Breeding Focus 2018 - Reducing Heat Stress

Edited by

Susanne Hermesch

Animal Genetics and Breeding Unit, University of New England, Armidale, Australia

Sonja Dominik

CSIRO Agriculture and Food, Armidale, Australia

Published by

Animal Genetics and Breeding Unit

University of New England

Armidale, NSW, Australia

Animal Genetics and Breeding Unit

University of New England

Armidale NSW 2351

Australia

http://agbu.une.edu.au

ISBN: 978-1-921597-78-7

Cover design by Susan Joyal

Book design by Kathy Dobos

First published, 2018

Contents

Preface

“Breeding Focus 2018 – Reducing Heat Stress” is the third workshop in the series. The Breeding Focus series was developed to provide an opportunity for exchange between industry and research across a number of agricultural industry sectors. With this goal in mind, workshops have included presentations across the livestock and aquaculture industries to take participants outside their area of expertise and encouraged them to think outside the box. This year we increased the scope even further by also inviting presentations from the cropping and horticulture industries. Since the topic of heat stress has recently gained increased attention, we will discuss a wide range of aspects associated with heat stress, such as the physiology of heat stress and phenotypic indicators, genetic approaches and industry impacts.

Heat stress in animals describes a situation where an animal is exposed to high temperatures and unable to dissipate body heat, which causes an increase in body temperature. In the short term, an animal will react to heat stress with behavioural strategies (e.g. seeking shade, panting) to reduce the heat load. With prolonged excessive heat load, feed intake is reduced and production losses occur. Under extreme circumstances, excessive heat load can lead to death. In plants, heat stress can be defined as irreversible damage to plant function and development as a consequence of hot temperatures. Environmental causes of heat stress in plants and animals include high temperatures and high humidity over a long period of time, which is exacerbated by low cloud cover and high solar radiation.

With raising average temperatures, agricultural industries are faced with the challenge to manage potential impacts of heat stress on their crops, their pasture base and welfare and production of their livestock or aquaculture species. Management strategies such as shade and irrigation are effective but costly and, depending on the severity of climatic conditions, may have limited success. Susceptibility of organisms to heat stress can vary due to factors such as age and general health, but also genetic factors, such as breed or variety. Further, as we will hear during the workshop, genetic variation exists within breeds that enables genetic approaches to address heat stress in plants and animals. Selective breeding provides a long term approach that facilitates improvement of the physiology of plants and animals to cope with excessive heat load. The challenge here is to obtain cost-effective phenotypes to describe heat stress.

The chapters of this book discuss where the current climate is trending, and outlines opportunities for the crop, orchard, livestock and aquaculture industries to describe and measure heat stress, all with the focus on genetic improvement.

We would like to thank everyone who has contributed to this event for their time and effort: the authors for their contributions to the book and presentations, the reviewers who all readily agreed to critique the manuscripts. We would like to express a special thanks to Kathy Dobos for her contributions into the organisation of this workshop and the publication. Thank you!

Susanne Hermesch and Sonja Dominik
Armidale, September 2018

Heat stress impacts and responses in livestock production

Rachelle Meyer, Ann-Maree Graham and Richard Eckard

Primary Industries Climate Challenges Centre, Faculty of Veterinary & Agricultural Sciences, University of Melbourne, Parkville, VIC 3010, Australia

Abstract

The negative impacts of heat stress on livestock and associated industries are well documented. Rising temperatures associated with climate change intensify these impacts. This paper summaries various effects of heat stress on livestock including impacts on production, fertility, diet, disease and mortality. Where available the costs of heat stress are presented and reviewed. The potential of on-farm management interventions as well as breeding for reduced heat stress are discussed. Decisions on heat stress management need to be made on a case-by-case basis as they will be influenced by multiple factors including the value of the production unit, the sensitivity of production to heat stress, the frequency of heat stress events and the cost and effectiveness of the proposed management intervention.

Introduction

The negative impacts of heat stress on livestock are well estabilished. These include impacts on milk production (Key and Sneeringer 2014; Mauger *et al*. 2015), weight gain (Mitlöhner *et al*. 2001; Gourdine *et al*. 2006), fertility (Bloemhof *et al*. 2008; Wright *et al*. 2014), occurrence of illness and/or parasites (White *et al*. 2003; Renaudeau *et al*. 2011), animal welfare (Polsky and von Keyserlingk 2017) and in extreme cases mortality (Collier and Zimbelman 2007). All these impacts are associated with financial and other costs, such as those affecting farmer well-being and social license to operate. In 2003 it was estimated that the losses from reduced productivity, decreased fertility, and increased mortality from heat stress in the United States were $897 million, $369 million and $299 million US for the dairy, beef, and swine industries, respectively (St-Pierre *et al*. 2003).

Climatic factors affecting an animal's ability to regulate body temperature and offload heat include temperature, humidity, solar radiation, and wind speed (Gaughan *et al*. 2010; Renaudeau *et al*. 2012). While climatic conditions are not the only factors influencing heat stress (others include species, breed, age, condition, etc.), the interplay of climatic conditions are crucial in understanding how heat load may impact an animal. Rising temperature, solar radiation and humidity increases an animal's heat load and impedes its ability to offload heat. In contrast, increasing wind speed enhances heat loss from an animal. This is further influenced by the duration of exposure (cumulative effect) and previous conditions allowing for short- or long-term acclimation to given conditions (Renaudeau *et al*. 2012).

As climate change progresses, so do the challenges of heat stress. Between 1880 and 2012 average global temperatures increased by 0.86 °C (Stocker *et al*. 2013). These increases are coupled with increases in the frequency of extreme high temperatures, as seen in Australia (Figure 1). The frequency of heat extremes is expected to continue to increase as the climate progressively warms (Bureau of Meteorology and CSIRO 2016). The average number of heatwave days per year in Australia are projected to increase by a median of about 50 days under moderate emissions reductions to over 120 days under a high emissions scenario by 2090. Heatwaves are defined as 6 or more consecutive days above the 90th percentile of daily temperatures from 1961-1990 (CSIRO and Bureau of Meteorology 2015). Projections of solar radiation, humidity and wind speed show little change through 2030 with the confidence in the long-term changes of these factors varying with location and season (CSIRO and Bureau of Meteorology 2015). Although it is possible that increased wind speeds and reduced humidity in some locations could alleviate conditions experienced by animals by 2090, these effects will not be apparent until the second half of the century. The impacts of increases in temperatures by that time may overwhelm the impacts of trends in other weather factors.

