Agricultural Innovation Hubs Program Technical Report

Activity 10

Improving the climate resilience of the Australian Sheep Industry

PROJECT LEAD: University of Adelaide

PREPARED BY: William van Wettere, Peter Hayman, Dane Thomas, Megan Tscharke, Michael Wilkes

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PROJECT SUMMARY

This section is compulsory for all projects

High ambient temperatures during mating and pregnancy impair sheep reproduction, costing the Australian sheep industry $168 million each year. This collaborative project quantified the benefits for sheep producers of using supplements known to alleviate the impact of heat (eg Melatonin, Vitamin ADE, Vitamin C and Betaine) on flock productivity and thermoregulation. Working alongside 6 farming systems groups and 1 Landscape Board, trials were conducted within 22 producer demonstration sites, using 12,000 ewes.

Melatonin and Vitamin ADE increased potential lambing rate by 19 and 6 percentage units, respectively, which increased the net position of a model flock of 1000 ewes by a $14,019 and $5,296, respectively. Betaine decreased water intake, which is indicative of increased hydration and reduced heat stress, demonstrating potential for use during periods of extreme heat and drought.

Two prototype calculators were also developed. The first, enables producers to predict the impact of Melatonin and Vitamin ADE, and other strategies as they develop, on productivity and profitability of their flocks. The second, enables producers to use climate data for their location to predict the impact of heat events during joining on their lambing rates and, thus, make informed decisions around the adoption of heat alleviating management strategies.

EXECUTIVE SUMMARY

The project "*Improving the climate resilience of the Australian Sheep Industry*" was a collaboration between the University of Adelaide, SARDI, six South Australian farming systems groups, one Landscape Board, and 22 producer demonstration sites. Exposure to high ambient temperatures, in isolation or in combination with high humidity levels, significantly impairs the health, welfare and productivity of sheep, and is common during the periods when ewes are typically mated and pregnant (late spring through early autumn). Each day in excess of 32°C during the week of mating reduces the number of lambs born per 100 ewes mated by 3.5%, with high temperatures during pregnancy retarding fetal growth and, thus, reducing lamb survival and weaning rates. Strategies which increase the capacity of sheep to tolerate heat and mitigate the negative impacts on reproduction are essential to maintain flock productivity and sustainability. It is also important to provide the sheep industry with the ability to predict the impact of heat events on flock productivity and make informed decisions around the adoption of amelioration strategies. In this way, the resilience of the Australian Sheep Industry to extreme and unpredictable climate events will be increased.

With this in mind, the current project demonstrated and quantified the impact of four, easy to implement, strategies for sheep producers to implement to mitigate the impacts of heat events, with the objective of equipping them with the ability to successfully implement these interventions in future years. The strategies were chosen based on ease of implementation and adoption, and their capacity to improve thermoregulation and reduce the physiological stress resulting from heat events. The strategies were Melatonin (delivered as a sub-cutaneous implant, Regulin®), Vitamins ADE (delivered as a long-lasting oral drench), Vitamin C and Betaine (both provided in the water). Alongside of this, the project delivered two prototype calculators which allow sheep producers and industry professionals to make informed decisions around the likely impact of heat events in their region on flock productivity, and quantify the financial impact of adopting the alleviation strategies demonstrated in this project.

Demonstration, validation, and quantification of the impacts of Melatonin or Vitamin ADE on the fertility and fecundity of ewes mated and pregnant during late spring through autumn was achieved in 21 producer demonstration sites across the major sheep producing regions of South Australia, from the South East through to the Upper North and Eyre Peninsula. The impacts of adding Betaine or Vitamin C to the water of ewes during summer on their thermoregulation and water intake was demonstrated at the Roseworthy Trial Site. When analysed across all demonstration sites, Melatonin resulted in an additional 19 potential lambs per 100 ewes mated, and Vitamin ADE increased potential lambing rate by 6 lambs per 100 ewes mated (potential lambing rate is based on the number of fetuses present half way through pregnancy, identified using ultrasound). Betaine supplementation reduced ewe water consumption by 0.66 of litre per day during cooler days (< 32°C) and 1.0 litre per day during hot days (≥ 32°C), and elicited a numerical, but not significant decrease in ewe temperature at the hottest part of the day, indicating a potential increase in the hydration status and heat tolerance of these animals.

Using climate data obtained directly from the producer demonstration sites during mating and early pregnancy, the potential impacts of heat events (days ≥ 32°C) during the week of joining on flock fertility and income were calculated. However, due to the mild nature of the 2022/2023 summer,

climate data obtained from the BoM was used to develop the prototype calculators. In partnership with SARDI Climate Applications, historical, region specific climate data (1957 to 2022), cost of production data obtained from the PIRSA Gross Margin Guide, and the quantified impact of Melatonin and Vitamin ADE obtained from the demonstration sites, were used to develop two prototype calculators. Calculator one, provides an easy to use tool for producers and industry professionals to predict the likely incidence of heat events (days ≥ 32°C) during the period of mating, and how the resulting decline in potential lambing rates impacts net income. Calculator two, allows the impact of using Melatonin and / or Vitamin ADE, and other alleviation strategies as they are developed, on lambing rates and income, at a production site specific level. Together, these calculators allow informed decisions to be made around the adoption of strategies to alleviate the impacts of heat.

Overall, the following objectives were achieved:

- Robust, and widely applicable data demonstrating and quantifying the impact of using Melatonin and Vitamin ADE to improve the fertility, and productivity of South Australian sheep flocks which mate between late spring and early autumn.
- Demonstration that adding Betaine to the water supply of ewes over summer has potential to improve thermotolerance
- Development of two prototype calculators which provide the ability at the enterprise level to: 1) predict the impact of heat events on productivity and profitability, and; 2) quantify the impact on productivity and profitability of adopting the heat alleviation strategies developed in this project, and future projects.

This project was designed to increase the climate resilience of the Australian Sheep industry, through demonstration sites and collaboration between producers, farming systems groups and researchers. This approach has ensured effective dissemination and awareness of the project outcomes, as well as the development of outcomes relevant to a wide range of producers.

Further adoption of the outcomes of this project can be supported in the following ways. One, maintain the demonstration sites for at least two more spring / summer periods to obtain additional accurate and robust quantification of the impacts of the current strategies, demonstrate the impacts of new heat alleviating strategies as they are developed and, facilitate producer – producer learning, uptake and, thus, practice change. Two, further develop the prototype calculators created in this project to include additional alleviation strategies as they are developed, and also to develop a more widely usable platform for their use (i.e. a webpage or app).

PROJECT BACKGROUND AND OBJECTIVES

Heat events during the mating (joining) period cost the Australian Sheep Industry approximately $168 million each year (van Wettere et al., 2020). Towards improving the climate resilience of the Australian Sheep Industry, we demonstrated practical and easily adoptable management strategies which improve thermoregulation of sheep, increase efficiency of feed utilisation during periods of extreme heat, and reduce the impacts of heat events on reproduction. We selected cost-effective, readily available interventions and management strategies which, based on previous research, have the potential to improve the productivity and wellbeing of sheep during periods of nutritional and climate induced stress. We quantified the improvement in flock productivity that occurs following their implementation within commercial farming systems. Alongside of this, we identified the climatic thresholds above which sheep thermoregulation is challenged by heat events which occur on commercial farms, and established the relationship between these thresholds and reductions in fertility. This enabled the development of prototype prediction models and calculators that sheep producers can use to predict when heat alleviating strategies need to be implemented. The overall aim of this project is, therefore, to take innovative research outcomes based on sheep physiology and quantify their benefits within commercial production systems, an approach designed to facilitate uptake by the broader industry and support commercialisation.

The project had two primary objectives: 1) Deliver easy to implement, hands-on practical on-farm demonstrations for sheep producers to mitigate the impacts of weather extremes, thus equipping them with the ability to successfully implement interventions in future years, and; 2) Deliver prototype calculators which can be used by sheep producers to make informed decisions around implementation of heat alleviating management strategies.

Through a collaborative process involving 6 South Australian farming systems groups, one Landscape Board, and 21 producer sites, this project delivered and demonstrated two practical, easily adoptable, strategies (Regulin Implants and Vitamin ADE drench) to improve potential lambing rates (lambs born per ewe joined), aimed at reducing the impact of heat events on flock reproduction rate and productivity. At the Roseworthy Trial site, this project delivered and demonstrated two commercially applicable strategies (water soluble Betaine and Vitamin C) to improve thermotolerance of ewes, thus enhancing drought and climate resilience of sheep flocks. These producer sites were situated across a range of agro-ecological zones, ranging from the South East region of South Australia, through the Mallee, Mid- and Upper – North, as well as the Eyre Peninsula, and were chosen to provide producers with region specific evidence of the benefits of adopting these strategies.

