Understanding the impacts of climate change on lamb survival and lambing date in Southern New Zealand

David R. STEVENS[1*] and Marie J. CASEY[2]
[1]*AgResearch Ltd, Invermay Research Centre, Private Bag 50034, Mosgiel New Zealand*
[2]*PGGWrightson Ltd, Private Bag 1960, Dunedin, New Zealand*
*Corresponding author: david.stevens@agresearch.co.nz

Abstract
Future variations in temperature, rainfall and storm intensity need to be translated into on-farm metrics to understand the impacts on lambing date and survival. A lamb survival model based on heat loss was developed and applied in a daily time step to present and future climate scenarios, at three regions throughout the lower South Island representing hill and lowland farms. Future scenarios (2040-2049) were modelled, based on forecast climate trends. Changes in temperatures from the 1990-1999 period to the 2000-2010 period matched or exceeded change predictions from global modelling. Predicted increases in temperature had little effect on lamb survival. Average air temperature over the period two weeks before to four weeks after planned start of lambing was ~7ºC in every region and topography, matching the rise in spring pasture growth. Future climate scenarios indicated the potential to schedule lambing 10 to 20 d earlier than current practice by 2040, hence increases in lamb liveweight of 1.5 to 5.5 kg by December 15th may be possible. Opportunities to lamb earlier as increased temperatures promote earlier grass growth in spring may help increase pre-summer lamb liveweight gain and mitigate the potential impacts of increased occurrence of summer dry periods.

Keywords: lambing date, rainfall, temperature, weaning weight

Introduction
Climate change is forecast to increase average temperatures whilst concentrating rainfall events (Ministry for the Environment 2018). Recent reports have highlighted increasing duration and severity of drought (Stats NZ 2020). The potential size of impact will differ, depending on the location (region, catchment or farm level) throughout New Zealand (Ministry for the Environment 2018).

Understanding the potential future impact of changing climate on farm performance provides an opportunity to plan and implement appropriate mitigations. One of the key drivers to financial success on sheep farms is the number of lambs that survive to sale (Williams 2017). Variability in the climate during lambing is known to have a major influence on this key performance driver (Everett-Hincks and Dodds 2007). This paper reports on the development of a method to investigate the potential effect of climate change on lamb survival and the potential influence on lambing date.

Materials and Methods
The impacts of future climate change predictions on lamb losses around birth were investigated. The process involved the development of a lamb survival model from local (Everett-Hincks and Dodds 2007) and international (Coronato 1999) data. This was validated using data from three regional farmer groups (Northern Southland, South Canterbury and West Otago), chosen to provide different farming systems (intensive (Flat) and extensive (Hill)) representing a range of temperature (Figure 1) and rainfall variation (Table 1). Weather data for each region and farm type from a ten-year baseline period of 2000-2009 was tested in the lamb survival model and results compared with farmer data to validate the model. Then daily temperature and rainfall were predicted for three future climate scenarios of low, medium or high warming in a ten-year period from 2040-2049 for each region and farm type. This data was used in the lamb survival model to predict lamb survival and test the potential to alter lambing date.

A general analysis of variance was used to compare lamb survival in past (1990-1999) and future climatic outcomes (2040-2049) of three future climate scenarios derived from potential greenhouse gas scenarios, (low, medium and high), with 2000-2009 conditions as the control (Genstat 20.1 2022) using year as the replication (n=10) in a factorial design.

Two farming systems (intensive and extensive) within each region (Northern Southland, West Otago and South Canterbury) were chosen to represent different six local climate zones (Table 1, Figure 1). Climate data was downloaded from the Virtual Climate Station network (Tait et al., 2006) to match local sites within the three regions of the catchments by the National Institute of Water and Atmospheric Research (Hendrikx et al., 2009).