This chapter will explore the current costs of various impacts of heat stress and, where available, projections of likely future costs. Factors influencing the cost effectiveness of options to alleviate heat stress are addressed. Following this, the use of breeding and breed selection mechanisms for reducing impacts of heat stress on livestock are discussed.

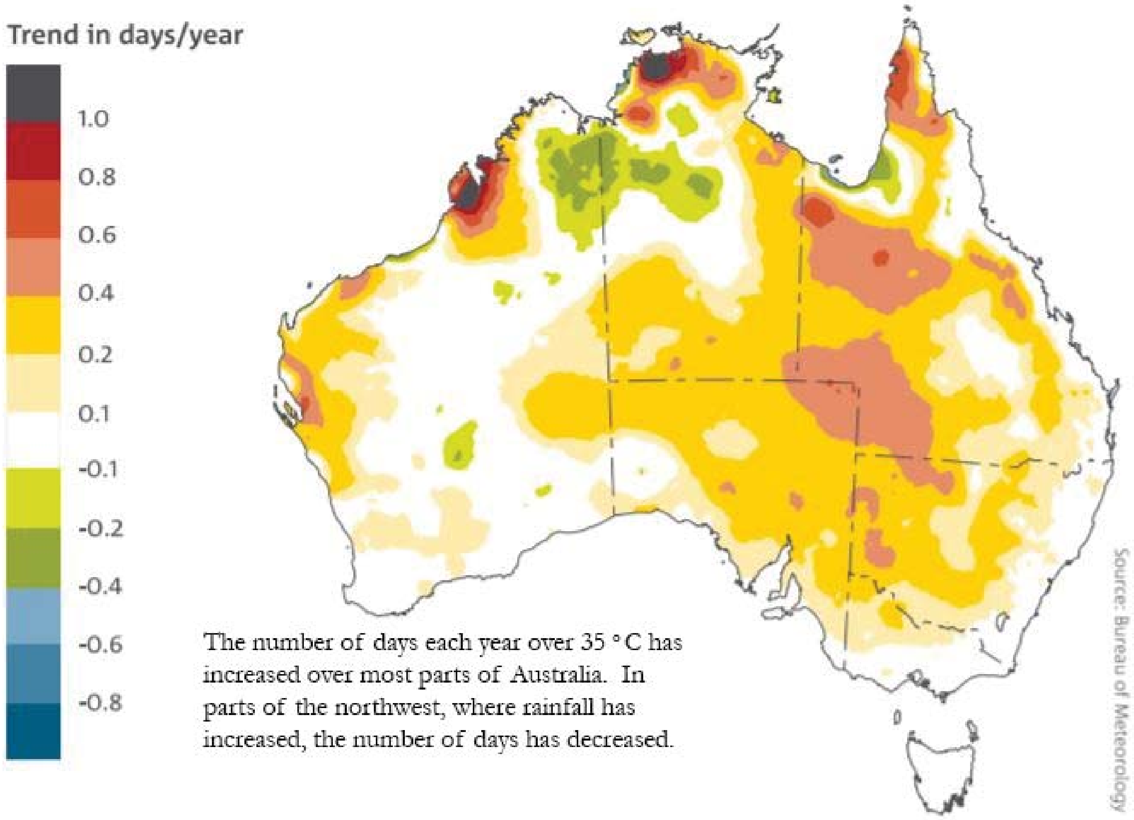

Figure 1. The trend in annual number of days per year above 35 °C from 1957-2015. An increase of 0.2 days/year since 1957 means, on average, that there are almost 12 more days per year over 35 °C. Reproduced by permission of the Bureau of Meteorology and CSIRO (2016),© Commonwealth of Australia 2018.

Impacts of heat stress

Production

Milk production is particularly sensitive to heat stress, given the high metabolic rate of dairy cows (Berman 2005; Collier and Zimbelman 2007). Based on 2014 prices, the cost of reductions in milk production due to heat stress was estimated at $1.2 billion US per year in the United States. By 2030, additional heat stress due to climate change is projected to reduce milk production from 0.6% to 1.35%, with larger declines of over 2% projected for dairies in the southern United States. The total value of lost production in the U.S dairy industry due to heat stress in 2030 is estimated to be between $106 and $269 million US depending on the global climate model used (Key and Sneeringer 2014). A separate estimate suggests heat stress costs the United States dairy industry $670 million US per year in milk losses and this is projected to increase to $1.7 billion per year in the 2050s and $2.2 billion per year in the 2080s. With optimal abatement this could be reduced to $1.2 billion in the 2050s and $1.6 billion in the 2080s. It is important to note that these losses are concentrated in the summer, which can have significant impacts on cash flow and business operations (Mauger et al. 2015). In contrast to the largely-intensive dairy industry in the USA in which nearly 10 million cows produce over 95 billion L of milk (National Agricultural Statistics Service 2018), Australia's dairy industry is generally pasture- based and produces over 9 billion L of milk from less than 2 million cows (ABARES 2014). In an examination of the potential of genomic selection, Hayes *et al*. (2013) extrapolated losses due to heat stress across the entire Australian dairy herd and estimated that every 1 °C increase over 18 °C equates to a daily loss of about 21,000 kg of protein. Estimated costs of milk losses due to heat stress on an example farm in Muswellbrook, NSW with 100 cows each producing about 25 L of milk per day at the start of summer ranged from $6,838 to $11,986 AU without heat abatement strategies and from $1,534 to $2,678 AU with shade and sprinklers (Mayer *et al*. 1999). A summary of the estimates of the value of milk losses currently and in the future are provided in Table 1. In most cases these are estimates of production losses in the U.S. dairy industy. However, the estimates of St-Pierre *et al*. (2003) include impacts on fertility, mortality as well as production. Estimates of Mayer *et al*. (1999) are based on production losses in a 100-cow case study farm in New South Wales. Production losses of heat stress due to a heatwave in November 2017 in Victoria are described in Box 1.