Using climate data obtained from the participating producer sites, we demonstrated the potential impact of heat events during joining on lambing rate within production systems. Further to this, we used historical data derived from the Bureau of Meteorology (BoM) to generate a prototype calculator that allows producers to predict the timing and extent of heat events during joining at their location, and demonstrate the impact on lambing rate. In addition to this, we also developed a prototype calculator which can be used by producers to calculate the benefit of using the strategies demonstrated in this project on the productivity of their flock.

The objective of the extension activities conducted was to provide farmers, industry professionals, researchers and farming systems groups with evidence of the benefits of adopting the chosen strategies, thus stimulating adoption and creating practice change. Further extension and adoption of these outcomes of these projects would be facilitated by developing producer demonstration sites, as well as region-specific fact sheets, and also replicating this trial work across an additional season (to provide producers with confidence of the observed outcomes).

Conducting these trials across regions and agro-ecological zones within South Australia ensures greater awareness of regional similarities and differences in climate during joining, and the impact on flock productivity, as well as facilitating adoption of strategies to increase the climate resilience of South Australian sheep flocks.

METHODOLOGY

Project Overview

The University of Adelaide was the lead organisation for this project, with the following participants also actively engaged in coordination and running of the project: South Australian Research and Development Institute (SARDI), MacKillop Farm Management Group (MFMG), Barossa Improved Grazing Group (BIGG), Upper North Farming Systems Group (UNFS), Northern and Yorke Landscape Board (NYLB), Mallee Sustainable Farming Systems Group (MSF), Murray Plains Farming Systems Group (MPF), and Agricultural Innovation and Research Eyre Peninsula (AirEP). Working in collaboration with the farming systems groups, 21 producers were selected to be involved in the project, with selection based on location, timing of mating (joining), willingness to participate in the project and ability to facilitate accurate data collection. A smaller, more intensive trial was also conducted on the Roseworthy Trial Site, based at the University of Adelaide's Roseworthy Campus. All animal work was approved by the University of Adelaide's Ethics Committee (S-2022-080). The use of both the Roseworthy Trial Site and commercial properties to conduct the trial enabled the requirements of "Activity 1 - Demonstration of commercially relevant strategies to minimise the impact of weather extremes on livestock wellbeing and productivity in commercial sheep production systems" as well as "Activity 2 - Deliver prototype calculators which can be used by sheep producers to make informed decisions around implementation of heat alleviating management strategies" to be met.

Demonstration of commercially relevant strategies to minimise the impact of weather extremes on livestock wellbeing and productivity in commercial sheep production systems

In collaboration with the farming systems groups (details above), and discussion with identified producers, trial work ran from the 20th November 2022 until July of 2023 within 21 producer sites (See Location details later in report), as well as the Roseworthy trial site. These discussions included capability to collect the required measures, means of identifying ewes individually, number of paddocks used, as well as which treatments the producers wanted to investigate. Just prior to joining, ewes were separated into three treatments consisting of Melatonin, Vitamin ADE and Control. The melatonin ewes received an 18 mg melatonin capsule (Regulin®) via a subcutaneous injection behind the ear, the Vitamin ADE ewes received a 10 ml oral drench of Maxivit Vitamin A, D & E Oral (Compass Feeds), and the Control ewes did not receive any treatment. Across all sites, ewes were subjected to routine husbandry (feeding, stocking rates etc), and the total number of ewes on trial by treatment was 4,426 (Control), 4,903 (Melatonin) and 2,419 (Vitamin ADE). All ewes were individually identified using either visual or electronic ear tags, or the use of branding paint. Pregnancy status and the number of fetuses carried by each ewe were determined by an experienced commercial operator using ultrasound. These data were used to calculate the following outcomes for each flock and each treatment: percentage of ewes pregnant, and the percentage of ewes carrying 1, 2, 3 or 4 fetuses, which in turn was used to calculate potential lambing rate (expressed as fetuses as a percentage of ewes joined and fetuses as a percentage of pregnant ewes). Additional captured data included ewe age at joining, with ewes put into three categories: joined at less than one year (ewe lambs), joined between 12 and 24 months of age (maiden ewes), and mixed age ewes (ewes having already had at least one lamb prior to joining in summer of 2022 / 2023.

Statistical analysis was conducted using SPSS (IBM). A general linear mixed model, with region, breed and age included in the model, was run to determine the impact of treatment on all parameters measured.

At the Roseworthy Trial Site, 240 multiparous Merino ewes were randomly assigned into one of three treatment groups; Betaine (Betafin, Feedworks, Australia), Vitamin C (Mount Compass Feeds) or Control (n = 80 ewes / treatment). Within each treatment group, 40 ewes were randomly allocated to be used to measure treatment effects on core temperature. Prior to treatment commencing a data storage temperature sensor (Micro-T, Star-Oddi, Iceland) measuring 8.3 x 25.4 mm and 3.3 g, inside a minimally-invasive silicon mould was inserted vaginally in the select ewes (n = 40 / treatment) for 18 days to collect internal temperature of the ewes every 10 minutes (12th to 30th January 2023. This approach to measuring core temperature in ewes has previously been validated by our research group (Lewis Baida et al., 2021 and 2022). Ten days prior to joining, treatment begun with ewes receiving either Vitamin C, Betaine or no supplement delivered via the uDose system from DIT AgTech, which is designed to deliver a calibrated dosage of supplements to the water provided to livestock. Consequently, intra-vaginal temperature was measured for 8 days prior to treatment start, and for 10 days after treatment start. The concentration of Betaine and Vitamin C provided in the water was calculated by measuring average water consumption over a 4 day period prior to treatment start. Based on this, Vitamin C was included in the water to achieve a dose of 6 ml per head per day (equivalent of 1.5 g of Vitamin C per head per day) and Betaine to achieve a dose of 4.82 ml of liquid Betaine per head per day (equivalent to 2 g of Betaine per head per day).

The uDose system measured daily water consumption per treatment and, thus, daily supplement intake. Ewes were naturally joined with purebred Merino rams (1 ram per 20 ewes) for 35 days covering two oestrous cycles (30th January to 6th March 2023). Rams were harnessed with a crayon to determine oestrus, with ram marks being recorded weekly. Post-joining the temperature sensors were re-deployed in the select ewes (n = 40 / treatment) for two weeks to obtain internal temperature every 10 minutes (6th to 20th March 2023). Treatment ended on day 45 of pregnancy (approximately), and 20 days later, pregnancy status and the number of fetuses carried by each ewe was determined by an experienced commercial operator using ultrasound. These data were used to calculate the following outcomes for each flock and each treatment: percentage of ewes pregnant, and the percentage of ewes carrying 1, 2, 3 or 4 fetuses, which in turn was used to calculate potential lambing rate (expressed as both fetuses as a percentage of ewes joined and fetuses as a percentage of pregnant ewes). Ewe condition score and weight at start and end of treatment was also recorded.

Statistical analysis was conducted using SPSS (IBM). A general linear mixed model, was run to determine the impact of treatment on water consumption. An ANOVA was run to determine the impact of treatment, time of day and ambient temperature on ewe core temperature.

Deliver prototype calculators which can be used by sheep producers to make informed decisions around implementation of heat alleviating management strategies.

On each producer site, at least one temperature device (tiny tag; Hastings Data Loggers) was placed in the paddock in which joining occurred, and was moved with the flock as required. The tiny tag was set to record ambient temperature and humidity at hourly intervals during the joining period. These data were used to understand the potential impact of climate on potential lambing rates, with each day over 32°C during the week of joining predicted to reduced lambing rate (number of fetuses per ewe joined) by 3.5% (Lindsay et al., 1975; Kleemann and Walker, 2005; van Wettere et al., 2021). The original objective was to use the climate data collected for each producer site to develop a prototype calculator for use by sheep producers to make informed decisions around implementation of heat alleviating strategies, which will hereon be referred to as the "*Sheep_Heat_Economics_HotDays*" calculator. However, due to the milder than normal climate experienced during summer of 2022 / 2023, it was decided to use historical climate data obtained from the Bureau of Meteorology (BoM) to develop this calculator. The additional benefit of using the BoM data is that it is a more robust data set, with data being available for the past 65 years, and is also available over a wider range of locations and is, thus, more relevant to a wider range of producers. The underlying premise for this calculator is that producers can insert their location, and receive outputs predicting the extent to which lambing rate is likely to be decreased by heat events (days > 32°C) in their location and for their chosen joining period, with each day > 32°C during joining (the average per week for the joining period) multiplied by 3.5 to give the expected reduction in lambing rate (fetuses per 100 ewes joined; as per Lindsay et al., 1975; Kleemann and Walker, 2005; van Wettere et al., 2021).

