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Lamb survival and weight at marking may be reduced in ewes lambing on forage oats after grazing lucerne during late pregnancy

Susan M. Robertson[A,B,*], Walter Morton[B], Michael A. Friend[C], Bruce Allworth[B,D] and Marie Bhanugopan[B]

For full list of author affiliations and declarations see end of paper

***Correspondence to:**
Susan M. Robertson
Gulbali Institute, Charles Sturt University, Locked Bag 588, Wagga Wagga, NSW 2678, Australia
Email: surobertson@csu.edu.au

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ABSTRACT

Context. Grazing of cereal forage crops is perceived as a risk for increased perinatal lamb mortality. **Aims.** This study evaluated whether grazing oat forage during late pregnancy and/or the lambing period increased lamb mortality compared with grazing a legume (lucerne)-based pasture. **Methods.** Merino ewes ($n = 636$) were allocated to two replicates of two litter sizes (singles or twins), which grazed the following three forage treatments: either legume-based pasture or oat forage (*Avena sativa*) from 42 days before and throughout a 4-week lambing period, or a legume-based pasture until 9–12 days pre-lambing before grazing oats throughout the lambing period. All groups were offered a calcium, magnesium and sodium mineral supplement to reduce the risk of deficiency. **Key results.** Lamb survival to marking was similar for ewes grazing legumes (84.2 ± 1.94%) or oat forage (78.5 ± 1.94%) throughout, but was reduced ($P = 0.022$) for ewes that grazed oats only during the lambing period (71.0 ± 1.94%) compared with those that remained on legumes. The latter was associated with a greater ($P = 0.016$) loss of condition score in the ewes. The weight of lambs at marking age was 2 kg higher ($P \leq 0.05$) when grazed on legume-based pasture during the 4 week lambing period rather than oats. Minimal ewe mortality (0.47%) occurred, no metabolic disease was observed and few ewes (1.3%) required assistance at parturition. None of the sampled ewes was subclinically deficient in calcium or magnesium. **Conclusions.** The study indicates lamb survival was not reduced by grazing oats for an extended period throughout late pregnancy and lambing. Further research is required to determine whether the recorded reduction in lamb survival from grazing oats only during lambing occurs consistently. **Implications.** Ewes may safely graze oat forage throughout late pregnancy and lambing when offered a calcium, magnesium and salt supplement, without this increasing perinatal lamb mortality relative to a legume-based pasture, but there may be a penalty in lamb growth rates and loss of ewe condition, and lamb survival may be reduced with an abrupt change to oats for the lambing period.

Keywords: farming systems, minerals, mortality, nutrition, pasture, reproduction, sheep, survival.

Introduction

Perinatal mortality is a major limitation to sheep production, with an average of 10% of singles and 30% of twin lambs failing to survive (Hinch and Brien 2014). Dystocia is one of the major causes of perinatal mortality, and overnutrition during late pregnancy can increase lamb birthweight (Behrendt *et al.* 2019), with above-optimal birthweights increasing the risk of dystocia and mortality (Horton *et al.* 2018). The mineral composition of feed also has the potential to influence perinatal mortality, with hypocalcaemia and hypomagnesaemia causing ewe mortality and potentially loss of the fetus or dependant lamb (for review see Friend *et al.* (2020)). The impact of subclinical deficiencies, where plasma calcium of <2.0 mmol/L (Suttle 2010) and plasma magnesium of <0.74 mmol/L (McCoy *et al.* 2001), is unclear, although insufficient mineral intake potentially increases the duration of parturition (Ataollahi *et al.* 2021) and, consequently, perinatal mortality.

Cereal forage crops are often able to fill autumn/winter feed gaps, but there is concern as to whether grazing these during late pregnancy/lactation would pose a health risk to ewes or increase perinatal mortality due to either providing ewes with excessive nutrition resulting in dystocia or by lowering calcium (Ca) and magnesium (Mg) concentrations and causing an imbalanced mineral status (Masters *et al.* 2018*a*).

