final report

Project Code: B.LIV.0247

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Date published: November 2007
ISBN: 9781741915846

PUBLISHED BY
Meat and Livestock Australia Limited
Locked Bag 991
NORTH SYDNEY NSW 2059

Respiratory heat and moisture generation of goats and deer – A literature review

Meat & Livestock Australia acknowledges the matching funds provided by the Australian Government to support the research and development detailed in this publication.

Abstract

The aim of this project was to recommend values for respiratory exchange and heat production of deer and goats that are appropriate for use in a project aimed at determining the ventilation requirements of these species onboard livestock transport aircraft. A literature search was conducted and recommendations made for carbon dioxide production, oxygen consumption, heat production, evaporative water loss and loss of water in urine and faeces for various sexes of goats and deer of various physiological states. All estimates were scaled according to body mass to facilitate flexibility in applying them to the model. It is anticipated that the data presented in this report will be of immediate assistance to those concerned with modelling the suitability of various aircraft ventilation systems for the transport of goats and deer.

Executive Summary

The export of live animals by air is a very small component of the livestock export industry, accounting for only 0.31% of cattle, 0.26% of sheep and 50.33% of goats exported during 2004–2005. Although mortality rates of livestock during air transport were not recorded until recently, the average mortality rate is extremely low because most livestock that are airfreighted are high-value breeding or slaughter animals. Most livestock consignments are carried in the holds of passenger aircraft. Recently, three major incidents involving excessive mortalities of goats and deer and several "near-incidents" have taken place. The near-incidents involved incompatible aircraft ventilation systems. As the ventilation of aircraft is technically complex and there are no simple guidelines on minimum aircraft ventilation requirements for livestock, exporters may experience difficulty in determining whether ventilation onboard a particular aircraft is suitable for the export of livestock. In many instances, exporters are reliant on recommendations of airline personnel and airport ground staff regarding the ventilation capacities of individual aircraft. Working in conjunction with the LiveAir organisation, the industry initiated a project to produce a readily available and simple guide to assist ground crews, freight forwarders, air crew and exporters to assess the suitability of the various aircraft ventilation systems for specific classes of livestock. Having commenced the project, it became apparent that information on respiratory gas exchange and heat generation of goats and deer was required.

The objectives of this project were to undertake a review of available literature pertinent to goats and deer of carbon dioxide production, sensible heat generation and humidity production and to recommend values for respiratory exchange and heat production of deer and goats that are appropriate for determining the ventilation requirements of these species onboard livestock transport aircraft.

The following recommendations were made subject to the caveat that appropriate safety margins should be applied:

Heat production, O_2 consumption and CO_2 production of goats during air transport:

Genotype	Age	Sex	Maintenance heat production ($kJ \cdot kg^{-0.75} \cdot d^{-1}$)	O_2 consumption ($L \cdot kg^{-0.75} \cdot d^{-1}$)	CO_2 production ($L \cdot kg^{-0.75} \cdot d^{-1}$)
Boer and indigenous	Growing	Mixed	489	24	30
Boer and indigenous	Growing	Females and castrates	452	23	29
Boer and indigenous	Growing	Intact males	526	26	33
Mixed	Mature	Females and castrates	423	21	26
Mixed	Mature	Intact males	486	24	30

Water production of goats during air transport

Water loss ($mL \cdot d^{-1} \cdot kg^{-0.82}$)	Evaporative water loss ($mL \cdot d^{-1} \cdot kg^{-0.82}$)	Water loss in faeces ($mL \cdot d^{-1} \cdot kg^{-0.82}$)	Water loss in urine ($mL \cdot d^{-1} \cdot kg^{-0.82}$)
129	83	28	18

O_2 consumption and CO_2 production of red deer during air transport.

Season	Maintenance heat production ($kJ \cdot kg^{-0.75} \cdot d^{-1}$)	O_2 consumption ($L \cdot kg^{-0.75} \cdot d^{-1}$)	CO_2 production ($L \cdot kg^{-0.75} \cdot d^{-1}$)
Winter	500	25	31
Summer	800	40	50

Water loss of red deer during air transport.