In addition to the "*Sheep_Heat_Economics_HotDays*" calculator, a second prototype calculator (the "*SheepHeat_Economics_Supplement*" calculator) was developed to provide sheep producers with the ability to determine the effect of using the supplements demonstrated in Activity One (Melatonin and ADE) on productivity and profitability of their flock). This calculator incorporates the cost of production values provided in the PIRSA Gross Margin Guide, and allows a range of scenarios to be modelled, whereby flock size, DSE rating, lambing rate, treatment type and efficacy (improvement in lambing rate), cost of production and lamb sale price can be altered to test the financial outcome. This calculator has the potential to be extended to include the impacts and efficacy of additional supplements as they are developed, as well as to include other indices of flock productivity (i.e lambs marked per ewe joined) as data for these are developed.

These prototype calculators are included as a soft copy as part of this final report. However, in the results section the prototype calculators were evaluated using hypothetical data to determine the effect of different parameters on the productivity and profitability of a flock of 1000 ewes.

LOCATION

Site # and name	Latitude (decimal degrees)	Longitude (decimal degrees)	Start of Joining
Trial Site #1 MFMG – Field	-35.865100	139.601571	23rd December 2022
Trial Site #2 UNFS – Spalding	-33.526571	138.629836	6th January 2023
Trial Site #3 UNFS – Orroroo	-32.578608	138.481329	9th January 2023
Trial Site #4 MFMG – MingBool	-37.688312	140.846397	8th March 2023
Trial Site #5 AIREP – Wudinna	-33.087636	135.352703	9th January 2023
Trial Site #6 UNFS - Cattowie	-33.108805	138.465620	19th January 2023
Trial Site #7 BIGG - Kyneton	-34.559970	139.147836	28th December 2022
Trial Site #8 MFMG – Mingbool	-37.658149	140.866653	8th March 2023
Trial Site #9 MPF – Murray Bridge	-35.153186	139.374990	25th November 2022
Trial Site #10 MPF – Murray Plains	-34.886679	139.027246	15th January 2023
Trial Site #11 AIREP – Kyancutta	-33.138001	135.689974	10th January 2023
Trial Site #12	-36.831161	140.675524	13th January 2023

Site # and name	Latitude (decimal degrees)	Longitude (decimal degrees)	Start of Joining
MFMG – Cadgee			
Trial Site #13 BIGG – Booborowie	-33.549770	138.754994	23rd November 2022
Trial Site #14 BIGG – Keyneton	-34.545590	139.142012	13th December 2022
Trial Site #15 NY Landscape – Carrieton	-32.426587	138.518340	19th December 2022
Trial Site #16 BIGG - Georgetown	-33.370889	138.361501	23rd December 2023
Trial Site #17 MSF – Lameroo	-35.346328	140.530005	28th November 2022
Trial Site #18 MSF – Lameroo	-35.203221	140.286128	1st December 2023
Trial Site #19 AIREP – Kyancutta	-33.137076	135.547900	20th December 2022
Trial Site #20 MFMG – Parawa	-35.565418	138.368316	6th February 2023
Trial Site #21 Farrell Flat	-33.834615	138.822836	25th January 2023

RESULTS

Demonstration of commercially relevant strategies to minimise the impact of weather extremes on livestock wellbeing and productivity in commercial sheep production systems

On farm demonstration of the impact of Melatonin (Regulin®) on ewe fertility and fecundity

Across all producer sites and regions, and regardless of ewe age / category, Melatonin (Regulin®) supplementation of ewes at joining significantly increased ewe fertility and fecundity (Table 1 and Figure 1). Specifically, for every 100 ewes joined, Regulin increased pregnancy rate by 4.6 ewes, decreased the number of ewes bearing a single fetus by 9.1, and increased the number of ewes bearing either 2 fetuses or 2 or more fetuses by 12.9 and 13.7, respectively. Consequently, Regulin administration resulted in an additional 19 potential lambs per 100 ewes joined and an additional 14 potential lambs per 100 pregnant ewes (where potential lambing rate is based on the number of fetuses present at pregnancy scanning).

Table 1 Effect of treating ewes in flocks across South Australia with Regulin® at joining on pregnancy rate and fetal number at pregnancy scanning

Treatment (*pooled across Region*)	Pregnant ewes (%)	Percentage of ewes joined with		
		1 fetus	2 fetuses	≥ 2 fetuses
Control	87.1 ± 0.91^a	45.3 ± 2.40^b	40.9 ± 2.52^a	41.8 ± 2.64^a
Regulin	91.7 ± 0.84^b	36.2 ± 2.21^a	53.8 ± 2.32^b	55.5 ± 2.43^b

[ab] Within column indicate differences between means; $P < 0.01$

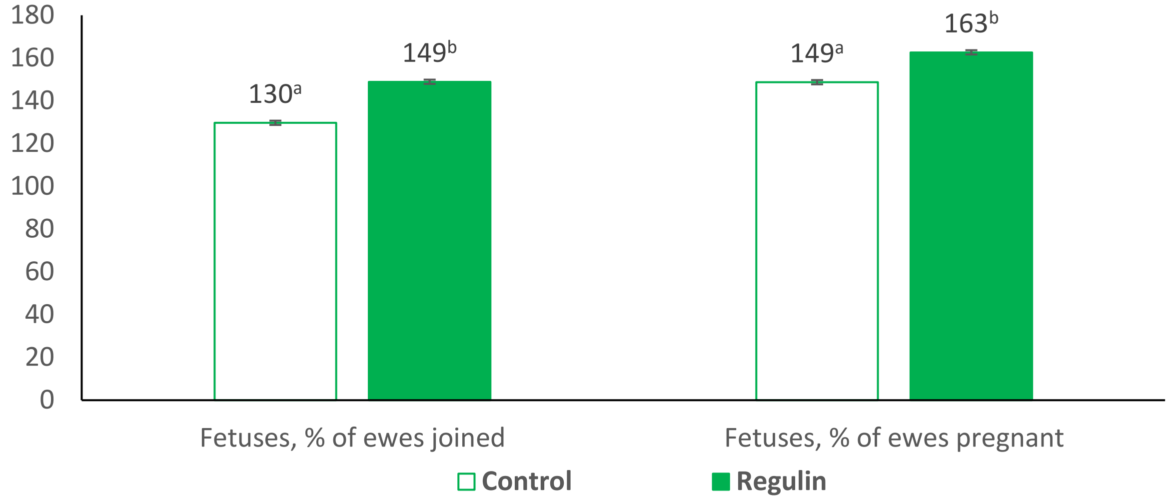

Figure 1 Effect of treating ewes in flocks across South Australia with Regulin ® at joining on fetal number at pregnancy scanning, presented as % of ewes joined with the ram and a % of ewes pregnant following joining with the ram. [ab] Within outcome indicates a significant difference; P < 0.01

On farm demonstration of the impact of Vitamin ADE on ewe fertility and fecundity

The impact of Vitamin ADE on ewe fertility and fecundity is expressed as the percentage change relative to the control (untreated ewes). Vitamin ADE treatment resulted in a numerical increase in the number of ewes pregnant (1.3 additional pregnant ewes per 100 ewes joined), a tendency for the proportion of ewes bearing a single fetus to decrease (3.2 fewer singleton bearing ewes per 100 ewes joined; P < 0.1) and the proportion of ewes bearing two or more fetuses to increase (3.4 more ewes per 100 ewes joined bearing multiple fetuses; P < 0.1; Figure 2). Vitamin ADE supplementation resulted in an additional 6 potential lambs per 100 ewes joined and an additional 4.7 lambs per 100 pregnant ewes (Figure 3; P < 0.01).