Heat stress commonly results in reduced weight gain due to reduced feed intake in cattle (Hahn 1981; Mitlöhner *et al*. 2001). In Australia, it has been estimated that heat stress costs the feedlot industry $16.6 million AU annually (Sackett *et al*. 2006). Experiments in the USA demonstrated that Hereford cattle exposed to gradually increasing temperatures to 35 °C over 4 weeks without diurnal variation were approximately 40 kg lighter than cows which were not exposed to heat stress. This effect was moderated only slightly over 6 weeks later. However, animals exposed to less extreme heat stress (30 °C over 4 weeks) were able to compensate for lost weight gain following exposure to high temperatures (Hahn 1981). Heifers grown in ambient conditions of northern Texas in 1999 that had access to shade reached their target weight three weeks earlier and weighed 27 kg more at the end of the 131-day trial than individuals without access to shade. The effect of shade resulted in a profit of $18 US/head. Although weight gain was significantly affected in this study, USDA quality grade did not differ between shaded and unshaded heifers (Mitlöhner *et al*. 2001). Other studies have found that heat stress can lead to greater muscle marbling, a potential benefit in some markets, but also increased dark cutting beef (Gregory 2010).

A reduction in growth with increasing temperature has also been observed in pigs (Gourdine *et al*. 2006; Renaudeau *et al*. 2011). Based on a meta-analysis, the average daily gain of pigs decreases at an accelerating rate with increasing temperature. Heavier pigs are more sensitive to heat than smaller pigs. The average daily gain of a 50 kg pig was about 1000 g/d at temperatures below 20 °C and fell to about 850 g/d at 29 °C (Renaudeau *et al*. 2011; Renaudeau *et al*. 2012). Reduced feed intake due to heat stress can result in lower pig carcass fatness (Renaudeau *et al*. 2012). In an experiment in the French West Indies, loss of body weight in sows increased by 5 kg and piglet growth rate was reduced by an average of 13 g/day in the hot season compared to the warm season (Gourdine *et al*. 2006).

Box 1. Impacts of the November 2017 heatwave on dairy production in Victoria

November of 2017 was the second hottest November on record for the state of Victoria and had the third hottest November nights on record. The average temperature for the state was 3.1 °C warmer than the 1961-1990 average. These conditions resulted in a significant reduction in milk production. Between the first and last weeks of November a 12% decline in total milk production across the state was observed. This reduction in milk production coincides with a rise in the temperature humidity index (THI) from ~55 on 5/11/17 to 68 by 14/11/17 and was likely exacerbated by the sustained high THI. THI was calculated using the formula Temp (°C) + 0.36 (DewPoint (°C)) + 41.2. In addition to the decline in milk production, an increase in cell count and decline in milk protein was observed. The northern, eastern and western regions of the state exhibited a 6% decline in milk protein during November. Averaged across farms, the reduction in milk production was 5,860 litres and in milk protein was 300 kg per farm. The estimated value of the lost production for the average Victorian dairy farm due to this heatwave was approximately $3000 AU, primarily in the second half of November. This assumes state-wide production and protein content would have stayed at levels observed in the first week of November in the absence of the heatwave event. Notably, this impact was observed during a period that did not exceed a THI of 72. These results support previous work suggesting a heat stress threshold of 68 for high-producing cows (Collier *et al*. 2011; Gantner *et al*. 2017). The extent to which the results presented here are reflective of a greater sensitivity of dairy cattle living in a temperate climate to heat stress and/or the influence of the first real warm period of the year during a high-productivity period is not clear.

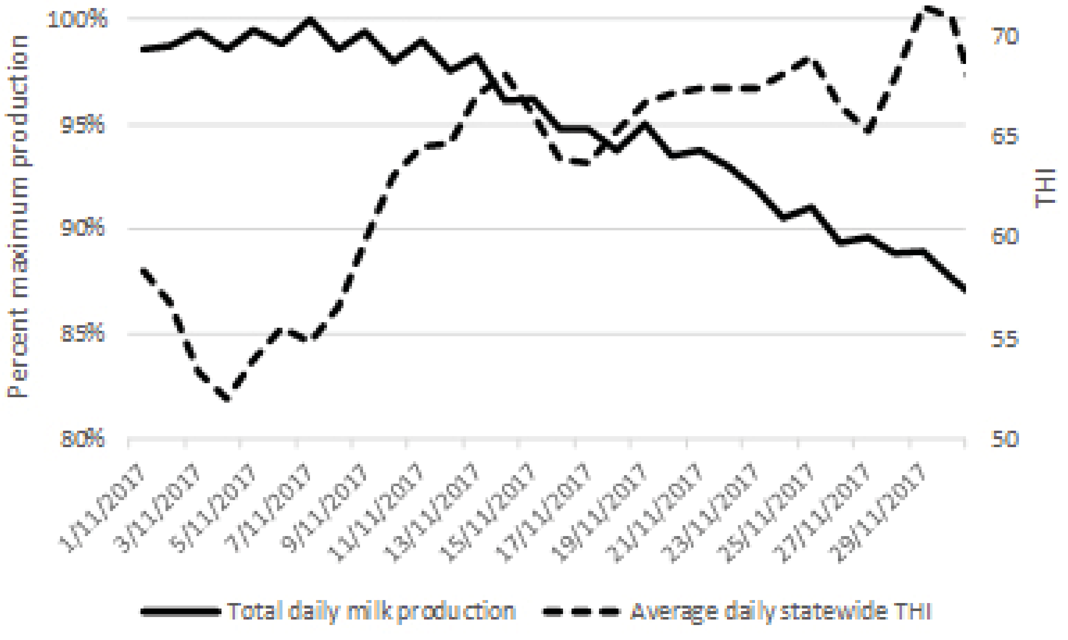

Table 1. Estimates of the value losses due to heat stress in dairy. In most cases these are production losses only for the U.S. dairy sector (see text for exceptions).

Citation	Citation Year	Reported losses per year	Estimate of costs/cow/year in current $ US
Current climate			
Mauger *et al.*	2015	$670 million US	67
St-Pierre *et al.*	2003	$897 million US	87.7
Key and Sneeringer	2014	$1.2 billion US	120
Mayer *et al.*	1999	$6,800-12,000 AU[a]	65-115[a]
Mayer *et al.*	1999	$1,530-2,700 AU[b]	14-26[b]
Future climates			
2030		$1.31-1.47 billion	Future herd size and currency conversions unavailable
Key and Sneeringer	2014		
2050		$1.7 billion	
St-Pierre *et al.*	2003		
2080		$2.2 billion	
St-Pierre *et al.*	2003		

[a] no management to alleviate heat stress

[b] using sprinklers and fans to alleviate heat stress

Sheep and goats have greater heat tolerance than cattle (Seo and Mendelsohn 2008; Seo *et al*. 2010). It has been estimated that sheep become heat stressed at THIs at or above 82 (Marai *et al*. 2007). However, the impacts on production in these species have not been well quantified (Harle *et al*. 2007).