Water loss ($mL \cdot d^{-1} \cdot kg^{-0.82}$)	Evaporative water loss ($mL \cdot d^{-1} \cdot kg^{-0.82}$)	Water loss in faeces ($mL \cdot d^{-1} \cdot kg^{-0.82}$)	Water loss in urine ($mL \cdot d \cdot kg^{-0.82}$)
259	166	57	36

It is anticipated that the data presented in this report will be of immediate assistance to those concerned with modelling the suitability of various aircraft ventilation systems for the transport of goats and deer.

Contents

1 Background

The export of live animals by air is a very small component of the livestock export industry, accounting for only 0.31% of cattle, 0.26% of sheep and 50.33% of goats exported during 2004–2005. Although mortality rates of livestock during air transport were not recorded until recently, the average mortality rate is extremely low because most livestock that are airfreighted are high-value breeding or slaughter animals. Most livestock consignments are carried in the holds of passenger aircraft. Recently, three major incidents involving excessive mortalities of goats and deer and several "near-incidents" have taken place. The near-incidents involved incompatible aircraft ventilation systems. As the ventilation of aircraft is technically complex and there are no simple guidelines on minimum aircraft ventilation requirements for livestock, exporters may experience difficulty in determining whether ventilation onboard a particular aircraft is suitable for the export of livestock. In many instances, exporters are reliant on recommendations of airline personnel and airport ground staff regarding the ventilation capacities of individual aircraft. Working in conjunction with the LiveAir organisation, the industry initiated a project to produce a readily available and simple guide to assist ground crews, freight forwarders, air crew and exporters to assess the suitability of the various aircraft ventilation systems for specific classes of livestock. Having commenced the project, it became apparent that information on respiratory gas exchange and heat generation of goats and deer was required.

2 Project Objectives

The objectives of this project were:

1. To undertake a review of available literature pertinent to goats and deer of
   a. Carbon dioxide production
   b. Sensible heat generation
   c. Humidity production
2. To recommend values for respiratory exchange and heat production of deer and goats that are appropriate for determining the ventilation requirements of these species onboard livestock transport aircraft.

3 Methodology

3.1 Respiratory gaseous exchange

During aerobic metabolism, electrons from chemical bonds in nutrients combine with oxygen (O_2) and hydrogen (H) to form water (H_2O) and carbon dioxide (CO_2). Cells couple this reaction to the production of ATP, which is used as a source of energy to sustain the body and its activities. The CO_2 produced leaves the body in expired breath and the H_2O leaves the body in urine, faeces, by evaporation from the surface of the body and in expired breath. The ratio of CO_2 produced to O_2 consumed (the respiratory quotient; RQ) is a function of the chemical composition (molecules of C, H and O) of the nutrient involved in the reaction. Therefore, by measuring the RQ after feeding an animal a particular diet, the net energy value of that food for the animal can be determined. All modern feeding standards are based on the results of trials in which RQ, and hence CO_2 production, was measured. The values and recommendations contained in this report were based on the results of such trials.

3.2 Heat production

Because the energy derived from the metabolism of food is ultimately lost as heat, fasting heat production is often used for estimating energy requirements. By adding an allowance for heat generated by the ingestion and metabolism of food, maintenance heat production can be estimated. Maintenance heat production is defined as that produced when the animal is neither gaining nor losing weight and is used as the baseline energy requirement in all feeding standards. The values and recommendations contained in this report were based on the results of trials in which such estimates were made.

3.3 Variables affecting respiratory gas exchange and heat production and assumptions made

3.3.1 Diet and the interval between feed consumption and air transportation

Metabolism of carbohydrates such as glucose results in an RQ of 1. The metabolism of fat consumes much more O_2 relative to CO_2 produced than glucose and results in an RQ of 0.7. The RQ for metabolism of protein is 0.9. If an animal were to consume a diet consisting only of carbohydrate, its RQ would approach 1; however, if an animal were fasted, the RQ would be closer to 0.7 because of metabolism of fat reserves. Thus, the diet consumed by an animal will affect the ratio between CO_2 production and O_2 consumption. As the amount of heat produced is proportional to the amount of O_2 consumed, heat production is also affected by diet.

