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Effects of climate changes on animal production and sustainability of livestock systems ☆

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ABSTRACT

The effects of climate change are controversial. This paper reviews the effects of climate change on livestock following the theory of global warming. Although, the effects of global warming will not be adverse everywhere, a relevant increase of drought is expected across the world affecting forage and crop production. Hot environment impairs production (growth, meat and milk yield and quality, egg yield, weight, and quality) and reproductive performance, metabolic and health status, and immune response. The process of desertification will reduce the carrying capacity of rangelands and the buffering ability of agro-pastoral and pastoral systems. Other systems, such as mixed systems and industrial or landless livestock systems, could encounter several risk factors mainly due to the variability of grain availability and cost, and low adaptability of animal genotypes. Regarding livestock systems, it will be strategic to optimise productivity of crops and forage (mainly improving water and soil management), and to improve the ability of animals to cope with environmental stress by management and selection. To guide the evolution of livestock production systems under the increase of temperature and extreme events, better information is needed regarding biophysical and social vulnerability, and this must be integrated with agriculture and livestock components.

1. Introduction

A huge increase in the demand of animal production is expected in the next decades. Food and water security will be one of the other priorities for humankind in the 21st century. Over the same period the World will experience a change in the global climate that will cause shifts in local climate that will impact on local and global agriculture.

The key conclusions of Working Group I of the Intergovernmental Panel on Climate Change (IPCC), the Fourth Assessment Report (AR4) (IPCC, 2007) were: a) warming of the climatic system is unequivocal; b) anthropogenic warming will probably continue for centuries due to the timescales associated with climate processes and feedbacks; c) the surface air warming in the 21st century by best estimate will range from 1.1 to 2.9 °C for a "low scenario" and of 2.4 to 6.4 °C for a "high scenario".

Moreover, the IPCC report estimates a confidence level >90% that there will be more frequent warm spells, heat waves and heavy rainfall and a confidence level >66% that there will be an increase in drought, tropical cyclones and extreme high tides. The magnitude of the events will vary depending on the geographic zones of the World.

The AR4 has been subjected to scientific criticism. It has been said that the report understates or overstates the dangers of climate change, and overstates the faults due to anthropogenic greenhouse gas concentrations.

Nevertheless, the recognized scientists contributing to the IPCC report and the results of our analysis of the evolution of temperature–humidity index (THI) in the Mediterranean area in the last five decades of 20th century (data unpublished) convince us to follow the theory of global warming.

The effects of global warming will not be adverse everywhere in the world. Thornton et al. (2007) forecast a

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slight increase in crop productivity at mid to high latitude for an increased local mean temperature of 1–3 °C. Also in these areas, frosts, heat waves or heavy rainfall can cancel the advantages of the increase in temperature. A lower increase of temperature, around 1–2 °C, however, could worsen crop and cereal production at lower latitudes. The areas affected most will be in the boreal hemisphere, in particular North America, Northern Europe, Northern Asia and, at a lower latitude, the Mediterranean basin and West-Central Asia (Easterling et al., 2007).

Some countries in these areas have a very high farm animal density and animal production comes mostly from industrialized livestock systems, which rear highly selected pigs, poultry and dairy cows. The indirect effects of global warming such as soil infertility, water scarcity, grain yield and quality and diffusion of pathogens may impair animal production in these systems more than the direct effects. Indeed, in these systems the animals can cope better with the direct effects of high temperature, i.e. heat stress, with the help of diet, techniques of cooling or farm management. On the other hand the employment of techniques to adapt air temperature of barns to the thermoneutrality of the animals causes higher energy consumption and therefore, worsens global warming and increases general costs of animal production. Moreover industrialized systems produce more manure than can be used as fertilizer on nearby cropland resulting in soil accumulation of phosphorous, nitrogen and other pollutants (Thorne, 2007).

We have to expect that the livestock systems based on grazing and the mixed farming systems will be more affected by global warming than an industrialized system. This will be due to the negative effect of lower rainfall and more droughts on crops and on pasture growth and of the direct effects of high temperature and solar radiation on animals.

These systems exist mainly in developing countries where the human demand for animal products is increasing due to the continuous growth in the population and per capita consumption (Delgado et al., 1999; Delgado, 2003; Holmes, 2001; Nardone, 2002). A loss of 25% of animal production by global warming (Seguin, 2008) is foreseen in these countries. A worse scenario is foreseen for Africa and some zones of Asia where extensive or pasture based systems remain the norm.

In any case at a World level, animal production has to increase in the next decades to satisfy the growing need. According to Cohen (2001) in the year 2050, the world population will reach 9.3 billion and more than 60% will live in towns. It is estimated that by then, global meat consumption will be twice that of today. How can we make animal production equal animal consumption in the next decades? The challenge will be how to better balance either the increase in the number of stock or the productivity per head, at the same time improving the sustainability of the livestock sector. This is an important task as today the billion land animals which are reared and slaughtered, either directly or indirectly contribute to total human induced greenhouse gas by 18% and total CO_2 emission by 9%.

The efficiency of water utilization will be another primary mission necessary to achieve sustainability of animal agriculture in expectation of increasing water scarcity and worsening quality. To save water means to grow plants and to rear animals in systems demanding less water.

The question is where and under what conditions in the World will it be convenient to produce animal products? Animal production requires high volumes of water per unit of product. An example is beef that demands about 23 tons of water per kg of product.

Animal agriculture will face hard challenges in many fields in the 21st century. Decision makers, research institutions and extension services have to support livestock activities to cope at best with the loss of production, worsening of animal products, enlargement of land desertification and the worsening of animal health under the effects of the climate change we expect in the next decades.