Predicting future climate scenarios
Climate information was generated for three future

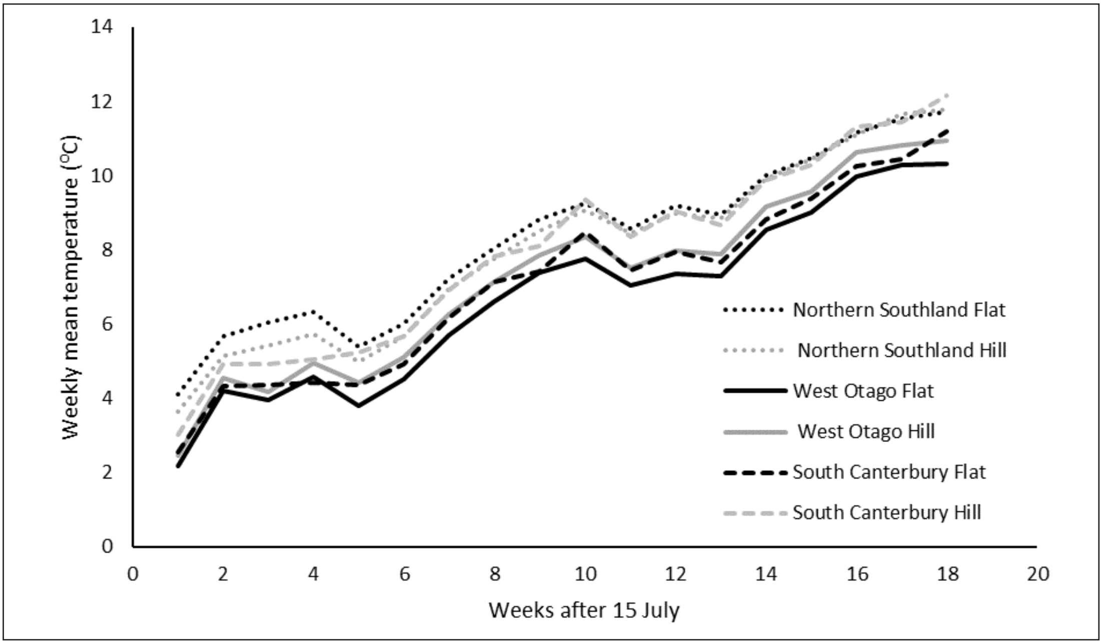

Figure 1 Weekly mean temperature (2000-2009) for three regions, Northern Southland, West Otago and South Canterbury, and two farm types (Flat and Hill).

(2040-2049) climate projections, associated with low (B1), medium (A1B), and high (A1F1) emissions scenarios, used by the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (IPCC 2007). These future changes in temperature and rainfall, based on different representative concentration pathways (RCP's), were similar to the IPCC Fifth Assessment global climate models as a stabilisation pathway RCP4.5 (B1) a moderate increase pathway RCP6.0 (A1B), and a high emissions pathway RCP8.5 (A1F1; Ministry for the Environment 2018).

The output of the global climate model had a low spatial resolution and was not appropriate to apply at the scale that was required for the type of local climate modelling required for this study. Therefore, the global model output was statistically downscaled (Ministry for the Environment 2008) to the 5 km grid intervals used in the VCS network. NIWA used the Virtual Climate Station (VCS) network (Tait et al., 2006; Tait 2008) to extract baseline climate data (1990-1999) from the closest grid points to appropriate locations within each catchment for the downscaling of regional climate model data. Average temperatures (Table 2) during lambing rose in all regions by between 0.5 and 1.4ºC for future low, medium and high scenarios.

Further variability was added to the future climate data by adjusting rainfall events. The percentage increase in extreme rainfall depths is currently expected to be approximately 8% per ºC increase (Ministry for the Environment 2008) and the data sets were adjusted

Table 1. Sites chosen for future climate and lamb loss prediction

Region	Topography	Longitude/Latitude	Altitude (masl)	Mating date	Rainfall during lambing[1] (mm)
Northern Southland	Flat	-45.675/168.325	256	15-Apr	86
	Hill	-45.425/168.575	480	15-Apr	96
South Canterbury	Flat	-44.125/170.825	300	9-Apr	80
	Hill	-43.975/170.925	577	25-Apr	143
West Otago	Flat	-45.725/169.425	422	1-May	95
	Hill	-45.725/169.175	626	10-May	100