In the context of air transport of livestock, it is important to note that the interval between an animal's last meal and the type of meal consumed will affect the consumption of O_2, heat generation and the production of CO_2 and water in expired breath. There are no data corresponding to heat production after a fasting period of 6–8 h (as may occur during road transportation of goats or deer destined for air transport). Sahlu et al. (2004) commented that "[The] effects of nutrient restriction on energy use by goats is deserving of research attention." In the literature, values for these variables are available for animals in the fasting and maintenance states. This invokes the question of which state would be most suitable for the current purpose.

The definition of a fasting state differs considerably between ruminants such as goats and deer and monogastric animals such as humans and pigs. When ruminants are fed a diet consisting entirely of concentrates (grain), all of the energy in the ingested feed will have been absorbed and metabolized within 12 h; however, when a roughage diet (hay or dry natural pasture) is fed, the absorption of nutrients can take as long as 48 h. When respiratory exchange and heat production of ruminants is determined in the laboratory, feed is usually withdrawn for 3 or 4 days before commencing measurements. It is thus unlikely that goats or deer destined for export by air would be in a true fasting state. The use of variables derived from animals in the fasting state is not recommended because such data may underestimate the true gas exchange and heat production of animals during air transport. In addition, fasting heat production is affected by the level of nutrition that the animal was exposed to before commencing a fast. It is unlikely that such information that would be readily available for all animals destined for air transport.

Estimates of maintenance heat production include a component for heat generation associated with the work of ingestion and digestion. However, livestock are not normally fed during road transportation to the airport or during air transport. The values and recommendations contained in this report were based on estimates of respiratory exchange and heat production for maintenance. As such values would overestimate the actual gas exchange and heat production during a flight, they are considered safer than values for the fasting state, which would underestimate the actual values.

It should be noted that if animals are fed immediately before a flight, heat production will increase by 21% or 38% for concentrate or forage diets, respectively, within 2 h of the meal and decrease gradually over the next 6 h to a level in excess of that before the meal (Puchala. et al., 2007). Corresponding changes in respiratory gaseous exchange would be expected. Caution should therefore be exercised in applying the recommendations in this report without adequate safety margins.

3.3.2 Scaling of variables according to live weight

Respiratory gaseous exchange and heat production is proportional to live weight (kg) to the power of 0.75 (Lou et al., 2004a). The values and recommendations contained in this report are expressed accordingly and should under no circumstances be scaled in any other manner for the purposes of assessing the suitability of aircraft ventilation systems.

3.3.3 Age and breed

Fasting respiratory gaseous exchange and heat production decreases with increasing stage of maturity (Lou et al., 2004a). Respiratory gaseous exchange and heat production differs between breeds. Where possible the age, mass and breed of animals used in the trials cited were noted and should be taken into account when assessing the suitability of aircraft ventilation systems for livestock transport.

3.3.4 Sex and physiological state

Respiratory gaseous exchange and heat production differs between sexes and between animals in different physiological states (e.g., lactating vs non-lactating). In their tables of the nutrient requirements of goats, Sahlu et al. (2004) assumed that heat production at maintenance for growing wethers and females was 7.5% less than the mean for all sexes determined by Lou et al. (2004b) and that heat production at maintenance for growing intact males was 7.5% greater than the mean. For mature goats, Sahlu et al. (2004) suggested that heat production at maintenance for mature intact males was 15% greater than the mean determined by Lou et al. (2004b), which was derived mainly from data for females and male castrates. Where necessary, values given in this report for animals of different sexes were estimated using the adjustments suggested by Sahlu et al. (2004).

3.3.5 Stress

Stress, such as that experienced by animals during air transportation, may cause heart rate to be elevated. An elevation in heart rate in goats has been associated with increased energy respiratory gaseous exchange and heat production (Puchala et al., 2007). It is recommended that appropriate safety margins be applied to the data contained in this report to account for possible stress during air transport.