There is an increased risk of inducing metabolic disease in late pregnant/lactating ewes by grazing cereal crops (Masters *et al.* 2018*a*), so Ca, Mg and sodium (Na) supplementation is recommended as best practice to reduce the risk (Masters *et al.* 2018*b*). However, ewes grazing pastures with a legume component have also been shown to be at risk of subclinical deficiencies. A survey of commercial flocks across southern Australia found that two thirds of late-pregnant ewe flocks contained ewes deficient in Ca or Mg (Hocking Edwards *et al.* 2018). As such, grazing alternatives to cereal crops may not prevent potential subclinical deficiencies in reproducing ewes. Further clarification of the risks of different forage types on lamb survival is therefore warranted.

The scant literature quantifying the impact of grazing late-pregnant or parturient ewes on cereal crops compared with pasture on lamb survival is conflicting. Ewes lambing on forage oats (*Avena sativa*) from 6 to 10 days prior to the lambing period have been reported to achieve a similar lamb survival as those grazing an unspecified pasture (Glover *et al.* 2008; Paganoni *et al.* 2008). In contrast, the survival of twin lambs was increased from 82% to 90% by lambing ewes on oats rather than a grassy legume pasture, but the survival of singleton lambs was reduced by 11% (Oldham *et al.* 2008), possibly owing to dystocia. An excessive increase in birthweight with an associated increase in dystocia is probable with above-maintenance nutrition during late pregnancy (Ocak *et al.* 2005), although increases to optimal birthweight often lead to improved lamb survival (Behrendt *et al.* 2019).

Anecdotal reports suggest that grazing ewes on oat forage during late pregnancy results in high rates of dystocia; however, it is unclear whether this is due to increased birthweights or another cause (Holst and Killeen 1976), nor whether restricting the duration of grazing oats can minimise the risks. Given the widespread use of cereal crops for grazing, there is a clear need to quantify the risks and develop strategies to optimise perinatal survival of lambs for ewes grazing cereal crops during pregnancy or lactation. Therefore, this study aimed to determine (1) whether grazing ewes on forage oats during late pregnancy and throughout the lambing period would reduce lamb survival, compared with grazing ewes on a legume-based pasture, when both were supplemented with Ca and Mg; and (2) whether delaying the grazing of oats to the start of the lambing period could improve survival.

Materials and methods

Experimental design

The study was performed during 2022 on a commercial property 40 km north of Wagga Wagga in southern New South Wales (NSW), Australia, with approval from the Charles Sturt University Animal Care and Ethics Committee (Approval number A22064). The randomised design included two replicates each of two litter sizes (singles or twins) in each of three forage treatments, with group of ewes the experimental unit. The forage treatments were as follows: lucerne, where ewes grazed lucerne-based pastures ((*Medicago sativa*) with varying proportions of annual grasses (*Lolium rigidum, Hordeum leporinum, Bromus* spp.)) from 6 weeks prior to the start of, and throughout the lambing period; oats where ewes grazed vegetative oat forage (*Avena sativa*) for a similar period; lucerne to oats where ewes grazed lucerne-based pastures from 6 weeks to 9–12 days prior to the start of lambing, then grazed oat forage throughout the lambing period. A timeline of the study is shown in Table 1. The study was designed to replicate commercial practice where oats are expected to have a higher biomass during winter than are legume pastures and ewes are set-stocked.