[1] Mean Rainfall (2000-2009) during the period from 14 d before until 51 d (three mating cycles) after the planned start of lambing

accordingly, by removing small rainfall events and adding them to large events at the quoted amount. A full description of the climate modelling and data outputs is given by Hendrikx et al., (2009). While temperature and rainfall changes can be altered based on consistent historical records, changes in average wind speed cannot be predicted at a local scale, so VCS network predictions of average wind speed from 2000-2009 were used for the 2040-2049 scenarios. Predicted average rainfall during lambing was similar to current rainfall amounts except the South Canterbury hill which had an increase of approximately 60% (Table 3).

Predicting lamb loss model

A model was developed to predict the number of lambs which expired because of heat loss due to air temperature, rainfall and average wind speed over the lambing period. The model first predicted the number of lambs born on each day, then determined heat loss potential for that day and, from this, calculated the proportion of lambs that would die because of heat loss. The model was applied to current (2000-2009) and future climate data (2040-2049) predicted for each of the three future climate scenarios.

Predicting number of lambs born per day

The number of lambs born (NLB) each day during lambing was calculated using a normal distribution around the mean predicted lambing date, using a gestation length of 153 d with a standard deviation of +/- 5 d, and distributed between mating cycles, assuming equal numbers of ewes are cycling each day, an 80% conception success in each cycle, for three mating cycles. Each cycle began 17 d apart. The

Table 2 Mean air temperature before and during lambing in three regions and hill or flat topography throughout the lower South Island at past (1990-1999), present (2000-2009) and in three future (2040-2049) climate change scenarios

Region	Topography	Climate scenarios				
		Past	Present	Low	Medium	High
		Mean Air temperature (°C)				
Northern Southland	Flat	7.21	8.24	7.74	8.03	8.49
	Hill	6.54	8.01	7.07	7.45	7.80
South Canterbury	Flat	6.93	7.34	7.61	7.94	8.35
	Hill	6.88	7.54	7.30	7.61	7.97
West Otago	Flat	6.96	7.78	8.00	8.17	8.49
	Hill	6.94	7.61	7.47	7.87	8.18
Mean	Flat	7.03	7.79	7.78	8.05	8.44
	Hill	6.79	7.72	7.28	7.64	7.98
	Overall	6.91	7.76	7.53	7.85	8.21

Table 3 Past (1990-1999), present (2000-2009) and future predicted (2040-2049) average rainfall under three greenhouse gas emissions scenarios around the time of lambing in three regions and hill or flat topography throughout the lower South Island.

Region	Topography	Climate scenarios				
		Past	Present	Low	Medium	High
		Rainfall during lambing (°C)				
Northern Southland	Flat	103	95	94	97	100
	Hill	93	103	84	87	90
South Canterbury	Flat	75	90	82	80	79
	Hill	102	108	163	163	163
West Otago	Flat	96	70	96	96	97
	Hill	103	95	101	101	102

proportion of singles, twins and triplets was predicted from the scanning percentage of the flocks, using equations derived from data presented by Davis et al. (1983). These were:

Proportion of lambs born single

(SINGLE) = 424.76 * e -0.014*scan% (Equation 1)

Where scan%=number of foetuses per 100 ewes pregnant assessed at between 70-90 d pregnant (Farmer and Davis 1999)

Proportion of lambs born twin

(TWIN)= 0.0096 * scan%^{2} + 3.4971 * scan% - 258.9 (Equation 2)

Proportion of lambs born triplet

(TRIPLET) = 0.005 * scan%^{2} - 1.5131 * scan% + 102.65 (Equation 3)

Predicting heat loss

Heat loss was calculated (Equation 4; Coronato 1999) using daily temperature, mean wind velocity and daily rainfall.