3.3.6 Temperature

At low temperatures, heat production is increased and the RQ is altered. At high temperatures, respiratory gaseous exchange increases, RQ changes and heat production is decreased. A general method of adjusting energy needs of animals for cold stress is given by the NRC (2000) and its application to goats is discussed by Sahlu et al. (2004). Acclimatization can also affect these variables; for example, heat production changes by 29 kJ per kg $^{0.75}$ for each degree Celsius that the mean ambient temperature experienced over the previous 30 d differs from 20 °C (Sahlu et al., 2004). Most of the values and recommendations contained in this report were based on the results of trials in which the ambient temperature would typically have been within the thermoneutral zone of the animals, i.e., conditions in which neither cold nor heat stress would be experienced. It is recommended that appropriate safety margins be applied to the data contained in this report in the event of possible exposure of livestock to cold or hot conditions.

4 Results and Discussion

4.1 Goats

4.1.1 Respiratory gas exchange and heat production of goats

The result of the literature search for respiratory gas exchange and heat production in goats is summarised in Table 1.

Table 1. Summary of published estimates of respiratory gas exchange and heat production in goats

Author	Breed	Sex	Weight (kg)	Diet	CO_2 production (L · kg$^{-0.75}$ · d^{-1})	RQ	O_2 consumption (L · kg$^{-0.75}$ · d^{-1})	Heat production (kJ · kg$^{-0.75}$ · d^{-1})	Maintenance heat production (kJ · kg$^{-0.75}$ · d^{-1})	Fasting heat production (kJ · kg$^{-0.75}$ · d^{-1})
Prieto et al. (2001)	Granadina	F	50–62; adult	Lucerne hay at maintenance level 18 h before measurement	314.9 ± 15.05 (mL · kg^{-1} · h^{-1})	Assumed 0.87	362 (mL · kg^{-1} BW · h^{-1})	7736 (J · kg^{-1} BW · h^{-1})		
Herselman et al. (1998)	Alpine	F	51; adult	Lucerne, maize, soybean ad lib	37.3–48.2	Assumed 0.86 and 1.0	43.4–56 (RQ = 0.86) and 37.3–48.2 (RQ = 1.0)	607–978	475–818	
Brody (1945)		F								386
Fujihara et al. (1973)		F								357
Roy-Smith (1980)		Castrated males								331
Aguilera et al. (1986)		Castrated males	26–33; 2–3 years						443	324
Prieto et al. (1990)									421	320
Tovar-Luna et al. (2007)	Boer cross	wethers	49.3; 19 months			0.79 (Fasting)			326	217
Puchala et al. (2007)	Boer cross	wethers	41 kg; 1.5 years	60% concentrate, 40% lucerne hay						
Lou et al. (2004a)									431	298
AFRC (1998)									438	315
NRC (1981)									424	
Luo et al. (2004b)	Meat goat (>50% Boer)		32.3						489	
Luo et al. (2004b)	Indigenous		14.9						488.5	
Luo et al. (2004b)			25.1 Mature						462.2	
Sahlu et al. (2004)			Mature						422.7	