Fertility

The negative impacts of heat stress on the fertility of dairy cows is well documented. Conception rate was reduced when heat stress occurred 20 to 50 days before artificial insemination (Chebel *et al*. 2004). Holstein-Friesian cows in Australia experiencing heat stress 5 weeks prior through to 1 week after insemination, show reduced conception rates. Days with a THI of 82 or days in which the THI was greater than 72 for 18 hours resulted in a 2.5% reduction in conception rate compared to days when THI was 72 or less (Morton *et al*. 2007). Profit decreased by $205 US/year/cow with dairy cows that needed 3 or more inseminations compared to those that required only 1 or 2 (González-Recio *et al*. 2004). An increased occurrence of abortions also occurs with heat stress (De Rensis and Scaramuzzi 2003; García-Ispierto *et al*. 2006), and this is more costly, with an average estimated cost of $640 US for the loss of a pregnancy in dairy cows (Thurmond *et al*. 1990; Chebel *et al*. 2004).

Heat-stressed beef cattle, pigs and sheep also show reduced fertility. Heat stress is associated with reduced fertility in beef cattle including shorter gestations (Wright *et al*. 2014) and reduced conception rate. In southeast Nebraska, pregnancy rate of beef cattle was reduced when THI was 72.9 or greater in the first 42 days of pregnancy (Amundson *et al*. 2006). Sows that were mated in the hot season had fewer piglets at farrowing (Gourdine *et al*. 2006) and heat stress resulted in fewer piglets born per first insemination, particularly in the Yorkshire breed (Bloemhof *et al*. 2008). Heat stress exacerbates reproductive failure in pigs largely because of the increased nutrient deficit (Prunier *et al*. 1996). In sheep, heat has been associated with declines in ram fertility and mortality of lambs (Harle *et al*. 2007).

Diet

Dietary interventions are important in minimising the impacts of heat stress events and can prevent illnesses associated with heat stress (see Disease/Parasites). Declines in feed intake with increasing heat stress have been repeatedly shown (West 2003; Renaudeau *et al*. 2011). Decreasing the amount of fibre (Hahn 1981) and increasing energy and nutrient density of the diet, including the use of concentrates and supplements (Renaudeau *et al*. 2012; Dunshea *et al*. 2017), allows heat-stressed animals to better meet their requirements despite reduced intake. Increased availability of food following heat stress allows for compensation that, in some cases, can totally offset the reductions in weight gain due to reduced feed intake during heat stress (Hahn 1981). Altering the diet is particularly well suited to intensive systems, such as dairies, feedlots and piggeries, as it is generally straightforword to implement these dietary strategies (Henry *et al*. 2012). The costs involved in this strategy are likely to be offset by the high value of the products (See Cost Effectiveness of Interventions) and the increased sensitivity to heat stress compared to animals on pasture (Renaudeau *et al*. 2012). Allowing access to feed during the cooler parts of the day is a low-cost option for increasing intake during heat stress events (Wolfe *et al*. 2008; Renaudeau *et al*. 2012).

Over the long-term, the effects of increases in average temperatures and the frequency of extreme heat will impact both pasture growth and composition. Heatwaves can dramatically reduce pasture productivity (Ciais *et al*. 2005). In south-eastern Australia, warmer and drier climates are likely to reduce pasture growth (Cullen *et al*. 2009; Meyer *et al*. In Press). A modelling study of broadacre livestock in southern Australia showed that reductions in net primary productivity led to greater reductions in profitability, with the farms having the lowest projected rainfall experiencing operational losses by 2070 (Moore and Ghahramani 2013). For sheep, the nutritional effects of these changes may have a greater impact than the direct effect of increased temperature (Harle *et al*. 2007; Gaughan 2017). These changes could lead to an increase in the demand for purchased feeds or significant reductions in stock numbers. A recent modelling study indicated that climate change resulted in an increase of up to 22% in purchased feeds (Harrison *et al*. 2017). Increasing demand for purchased feed at a regional level would also lead to increased costs of feed (Key and Sneeringer 2014; Harrison *et al*. 2017). However, it has been suggested that switching to deep-rooted and heat-tolerant grasses may help address this issue to some extent (Howden *et al*. 2008; Cullen *et al*. 2009).

Climate change could lead to changes in species composition and forage quality (Ainsworth and Long 2005; Taub *et al*. 2008). For instance, C4 grasses may become dominant in areas where rainfall is projected to remain or become evenly distributed across seasons or summer-dominant (Howden *et al*. 2008). C4 grasses are generally less nutritious than C3 species, which have more protein, lower fibre, and lower carbohydrate to protein ratios. This trend is expected to remain in future climates (Barbehenn *et al*. 2004). Craine *et al*. (2017) estimated the replacement value of crude protein decline in pastures of the United States over the last two decades was $1.9 billion US annually.

Diseases and Parasites

Heat is also associated with an increased occurrence of illness and/or parasites including the occurrence of cattle ticks (White *et al*. 2003), mastitis (St-Pierre *et al*. 2003), and acidosis and laminitis in dairy cows associated with variations in dry matter intake as temperatures rise and fall (Roenfeldt 1998). The cost of treating acidosis has been estimated at about $10 US per cow (Snyder and Credille 2017) while estimated costs of laminitis are much higher at $90-300 US per cow (Ronk 2016). This highlights the importance of implementing appropriate dietary responses to address heat stress. The increasing abundance of pests with higher temperatures may lead to more heat stress than temperatures alone would suggest. For instance, cattle crowding behaviours associated with stable flies are increase heat stress. The heat stress accounted for 71.5% of the reduction in weight gain associated with stable flies and crowding (Wieman *et al*. 1992).