Heat Loss HL (W/m^2) = 40.38 – 2.12T + 5.84V + 0.73x (Equation 4)

T = mean daily temperature (°C)
V = daily mean wind velocity (m.s-1)
x = daily rainfall (mm)

Average heat loss was calculated for three periods

HL1 = average daily ewe heat loss (W/m^2) in the two weeks prior to birth
HL2 = average daily ewe heat loss (W/m^2) in the week prior to birth
HL3 = average daily heat loss exposure (W/m^2) in the 3 d after birth

Predicting lamb loss model

Lamb death risk was then calculated using empirical equations from Everett-Hincks and Dodds (2007). These were split into heat loss of the dam before lambing (Equations 5 and 6) and heat loss of lamb in the 3 d after birth (Equation 7 and 8).

Lamb death risk at birth

(LDRB, proportion of lambs born) = -0.001 x HL1 + 0.003 x HL2 (Equation 5)

Lamb loss at birth (LLB) was then calculated

LLB = LDRB * NLB (Equation 6)

Lamb death risk due to heat loss after birth were then calculated independently from the remaining lambs

Lamb death risk

(LDR, as a proportion of lambs alive at birth) = A x HL3 (Equation 7)

Where A = 0.0019 for single born lambs
A = 0.0023 for twin born lambs
A = 0.00203 for triplet born lambs

Finally, the lamb loss after birth was calculated
Lamb loss after birth

(LLAB) = LDR * (NLB- LLB) (Equation 8)

Predicting potential future lambing dates

Temperature data for each scenario was collected from 14 d prior to and until 28 d after planned start of lambing (day 144 of gestation), a period of 42 d. A linear function was applied to this data to describe the relative warming of air temperature over this time. The midpoint of this relationship under past (1990-1999) conditions was deemed the point of average temperature during lambing. The date at which average lambing temperature was reached in each of the other scenarios was then calculated. An example of the graphical representation of this approach is provided for South Canterbury Flat (Figure 2). The vertical line depicts the current lambing date. Where this line intersects with the horizontal line represents the average temperature at lambing.

Future lambing dates were then assigned to be where their temperature line crossed the horizontal line. Thus, in Figure 2, the past temperature threshold was 6.9ºC with a lambing date of 9th September. Predicted potential lambing dates, where present and future climate scenarios meet this temperature threshold, are 4th September, 31st August, 26th August and 20th August for present, low, moderate and high climate scenarios respectively.

Results and discussion

Testing validity of model by comparing predicted and actual lambing percentages

Predicted lambing outcomes (Table 4) from ten years weather data over lambing were similar to actual lambing outcomes reported by the associated regional farmer groups. Variations between the predicted and actual lambing percentage may have reflected local conditions, such as slope and aspect, and mitigations, such as shelter, that the farmers already have in place.

This model used an empirical approach to determining lamb survival and successfully reflected actual on-farm data. Other mechanistic models are available (Donnelly et al., 1997), though they too are based on empirical data from experimental data sets (Donnelly 1984). The relative success of this model to reflect