Before 1998, the most reliable estimate of heat production at maintenance was that of the American National Research Council (NRC, 1981), which was derived from 10 studies conducted between 1950 and 1980. Subsequently, the British Agriculture and Fisheries Research Council (AFRC, 1998) published an estimate based on 17 studies conducted between 1868 and 1990, with similar results (438 vs 424 kJ · $kg^{-0.75}$ · d^{-1} for AFRC and NRC, respectively). Because the recommendations of the NRC and AFRC were based on limited numbers of observations and because data had subsequently accumulated indicating that heat production at maintenance may differ according to age and breed, researchers at the E(Kika) de la Garza American Institute for Goat Research compiled and analysed a database of all published data pertinent to the subject. Their analysis showed that breed and age affect heat production at maintenance. Consequently, they segregated their data into meat goats (>50% Boer goat genotype), indigenous goats and dairy goats and into the following age categories: pre-weaning, growing and mature. Their estimate of 489 kJ · $kg^{-0.75}$ · d^{-1} for growing meat goats of predominantly Boer goat genotype was derived from 60 treatment means from 11 publications, representing 548 goats (Luo et al., 2004b). This estimate is 13% and 10% greater than that of the NRC (1981) and AFRC (1998), respectively, but is considered the most reliable estimate for the purpose of modelling respiratory exchange and heat production during air transport of goats. In a subsequent publication, this group developed tables of nutrient requirements for goats from this data (Sahlu et al., 2004) and recommended that the general estimate for heat production at maintenance determined by Luo et al. (2004b) for growing goats of all sexes be discounted by 7.5% for growing wethers and females and increased by 7.5% for growing intact males. The estimate of Luo et al. (2004b) for heat production at maintenance for growing indigenous goats was derived from 157 treatment means from 34 publications representing 1024 goats, and was equal to that for meat goats (489 kJ · $kg^{-0.75}$ · d^{-1}). For mature goats, heat production at maintenance was estimated to be 423 kJ · $kg^{-0.75}$ · d^{-1} Luo et al. (2004b). This estimate was derived from 69 treatment means from 23 publications representing 495 goats of 14 breeds. Subsequently, Sahlu et al. (2004) suggested that this estimate, which was derived mainly from data for females and male castrates (wethers), should be increased by 15% for mature intact males.

It is recommended that the following estimates for heat production of goats be adopted for air transport and that adequate safety margins be applied before implementation under practical situations.

Table 2. Recommended values for heat production of goats during air transport

Genotype	Age	Sex	Maintenance heat production (kJ · $kg^{-0.75}$ · d^{-1})
Boer and indigenous	Growing	Mixed	489
Boer and indigenous	Growing	Females and castrates	452
Boer and indigenous	Growing	Intact males	526
Mixed	Mature	Females and castrates	423
Mixed	Mature	Intact males	486

There are few data available on CO_2 production or O_2 consumption for goats. Prieto et al. (2001) published estimates for Spanish Grenadina goats but unfortunately expressed the data per kg body weight and not per $kg^{0.75}$ (see Table 1). Because of the small number of goats (6) and the large variation in body weight (50–62 kg), expression of this mean per $kg^{0.75}$ is not recommended. Herselman et al. (1998) published appropriately scaled data but used dairy goats (Alpine breed). As dairy goats have been shown to have a greater rate of heat production than meat goats (Luo et al., 2004b), these data are also considered unsuitable. Other sources that were consulted but were considered unsuitable were Junghans et al. (1997), who published respiratory exchange data for two male African dwarf goats and Martin and Mitchell (1993), who recorded CO_2 production rates for seven adult female goats but did not mention the breed of the animals or express the results on a body mass basis.

Although suitable experimental data on CO_2 production and O_2 consumption do not appear to be readily available, indirect estimates of these parameters can be derived from data on heat production. To convert heat energy to litres of O_2 consumed, it is necessary to know the type of food consumed, as one litre of O_2 will release different amounts of energy from carbohydrate, fat or protein. The thermal equivalent of consumed O_2 varies by 12% between pure carbohydrate and pure fat (Walsberg et al., 1997). However, in animals fed conventional diets, the energy yield of O_2 varies by only 6%, from 19.7 kJ/L O_2 in unfed animals to 21.5 kJ/L O_2 in animals fed at twice the maintenance level (Ketelaars and Tolkamp, 1996). Errors can be much larger when CO_2 production is estimated from heat production because the thermal equivalent of CO_2 can vary by 34% between pure substrates and by 11% between RQs of 0.76–0.86 (Walsberg et al., 1997). The estimates of O_2 consumption presented in Table 3 were derived by applying an assumed value of 20 kJ/L O_2 to the estimates of heat energy for maintenance presented in Table 2. An RQ of 0.8 was assumed, which corresponds to the value measured by Tovar-Luna et al. (2007) for fasting 49 kg Boer-cross castrates. Estimation of CO_2 production from O_2 consumption using an RQ for fasting is likely to overestimate the actual CO_2 production, providing a safety margin. The estimates of O_2 consumption and CO_2 production were derived from the maintenance heat production data of Luo et al. (2004b) as modified according to Sahlu et al. (2004) (see Table 2).