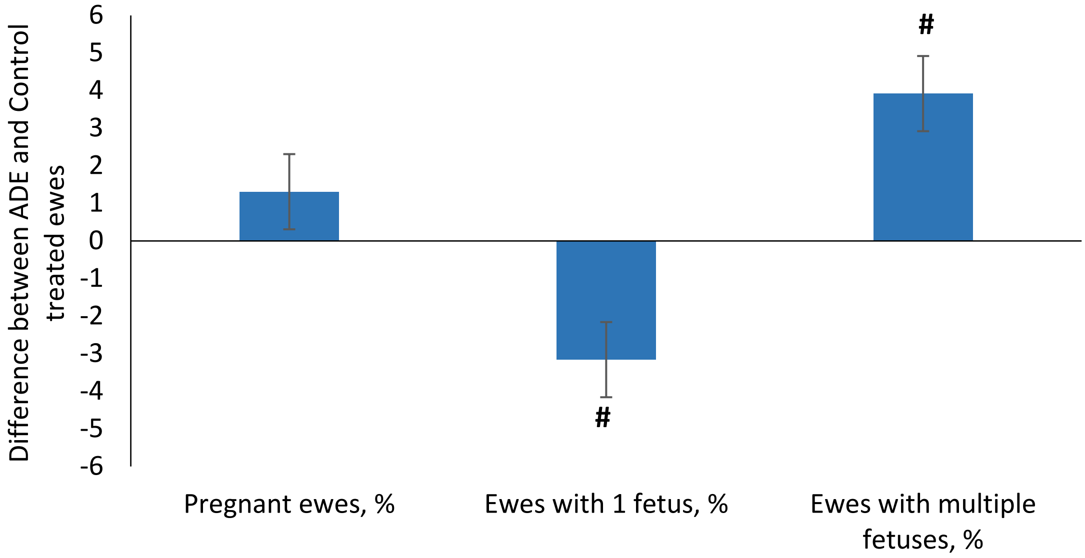

Figure 2 Difference in pregnancy rate and fetal number at pregnancy scanning between ewes treated with a Vitamin ADE drench at joining and control ewes in flocks across South Australia # Within outcome indicates a difference between Vitamin ADE versus Control ewes; P < 0.1

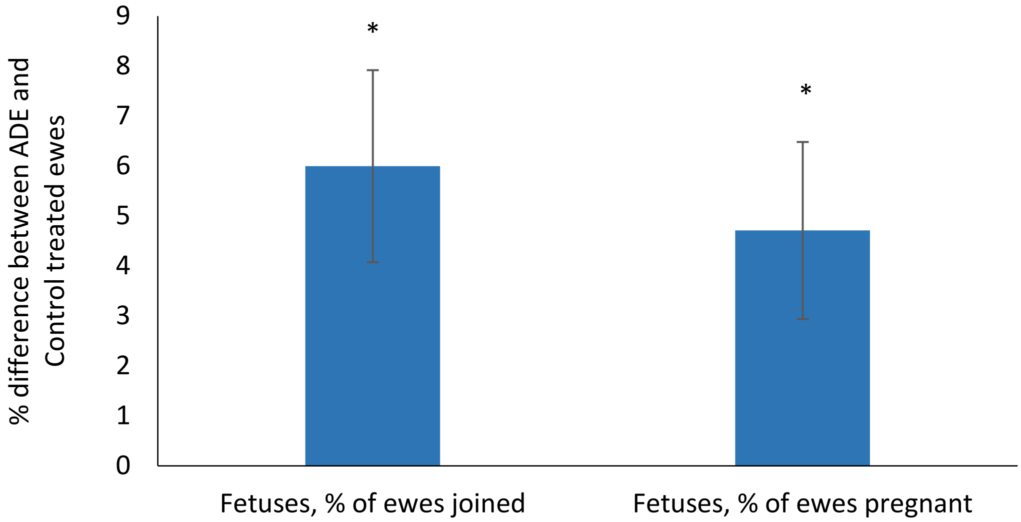

*Figure 3 Difference between ewes treated with a Vitamin ADE drench at joining and control ewes in fetal number at pregnancy scanning, presented as % of ewes joined with the ram and a % of ewes pregnant following joining with the ram. * Within outcome indicates higher levels in Vitamin ADE treated compared with Control ewes; P < 0.01*

Demonstrate the impacts of Betaine and Vitamin C delivered in water on ewe thermoregulation, water consumption and fertility

Ewe age, weight and body condition score were similar for all three treatments; however, weight loss during joining was, numerically, lower for Betaine (8.4kg) compared with Vitamin C (9.8kg) and Control (10.0 kg). Reproduction data for the three treatment groups is presented in Table 2. During the trial period, climate was as follows: mean, maximum and minimum temperatures were 30.2°C, 41.8 °C and 20.0 °C, respectively; there were 22 days with a temperature ≥ 32 °C, and 47, 33 and 19 days on which sheep experienced days of moderate (THI > 71), severe (THI > 74) or extreme (THI > 78) heat stress, respectively.

Table 2 Reproduction data for ewes in the Control, Betaine and Vitamin C treatment groups

Treatment	Pregnant ewes (%)	Percentage of ewes joined with			Fetuses, % of ewes joined	Fetuses, % of ewes pregnant
		1 fetus	2 fetuses	≥ 2 fetuses		
Control	94	40	52	54	149	158
Betaine	86	43	43	43	129	150
Vitamin C	90	48	42	42	132	146

Water intake was lower ($P < 0.05$) for ewes in the Betaine compared with Control ewes, and was similar for Vitamin C and Control ewes (Table 3). Betaine ewes consumed on average 0.66 and 1.0 litre less water per day on days cooler than and greater than 32°C, respectively.

Table 3 Daily water intake of ewe consuming Betaine or Vitamin C supplemented water and non-supplemented water (Control) on days with a mean temp <32°C or ≥ 32°C.

Treatment	Water intake (L/day)		Supplement intake (g/day)	
	Ambient Temp < 32C	Ambient Temp ≥ 32C	Ambient Temp < 32C	Ambient Temp ≥ 32C
Control	1.77 ± 0.13[a]	3.53 ± 0.34[a]	-	-
Betaine	1.11 ± 0.11[b]	2.53 ± 0.21[b]	1.93 ± 0.19	4.40 ± 0.37
Vitamin C	1.53 ± 0.15[ab]	3.54 ± 0.24[ab]	0.72 ± 0.07	1.66 ± 0.11

[ab] Within column indicate differences between means; $P < 0.01$

Treatment effects on ewe temperature are presented in Table 4, with daily maximum and daily variation in temperature lowest in Betaine supplemented compared with Vitamin C supplemented ewes (P < 0.05), with Control ewes in between. Differences in ewe temperature at the hottest part of the day on a cool (23 to 26°C) and hot (36 to 39°C) summer's day are presented in Table 5, with Betaine supplemented ewes having a numerically, but not significantly, lower temperature at the peak of the day's heat.

Table 4 Effect of Treatment (Control versus Betaine versus Vitamin C) and Ambient Temperature (Cool; < 32°C versus Hot; ≥32°C) on ewe core temperature

Treatment	Daily Mean Ewe Temp (°C)	Daily Max Ewe Temp (°C)	Daily Min. Ewe Temp (°C)	Daily Variation in Ewe Temp (°C)
Control	38.61	39.68^{ab}	37.44	2.24^{ab}
Betaine	38.64	39.64^{a}	37.42	2.22^{a}
Vitamin C	38.71	39.71^{b}	37.41	2.29^{b}
Pooled SEM	*0.016*	*0.017*	*0.017*	*0.02*
Ambient Temperature				
Cold (< 32°C)	38.33^{a}	39.52^{a}	36.63^{a}	2.89^{a}
Hot (≥ 32°C)	38.98^{b}	39.83^{b}	38.22^{b}	1.61^{b}
Pooled SEM	*0.013*	*0.014*	*0.014*	*0.016*

^{ab} Within column and main effect indicate differences between means; P < 0.05

Table 5 Effect of Treatment (Control versus Betaine versus Vitamin C) on ewe temperature at the hottest part of the day on a cool day (23 - 26°C) and hot day (36 - 39°C).

Treatment	Cool day (23 - 26°C)	Hot day (36 - 39°C)	Mean (Cool and Hot days)
Betaine	39.16	39.62	39.39
Control	39.22	39.64	39.43
Vitamin C	39.22	39.67	39.44
Pooled SEM	*0.03*	*0.03*	*0.02*

Deliver prototype calculators which can be used by sheep producers to make informed decisions around implementation of heat alleviating management strategies.

Producer site climate data, and predicted impacts on lambing rates

Using the data obtained from the tiny tags on each of the producer sites, the number of days ≥ 32°C was calculated for the period of joining, this was then divided by the duration of joining to calculate the mean number of days ≥ 32°C during each week of joining. Using the equations developed by Lindsay et al. (1975) and Kleemann and Walker (2005), the number of days per week ≥ 32°C were multiplied by 3.5 to generate the impact on potential lambing rates (Table 6). For each farming systems group, the proportion of days within the joining periods that sheep were exposed to days ≥ 32, days of moderate heat stress (Temperature Humidity Index (THI) > 71), severe heat stress (THI > 74) and extreme heat stress (THI > 78) (THI thresholds from Hahn et al., 2009) were also calculated (Figure 4). From these data it is evident that sheep joined in the Upper North experience the most heat events during joining, with those joined in the SE region of South Australia experiencing the least (Table 6).