Mortality

In the worst cases, severe heat stress causes livestock deaths, which have direct economic costs as well as indirect and non-monetary costs. In Australia, a heat wave in 2004 resulted in over 900 cattle deaths (Gaughan *et al*. 2009), and more recently over 40 dairy cows died in a heatwave in New South Wales in 2017 (Crawford 2017). A severe heatwave in Nebraska in late July of 1999 resulted in cattle deaths and performance losses that cost producers more than $20 million US (Collier and Zimbelman 2007). Based on the average prices in the US in the late 1990s, it was estimated that the daily cost of culling due to heat stress induced reproductive failures was $1,200 for dairy and $700 US for beef cows. Mortality due to heat stress was estimated to cost $1,800, $1,200 and $250 US per animal for dairy cows, beef cows, and sows, respectively (St-Pierre *et al*. 2003).

Mortality of sheep due to heat stress during transport from Australia to the Middle East has been a reoccurring issue that has received media attention (Logan 2017; Worthington 2018). Mortalities can be quite high in some cases, with a 2017 incident resulting in 2400 sheep deaths on a ship bound for Doha (Logan 2017). This event illustrates the potential of heat stress events to impact consumer support based on animal welfare concerns and, consequently, the loss of social license to operate (Hunter 2018). Instances of severe heat stress resulting in mortality are also associated with high stress situations that impact farmer well-being (Condon 2013; Crawford 2017).

While this paper is focused on livestock heat stress and its economic consequences, it would be remiss not to acknowledge the ethical and moral issues that extend beyond accounting. In the Australian context, several decades of work have produced the *Model Codes of Practice for the Welfare of Animals* and the *Australian Animal Welfare Standards and Guidelines*. While external standards and guidelines may be set, the moral role of the producer, handler, processor etc. is not necessarily set by law and is influenced by personal choices and sense of responsibility. This is an area of complexity with internal and external drivers that will vary between cultures, countries and individuals along the supply chain. Thus, a more detailed discussion of these issues is beyond the scope of this paper.

Cost effectiveness of interventions

Several factors influence the cost effectiveness of options for reducing heat stress: 1) the cost of implementing and maintaining a given option, 2) the option’s effectiveness in reducing heat stress, and 3) the cost of losses due to heat stress, which incorporates the occurrence of high THI, the sensitivity of production to heat stress, and the value of the product impacted by heat stress (Renaudeau *et al*. 2012; Henty and Griffth 2017). Thus, cost effectiveness of a given option varies with industry and location (St-Pierre *et al*. 2003). Options that require large investments, increases in running costs, and/or ongoing maintenance costs will be cost effective only when the value of production and reduction in heat load is high enough to offset the expense of implementation. For instance, based on modelling of livestock production and climate in the United States, depending on the location, high and intensive levels of heat abatement were optimal for dairying operations and minimum to high levels of heat abatement were optimal for piggery operations. In contrast, no heat abatement strategy was optimal for beef production at the state level based on the costs and benefits assumed (St-Pierre *et al*. 2003).

Evaporative cooling, one of the most expensive options available, has been shown to be cost effective in some intensive dairies (Collier *et al*. 2011; Renaudeau *et al*. 2012). For instance, the use of evaporative cooling in dairies in Arizona during the summer expanded rapidly, due to adequate technical suitability and favourable cost-benefit ratios (Hahn 1981). In Arizona, with a herd of 3000 cows the use of a Korral Kool evaporative cooler to reduce THI from 72 to 68 was estimated to provide a potential income of $1,491 US a week, not including benefits such as increased fertility (Collier *et al*. 2011). Sows in an experimental group exposed to an evaporative snout cooling system in subtropical Brazil lost significantly less weight and litters were significantly heavier at weaning than those in the group subjected to the traditional temperature control system. However, the cost-benefit of this improvement was not determined (Perin *et al*. 2016). The use of more efficient cooling options, such as geothermal cooling, could make currently expensive options attractive to more industries in more locations (Collier *et al*. 2011). Evaporative systems may be less effective in humid environments, although they can be used during the day when humidity is relatively low (Renaudeau *et al*. 2012).

Shade is typically a low to moderate cost option that can be cost effective for most intensive livestock industries. Shade has been demonstrated to ameliorate the impacts of heat stress on feedlot and beef cattle, as well as milk production and fertility in dairy cattle (Renaudeau *et al*. 2012). In extreme cases it can reduce mortality (Hahn 1981; Renaudeau *et al*. 2012). The advantages are more consistently observed in arid regions and the cost effectiveness varies with year and breed of cow (Renaudeau *et al*. 2012). A 2017 study on the profitability of a permanent shade structure for a dairy found that payback time for a shelter incorporating maintenance costs depended on location, production level, and milk price, but the payback time was less than 20 years in any scenario and less than 10 years in any scenario that included effects of climate change (Henty and Griffth 2017). In a study focused on feedlot beef, the cost of the structure amortised over a 20-year period resulted in an annual cost of under $10 AU/head, although this would be highly variable based on frequency and severity of heatwaves (Sackett *et al*. 2006). This cost is less than the increased profit attributed to having shade ($18 US/head) in a study on beef cattle in Texas (Mitlöhner *et al*. 2001).

There are several other options for cooling animals including fans, sprinklers and/or misters, altering timing of calving or other events, moving animals to cooler areas, and wetting the soil of feedlots. The cost-benefit of these options in isolation is not well researched. Fans used in combination with sprinklers and shade have been shown to be effective at reducing heat stress in dairy cows in humid environments. In Kentucky, dairy cows exposed to sprinklers and fans had 15.8% greater milk production than those with no cooling system. The cost effectiveness of this system was not determined (Turner *et al*. 1992). Changes in timing can have large system-wide implications and costs that need to be assessed. Very low-cost options such as wetting feedlots and moving animals to cooler areas would be cost effective in most circumstances. In addition, it has been suggested that low cost options, including shade, could be considered a form of insurance (Hahn 1981).