Table 3. Recommended values for O_2 consumption and CO_2 production of goats during air transport

Genotype	Age	Sex	Maintenance heat production ($kJ \cdot kg^{-0.75} \cdot d^{-1}$)	O_2 consumption ($L \cdot kg^{-0.75} \cdot d^{-1}$)	CO_2 production ($L \cdot kg^{-0.75} \cdot d^{-1}$)
Boer and indigenous	Growing	Mixed	489	24	30
Boer and indigenous	Growing	Females and castrates	452	23	29
Boer and indigenous	Growing	Intact males	526	26	33
Mixed	Mature	Females and castrates	423	21	26
Mixed	Mature	Intact males	486	24	30

4.1.2 Moisture production of goats

Animals derive their water from water consumed, water contained in feed and water formed during the metabolism of nutrients and breakdown of body tissue (metabolic water). According to McGregor (2004), water intake for maintenance of live mass is 107 mL· d^{-1} · $kg^{-0.75}$ for non-lactating, non-pregnant goats. This is slightly lower than that reported by Mengistu et al. (2007) for male Ethiopian Somali goats (18 kg live weight) exposed to temperatures that varied between 21 °C and 31 °C (128 mL· d^{-1} · $kg^{-0.75}$). Teixerira et al. (2006) reported a water consumption of 344 mL· d^{-1} · $kg^{-0.75}$ for Boer × Saanen kids (15–25 kg live mass). The disparity between these results and the others is probably because the mean ambient maximum temperature during the trial of Teixerira et al. (2006) was excessive (32 °C and 69% relative humidity). According to sources cited by McGregor (2004), water intake should be expressed to an exponent of 0.82, not 0.75. In these terms, the water intake of the Angora goats studied by McGregor (2004) was 104 mL· d^{-1} · $kg^{-0.82}$ (mean ambient temperature, 25 °C), which they considered close to cited estimates of 114 mL· d · $kg^{-0.82}$ for 37 kg East African goats studied under conditions of minimal shade provision. McGregor (2004) also cited estimates of 129 mL· d^{-1} · $kg^{-0.82}$ for Boer goat castrates (26 kg) fed indoors during the spring and early summer. The latter estimate was adopted for the purposes of estimates made in this report because the Boer genotype is more appropriate to the type of animals that are exported by air from Australia than Angora goats; moreover, the adoption of this mean, which is 24% greater than that recommended by McGregor (2004) should ensure a margin of safety.

Animals loose water in faeces, urine and by evaporation from the skin and mouth. Of these routes, 63%–65% of water is lost via evaporation, 6%–18% via faeces and 19%–24% via urine (Teixeira et al. 2006; Aganga, www.fao.org/docrep/U8750T/u8750T07.htm). According to McGregor (2004), 60% of the evaporative loss occurs via respiration and 40% via sweating under hot dry conditions. The following assumptions were made in deriving the estimates presented in Table 5: water intake/loss, 129 mL· d^{-1} · $kg^{-0.82}$; total evaporative water loss, 64%; water loss in urine, 22%; water loss in faeces, 14%.

Table 4. Recommended values for water production of goats during air transport

Water loss (mL· d^{-1} · $kg^{-0.82}$)	Evaporative water loss (mL· d^{-1} · $kg^{-0.82}$)	Water loss in faeces (mL· d^{-1} · $kg^{-0.82}$)	Water loss in urine (mL· d^{-1} · $kg^{-0.82}$)
129	83	28	18

4.2 Deer

4.2.1 Respiratory gas exchange and heat production of deer

Deer differ from other livestock species in that their metabolism (and consequently, respiratory exchange and heat production) varies with season. This seasonal cycle is present as early as 18 months of age. Summer maintenance heat production of adult females is lower than that of yearlings and males. The results of the literature search for heat production in deer are summarised in Table 5.

