the losses in cheese yield and the alteration of cheese making properties during summer in Italy. Heat stress also affects the freezing point of milk: we found −0.515°C in summer *vs* −0.525°C in spring (unpublished data). Although dairy cows fare better with cold than with heat, animals experiencing cold stress also reduce milk yield. The drop starts around −4°C and marked yield depression occurs at −23°C. According to other authors, the lower critical temperature is −40°C or −45°C with a daily milk yield of 36 kg (Broucek *et al.*, 1991).

Other Species

The lower importance of sheep, goat and buffalo milk production in the world, lower selection for high productivity in these species, and their higher adaptability to hot environments, explain the fact that less interest has been shown for investigations of HS in these species than in cattle. Milk production traits in ewes seem to have 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 HS seem to be quite different among sheep breeds (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 Comisana ewes (Sevi *et al.*, 2001). Even goats are affected by high air temperatures, reducing milk yield and the content of milk components. In particular, if lactating goats are deprived of water during HS 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).

MEAT AND EGG PRODUCTION

Ruminants

Worldwide beef cattle are reared outdoors with consequent exposure to natural conditions and are only maintained in housing systems to a limited extent. Under these conditions, it is not easy or economically convenient to provide protection from extreme meteo-climatic factors. In temperate zones, young fattening bulls grow more in spring and autumn seasons than in winter and summer. Temperatures between 15–29°C do not seem to exert any influence on growth performance.

Above 30°C adverse effects are recorded in daily weight gain. Under high ambient air temperature and solar radiation, steers reduce daily dry matter intake, hence average daily gain and carcass weight fall down, fat thickness drops (Mitlöhner *et al.*, 2001) and an increase in disease incidence can occur. The effects of HS on feed intake are remarkable even in buffaloes. Morand-Feher and Doreau (2001) report an decline in feed intake ranging from 40 to 60% in 15-month-old buffaloes caused by variation of temperature and humidity (from 21.5 to 38.5°C and from 59.0 to 76.5 RH, respectively).

Pigs

The negative effects of high air temperatures on pork production become evident during the suckling period. Above 25°C sows reduce feed intake by 5–6 times with respect to that at 18–25°C. Thus, as body reserves are usually not sufficient to counterbalance the reduced feed intake, the milk yield of the sow decreases, hence growth, viability and survival of piglets also decline (Renaudeau *et al.*, 2004). In high ambient air temperature, as for dairy cows, the heavier the pigs, the more they reduce appetite and growth. Because protein deposits require more energy than fat deposits, the carcasses are leaner at slaughter. Compared to those reared in an optimal climate, Rinaldo and Mourot (2001) found that Large White pigs (between 35 and 94 kg body weight) reared in a tropical climate had a lower voluntary feed intake (−9%, −13%) and daily weight gain (−9%, −12%), leaner carcass, higher pH, lower moisture loss and decreased lipid content of leaf fat in the entire backfat, concluding that tropical climate may have a favourable effect on pork quality. The adaptation in pigs to heat affects carcass characteristics by the re-allocation of fat depots from subcutaneous sites (bardiere) towards inner sites (panne) to facilitate thermal conductance (Le Dividich and Rinaldo, 1989).

Broilers

Environmental temperatures above 30°C in the rearing area cause high mortality of broiler chickens (De Basilio and Picard, 2002) or reduction in feed intake, body weight, carcass weight, carcass protein and muscle calorie content (Tankson *et al.*, 2001).

Eggs

Significant reduction of body weight and feed consumption occur in heat-stressed hens. Egg production, egg weight, shell weight and shell thickness are considerably compromised by heat exposure (Mashaly *et al.*, 2004). Moreover, high air temperatures increase egg breakage.

CONCLUSION

Even if to varying extents, all productive traits of livestock are affected by climate. Heat associated with high humidity or drought represents the most stressful constraint for animal production. Technical and managerial solutions to avoid the negative effects of adverse climatic phenomena are not always accessible or effective; on otherwise they may not be economically convenient. Little attention has been given by researchers to the effects of climate on product quality, welfare, immuno-response of animals, genetic differences among species, breeds and animals in coping with climatic constraints and to the risk of epizooties due to climatic changes. Selection for highly productive animals increases their susceptibility to HS and the diffusion of selected breeds is affecting genetic diversity. Future research studies on the abovementioned fields may increase knowledge in the area of animal biometeorology, which will increase the opportunities for selection of traits of thermotolerance and improve management of livestock, either in conditions of long lasting heat or when extreme climate events, such as heat waves, occur.

ACKNOWLEDGEMENTS

The authors acknowledge M. Stella Ranieri for her valuable collaboration.

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