Potential for breeding for heat tolerance

Within breed selection should aim to breed animals adapted to a climate they are likely to encounter in the future. Prioritising individuals that perform better in stressful environments would not comprise adaptability. However, the most productive individuals in each environment must be identified (Naskar *et al*. 2012). Challenges in developing a breeding index that incorporates several traits (e.g. heat tolerance, disease resistance, feed conversion efficiency, fertility, productivity, etc), include determining phenotypes relevant to the traits that are easily measurable and are at least moderately heritable (Naskar *et al*. 2012; Renaudeau *et al*. 2012). The process is complicated when desired traits are unfavourably associated. For instance, it has been estimated that an increase in milk production from 35 kg/d to 45 kg/d decreases the heat stress threshold by 5 °C (Berman 2005). However, it is still possible to select for traits with unfavourable genetic associations. In this publication, Nguyen *et al* (2018) provide an example of developing a genomic breeding value for heat tolerance in dairy cows. Incorporating heat tolerance and other factors, including productivity and fertility, in selection decisions requires a comprehensive assessment of their net economic impact (Nguyen *et al*. 2016).

The trade-off between heat tolerance and productivity is also an issue in breed selection. The most resilient breeds are typically less productive. For instance, Jersey cows are more heat tolerant than Holsteins (Smith *et al*. 2013) but produce less milk in optimal conditions (Srikandakumar and Johnson 2004). Yorkshire line pigs have high productivity in optimal conditions, but this drops below the level of Large White line pigs when heat stressed (Bloemhof *et al*. 2008). Heat load index thresholds for various breeds and crosses of cattle are shown in Table 2, although it should be noted these are subject to substantial genotype by environment variability. The heat load index is a measure of heat stress that incorporates black globe temperature, relative humidity, and wind speed (Gaughan *et al*. 2010).

Table 2. The Heat Load Index (HLI) thresholds for various genotypes

Genotype	Threshold
Bos taurus (British, 100%, no shade)	86
Bos taurus (European, 100%)	89
Bos taurus (75%) x *Bos indicus* (25%)	90
Bos taurus (50%) x *Bos indicus* (50%)	93
Bos taurus (25%) x *Bos indicus* (75%)	94
Bos indicus (100%)	96

Reprinted with permission from Springer, International Journal of Biometeorology (Gaughan *et al*. 2010).

In harsh conditions the more resilient animal is often better for long-term performance. For instance, in areas with hot climates, disease concerns and/or poor nutritional resources, use of resilient breeds is a lower risk option compared to attempting to maintain a healthy US or European breed which can be costly and perform poorly (Eisler *et al*. 2014). There is also potential for crossbreeding commercial breeds with locally adapted breeds to improve performance in challenging conditions (Renaudeau *et al*. 2012), although this may require maintaining the progeny at the F1 stage to realise the full benefit. Breeds that are particularly well suited to these environments are listed by Naskar *et al*. (2012). Particularly harsh conditions may require a switch in species. For instance, in Africa, the net revenue in cattle operations is lower in warmer areas. Thus, farmers in these areas switch to goats and sheep. In these conditions, commercial dairies and beef systems were less able to diversify in response to climate changes and were thus, less resilient than small farms (Seo and Mendelsohn 2008). Similarly, an increase in sheep farming is likely with a hot and dry scenario in South America (Seo *et al*. 2010).

Similar to the cost effectiveness of environmental options, the choice of optimal breed, or combination of breeds, depends on several factors including the degree to which the high-producing breed outperforms other breeds in cool conditions, the sensitivity of all available breeds to heat stress, and the frequency and severity of heat stress events. For instance, Large White sows had greater farrowing rates and number of piglets born at first insemination than Yorkshire sows when the maximum temperature on the day of insemination was less than about 24 C, while the opposite was true at higher temperatures (Bloemhof *et al*. 2008). The ability of a farmer to ensure insemination occurs on days less than 24 °C would be one factor in considering which of these breeds would be most suited to a given farm. In contrast, despite substantial reductions in performance with high temperatures the Large White sows still had greater milk production per piglet in hot conditions than Creole sows, which showed little effects of heat stress. This suggests that under the conditions of the specific study, White Line sows would always be superior to Creole sows based on milk production per piglet (Gourdine *et al*. 2006).

Conclusions

The cost of heat stress is significant across the livestock industries, with impacts on production, fertility, feed intake and nutritional requirements, welfare, risks of illness, and mortality. As the climate warms, the risk of heat stress and high cumulative heat loads increases, resulting in more expensive mitigation options becoming cost effective. Decisions regarding available options to minimise the impacts of heat stress must incorporate a clear understanding of the cost of implementation, the effectiveness of the option, and the value of the avoided losses that include the risk of heat stress on an operation. For breed selection valuing the benefits of increased heat tolerance includes accounting for the sensitivity of available breeds to heat stress, productivity of the breeds in thermoneutral conditions, and the likelihood of exceeding heat stress thresholds. A major next step for within breed selection within the dairy sector is an assessment of net economic impact of multiple trait breeding indices. Strategic decisions addressing heat stress should be addressed at whole-farm and supply chain level and integrate logistical feasibility and long-term economic sustainability.

References

ABARES (2014) Agricultural commodity statistics 2014. Australian Bureau of Agricultural and Resource Economics and Sciences, Canberra.

Ainsworth, EA, Long, SP (2005) What have we learned from 15 years of free-air CO2 enrichment (FACE)? A meta-analytic review of the responses of photosynthesis, canopy properties and plant production to rising CO2. *New Phytologist* **165**, 351-372.

Amundson, J, Mader, TL, Rasby, RJ, Hu, Q (2006) Environmental effects on pregnancy rate in beef cattle 1. *Journal of Animal Science* **84**, 3415-3420.

Barbehenn, RV, Chen, Z, Karowe, DN, Spickard, A (2004) C3 grasses have higher nutritional quality than C4 grasses under ambient and elevated atmospheric CO2. *Global Change Biology* **10**, 1565-1575.

Berman, A (2005) Estimates of heat stress relief needs for Holstein dairy cows *Journal of*

Animal Science **83**, 1377-1384.

Bloemhof, S, Van der Waaij, E, Merks, J, Knol, E (2008) Sow line differences in heat stress tolerance expressed in reproductive performance traits. *Journal of Animal Science* **86**, 3330-3337.

Bureau of Meteorology, CSIRO (2016) State of the Climate 2016. Commonwealth of Australia Available at http://www.bom.gov.au/state-of-the-climate/State-of-the-Climate-2016.pdf.

Chebel, RC, Santos, JE, Reynolds, JP, Cerri, RL, Juchem, SO, Overton, M (2004) Factors affecting conception rate after artificial insemination and pregnancy loss in lactating dairy cows. *Animal Reproduction Science* **84**, 239-255.