Table 5. Published estimates of heat production in deer

Reference	Winter maintenance heat production ($kJ \cdot kg^{-0.75} \cdot d^{-1}$)	Summer maintenance heat production ($kJ \cdot kg^{-0.75} \cdot d^{-1}$)	Fasting heat production ($kJ \cdot kg^{-0.75} \cdot d^{-1}$)	
Hudson	450–550	720–876	330–400	Values derived from a survey of the literature
Simpson et al. (1978)	450	500		three animals
Semiadi et al. (1996)	480–530			four animals
Semiadi et al. (1998)		567		four animals

As the estimates of winter heat production listed in Table 5 are reasonably consistent, it is recommended that a value of 500 $kJ \cdot kg^{-0.75} \cdot d^{-1}$ be adopted for purposes of air transport of red deer. The estimates for summer heat production vary considerably. To ensure an adequate margin of safety, a value for heat production of 800 $kJ \cdot kg^{-0.75} \cdot d^{-1}$ is recommended for red deer during air transport.

Recommended values for O_2 consumption and CO_2 production of deer during air transport are presented in Table 6. These estimates were derived using the recommended means for winter and summer heat production, a thermal equivalent of 20 kJ/L O_2 and an RQ of 0.8, as described for goats. The estimates for CO_2 and heat production shown in Table 6 are of the same order as values derived by Haggarty et al. (1998) for 107 kg female red deer (age, 6 years) grazing lowland pasture under typical farming conditions (CO_2 production, 38 $L \cdot kg^{-0.75} \cdot d^{-1}$; heat production, 757 $kJ \cdot kg^{-0.75} \cdot d^{-1}$).

Table 6. Recommended values for O_2 consumption and CO_2 production of red deer during air transport

Season	Maintenance heat production ($kJ \cdot kg^{-0.75} \cdot d^{-1}$)	O_2 consumption ($L \cdot kg^{-0.75} \cdot d^{-1}$)	CO_2 production ($L \cdot kg^{-0.75} \cdot d^{-1}$)
Winter	500	25	31
Summer	800	40	50

4.2.2 Moisture production of deer

The only data that was found on water consumption of red deer was that of Haggarty et al. (1998), who recorded a value for water flux of free-ranging adult females of 259 $mL \cdot d^{-1} \cdot kg^{-0.82}$. The estimates presented in Table 7 were derived from this data as described for goats.

Table 7. Recommended values for water loss of red deer during air transport

Water loss (mL· d^{-1} · kg$^{-0.82}$)	Evaporative water loss (mL· d^{-1} · kg$^{-0.82}$)	Water loss in faeces (mL· d^{-1} · kg$^{-0.82}$)	Water loss in urine (mL· d · kg$^{-0.82}$)
259	166	57	36

5 Success in Achieving Objectives

5.1 Goats

Although far less data are available for goats than sheep or cattle, sufficient estimates of maintenance heat production are available for the purposes of this project. As there are few data available on CO_2 production or O_2 consumption for goats, these parameters were estimated from maintenance heat production. Caution should therefore be exercised in applying the recommendations regarding these parameters without adequate safety margins. Data on total water secretion of goats vary considerably. As there are no suitable published estimates of evaporative water loss in goats, this parameter was estimated from data on total water loss. Caution should therefore be exercised in applying the recommendations regarding these parameters without adequate safety margins.

5.2 Deer

There is a paucity of information on gas exchange or water loss in deer. Estimates presented in this report were made using the same methodology as described for goats. Caution should therefore be exercised in applying the recommendations regarding these parameters without adequate safety margins.

6 Impact on Meat and Livestock Industry – now & in five years' time

It is anticipated that the data presented in this report will be of immediate assistance to those concerned with modelling the suitability of various aircraft ventilation systems for the transport of goats and deer. It is anticipated that in five years' time, the production of a readily available and simple guide to assist ground crews, freight forwarders, air crew and exporters to assess the suitability of the various aircraft ventilation systems for specific classes of livestock will have resulted in a further improvement in the high standards of animal health and welfare of goats and deer during the live export process.

7 Conclusions and Recommendations

It is recommended that appropriate safety margins be applied to the data and recommendations presented in this report.

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