The position of this paper is not to foresee the global evolution of animal production and livestock systems under the effects of climate change owing to the enormous number of components under either direct or indirect climatic effects that shape livestock systems. A precise study would require a lot of knowledge and data in many disciplines and would be very long. The paper therefore presents an analysis of some relevant effects of global warming on livestock production and on the forecast of the evolution of major livestock systems.

2. Impact of climate change on animal health

The effects of climate change on the health of farm animals have not been studied in depth. However, it can be assumed that as in the case of humans, climate change, in particular global warming, is likely to greatly affect the health of farm animals, both directly and indirectly. Direct effects include temperature-related illness and death, and the morbidity of animals during extreme weather events. Indirect impacts follow more intricate pathways and include those deriving from the attempt of animals to adapt to thermal environment or from the influence of climate on microbial populations, distribution of vector-borne diseases, host resistance to infectious agents, feed and water shortages, or food-borne diseases.

Acclimation is a phenotypic response developed by the animal to an individual source of stress within the environment (Fregley, 1996). The acclimation of the animals to meet the thermal challenges results in the reduction of feed intake and alteration of many physiological functions that are linked with impaired health and the alteration of productive and reproductive efficiency (Beede and Collier, 1986; Lacetera et al., 2003a). Acclimation to high environmental temperatures involves responses that lead to reduce heat load. The immediate responses are the reduction of feed intake, increase in respiration rate and water intake and changes in hormonal signals that affect target tissue responsiveness to environmental stimuli (Collier and Zimbelman, 2007). The decrease in energy intake due to reduced feed intake, results in a negative energy balance (NEB), and partially explains why cows lose significant amounts of body weight and body score when subjected to heat stress (Lacetera et al., 1996).

If exposure to high air temperature is prolonged, lower feed intake is followed by a decline in the secretion of calorigenic hormones (growth hormone, catecholamines and glucocorticoids in particular), in thermogenic processes of digestion and metabolism, and metabolic rate (Johnson, 1980; Webster, 1991). All these events together (lower feed intake, change in endocrine status and lower metabolic rate) tend to reduce metabolic heat production (Yousef, 1987) and might be responsible for modifications of energy, lipids, protein and mineral metabolism, and liver function.

Our previous studies (Lacetera et al., 1996; Nardone et al., 1997; Ronchi et al., 1995, 1997, 1999) and studies done by others (Itoh et al., 1998a,b; Moore et al., 2005; O'Kelly, 1987; Sano et al., 1983, 1985; Vizcarra et al., 1997) clearly demonstrated the alteration of glucose, protein and lipid metabolism and alteration of liver functionality in heat-stressed subjects.

Blood glucose is usually reduced in heat-stressed subjects and this reduction is not all attributable and justified by the lower feed intake occurring in a hot environment (Itoh et al., 1998b). Also, non-esterified fatty acids (NEFA) are usually reduced under hot conditions (Ronchi et al., 1999; Sano et al., 1983). The changes of plasmatic concentrations of NEFA under hot environment are in contrast with NEB and loss of BCS, which generally occur in very hot conditions (Lacetera et al., 1996; Ronchi et al., 1999). Considering, these facts, the lower values of plasma NEFA in heat-stressed animals would not seem explainable by the lower feed intake.

Recently Baumgard et al. (2007) and Wheelock et al. (2006) described lower glucose and lower NEFA in heat-stressed cows compared with pair-fed cows. In addition, these authors demonstrated that glucose disposal (rate of cellular glucose entry) was greater in heat-stressed compared to thermal neutral pair-fed cows, and heat-stressed cows had a much greater insulin response to a glucose challenge when compared to underfed cows. The consequence of the reduction of hepatic glucose synthesis, the alteration of glucose turnover and the increased glucose demand for energy need is the lower availability of glucose for mammary gland lactose synthesis (Nardone et al., 1992, 1997). Since, lactose production is the primary osmoregulator and thus determinant of milk yield, reduction of glucose availability leads to the reduction of milk yield and may account the reduction of milk yield not explainable by the reduction of feed intake under hot conditions (Baumgard et al., 2007; Johnson, 1967).

Our research evidenced the alteration of liver functions in heat stressed subjects. The reduction of cholesterol and albumin secretion and liver enzyme activities clearly indicated a reduction in liver activity in heat-stressed cattle (Bernabucci et al., 2006; Ronchi et al., 1999). We also demonstrated that hot conditions, capable of producing moderate or severe heat stress, cause oxidative stress in transition dairy cows (Bernabucci et al., 2002a, 2003). More recently, Lin et al. (2006) concluded that the oxidative stress should be considered as part of the stress response of broiler chickens to heat exposure.

Alteration of glucose and lipid metabolism, liver function and oxidative status may be responsible for the increased sensitivity of heat-stressed animals to metabolic diseases with negative consequences on production, reproduction and infectious disease sensitivities in intensive and extensive livestock production systems.

The increased respiration rate results in enhanced CO_2 being exhaled. Under a hot environment, hyperventilation induces a decrease in blood CO_2 and the kidney secretes HCO_3^- to maintain this ratio (Schneider et al., 1988). This reduces the availability of HCO_3^- that can be used (via saliva) to buffer and maintain a healthy rumen pH. In addition, panting ruminants drool and drooling reduces the quantity of saliva that would have normally been deposited in the rumen. Furthermore, due to reduced feed intake and reduced forage/concentrate ratio, heat-stressed ruminants ruminate less and therefore produce less saliva. The reduction in the amount of saliva produced and salivary HCO_3^- content, the decreased amount of saliva entering the rumen and the reduced forage intake make the heat-stressed cow much more susceptible to sub-clinical and acute rumen acidosis (Kadzere et al., 2002), which indirectly enhances the risk of other concurrent health and productive problems (laminitis, milk fat depression, etc.). These circumstances are more typical for intensive cattle production systems (dairy and beef).