Ciais, P, Reichstein, M, Viovy, N, Granier, A, Ogée, J, Allard, V, Aubinet, M, Buchmann, N, Bernhofer, C, Carrara, A (2005) An unprecedented reduction in the primary productivity of Europe during 2003 caused by heat and drought. *Nature* **437**, 529-533.

Collier, R, Zimbelman, R, Rhoads, R, Rhoads, M, Baumgard, L (2011) ‘A re-evaluation of the impact of temperature humidity index (THI) and black globe humidity index (BGHI) on milk production in high producing dairy cows, Western Dairy Management Conf. Reno, NV. USA.’

Collier, RJ, Zimbelman, RB (2007) ‘Heat Stress Effects on Cattle: What we know and what de don’t know, 22nd annual Southwest Nutrition and Management Conference.’ Tempe, AZ. Department of Animal Sciences, University of Arizona.

Condon, J (2013) ‘Warning over summer feedlot heat stress with shift to softer cattle.’ Available at https://www.beefcentral.com/lotfeeding/warning-over-summer-feedlot-heat-stress-with-shift-to-softer-cattle/ [Accessed 15 March 2018].

Craine, JM, Elmore, A, Angerer, JP (2017) Long-term declines in dietary nutritional quality for North American cattle. *Environmental Research Letters* **12**, 044019.

Crawford, R, 2017. Hot weather toll on Shoalhaven farmers. The Land. Rural Press, North Richmond, NSW. 2018:

CSIRO, Bureau of Meteorology (2015) Chapter 7: Projections: Atmosphere and the land. In ‘Climate Change in Australia Information for Australia’s Natural Resource Management Regions: Technical Report.’ (CSIRO and Bureau of Meteorology: Australia)

Cullen, B, Johnson, I, Eckard, R, Lodge, G, Walker, R, Rawnsley, R, McCaskill, M (2009) Climate change effects on pasture systems in south-eastern Australia. *Crop and Pasture*

Science **60**, 933-942.

De Rensis, F, Scaramuzzi, RJ (2003) Heat stress and seasonal effects on reproduction in the dairy cow—a review. *Theriogenology* **60**, 1139-1151.

Dunshea, F, Gonzalez-Rivas, P, Hung, A, DiGiacomo, K, Chauhan, S, Leury, B, Celi, P, Ponnampalam, E, Cottrell, J (2017) Nutritional Strategies to Alleviate Heat Stress in Sheep. In 'Sheep Production Adapting to Climate Change.' (Eds V Sejian, R Bhatta, J Gaughan, PK Malik, SMK Naqvi, R Lal.) pp. 371-388. (Springer: Singapore)

Eisler, MC, Lee, M, Tarlton, JF, Martin, GB, Beddington, J, Dungait, J, Greathead, H, Liu, J, Mathew, S, Miller, H (2014) Agriculture: Steps to sustainable livestock. *Nature* **507**, 32.

Gantner, V, Bobic, T, Gantner, R, Gregic, M, Kuterovac, K, Novakovic, J, Potocnik, K (2017) Differences in response to heat stress due to production level and breed of dairy cows. *International Journal of Biometeorology* **61**, 1675-1685.

García-Ispierto, I, López-Gatius, F, Santolaria, P, Yániz, J, Nogareda, C, López-Béjar, M, De Rensis, F (2006) Relationship between heat stress during the peri-implantation period and early fetal loss in dairy cattle. *Theriogenology* **65**, 799-807.

Gaughan, J (2017) Projected Impacts of Climate Changes and Sustainability of Sheep Production Systems. In 'Sheep Production Adapting to Climate Change.' (Eds V Sejian, R Bhatta, J Gaughan, PK Malik, SMK Naqvi, R Lal.) pp. 189-196. (Springer: Singapore)

Gaughan, J, Lacetera, N, Valtorta, SE, Khalifa, HH, Hahn, L, Mader, T (2009) Response of domestic animals to climate challenges. In 'Biometeorology for adaptation to climate variability and change.' (Eds KL Ebi, I Burton, G McGregor.) pp. 131-170. (Springer Netherlands)

Gaughan, J, Mader, T, Holt, S, Sullivan, M, Hahn, G (2010) Assessing the heat tolerance of 17 beef cattle genotypes. *International Journal of Biometeorology* **54**, 617-627.

González-Recio, O, Pérez-Cabal, M, Alenda, R (2004) Economic value of female fertility and its relationship with profit in Spanish dairy cattle. *Journal of Dairy Science* **87**, 3053-3061.

Gourdine, J, Bidanel, J, Noblet, J, Renaudeau, D (2006) Effects of breed and season on performance of lactating sows in a tropical humid climate 1. *Journal of Animal Science* **84**, 360-369.

Gregory, N (2010) How climatic changes could affect meat quality. *Food Research International* **43**, 1866-1873.

Hahn, GL (1981) Housing and management to reduce climatic impacts on livestock. *Journal of Animal Science* **52**, 175-186.

Harle, K, Howden, S, Hunt, LP, Dunlop, M (2007) The potential impact of climate change on the Australian wool industry by 2030. *Agricultural Systems* **93**, 61-89.

Harrison, MT, Cullen, BR, Armstrong, D (2017) Management options for dairy farms under climate change: Effects of intensification, adaptation and simplification on pastures, milk production and profitability. *Agricultural Systems* **155**, 19-32.

Hayes, BJ, Lewin, HA, Goddard, ME (2013) The future of livestock breeding: genomic selection for efficiency, reduced emissions intensity, and adaptation. *Trends in Genetics* **29**, 206-214.

Henry, B, Charmley, E, Eckard, R, Gaughan, JB, Hegarty, R (2012) Livestock production in a changing climate: adaptation and mitigation research in Australia. *Crop and Pasture Science* **63**, 191-202.

Henty, S, Griffth, G (2017) The Effect of Heat Stress on Milk Production and the Profitability of Investing in a Permanent Shade Structure. *Australian Farm Buisness Management Journal* **14**, 25-46.

Howden, S, Crimp, S, Stokes, C (2008) Climate change and Australian livestock systems: impacts, research and policy issues. *Australian Journal of Experimental Agriculture* **48**, 780-788.