Table 6 Days per week of joining ≥ 32 °C and potential decrease in lambing rate for an average joining week on a subset of producer sites

Trial Site	Region	Days per week of joining ≥ 32 °C	Potential decrease in lambing rates for an average joining week
7	Barossa	3	10.5%
19	Eyre Peninsula	4.6	16.1%
5	Eyre Peninsula	3	10.5%
17	Mallee	2.4	8.4%
6	Upper North	3.8	13.3%
16	Upper North	5.4	18.9%
2	Upper North	4.2	14.7%
3	Upper North	3.6	12.6%
9	Murray Plains	1.4	4.9%
10	Murray Plains	1.6	5.6%
12	South East	2.4	8.4%
1	South East	1.4	4.9%
4	South East	0.6	2.1%

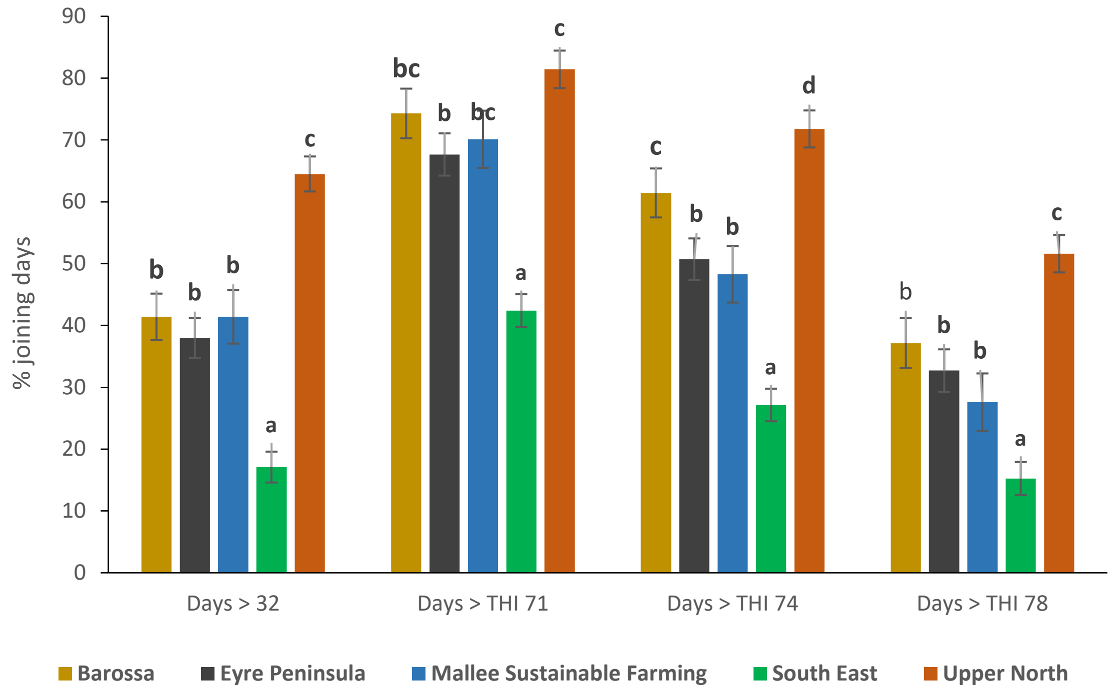

Figure 4 Percentage of days during joining that exceeded climate thresholds associated with impacting thermoregulation and reducing fertility in sheep for the five regions, specifically Days > 32°C; moderate heat stress (THI > 71), severe heat stress (THI > 74) and extreme heat stress (THI > 78). [abcd] within climate threshold indicate difference; P < 0.01

Using historical BoM data (1957 to 2023), and five sites across South Australia chosen as representative of climate, the incidence of days ≥ 32°C during typical joining periods (late December through to end of January) was calculated, and used to calculate the loss of potential lambs. This was done for an average joining period, as well as the hottest joining period since 1957. These data are presented in Figure 5, and in Figure 6 the financial impost of these losses are presented, based on a flock of 100 ewes.

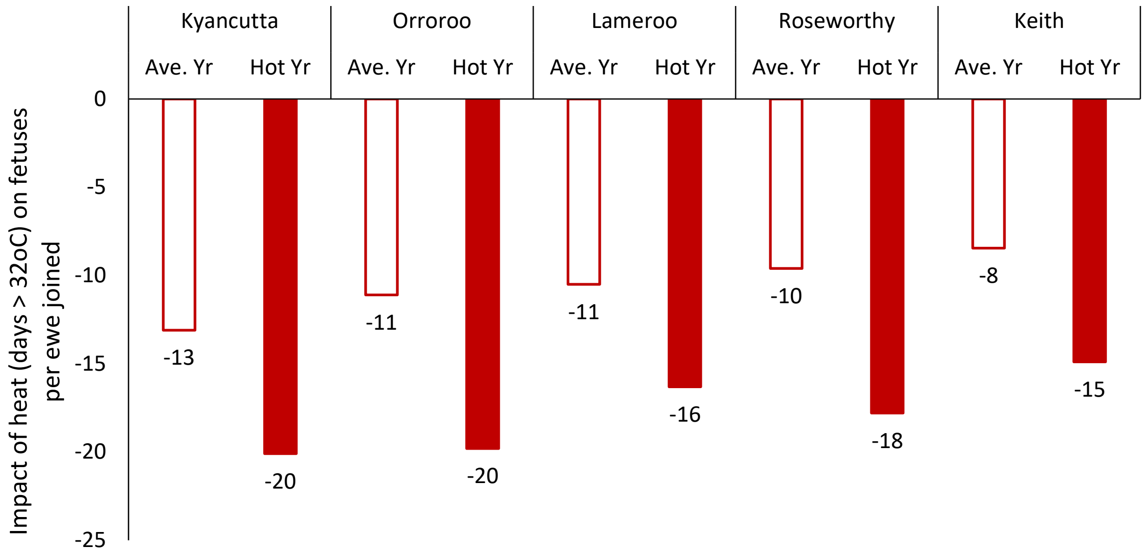

Figure 5 Impact of days ≥ 32 during joining on potential lambing rate (fetuses per ewe joined) in an average summer joining period and the hottest summer period since 1957.

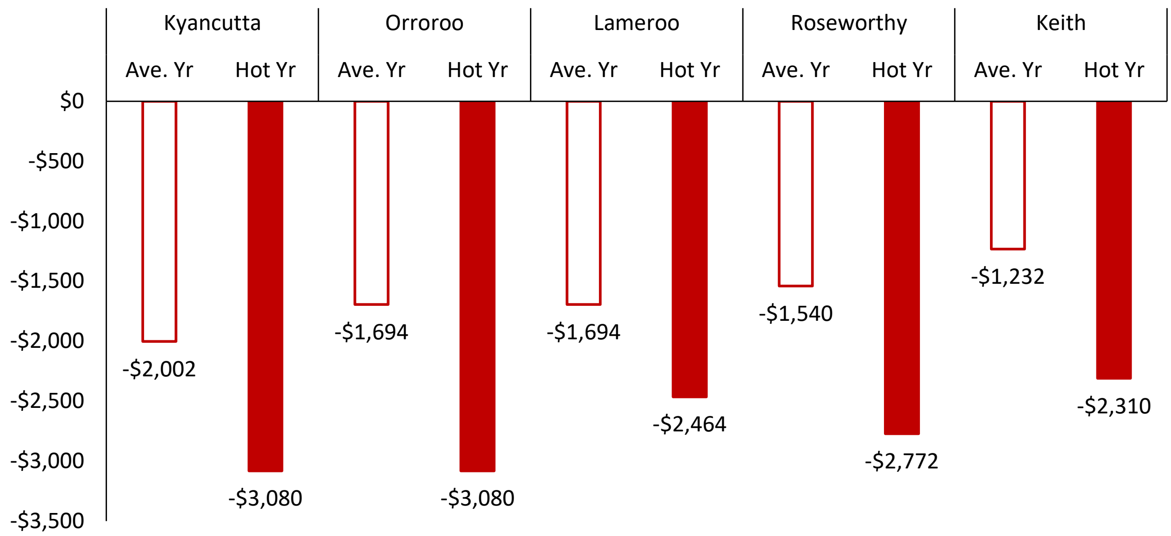

Figure 6 Financial loss due to the reduction in lambing rates that occur when 100 ewes are exposed to days ≥ 32 during the week of joining. Calculated for an average summer joining period and the hottest summer joining period since 1957. Assumptions: lamb price of $130 / head minus $21 COP / head and a base line lambing rate of 140%.

Testing the prototype calculators using real world data

The development of the calculators “SheepHeat_Economics_Supplement” and “Sheep_Heat_Economics_HotDays” was undertaken using the results of the field work undertaken in this project, alongside the cost of production values from the PIRSA Gross Margin guide and Bureau of Meteorology climate data. These prototype tools were then evaluated using hypothetical data to determine the effect of different parameters on sheep flock productivity and profitability. Evaluation was undertaken as two separate components- namely “Impact of treatments on lambing rate on flock productivity and Profitability” and “Impact of heat of lambing rate”.