In a recent retrospective study carried out for years 2001–2006 in the geographic area known as the Po Valley, and including the regions Lombardia and Emilia Romagna (Italy), we analyzed seasonal variations of mortality rate in dairy cows (Vitali et al., 2009). For all these years and for both regions, the analysis of the standard mortality rate showed that during the summer season the observed deaths (OD) were significantly higher than the expected deaths (ED). In the summer season the OD overcame ED by values ranging from +14% (year 2002, Emilia Romagna) to +60% (year 2003, Lombardia); the corresponding 95% confidence intervals were 1.10–1.18 and 1.57–1.64 for the years 2002 and 2003, respectively.

Results of an epidemiology study carried out in California (Martin et al., 1975) documented higher mortality rates in summer calves. Others have reported that heat stress may be responsible for impairment of the protective value of colostrum both in cows (Nardone et al., 1997) and pigs (Machado-Neto et al., 1987), and also for alteration of passive transfer of immunoglobulin in neonatal calves (Donovan et al., 1986; Lacetera, 1998). On the other hand, results on the negative influence of heat stress on colostral immunoglobulin is likely to explain the higher mortality rate of newborns observed during hot months (Martin et al., 1975).

A series of studies carried out in dairy cows indicated a higher incidence of mastitis during periods of hot weather (Chirico et al., 1997; Giesecke, 1985; Hogan et al., 1989). However, the mechanisms responsible for the higher occurrence of mammary gland infections during summer months have not been elucidated. The hypothesis advanced to explain these observations include the possibility that high temperatures may facilitate survival and multiplication of pathogens (Hogan et al., 1989) or their vectors (Chirico et al., 1997), or a negative action of heat stress on defensive mechanisms (Giesecke, 1985).

Several studies have assessed the relationships between heat stress and immune responses in cattle, chickens or pigs. However, results of those studies are conflicting. In particular, some authors reported an improvement (Beard and Mitchell, 1987; Regnier and Kelley, 1981; Soper et al., 1978), others described an impairment (Elvinger et al., 1991; Kamwanja et al., 1994; Morrow-Tesch et al., 1994; Regnier and Kelley, 1981), and others indicated no effects (Bonnette et al., 1990; Donker et al., 1990; Kelley et al., 1982; Lacetera et al., 2002; Regnier et al., 1980) of high environmental temperatures on immune function. Recently, in a field study carried out in Italy during the summer 2003 (Lacetera et al., 2005), which was characterized by the occurrence of at least three severe heat waves, we observed a profound impairment of cell-mediated immunity in high yielding dairy cows. The large variety of experimental conditions in terms of species, breeds, severity and length of heat stress, recovery opportunities, and also of the specific immune functions taken into consideration are likely to explain the discrepancy among results of different studies. For instance, in a recent *in vitro* study we observed that peripheral blood mononuclear cells from Brown cows are less tolerant to chronic heat exposure than those from Holstein cows, and that the lower tolerance is associated with higher expression of heat shock proteins 72 kDa, suggesting that the same level of hyperthermia may be associated with a differential decline of immune function in the 2 breeds (Lacetera et al., 2006).

As already reported above, global warming will also affect the biology and distribution of vector-borne infections. Wittmann et al. (2001) simulated an increase of temperature values by 2 °C, and under these conditions, their model indicated the possibility of an extensive spread of *Culicoides imicola*, which represents the major vector of the bluetongue virus.

Another mechanism through which climate change can impair livestock health is represented by the favourable effects that high temperatures and moisture have on growth of mycotoxin-producing fungi. With regard to the alteration of animal health, mycotoxins can cause acute disease episodes when animals consume critical quantities of these toxins. Specific toxins affect specific organs or tissues such as the liver, kidney, oral and gastric mucosa, brain, or reproductive tract. In acute mycotoxicoses, the signs of disease are often marked and directly referable to the affected target organs. Most frequently, however, concentrations of mycotoxin in feeds are below those that cause acute disease. At lower concentrations, mycotoxins reduce the growth rate of young animals, and some interfere with native mechanisms of resistance and impair immunologic responsiveness, making the animals more susceptible to infections. Studies have shown that some mycotoxins can alter lymphocyte function in domestic ruminants through alteration of DNA structure and function (Lacetera et al., 2003b; Vitali et al., 2004).

3. Impact of climate change on reproduction

High environment temperatures may compromise reproductive efficiency of farm animals in both sexes and hence negatively affect milk, meat and egg production and the results of animal selection.

Wolfenson et al. (2000) reported that over 50% of the bovine population is located in the tropics and it has been estimated that heat stress may cause economic losses in about 60% of the dairy farm**s** around the world. 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 (Bényei et al., 2001; Hansen, 2007; Wolfenson et al., 2000). 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 can occur in summer of about a 20–27% in conception rates (Chebel et al., 2004; Lucy, 2002) or a decrease in 90-day non-return rate to the first service in lactating dairy cows (Al-Katanani et al., 1999). 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. Also, beef cows are negatively affected by heat stress. In a ten-year study of calving records, 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.

Roy and Prakash (2007) reported a lower plasma progesterone and higher prolactin concentration during oestrus cycle in Murrah buffalo heifers. These authors concluded that prolactin and progesterone profiles during the summer and winter months are directly correlated with the reproductive performance of buffaloes, and that hyperprolactinaemia may 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 are 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. Conversely, Karagiannidis et al. (2000) refer an improvement of semen characteristics of goat bucks reared in Greece during summer and autumn.