Sheep management

The flock of Merino ewes had been naturally joined with Merino rams for 33 days from 26 February, were due to lamb between 26 July and 27 August, and had been shorn in March. The ewes were mixed age, with 95% being 2.5–4.5 years of age when joined. Fetal number was determined using abdominal ultrasound on 3 June, and equal numbers of single- and twin-bearing ewes (total $n = 636$) were allocated to the experiment. Within fetal classes, the ewes were stratified by age, then randomly allocated to one of six single- and six twin-bearing groups ($n = 53$ ewes per group) on 14 June, 42 days before the due lambing period. They were drenched with Q-Drench® containing four classes of anthelmintic (levamisole hydrochloride, closantel, albendazole and abamectin) (Jurox Animal Health, Rutherford, Australia) and vaccinated with Glanvac 6® (Zoetis Australia, Rhodes, Australia) against *Corynebacterium pseudotuberculosis* (cheesy gland) and clostridial diseases, before being placed in either lucerne-based pasture or a sown oat crop as separate single- or twin-bearing paddocks. A mineral supplement was offered to all groups as a loose lick of agricultural lime (Omya Australia, North Shore, Australia) calcined MgO (Causmag) (Causmag International, Young, Australia), and salt (Lake Charm Salt Pty Ltd, Lake Charm, Australia) in a 2:2:1 ratio by weight, at a rate of 30 g/ewe per day, fed twice weekly in troughs from allocation until the end of the experiment. Any refusals were dried and weighed once per week. The ewes were not offered grain or other feed supplements.

The lucerne to oats groups of ewes were moved from lucerne to oat paddocks 9–12 days prior to the due lambing

Table 1. Timeline of the experiment indicating key sheep activities and measurements.

Action	Allocation to groups	Moving to lambing paddocks	Lambing	Calculating survival
Timing	42 days pre-lambing	9–12 days pre-lambing		Post-lambing
Date	14 June 2022	14 and 17 July 2022	26 July to 30 August 2022	8–11 September 2022
Number of ewes	*n* = 53 ewes/group	*n* = 53 ewes/group	*n* = 53 ewes/group	*n* = 53 ewes/group
Groups grazing oats	2 × singles; 2 × twins	4 × singles; 4 × twins	4 × singles; 4 × twins	4 × singles; 4 × twins
Groups grazing lucerne	4 × singles; 4 × twins	2 × singles; 2 × twins	2 × singles; 2 × twins	2 × singles; 2 × twins
Measurements	Weight	Weight	Birthweight (*n* = 250)	Weights (ewe + lamb)
	Condition score	Condition score		Condition score
	Blood sample	Blood sample		Sex of lamb

period. During the lambing period, all groups were checked at least twice per week, and ewes were assisted to deliver lambs if required, by correcting fetal position and applying traction. Assistance and any ewe deaths were recorded. Lambs were generally not tagged and weighed at birth because of resource constraints. However, on the same 13 days for each paddock, 250 lambs, in total, of age from 0 to an estimated <24 h were caught, eartagged, weighed and their sex was recorded. Post-mortem examinations were conducted on 53 lambs found dead (McFarlane 1965). All treatment groups of sheep in one replicate were yarded on 1 day, with each replicate yarded between 8 and 11 September for lamb marking (tagging, castration, tail docking and vaccination). At this time, the estimated age of lambs was between 9 and 47 days, and lambs were counted, weighed and their sex was recorded. Percentage lamb survival was calculated for each group of ewes on a paddock basis as follows: number of lambs present at marking / fetuses placed in paddocks × 100.

Sheep measurements and laboratory analyses

Ewes were condition scored on a scale of 1–5 (1 = emaciated, 5 = obese) (Jefferies 1961) at allocation, pre-lambing, and at the end of the experiment. All ewes had coloured eartags corresponding to the year of birth, although not all were uniquely numbered. At allocation, four ewes per group (*n* = 48 ewes per forage treatment) were randomly selected from those uniquely eartagged, and blood was sampled, with the same ewes re-sampled when moved to lambing plots 9–12 days pre-lambing. Blood samples were collected by jugular venepuncture by using 9 mL lithium heparinised BD vacutainers® (Becton, Dickinson and Company, Plymouth, UK) for analysis of mineral concentrations, and also 5 mL sodium fluoride and potassium oxalate vacutainers for analysis of glucose concentrations. Blood samples were stored on ice before centrifugation, with plasma separated and frozen at −20°C until analysis. The plasma concentrations of glucose (Enzymatic UV test, hexokinase method), beta hydroxybutyrate (BHB), Mg (xylidl blue method), Ca (arsenazo III complex method), phosphate (P) (molybdate complex method), potassium (K) and sodium (Na) were analysed using BLOSR kit in a Beckman Coulter AU480 analyser (Beckman Coulte, UK) at the Veterinary Diagnostic Laboratory, Charles Sturt University, NSW, Australia.