Impact of treatments on lambing rate on flock productivity and Profitability

The “SheepHeat_Economics_Supplement” calculator allows a range of scenarios to be modelled whereby flock size, DSE rating, lambing rate, treatment type and efficacy (improvement in lambing rate), cost of production and lamb sale price can be altered to test the financial outcome.

In this instance treatment effects have been reported independently of extreme heat events, and as such are deemed to be indicative of the maximum fertility response that can be achieved with these treatments.

Using this calculator will allow advisors and producers to understand what effect treatments will have on whole flock productivity and profitability, and determine where treatment cost, efficacy or end-market value will limit a return on the investment.

A “test” flock was modelled to investigate the impact of lambing rate, market price and treatment efficacy with traits as outlined in Table 7.

Table 7: "Test" flock traits and parameters

Ewes joined	1000
Ram percentage	2.5%
Joining period	1-Dec-5-Jan
Ewe DSE	1.8
Ram DSE	2
Lambing rate (% of ewes joined)	95
Price of lamb sold	$120

Cost of lamb to sale	default PIRSA GM figures, excluding modification to feeding: 6 weeks fed @2.5kg/week by $350/tonne
Treatment efficacy	Regulin- 19% ADE- 6%
Treatment cost	Regulin- $6.90/ewe ADE- $0.50/ewe

Impact of current lambing rate

The calculator was used to investigate the effects of Regulin and ADE independently on flock profitability as the current flock lambing rate increased from 80-120%. The cost, productivity and financial figures are detailed in Table 8. Assuming consistent treatment effects of 19% and 6% for Regulin and Vitamin ADE respectively, the Partial budget (Income-Costs) was positive across all lambing rates from 80-120%. Regulin treatments increased the net position of the flock by an average of $14018.58, whilst ADE resulted in a $5295.98 increase (Figure 7). There is clear positive financial benefit from investing in these treatments irrespective of current lambing rate.

Table 8: Production and financial parameters for Regulin and ADE treatment of the "Test" flock as pre-treatment lambing rate increases

		Lambing %				
		80	90	100	110	120
REGULIN	Total Supplement cost	6900.0	6900.0	6900.0	6900.0	6900.0
	Supplement cost per DSE	3.7	3.7	3.7	3.7	3.7
	Benefit Lambs per Flock	190.0	190.0	190.0	190.0	190.0
	Benefit Lambs per DSE	0.1	0.1	0.1	0.1	0.1
	Income per Flock	20712.0	20833.4	20934.5	21019.9	21093.0
	Income per DSE	11.2	11.3	11.3	11.4	11.4
	Partial Budget per Flock	13812.0	13933.4	14034.5	14119.9	14193.0
	Partial Budget per DSE	7.5	7.5	7.6	7.6	7.7
ADE	Total Supplement cost	500.0	500.0	500.0	500.0	500.0

	Supplement cost per DSE	0.3	0.3	0.3	0.3	0.3
	Benefit Lambs per Flock	60.0	60.0	60.0	60.0	60.0
	Benefit Lambs per DSE	0.0	0.0	0.0	0.0	0.0
	Income per Flock	5789.9	5793.6	5796.5	5798.9	5801.0
	Income per DSE	3.1	3.1	3.1	3.1	3.1
	Partial Budget per Flock	5289.9	5293.6	5296.5	5298.9	5301.0
	Partial Budget per DSE	2.9	2.9	2.9	2.9	2.9

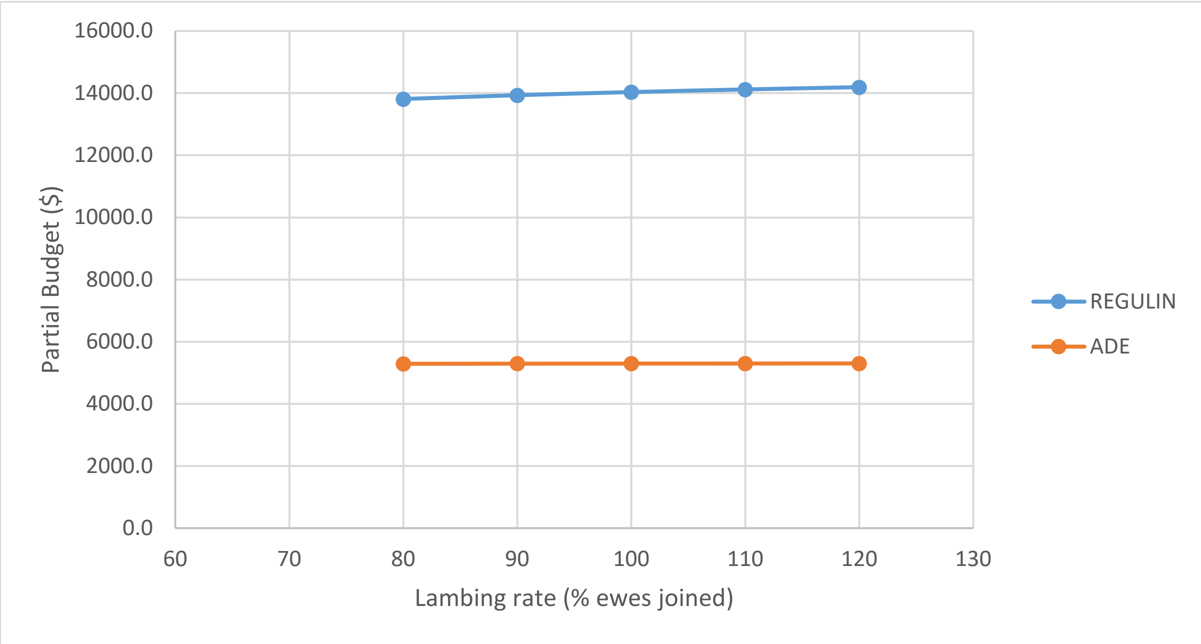

Figure 7: Lambing rate vs. Partial budget (income-costs) for Regulin and ADE treatments in the "Test" flock

<u>Impact of Price of lamb sold.</u>

With current (and historical) fluctuations in the lamb market, it is paramount that any treatments be tested against changing sale price to determine the impact on margin, and where the "break-even" point for investment is.

At 95% lambing rate (current), the break-even lamb sale price is $62.10 under Regulin treatment, and $26.61 for the Vitamin ADE treatment. These values indicate that if the reported treatment efficacy is achieved, the financial benefits are extremely robust, and lamb market value would have to be significantly below current prices before financial returns would be negatively impacted (Figure 8 and Table 9).

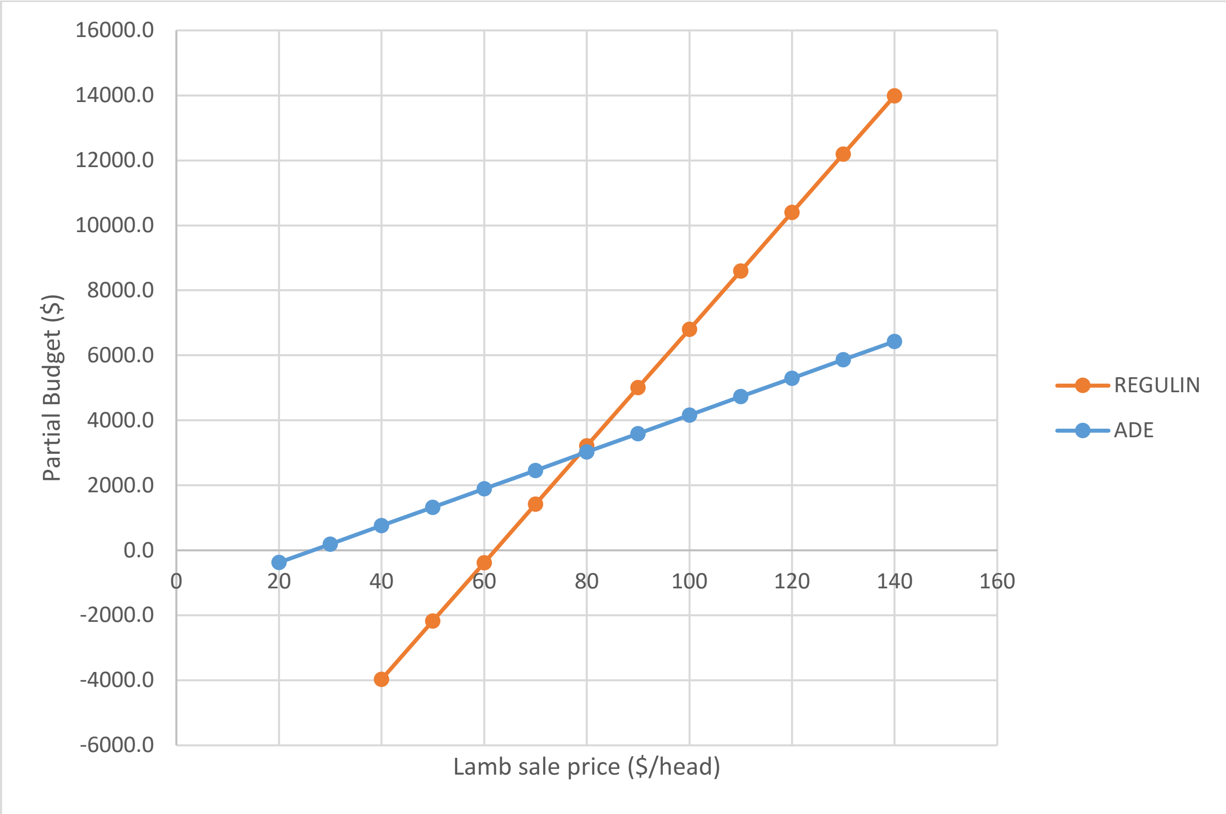

Figure 8: Impact of lamb sale price ($/head) on Partial Budget (Income-Costs) for Regulin and ADE treatments on partial budget