Pigs are very sensitive to hot conditions. This is mainly due to the low sweating capacity. Increase in air temperature has a tremendous effect on periparturient sows. D'Allaire et al. (1996) reported 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. Barati et al. (2008) reported that exposure of porcine oocytes to an elevated temperature (41 °C) had a detrimental effect on the meiotic competence and on quality of oocytes. Kunavongkrita et al. (2005) refer to lower sperm concentration (174×10^6 sperm per ml in summer compared with 266×10^6 sperm per ml in winter) and volume (128 ml in summer and 145 in winter) during the hot season, 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.

Exposure to elevated ambient temperature decreases fertility even in poultry, rabbits and horses. Male birds appear to contribute more than females to heat stress related 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). Exposure of adult New Zealand White rabbits to severe heat stress strongly reduced conception rate (Marrai et al., 2001). In a recent study Mortensen et al. (2009) reported changes in ovarian follicle development and ovulation, and a reduction in embryo recovery in exercising mares exposed to hot and humid environment.

4. Impact of climate changes on animal production

Climate change, particularly global warming, may strongly affect production performances of farm animals and impact worldwide on livestock production (Nienaber et al., 1999).

Heat stress is a major source of production loss in the dairy and beef industry and whereas new knowledge about animal responses to the environment continues to be developed, managing animals to reduce the impact of climate remains a challenge (Hahn, 1995, 1999; Hahn et al., 2003a,b; Sprott et al., 2001). During the 2006 heat wave in California, dairy producers lost more than \$1 billion in milk and animals. During 1990s severe heat wave in Nebraska, cattle deaths and performance losses cost Nebraska producers more than \$20 million. Between July 11 and 12, 1995, a combination of deadly heat and humidity with clear skies and no wind caused the deaths of over 3700 cattle in a thirteen counties of western Iowa (Collier and Zimbelman, 2007). As reported before, also in Italy, heat stress can be responsible for the increase in mortality and economic losses (Vitali et al., 2009). Mader (2007), in a recent review, reported that in 1992, 1995, 1997 and 1999, individual feedlots lost >100 head during severe heat episodes. The heat waves of 1995 and 1999 were particularly severe with cattle losses in individual Midwestern states approaching 5000 head each year. Economic losses as a result of the 1995 heat wave were estimated to be \$31 million in Iowa alone. Mader et al. (2002) estimated direct and indirect losses (cattle death and loss of performance) as a result of adverse weather, averaged between \$4000 and \$5000 for each animal that dies. These examples forecast an increase of economic losses in the future due to global warming both in intensive and extensive livestock production systems. St-Pierre et al. (2003) estimated a total economic loss that US farm animals suffered due to heat stress at between 1.69 and 2.36 billion US dollars. About 58% of this occurred in the dairy industry, 20% in the beef industry, 15% in pigs and the remaining 7% in the poultry industry.

4.1. 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. Johnson et al. (1962) 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 per unit of THI for DMI and milk yield, respectively. Our 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.

The extent of milk yield decline observed in heat-stressed cows is dependent on several factors that interact with high air temperature.

The milk yield losses seem positively related with milk yield of cows (Berry et al., 1964). Johnson et al. (1988) found a higher average persistency decline in cows with milk yield higher than 30 kg/day (−0.059%/day) compared with cows yielding less than 25 kg/day (−0.019%/day). 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). For example, heat production of cows producing 18.5 and 31.6 kg/day of milk was 27.3 and 48.5 % higher than non-lactating cows (Purwanto et al., 1990). Moreover, a cow weighing 700 kg body weight (BW) and yielding 60 kg/day of milk, produces about 44 171 kcal/day; the same cow produces 25,782 kcal/day at the end of lactation, with a milk yield of 20 kg/day. 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) derived similar results in a field study. These authors 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.

Hot environment negatively affects milk quality as well (Bernabucci and Calamari, 1998; Calamari and Mariani, 1998).

Above 72 THI value milk protein content declines, whereas the response of fat yield seems delayed and results are very contradictory. 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., 2002b). 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 loss in cheese yield and the alteration of cheese making properties during summer in Italy (Calamari and Mariani, 1998).

The minor importance of sheep, goat and buffalo milk production in the world, lower selection for high productivity in these species and their supposed higher adaptability to hot environments, explain the fact that less attention has been given to the effects of heat stress in these species. 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 Comisana ewes (Sevi et al., 2001).

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).

Table 1
Mean and standard deviation of wither height (WE) and body weight (BW) for cattle, sheep and goat breeds in the European (Eu) [a], Asian (As) [b] and African (Af) [c] Mediterranea Area (MA) (Nardone, 2000).