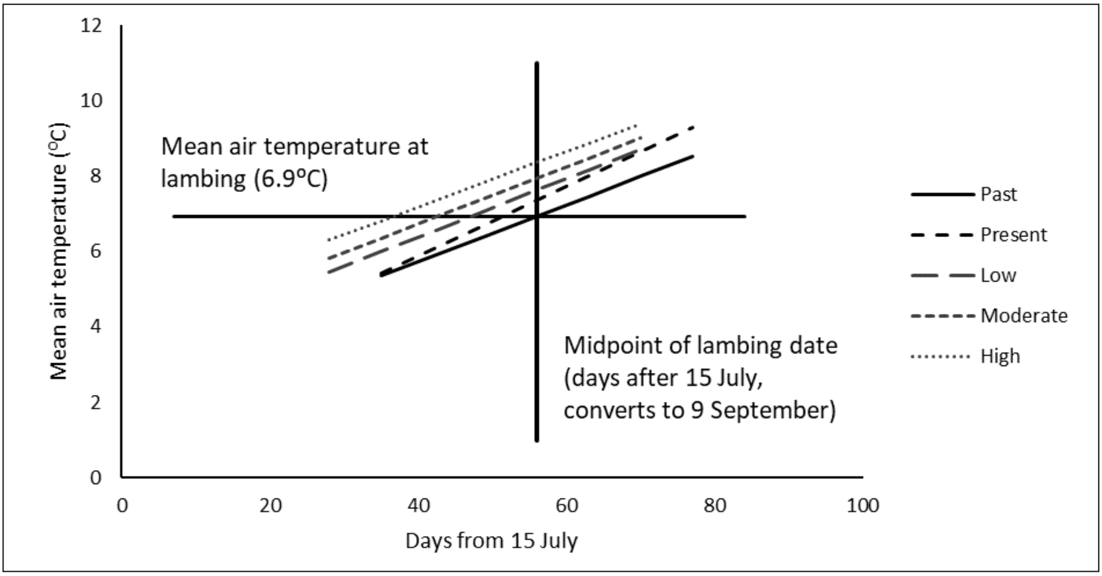

Figure 2 Linear representation of temperature increases around lambing of past, (1990-1999), present (2000-2009), and future (2040-2049) low, medium and high climate scenarios for the South Canterbury Hill site.

local farm conditions may be derived from the large data set sourced from the Otago and Southland regions (Everett-Hincks and Dodds 2007). This approach was aligned with current machine-learning approaches and may only be suitable within the boundaries of the conditions under which the data was collected. Hence, caution should be taken if attempting to use this model beyond New Zealand conditions. The relationship between climatic conditions leading up to lambing and lamb survival apparent in the research (Everett-Hincks and Dodds 2007) was interpreted as an indicator of nutritional status of the ewe.

Changing climate

Lambing date

The choice of mating date in each region reflected the expected temperature conditions at lambing, and these were similar at each site (Table 2). The air temperature of approximately 7ºC reflected the threshold temperature for significant growth of many grasses (Mitchell 1956), which matched the rapid increase in feed demand for the lambing ewe with the onset of pasture growth. As the climate warms this threshold will be reached earlier each year.

Average temperatures around lambing in the present

Table 4 Actual lambing percentages reported by regional farmer groups and those predicted from the lamb survival model using weather data over the period 2000-2009.

		Actual		
Region	**Topography**	**Scan %[1]**	**Lamb %**	**Lamb % Predicted**
Northern Southland[2]	Flat	174	144.2	138.3
	Hill	174	126.2	132.9
South Canterbury[3]	Flat	182	144.3	139.7
	Hill	155	121.3	119.9
West Otago[4]	Flat	177	130.1	134.0
	Hill	177	134.1	129.6
LSD				2.3

[1]Full scanning including triplets and quadruplets
[2]Northern Southland discussion group 2007-2009
[3]South Canterbury FT2000 Benchmarking group 2002-2004
[4]West Otago Monitor Farm 2008-2010

scenarios (2000-2009) were markedly higher than past (1990-1999) scenarios in every region. These present temperatures were often higher than those predicted under low emissions scenarios. This highlighted the uncertainty in modelling future predictions based on modifying historical data, which is how current regional down-scaling approach is applied (Ministry for the Environment 2008).

The different climate change scenarios provide an opportunity for farmers to adjust lambing date to match potential changes in pasture growth as the spring temperatures increase earlier (Table 5). This adjustment may vary from 1 d every two years to 1 d each year over the next 20 years. This may provide an opportunity for farmers to change lambing date, by, on average 10 d over the next 20 years.

In regions where summer moisture deficits are now, or will be an issue in the future, the advancement of lambing date will be particularly important to provide a supply of finished lambs before the onset of the summer dry period. This may provide farmers with a longer window of time to grow lambs to marketable size and offset potential increases in the frequency and duration of drought (Stats NZ 2020). The effect of earlier lambing date on lamb liveweight by 15th December using a preweaning growth rate of 250 g/d varies depending on region and may result in an average increase in lamb liveweight of between 1.5 and 5.5 kg/lamb (Table 6). There appeared

Table 5 Potential mating dates in present (2000-2009) and future climatic conditions (2040-2049) induced by low, medium or high climate change scenarios that would match the mean air temperature during lambing of past (1990-1999) conditions in three regions and hill or flat topography throughout the lower South Island.