Table 9:Impact of price of lamb sold ($/head) on profitability of Regulin and ADE treatments

		Lamb sale price ($/head)												
		140	130	120	110	100	90	80	70	60	50	40	30	20
REGULIN	Total Supplement cost	6900.0	6900.0	6900.0	6900.0	6900.0	6900.0	6900.0	6900.0	6900.0	6900.0	6900.0		
	Supplement cost per DSE	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7		
	Benefit Lambs per Flock	190.0	190.0	190.0	190.0	190.0	190.0	190.0	190.0	190.0	190.0	190.0		
	Benefit Lambs per DSE	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1		
	Income per Flock	20886.2	19090.7	17295.2	15499.7	13704.2	11908.7	10113.2	8317.7	6522.2	4726.7	2931.2		
	Income per DSE	11.3	10.3	9.3	8.4	7.4	6.4	5.5	4.5	3.5	2.6	1.6		
	Partial Budget per Flock	13986.2	12190.7	10395.2	8599.7	6804.2	5008.7	3213.2	1417.7	-377.8	-2173.3	-3968.8		
	Partial Budget per DSE	7.6	6.6	5.6	4.6	3.7	2.7	1.7	0.8	-0.2	-1.2	-2.1		
ADE	Total Supplement cost	500.0	500.0	500.0	500.0	500.0	500.0	500.0	500.0	500.0	500.0	500.0	500.0	500.0
	Supplement cost per DSE	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
	Benefit Lambs per Flock	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0
	Benefit Lambs per DSE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Income per Flock	6929.1	6362.1	5795.1	5228.1	4661.1	4094.1	3527.1	2960.1	2393.1	1826.1	1259.1	692.1	125.1
	Income per DSE	3.7	3.4	3.1	2.8	2.5	2.2	1.9	1.6	1.3	1.0	0.7	0.4	0.1
	Partial Budget per Flock	6429.1	5862.1	5295.1	4728.1	4161.1	3594.1	3027.1	2460.1	1893.1	1326.1	759.1	192.1	-374.9
	Partial Budget per DSE	3.5	3.2	2.9	2.6	2.2	1.9	1.6	1.3	1.0	0.7	0.4	0.1	-0.2

Impact of treatment efficacy

Although the treatment efficacy used herein are well validated by the commercial research trials undertaken in this project, it is important to understand that variation may occur due to environmental conditions and management factors. As such, it is important to understand the effect of variation in treatment efficacy and the relative risk of financial loss should results differ to that expected.

When treating ewes in the “Test” flock with Regulin, the reported treatment efficacy (19%), returned a Partial budget value of $10395.20 across the 1000 ewe flock (Table 8). Reducing treatment efficacy in 2% increments resulted in a linear decrease in partial budget figure to a break-even efficacy of 7.63% (Figure 9).

Treatment with Vitamin ADE at joining across the “Test” flock returns a predicted Partial budget figure of $5295.09 across the 1000 ewes (Table 10). Reducing the treatment efficacy in 1% increments revealed that the break-even point for this lower-cost treatment was 0.52% (Figure 9).

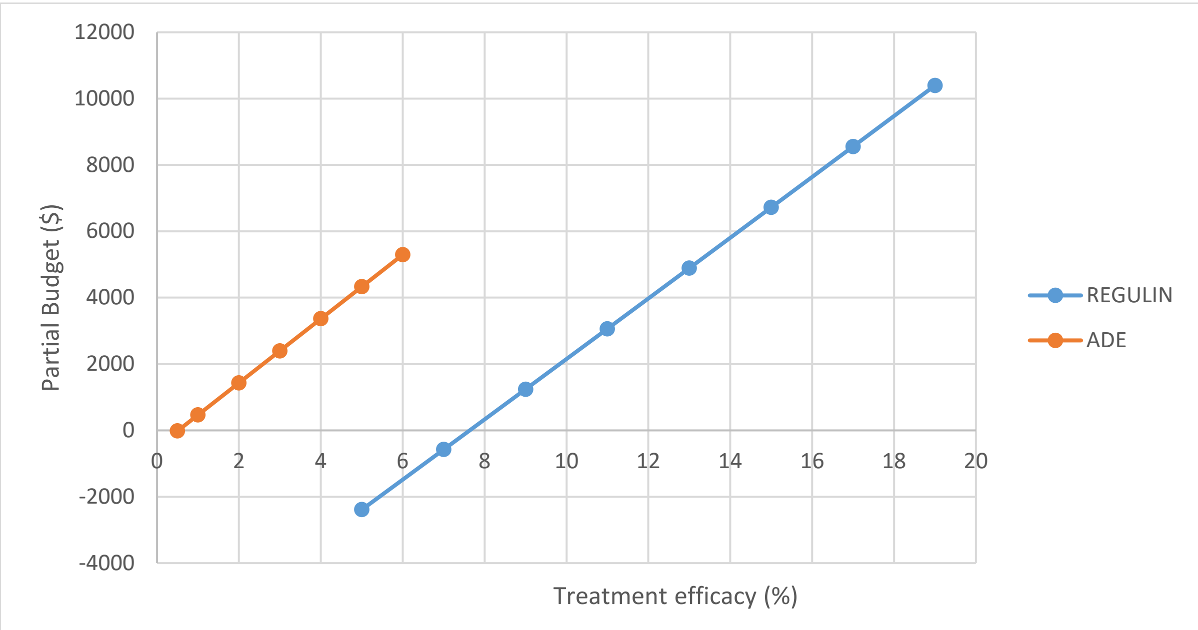

Figure 9: Impact of treatment efficacy on Partial Budget (Income-Costs) for Regulin and ADE treatments

Table 10: Effect of treatment efficacy on flock performance and financial outcome for Regulin and ADE treatments

		Treatment efficacy (%)							
		19	17	15	13	11	9	7	5
REGULIN	Total Supplement cost	6900.0	6900.0	6900.0	6900.0	6900.0	6900.0	6900.0	6900.0
	Supplement cost per DSE	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7
	Benefit Lambs per Flock	190.0	170.0	150.0	130.0	110.0	90.0	70.0	50.0
	Benefit Lambs per DSE	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0
	Income per Flock	17295.2	15456.3	13621.1	11789.8	9962.8	8140.1	6322.1	4509.0
	Income per DSE	9.3	8.4	7.4	6.4	5.4	4.4	3.4	2.4
	Partial Budget per Flock	10395.2	8556.3	6721.1	4889.8	3062.8	1240.1	-577.9	-2391.0
	Partial Budget per DSE	5.6	4.6	3.6	2.6	1.7	0.7	-0.3	-1.3
		Treatment efficacy (%)							
		6.0	5.0	4.0	3.0	2.0	1.0	0.5	
ADE	Total Supplement cost	500.0	500.0	500.0	500.0	500.0	500.0	500.0	
	Supplement cost per DSE	0.3	0.3	0.3	0.3	0.3	0.3	0.3	
	Benefit Lambs per Flock	60.0	50.0	40.0	30.0	20.0	10.0	5.0	
	Benefit Lambs per DSE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
	Income per Flock	5795.1	4829.0	3863.0	2897.1	1931.3	965.6	482.8	
	Income per DSE	3.1	2.6	2.1	1.6	1.0	0.5	0.3	
	Partial Budget per Flock	5295.1	4329.0	3363.0	2397.1	1431.3	465.6	-17.2	
	Partial Budget per DSE	2.9	2.3	1.8	1.3	0.8	0.3	0.0	

Impact of heat on lambing rate.