Area	Breeds n.	WE of adult males (cm)	WE of adult females (cm)	BW of adult males (kg)	BW of adult females (kg)
Cattle					
Eu MA	138	141.5 ± 12.1	132.4 ± 11.0Bb	809.4 ± 267.5B	533.5 ± 157.4B
As MA	14	135.6 ± 13.7	120.4 ± 11.4A	467.1 ± 91.4A	341.4 ± 103.3A
Af MA	6	135.0 ± 0.0	120.5 ± 5.0a	400.0 ± 38.5A	323.7 ± 34.7A
Sheep					
Eu MA	186	73.1 ± 1.0	65.4 ± 8.3b	72.1 ± 21.8b	52.9±14.6b
As MA	27	71.2 ± 3.6	64.4 ± 3.0ab	60.7 ± 12.9a	47.4 ± 10.5a
Af MA	23	70.4 ± 14.8	60.6 ± 14.3a	67.1 ± 11.0ab	7.2 ± 9.7b
Goat					
Eu MA	69	75.1 ± 9.0	66.4 ± 7.9	64.0 ± 12.8Bb	47.8 ± 8.7C
As MA	16	74.1 ± 7.3	63.4 ± 7.3	55.7 ± 11.4a	40.0 ± 7.3B
Af MA	12	69.9 ± 4.1	60.8 ± 6.0	44.7 ± 10.3A	31.6 ± 5.3A

a, b = P<0.05; A, B, C = P 0.01.
[a] Countries in Eu MA: AL, BiH, HC, F, GR, I, MK, M, P, SCG, SLO, E.
[b] Countries in As MA: CY, IL, JOR, RL, SYR, TR.
[c] Countries in Af MA: DZ, ET, LAR, MA, TN.

4.2. Meat and egg production

Worldwide, beef cattle are generally reared outdoors with consequent exposure to natural conditions and are only maintained in housing systems to a limited extent. Beef cattle are particularly vulnerable not only to extreme environmental conditions, but also rapid changes in these conditions. In particular, fatter cattle (fat under the skin provides an insulation layer trapping heat inside the animal), cattle with a heavier hair coat (more insulation) and darker coated animals (black and dark red cattle) are very sensitive to heat.

The Scientific Committee on Animal Health and Animal Welfare (SCAHAW, 2001) suggested that the higher threshold temperature for beef cattle is 30 °C with relative humidity below 80% and 27 °C with relative humidity above80 %. Temperatures between 15 and 29 °C do not seem to exert any influence on growth performance. In contrast, above 30 °C adverse effects are recorded in daily weight gain. Mitloehner et al. (2001) reported a reduction of daily dry matter intake and average daily gain, carcass weight loss, lower fat thickness and an increase in disease incidence in steers kept under high environmental air temperature and solar radiation.

Nardone (2000) reported a remarkable reduction in body size standards of cattle, sheep and goats breeds from north to south of the Mediterranean area (Table 1) related to the number of dry months (Fig. 1). In our previous study, we observed 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). These evidences induce us to believe that with global warming there could be a risk of reduction in average carcass weight, at least in ruminants.

Kadim et al. (2004) found strong negative effects of the hot season (average temperature of 34.3 ± 1.67 °C and 48.8 ± 7.57% relative humidity) on the quality characteristics of beef meat. In particular, these authors reported higher ultimate pH, lower Warner–Bratzler shear force and darker meat of *m. longissimus thoracis* in heat-stressed beef cattle when compared with muscle samples collected during the cool season.

Hot weather adversely affects the performance of pig production. Lucas et al. (2000) observed an association between significant duration and intensity of the heat stress periods with the high losses in pig production. The negative effects of high air temperature 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.

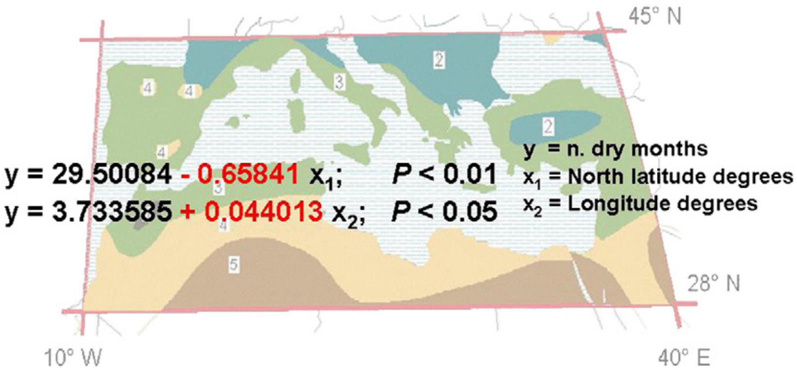

Fig. 1. Estimation of aridity in Mediterranean Area based on number of dry months calculated by ombrothermic diagram of 86 meteorological stations.

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). Under hot environments, as for beef cattle, the heavier the pigs, the more appetite and growth are reduced. Since protein deposits require less 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 back-fat, that could mean tropical climate may have a favourable effect on pork quality. The adaptation of pigs to heat affects carcass characteristics by the re-allocation of fat deposits from subcutaneous sites (bardiere) towards inner sites (panne) to facilitate thermal conductance (Le Dividich and Rinaldo, 1989).

Temperatures >30 °C are conditions for heat-stress for birds (Ensminger et al., 1990). Especially in the hot regions, heat stress is of major concern for the poultry industry because of the resulting poor growth performances (lower body weight gain and carcass yield) and high mortality rates (Bottje and Harrison, 1985; Geraert et al., 1993; Smith, 1993; Yahav et al., 1995). Selection for rapid growth has been associated with increased susceptibility of broilers to heat stress (Berong and Washburn, 1998; Cahaner et al., 1995). 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). Feng et al. (2008) observed significant decrease of initial pH and increased L*, drip loss, and shear force of breast muscle in heat-stressed broilers.

Heat stress reduces the reproductive performance of laying hens by interrupting egg production. This may be caused not only by a reduction in feed intake but also by a disruption of hormones responsible for ovulation and a decrease in responsiveness of granulosa cells to luteinizing hormone (Donoghue et al., 1989; Novero et al., 1991). 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, heat stress negatively affects the strength, weight, thickness, and ash content of the eggshell (DeAndrade et al., 1976, 1977; Miller and Sunde, 1975) resulting in the increased egg breakage. These responses may involve various aspects of calcium metabolism, including a reduction in free ionized calcium in the blood (Odom et al., 1986). Recently, Franco-Jimenez et al. (2007) in Hy-Line Brown, W36, and W98 hens housed for 2 weeks at 22 °C and exposed to 35 °C heat stress for 2 weeks, and 2 weeks of recovery at 22 °C, reported reduction in egg production, egg quality measures, and feed intake.