		Climate scenarios				
Region	Topography	Past	Present	Low	Medium	High
		Mating date				
Northern Southland	Flat	15-Apr	3-Apr	6-Apr	2-Apr	27-Mar
	Hill	15-Apr	30-Mar	7-Apr	3-Apr	28-Mar
South Canterbury	Flat	9-Apr	4-Apr	31-Mar	26-Mar	20-Mar
	Hill	25-Apr	15-Apr	19-Apr	15-Apr	8-Apr
West Otago	Flat	1-May	5-Apr	16-Apr	14-Apr	9-Apr
	Hill	10-May	14-Apr	2-May	27-Apr	22-Apr

Table 6 Potential increases in liveweight gain per lamb born if mating dates, in present (2000-2009) and future climatic conditions (2040-2049) induced by low, medium or high climate change scenarios, were altered to match the mean air temperature during lambing of past (1990-1999) conditions in three regions and hill or flat topography throughout the lower South Island. A liveweight gain of 250 g/d were used for these estimates.

		Climate scenarios							
		Present	Low	Medium	High	Present	Low	Medium	High
Region	Topography	Days earlier that lambing may commence				Liveweight gained to 15 December (kg/lamb)			
Northern Southland	Flat	12	9	13	19	3.00	2.25	3.25	4.75
	Hill	16	8	12	18	4.00	2.00	3.00	4.50
South Canterbury	Flat	5	9	14	20	1.25	2.25	3.50	5.00
	Hill	10	6	10	17	2.50	1.50	2.50	4.25
West Otago	Flat	26	15	17	22	6.50	3.75	4.25	5.50
	Hill	26	8	13	18	6.50	2.00	3.25	4.50
Mean	Flat	14	11	15	20	3.58	2.75	3.67	5.08
	Hill	17	7	12	18	4.33	1.83	2.92	4.42
Overall		16	9	13	19	3.96	2.29	3.29	4.75

to be an advantage to Hill environments, even under present conditions. When current lambing percentages were used (Table 4) this translated into a significant increase in productivity of between approximately 200 and 700 kg lamb liveweight/100 ewes lambing.

The choice of lambing date to coincide with the onset of pasture growth meant that the temperature around lambing was similar across regions. This meant that temperature around lambing was similar in all regions (Table 3). This implied that the major climatic influences which created variation in lamb survival, in these specific circumstances, were rainfall and wind, rather than temperature. The impact of rainfall will be relatively hard to counteract, except through interventions such as adequate soil drainage and feeding levels. The impact of wind chill is more easily mitigated using shelter. The economic benefits to shelter, however, vary from site to site depending

Table 7 Predictions of present (2000-2009) and future (2040-2049) lamb survival and live lambs, on farms in hill or rolling topography in three regions in the lower South Island, due to predicted climatic conditions around lambing under three climate change scenarios.

		Climate change scenario					
		Present	**Low**	**Medium**	**High**	**Mean**	**LSD[1]**
Region	**Topography**	**Lamb survival rate (per 100 lambs present at scanning)**					
Northern Southland	Flat	79.1	78.2	78.5	78.8	77.7 A[7]	0.46[2]
	Hill	75.9	74.8	75.0	75.4	74.3 B	0.65[3]
	Mean	77.5 a[8]	76.5 b	76.8 b	77.1 a	76.0 BB[9]	1.03[4]
South Canterbury	Flat	80.8	80.3	80.7	81.1	81.0 A	
	Hill	77.4	77.7	76.8	78.2	76.7 B	
	Mean	79.1 a	79.0 a	79.2 a	79.7 a	78.8 AA	
West Otago	Flat	75.7	76.2	76.4	76.7	76.5 A	
	Hill	73.2	73.5	73.7	74.0	74.2 B	
Mean	74.5 a	74.8 a	75.1 a	75.4 a	75.3 CC		
							1.46[5]
Overall mean		77.0 ab	76.8 b	77.0 ab	77.4 a		0.59[6]
		Lamb survival (per 100 ewes mated)					
Northern Southland	Flat	138.3	135.9	136.4	137.0	136.9 A	0.79[2]
	Hill	132.9	129.9	130.4	131.0	131.1 B	1.12[3]
	Mean	135.6 a	132.9 b	133.4 b	134.0 ab	132.3 BB	1.77[4]
South Canterbury	Flat	139.7	138.0	138.6	139.4	138.9 A	
	Hill	119.9	120.6	119.9	121.4	120.5 B	
	Mean	129.8 a	129.3 a	129.3 a	130.4 a	132.5 AABB	
West Otago	Flat	134.0	134.6	135.1	135.7	134.9 A	
	Hill	129.6	129.9	130.4	130.9	130.2 B	
	Mean	131.8 a	132.3 a	132.8 a	133.3 a	133.2 AA	
							2.5[5]
Overall mean		132.4 ab	131.5 b	131.8 ab	132.6 a		1.02[6]