The "Sheep_Heat_Economics_HotDays" calculator allows a range of scenarios to be modelled alongside historical climate data to test the impact of heat on lambing rate and the resultant financials of any mitigation effort.

Heat effects on lambing rate were derived from Lindsay *et al.* (1975), and a based on a 3.5% reduction in lambing rate for every day above 32°C per week during the joining period. Historical Bureau of Meteorology climate data from 1958-2022 was used for 22 locations across South Australia. Based on the number of days above 32°C per week during the joining period, the total number of lambs lost per flock can then be calculated. Incorporating the flock and treatment impact calculations from the "SheepHeat_Economics_Supplement" tool, the reduction in potential lambs lost to heat and the associated financials will be able to be determined.

At the time of this report, there is insufficient data to model the exact heat mitigating effects of either the Regulin or ADE treatment. Once this data is confirmed then scenarios can be run using this tool and the production and financial implications determined. Currently this tool can be used to interrogate the historical climate data and determine what the long-term average number of days above 32°C per week during the joining period are, and as a result what the potential lamb losses from that heat could be.

To investigate the current functionality of the tool, the "test" flock outlined in Table 7 was included in the tool to investigate the historical average effects of heat on the 1000 ewe flock across regions in South Australia. The results of this scenario are detailed in Table 8. Across South Australia, the average days >32°C per week during the joining period was 9, resulting in a predicted loss of 60 lambs across the 1000 ewes. Regional effects were as expected, with Millicent in the lower South-East of SA yielding the least impact (3 days > 32°C per week during the joining period and 2 lost lambs), whilst Kyancutta on the Eyre peninsula had an average of 15 days >32°C per week during the joining period and a predicted loss of 103 lambs per 1000 ewes (Table 11).

The" Sheep_Heat_Economics_HotDays" tool enables regional variation in heat to be easily understood and would also allow users to alter joining date to study the impacts of heat and potential lamb loss. The ability to include treatments that increase lambing rate, and their cost will allow heat-mitigating treatments to be included in the future, as their effects on heat-mitigation are confirmed.

This project received funding from the Australian Government's Future Drought Fund

Table 11: Average total days above 32 degrees centigrade and Average predicted lamb losses associated with heat during joining for 22 locations across South Australia.

	Total Warm days during joining period	Average lambs lost (prediction)
Ceduna	9	63
Minnipa	13	88
Kyancutta	15	103
Wudinna	14	96
Cummins	6	38
Cleve	8	53
Orrooroo	12	83
Clare	9	63
Snowtown	13	84
Eudunda	9	58
Roseworthy	11	72
Maitland	8	51
Loxton	13	86
Karoonda	10	68
Lameroo	11	75
Keith	9	61
Meningie	5	36
Naracoorte	7	46
Millicent	3	22
Lucindale	5	35
Mt Gambier	4	27
Parndana	3	21
AVERAGE	9	60
MIN	3	21
MAX	15	103

Within the scope of the project there has been no capacity to measure adoption, as the project only ran for one joining season (summer of 2022 / 2023). However, producer feedback has been positive with the majority of producer sites on which trials were run as part of this project expressing their interest in being involved in further trial work in 2023 / 2024.

CONCLUSION

Key Findings and Benefits to industry

This project has demonstrated two easy to implement, highly adoptable and effective strategies to improve the fertility and, thus, productivity of sheep flocks which mate their ewes during late spring to early autumn (November to March). These strategies, Melatonin implants (Regulin® and Vitamin ADE oral drench), increased potential lambing rates per 100 ewes joined by 19 and 6 lambs, respectively. Considering their mode of action, which relates to improved thermoregulation, as well as improved development and survival of embryos (eg Bouroutzika et al., 2020 and 2022; Contreras-Correa et al., 2023; Viola et al., 2023), adoption of these supplements is likely to improve the climate resilience of the South Australian sheep flock, and help to ensure its sustainability and productivity in the face of climate change.

In addition to declining productivity, typical signals of heat stress amongst livestock include an elevated core body temperature, higher respiration rates and increase in water consumption (Marquez-Acevedo et al., 2023). This project has demonstrated that supplementing ewes with betaine via a commercial water dispensing system (uDOSE, DIT AgTech), reduced water consumption by 0.66 litres per day in cooler (< 32°C) days and 1.0 litres per day on hot (≥ 32°C) days. Betaine is an organic osmoprotectant, and accumulates in cells that are osmotically stressed, serving to maintain cell function and volume, thereby reducing requirements to consume water and increasing hydration. Importantly, trial work conducted within our group (Lewis-Baida et al., 2023) and other groups (DiGiacomo et al., 2016 and 2023), demonstrated that adding betaine to feed can ameliorate the impacts of heat stress in sheep, including reducing core temperature. Importantly, the impact of betaine on heat tolerance are dose dependent, with 2 g / day of Betaine intake appearing to be optimal (DiGiacomo et al., 2016). In the current study, betaine supplementation via the water failed to significantly reduce core temperature; however, this is likely because the reduced water consumption resulted in ewes consuming inadequate quantities of betaine (0.47 g versus 1.5 g per day) to elicit a positive effect on thermoregulation. It is worth noting that ewe temperatures at the hottest part of the day were lowest (albeit not significantly) for betaine supplemented ewes. Therefore, based on the current findings, as well as previous research, it is suggested that betaine has significant potential to increase the drought resilience of sheep flocks by reducing water requirements of ewes, but that future work should demonstrate the benefits of delivering betaine to sheep via their feed on thermotolerance, and reproductive performance.

This project has developed two useful prototype tools to model the financial and production impacts of treatments that increased lambing rate. Both tools provide useful insights to sheep advisors and producers and inform decision-making, particularly relating to supplementation with Regulin or Vitamin ADE. The developed "SheepHeat_Economics_Supplement" tool enables advisors and producers to include the specifics of their flock, cost of production and resultant treatment effect (Regulin, ADE, or "custom") to inform their decision. Further validation of the heat-mitigating effects of these supplements will then allow a complex prediction of potential heat-related fertility loss and treatment impact to be determined through the use of the " Sheep_Heat_Economics_HotDays" tool.

Treating ewes with Regulin and ADE at joining to increase lambing rate results in a significant increase in profitability in a 'test' sheep flock. Reducing or increasing the lambing rate pre-treatment (current lambing rate) within realistic commercial ranges results in a moderate change in financial return across the flock. Investigation of treatment effects in high fecundity flocks is warranted to determine if the response is similar at higher current lambing rates (>120%). Overall, the impact of current lambing rate on financial outcome is low, and there is little reason not to implement either of these supplementation strategies into sheep flocks to improve lambing rate and drive profitability.

Modifying lamb sale price impacted the financial returns of both treatments to a greater extent than current lambing rate, with break-even lamb sale prices of $62.10 and $26.60 for Regulin and ADE respectively. Although current market prices are below $60 for store lambs, the modelling herein is factoring sale price for a heavy store-light finished lamb, which are currently above those market figures.

Profitability remained achievable across both treatments with reductions in treatment efficacy of up to 59% and 91% for Regulin and ADE respectively. This provides significant margin for variation in treatment effect, assuming a consistent lamb sale price.

Overall, Regulin and ADE treatment of ewes to increase lambing rate appears a robust, profitable management practice. Treatment efficacy and lamb sale price will impact the return on investment of Regulin and ADE treatments and should be considered when deciding to implement these practices. Further confirmation of the true heat-mitigating effects of these treatments on sheep flock fertility will then allow complex predictions of financial return across different production environments.

Future adoption opportunities

There are no practical reasons why the use of Melatonin, delivered as an implant (Regulin®) or Vitamin ADE delivered as a long-lasting oral drench cannot be adopted as a strategy to alleviate the impacts of heat. Both strategies are easy to apply within a commercial setting, and based on the model scenario run, their incorporation within a production system is profitable. Having said that, wide-spread adoption and, potential practice change, likely requires the demonstration of the efficacy of these strategies over at least one more summer joining period, with the development of producer demonstration sites likely to further increase producer confidence in their efficacy and, thus, adoption and practice change. These producer demonstration sites could also provide the opportunity to demonstrate additional strategies to improve drought and heat tolerance of sheep flocks, as they are developed.

Future adoption opportunities for the use of Betaine to improve heat and drought tolerance of sheep, and sheep flocks, lies in demonstrating the potential of dietary betaine to improve thermotolerance, reduce water consumption and at least maintain reproductive performance.

Adoption of the prototype calculators would be facilitated by 1) including additional years of data on the efficacy with which supplements improve the productivity of sheep flocks joined during spring through autumn and, 2) by incorporating the calculators into a more widely accessible platform, such as a website or app.

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