5. Effect of climate change on livestock production systems

Predictions of the impact of climate change on agriculture and livestock production systems are more reliable on a large-scale basis than at local levels. Principally the prediction is qualitative, rather than quantitative (Campbell et al., 1996). Climate change and variability will affect land-use and land-cover differently in different parts of the world (Table 2), as a result of strong interactions between environmental and socioeconomic drivers of land-use, which define vulnerability and resilience of each productive system (Thornton et al., 2007).

Even though future climate changes will be highly spatially variable, some model climate projections suggest that precipitation will increase at high latitudes, and will decrease in the tropical and subtropical land regions (IPCC, 2007). Crop yields are projected to fall in the tropics and subtropics by 10 to 20% by 2050 due to combination of warming and drying, but in some places yield losses could be more severe (Jones and Thornton, 2003). Thus in these areas crop productivity will be a critical constraint for livestock systems.

Through the years, several authors have proposed classifications of livestock systems (Boyazoglu and Flamant, 1990; Seré and Steinfeld, 1996; Nardone, 1996; Sørensen et al., 2006 and many others). Recently, Steinfeld et al. (2006) indicated 11 livestock systems and Devendra (2007) gave a comprehensive classification of integrated livestock systems in the Oceania area. Taking these into account, we will focus on three main categories of systems.

The first category includes the grazing or pastoral (and basic agro-pastoral) systems. These systems utilize more than 3 billion hectares of arid pasture, where agriculture is not feasible. Pastoral systems are located mainly in Africa, Asia, Australia, some areas of America and Europe. Ruminants represent the most common domestic animals reared in those systems, and provide more than 20% of the total world beef and 30% of small ruminant meat.

The second includes the mixed agro-zootechnical or crops livestock systems. These systems utilize about 2.5 billion hectares. According to Seré and Steinfeld (1996) we can subdivide these systems in two sub-categories: a) rain-fed mixed systems and b) irrigated mixed systems.

The rain-fed system is located mainly in Central and Eastern Europe, India, Eastern-South America and Central Africa and on the border between the United States and Canada. The irrigated mixed systems are located primarily in Central Europe, Southern and Eastern Asia and in some zones of Oceania, United States of America and Central America.

All the main species of farm animals are reared in mixed systems, where we can find farms specialized in a single purpose production system and rearing animals of only one specie or non-specialized farms rearing several species. On the whole we can estimate that today these livestock systems

Table 2
Examples of foreseeable land use changes under new climatic scenarios (adapted from Thornton et al., 2007).

Areas and climatic change	Land use changes
Temperate areas → warmer	Increase maize cultivation
Subtropical arid → warmer, drier	Substitution of maize with sorghum and millet; Conversion from a crop-livestock to a rangeland-based system.
Tropical arid → warmer, drier	Desertification

provide the largest amount of world meat and milk production. An estimate based on FAO data shows the production in all mixed systems of about 90% of world milk, 70% of world meat from ruminants, more than 25% of world meat from monogastric livestock and about 40% of world egg production. These mixed livestock systems all have the common characteristic of producing crops to supply feed for animals, totally or partially.

The third category comprehends the industrial and landless livestock systems. They are located mainly in Central and Southern US, in Europe, in vast areas of Eastern Asia and in some zones of the Near East and Oceania.

The industrial systems are the most important source of pigs and poultry. Today they provide world consumers about 70% of poultry meat, 60% of eggs and 55% of pork. In some zones, for example in Italy, these systems also produce beef, but globally furnish only 6% of world beef.

Possible future impacts of climate change on livestock production systems will largely depend on interactions of multiple processes and components. The foreseeable impacts will be governed by exposure to climate hazards and will be dependent on two main types of vulnerability: a) biophysical vulnerability (sensitivity of natural environment to hazards); b) social vulnerability (sensitivity and adaptability of human environment) (Thornton et al., 2007).

Adaptability represents the key tool to improve sustainability of livestock production systems under the pressure of climate and weather factors (Table 3). An advanced planning of production management systems is required, with an understanding of animal responses to thermal stress and ability to provide management options to prevent or mitigate adverse consequences (Nienaber and Hahn, 2007).

The main questions regarding the influence of climate change on livestock systems are: how much those three livestock systems are dependent on climate, which components of these systems will be mainly affected and what can we do to cope with these effects.

The level of dependence on climate estimates how much the animal performance, health, welfare; nutrition and production may be affected by the climatic conditions in a short or in a medium period in each system.

5.1. Impact on grazing or pastoral systems

In the extensive production systems constraints due to climate stress are substantial, aggravated by current degradation of natural resources, poor access to technologies and lack of investments in production (e.g. infrastructures). The animals are likely to experience heat stress for a prolonged period, especially in subtropical-Mediterranean zones (Silanikove, 2000).

Table 3
Adaptation options in livestock farming systems to climate change and vulnerability.

Adaptation options	Livestock systems		
	Grazing	Crop-livestock	Industrial
Crop/livestock diversification	*	***	
Livestock management	*	**	**
Developing extension services	*	**	**
Improving forecast models	*	**	**
Modernisation of farm operations	*	**	***
Irrigation efficient water use		**	
Temporary/permanent migration	***		
Crop/livestock insurance		*	**
Support of institutional structures	*	**	**

Perspectives: ***High; **Medium; *Low.