Hunter, F, 2018. Turnbull government MP will introduce a bill to ban live sheep exports. The Sydney Morning Herald. Fairfax media, Sydney.

Key, N, Sneeringer, S (2014) Potential effects of climate change on the productivity of US dairies. *American Journal of Agricultural Economics* **96**, 1136-1156.

Logan, T (2017) 'Documents reveal how thousands of sheep died from extreme heat aboard live export vessel.' Available at http://www.abc.net.au/news/rural/2017-08-09/documents-reveal-how-sheep-died-from-heat-live-export-ship/8790918 [Accessed 5 April 2018].

Marai, I, El-Darawany, A, Fadiel, A, Abdel-Hafez, M (2007) Physiological traits as affected by heat stress in sheep—a review. *Small Ruminant Research* **71**, 1-12.

Mauger, G, Bauman, Y, Nennich, T, Salathé, E (2015) Impacts of climate change on milk production in the United States. *The Professional Geographer* **67**, 121-131.

Mayer, D, Davison, T, McGowan, M, Young, B, Matschoss, A, Hall, A, Goodwin, P, Jonsson, N, Gaughan, J (1999) Extent and economic effect of heat loads on dairy cattle production in Australia. *Australian Veterinary Journal* **77**, 804-808.

Meyer, RS, Cullen, BR, Whetton, PH, Robertson, FA, Eckard, RJ (2018) Potential impacts of climate change on soil organic carbon and productivity in pastures of south eastern Australia. *Agricultural Systems* **167**, 34-46.

Mitlöhner, F, Morrow, J, Dailey, J, Wilson, S, Galyean, M, Miller, M, McGlone, J (2001) Shade and water misting effects on behavior, physiology, performance, and carcass traits of heat-stressed feedlot cattle. *Journal of Animal Science* **79**, 2327-2335.

Moore, AD, Ghahramani, A (2013) Climate change and broadacre livestock production across southern Australia. 1. Impacts of climate change on pasture and livestock productivity, and on sustainable levels of profitability. *Global Change Biology* **19**, 1440-1455.

Morton, J, Tranter, W, Mayer, D, Jonsson, N (2007) Effects of environmental heat on conception rates in lactating dairy cows: Critical periods of exposure. *Journal of Dairy Science* **90**, 2271-2278.

Naskar, S, Gowane, GR, Chopra, A, Paswan, C, Prince, LLL (2012) Genetic Adaptability of Livestock to Environmental Stresses. In 'Environmental Stress and Amelioration in Livestock Production.' (Eds V Sejian, SMK Naqvi, T Ezeji, J Lakritz, R Lal.) pp. 317-378. (Springer Berlin Heidelberg: Berlin, Heidelberg)

National Agricultural Statistics Service (2018) Milk Production. National Agriculture Statistics Service, Agricultural Statistics Board, United States Department of Agriculture, Washington D.C. Available at http://usda.mannlib.cornell.edu/usda/current/MilkProd/MilkProd-03-20-2018.pdf.

Nguyen, T, Garner, J, Pryce, J (2018) A tool to breed for heat tolerant dairy cattle. In 'Breeding Focus 2018- Reducing Heat Stress.' (Eds S Hermesch, S Dominik.) (Animal Genetics and Breeding Unit: Armidale, NSW)

Nguyen, TT, Bowman, PJ, Haile-Mariam, M, Pryce, JE, Hayes, BJ (2016) Genomic selection for tolerance to heat stress in Australian dairy cattle. *Journal of Dairy Science* **99**, 2849-2862.

Perin, J, Gaggini, TS, Manica, S, Magnabosco, D, Bernardi, ML, Wentz, I, Bortolozzo, FP (2016) Evaporative snout cooling system on the performance of lactating sows and their litters in a subtropical region. *Ciência Rural* **46**, 342-347.

Polsky, L, von Keyserlingk, MA (2017) Invited review: Effects of heat stress on dairy cattle welfare. *Journal of Dairy Science* **100**, 8645-8657.

Prunier, A, Quesnel, H, de Bragança, MM, Kermabon, A (1996) Environmental and seasonal influences on the return-to-oestrus after weaning in primiparous sows: a review. *Livestock Production Science* **45**, 103-110.

Renaudeau, D, Collin, A, Yahav, S, De Basilio, V, Gourdine, J, Collier, R (2012) Adaptation to hot climate and strategies to alleviate heat stress in livestock production. *Animal* **6**, 707-728.

Thurmond, M, Picanso, J, Jameson, C (1990) Considerations for use of descriptive epidemiology to investigate fetal loss in dairy cows. *Journal of the American Veterinary Medical Association* **197**, 1305-1312.

Turner, L, Chastain, J, Hemken, R, Gates, R, Crist, W (1992) Reducing heat stress in dairy cows through sprinkler and fan cooling. *Applied Engineering in Agriculture* **8**, 251-256.

West, J (2003) Effects of heat-stress on production in dairy cattle. *Journal of Dairy Science* **86**, 2131-2144.

White, N, Sutherst, RW, Hall, N, Whish-Wilson, P (2003) The vulnerability of the Australian beef industry to impacts of the cattle tick (Boophilus microplus) under climate change. *Climatic Change* **61**, 157-190.

Wieman, G, Campbell, J, Deshazer, J, Berry, I (1992) Effects of stable flies (Diptera: Muscidae) and heat stress on weight gain and feed efficiency of feeder cattle. *Journal of Economic Entomology* **85**, 1835-1842.

Wolfe, DW, Ziska, L, Petzoldt, C, Seaman, A, Chase, L, Hayhoe, K (2008) Projected change in climate thresholds in the Northeastern U.S.: implications for crops, pests, livestock, and farmers. *Mitigation and Adaptation Strategies for Global Change* **13**, 555-575.

Worthington, B (2018) ‘Federal Agricultural Minister David Littleproud slams live export sheep deaths.’ Available at http://mobile.abc.net.au/news/2018-04-05/agriculture-minister-david-littleproud-live-export-sheep-deaths/9623202?pfmredir=sm [Accessed 8 April 2018].

Wright, E, Boehmer, B, Cooper-Prado, M, Bailey, C, Wettemann, R (2014) Effect of elevated ambient temperature at parturition on duration of gestation, ruminal temperature, and endocrine function of fall-calving beef cows. *Journal of Animal Science* **92**, 4449-4456.