[1]Least significant difference;
[2]LSD for region;
[3]LSD for topography within region;
[4]LSD for climate scenario within region;
[5]LSD for full interaction climate scenario;
[6]LSD for climate scenarios;
[7]Capital letters indicate significance within the column;
[8]Lower case letters indicate significance within the row;
[9]Double capital letters indicate significance for region effects

on the total wind run and year to year variation. A significant gap in climate change scenarios is wind prediction. Given the major impact on lamb survival (Coronato 1999), as well as influencing potential evapotranspiration and hence pasture production, wind speed prediction requires further investigation to help our understanding of future impacts.

Future lamb survival

Temperature, rainfall and the chilling effects of wind all have a significant impact on lamb survival (Alexander 1962; Donnelly et al., 1997; Coronato 1999). Variations in both temperature and rainfall indicated that climate change will influence the number of lambs surviving to sale. However, these factors interacted, as increasing temperature offset, for example, increasing rainfall.

Future predicted changes in climate increased the average temperature around lambing (Table 3) resulting in a small, but significant, increase in both lamb survival and the number of live lambs per 100 ewes mated (Table 7). The South Canterbury region had the highest lamb survival rate, while West Otago had the lowest (P<0.01; Table 7). Farms with flat topography had higher lamb survival than hills (P<0.01; Table 7). Variability between regions and topography was represented in the data with a significant interaction (P<0.01) across the whole data set (Table 7). This variability is common in sheep farming and indicative of the combination of conditions on any given day and provided a view that actual impacts of climate change will be within the experiences already managed by farmers.

Climatic variation is the most pressing issue for farmers in the potential for future climate change (Keller et al., 2021). Using the virtual climate station network, in conjunction with future climate change predictions, provided insight into the nature of those changes. The variable nature of the current climate in New Zealand already provides significant challenges for farmers and their understanding of managing that variation is already good (Gray et al., 2008). Future predicted changes appear to add little extra challenge to those farmers which they already face year on year.

The integration of data from these various sources provides insight to improve understanding of the impact of climate variations on the sustainability of farm production systems into the future.

Conclusions

Variability in New Zealand climate is expected, given the country's variation in topography and maritime influence. Future trends towards more climatic variability will only reinforce the types of resilient farms systems that are now in place. Current lambing dates chosen by farmers reflects air temperatures when pasture growth begins to rapidly increase.

Increases in temperature due to predicted global warming will provide only small gains in lamb survival in Southern New Zealand. However, these shifts are already providing an opportunity to lamb earlier and increase liveweight by mid-December. As temperatures rise, farmers may have the opportunity to shift lambing approximately 1 d earlier every one to two years, helping mitigate potentially higher risk of drought-induced summer feed deficit.

Changes in rainfall are predicted to be small, and current variability seems to be conserved, with maximum and minimum rainfall during lambing remaining relatively similar. Wind run records are limited and prediction of future wind run is not currently available. However, given the trends with temperature and rainfall, variation in wind chill may be adequate to help predict future lamb survival.

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