The increase of climatic variability will exert a strong influence on pastoral systems, even though they have developed the capability to cope and adapt to climate uncertainty. But for conditions that deviate many degrees from a “coping range” pastoral system will also became vulnerable if there is no adaptive capacity.

Pastoral systems will be exposed to climatic effects particularly in Africa, Australia, Central America and Southern Asia. In these areas some studies forecast up to 50% loss of available biomasses. In contrast, in North America, Northern Europe and North-Eastern Asia the increase in temperature and rainfall could determine an advantage for livestock.

However, since pastoral systems are totally dependent on availability of natural resources, the increase of inter-annual and seasonal variation of forage availability will contribute to reduce the overall sustainability, both from a social–economic and from an ecological perspective.

Solar radiation determines the major effect on thermoregulation of animals reared under extensive systems, usually grazing in areas where natural shade is not always available and provision of artificial shade is not always possible. In addition, for animals reared in extensive farming systems the mechanical work to explore grazing areas contributes to increasing the metabolic rate and, consequently, the rate of heat production that must be dissipated to avoid heat stress.

As reported before, animals reared under extensive systems may be exposed during summer months to an increased risk of health problems. A very common consequence is the increase of external parasites and vector-borne diseases (Patz et al., 2000; Wittmann et al., 2001). Moreover, under hot and humid environmental conditions there is an explosion of internal parasite populations.

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 derive 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 reduction of vulnerability of grazing/pastoral systems to climate changes should be based on the analysis of specific characteristics of the systems adopting new technologies (i.e. remote sensing) to evaluate feed and water availability, movement of the flocks, to establish feeding strategies to adopt during exceptional events in connection with local decision-making processes.

In extensive farming systems under hot environments, where environmental stress is usually intense and prolonged, and where forage and concentrate resources are limited in quantity and quality, the presence of a large animal biodiversity is of basic importance. In contrast, some small local animal populations, which are well adapted to pre-existing environmental conditions, risk disappearing, thus compromising animal biodiversity. Differences among domestic ruminants in adaptability to heat stress represent a key criterion for the selection of the most appropriate type and the possibility to obtain animal products for human needs (Devendra, 1990). One way to improve animal production in the extensive systems is to select animals, carefully balancing the weight of each vital trait and productive trait in the breeding schemes. An example is the estimation of the ecological total breeding value in cattle (Postler and Bapst, 2000). Another way is to cross animals of different breeds to take advantage of heterosis. For this second strategy it is necessary to maintain a correct proportion of animals of pure-breed and cross-breed, avoiding the risk of destroying pure breeds and jeopardizing biodiversity (Nardone and Villa, 1997). Finally, we have to expect as an effect of climate change, a reduction of stock and production especially in zones negatively affected by the warming conditions. Although these systems can 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.

5.2. Impacts on mixed agro-zootechnical or crop-livestock systems

Climate changes can affect crop-livestock systems, such as dairy cow farming, beef cattle farming, dairy sheep and goat farming, mainly acting on forage availability and quality, animal health and productivity.

In mixed rain-fed systems the effects will be higher than in irrigated systems. The possibility to cope with the effects of climate change will vary according to the area where the livestock is located, the species and breeds reared and the available technologies and extension services.

The Canadian Climate Centre predicts for 2030 potential losses in dairy cow farming systems ranging from 1.2% to 2.7% of current production levels, and for 2090 a reduction from 5.1 to 6.8% (Frank et al., 2000).

As reported before, heat stress conditions represent one of the most important limiting factors for dairy cow farming, responsible for many problems also in farms provided with appropriate controlled environmental techniques regarding livestock. Particularly devastating are the effects of extreme heat waves, especially when occurring in the early summer, when animals are not acclimatized (Nienaber and Hahn, 2007). Problems due to heat stress are particularly evident for high-producing dairy cows, because animals of a better genotype have a greater metabolic activity and encounter more difficulties in maintaining an optimal thermal equilibrium in hot environments (West, 1994). High-producing dairy cows require high nutrient intake and consequently produce large amounts of metabolic heat. A modification of the animal species and breeds reared in the mixed systems can be foreseen.

Less productive and better thermo-tolerant dairy cows, could substitute highly selected cows, in many areas. We can predict that global warming could seriously damage either beef or milk production, especially in mixed rain-fed systems.

Also, pork and poultry production, and eggs in these systems could be strongly affected depending on the characteristics of housing and on the economical possibility to adapt to microclimatic conditions and to access grain from the market. Thus adaptation strategies will be important in limiting negative effects of climate changes and adversities: physical modification of the environment (shading, cooling, etc.); improvement of animal feeding practices (West, 2003); improvement of forage and pasture management (changes in forage plants and varieties, grazing management); genetic development of heat-tolerant animals.

The extent of adaptation will be conditioned by availability of technologies and funds, together with rates of climate change and biophysical constraints.

Pro-active adaptation responses should be directed to capitalise opportunities deriving from climate change and to minimise potential threats. Options may include greater use of forage plants with greater tolerance of UV radiation and alternative summer species.

5.3. Impacts on industrial and landless livestock systems

The impact of climate change and variability on industrial and landless livestock production systems such as pig and poultry farming will be less severe compared with pastoral and crop-livestock systems, due to the possibilities of controlled environmental parameters, and because of the possibility to manage feeding variables. However, increased capital investment will be needed for improving cooling systems and thermal isolation of buildings. The integrated models used to assess the likely effects of climate changes on animal health and productivity show some weak points (Turnpenny et al., 2001). New climate scenarios may induce negative effects even on industrial livestock systems, acting on feed resources, because they are completely dependent on the market for animal feeding. Cost variations of grains, and their availability at the market, will strongly influence profitability and sustainability of enterprises. Together with economic components, not strictly related to agriculture production systems, climate changes will influence crop production and relative costs, influencing for example costs for irrigation, especially for corn production, and for pest treatment. The increase of CO_2 concentration will influence in some ways grain yield, such as maize and soybean, with different and contrasting foreseeable effects (AIACC, 2006), also depending on agronomic management (planting date, fertilization, and irrigation). In the near future the availability of some grains for animal feeding could be reduced, due to an increasing demand for human consumption and to the perspective of agriculture fuels.

In any case we are able to predict that the difficulties in substantially increasing animal production in the other systems will favour further development of intensive, specialized systems to produce more pork and poultry and, to a certain extent, cow milk and beef. Consequently the absolute reduction of gas emission per unit of product could represent an important environmental advantage. On the contrary, the concentration of many animals on a small surface will determine problems because of the huge amount of manure that must be disposed of.

5.4. The problem of water

Under global warming, water will be the main common weak point in all livestock systems. The phenomenon of water salination is spreading in many areas of the World.

Other than salination, water may contain chemical contaminants, either organic or inorganic, high concentrations of heavy metals and biological contaminants. Animals exposed to hot environments drinking an amount of water 2–3 times more 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.

Likely, all global warming effects on water availability could force the livestock sector to establish a new priority in producing animal products that need less water.

For estimating the water requirements per animal product we can compare water consumption of different animal species, referring the total need of water (for feed, drinking, cleaning, etc.) to produce 1 unit of protein. We can assume one unit of protein corresponds to 30 g of proteins, which is about the daily animal protein requirement for humans.

Table 4 shows that to produce 30 g of protein from beef, about 3.7 tons of water is needed. This value is about 6 times the amount of water required to produce the same quantity of protein from pigs. The differences are related to the water source and utilization for producing feed for beef cattle or pigs: i.e. pasture for beef cattle in grazing systems or in rain-fed mixed systems *vs.* irrigated farming producing grain to feed pigs in industrial livestock systems.

The total requirements of water to produce world-wide animal products per year is approximately 2800 km^3 of water, which represents the 7.8% of the net precipitation on land masses of the globe (36,000 km^3 = 107,000 km^3 total precipitation − 71,000 km^3 evapo-transpiration).

Will it be possible to recuperate a share of available freshwater that we are lacking today? And, where and how will it be more feasible to do this? This will be a vital task for the future.

6. Conclusions

Considering the elements we have examined so far, what conclusions can we come to?

Increase in temperatures cause severe damage to the physiology, the metabolism and to the healthiness of animals. Modification of existing regimes of precipitation and the increase of aridity will have repercussions on the availability of feedstuff for animals. The increased difficulty in livestock production in the world will correspond to the increasing needs in animal products. The answers of the livestock systems to these requisites will be diverse.

The grazing and mixed rain-fed systems, which count on the availability of pastures and farm crops, will be the most damaged by climate change.

The positive trend both in the number of heads and in productivity that we observed in recent decades could slowdown or even become negative, if an effort is not made to adapt.

Damage could be considerable, since grazing and mixed rain-fed systems raise almost 70% of all ruminants in the world. Worldwide they produce almost 2/3 of the milk and meat from ruminants. Moreover more that 50% of this production is raised in developing countries where the need of animal products will increase more.

At the moment it seems difficult to evaluate whether or not the areas lost to desertification caused by climate change, will be compensated by the zones favoured by the change in climate.

The need for twice the amount of animal products in the next 4 decades should be satisfied essentially by the irrigated and industrial systems.

How could this happen? An increase in heads and also better indices of productivity in these systems are predictable. Therefore, we will have more pigs and poultry, point that is already being confirmed by the growing trend in pork and poultry production. Furthermore, because of the difficulties of grazing and rain-fed systems, milk and beef production will shift to industrialized systems, even though this increase in industrialized production will be more moderate than poultry and pork.

Scientific research can help the livestock sector in the battle against climate change. All animal scientists must collaborate closely with colleagues of other disciplines, first with agronomists then, physicists, meteorologists, engineers, economists, etc.

The effort in selecting animals that up to now has been primarily oriented toward productive traits, from now on, must be oriented toward robustness, and above all adaptability to heat stress. In this way molecular biology could allow to directly achieve genotypes with the necessary phenotypic characteristics.

Research must continue developing new techniques of cooling systems such as thermo-isolation, concentrating more than in the past on techniques requiring low energy expenditure.

New indices that are more complete than THI to evaluate the climatic effects on each animal species must be developed and weather forecast reports must also be developed with these indices, to inform the farmers in advance.

Above all to beat the climate change or in any case not to let the climate beat livestock systems, researchers must be very aware of technologies of water conservation.

In the future we can profit, more than in the past, from the years of experience of the people living in arid zones by applying our scientific knowledge to useful traditional practices.

Table 4
Tons of water to produce one unit of animal protein (UAM). UAM = daily human requirements of animal proteins (30 g/day).

	Virtual water content [a]	Protein content [b]	Virtual water content
	m^3/t products	%	t/UAM
Beef	23,685	19.0	3.740
Pork	3681	18.5	0.597
Sheep meat	11,662	18.7	1.871
Milk	820–2250 [c]	3.5	0.703–1.929

[a] Data from Chapagain and Hoekstra, 2003.
[b] Data from Paleari (unpublished).
[c] Data from Nardone and Matassino, 1989.

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