Pasture measurements and weather

The paddocks varied in size and were only partially blocked, because of the use of established lucerne pastures and their proximity to the sown oat crops. However, all paddocks were either adjacent or within a 2 km range. Two separate oat paddocks, which had been sown in March, were subdivided into 5.3 ha paddocks, such that the lucerne to oats paddock was adjacent to oats paddocks. The oats paddocks within the lucerne to oats forage treatment were grazed by non-experimental sheep prior to the lambing period to ensure that the biomass at lambing would be similar to that of the oats paddocks. These sheep had received an anthelmintic drench at a time similar to that for the experimental ewes to minimise bias in worm burdens among paddocks.

The lucerne paddocks varied from 8 to 32 ha and ewes were set-stocked on these paddocks for the late gestation and/or lambing period. The lower stocking rate for ewes grazing lucerne (1.6–6.6 ewes/ha) versus oat (10 ewes/ha) paddocks was considered necessary to maintain adequate pasture availability because of an expected slower growth rate of lucerne and annual legumes during winter, and represents commercial practice. The study aimed for paddock sizes that would provide sufficient green herbage to avoid the need for supplementary feeding while using existing paddocks where possible. A similar herbage availability was not a target because of the higher expected biomass and growth rate of cereal forage than legumes and probable differences in intake owing to sward structure. A uniform mob size (number of ewes per paddock) was considered more important in avoiding impacts on lamb survival, because at the levels used, higher stocking rates do not consistently reduce lamb survival (Kleemann *et al.* 2006; Lockwood *et al.* 2020), particularly when pasture available is abundant. Hence, use of paddocks of differing size, within the range used, would be unlikely to affect survival.

The quantity of live herbage available was estimated at the times of allocation to paddocks, pre-lambing and at lamb marking. Visual estimates (n = 30) were recorded in a diagonal transect across each paddock, and were calibrated using 10 quadrat cuts (0.1 m^2) each for lucerne and oats, which were dried at 60°C, then weighed (Haydock and Shaw 1975). The composition of live pasture was visually estimated pre-lambing only. Samples for estimation of the nutritive value of pastures were not collected owing to lack of resources and expected differences in biomass, sward structure and diet selection affecting intake, with changes in sheep weights being considered a better estimate of the nutritive value of different pasture types. Weather data for the grazing period were obtained for the nearest station, Number 072150, at Wagga Wagga, (www.bom.gov.au, accessed 24 October 2022). A chill index (Donnelly 1984) was calculated from these data for the period ewes were in lambing paddocks, with 1000 $kJ/m^2.h$ being indicative of a high risk of chill to newborn lambs.

Statistical analyses

One ewe was removed from the study soon after allocation because of abnormal behaviour, so calculations are based on 52 ewes for that group.

The experimental unit for analyses was the ewe group. Data were assessed for assumptions of normal distribution and homogeneity following analysis using Genstat® 21st edition (VSN International, Hemel Hempstead, UK). Only herbage availability required data transformation by natural logarithm. Linear mixed modelling was used to analyse ewe condition score and lamb weights using year born (for condition only) + time × fetal number × treatment as the fixed term and replicate as the random term. Loss of condition was calculated only from uniquely eartagged ewes that had records at both pre-lambing and at marking ($n = 446$). Plasma concentrations (with the exception of Mg) were similarly analysed, but excluded year born and included ewe as a random term to account for repeated measures on the individual. Lamb survival and the total weight of lamb marked per ewe lambing were analysed using ANOVA, with fetal number × treatment as the fixed term and replicate as the random term. A posthoc Bonferroni correction was applied to determine differences among individual means. The median percentage of lambs marked per ewe lambing and plasma Mg concentrations were analysed using the non-parametric Wilcoxon rank-sum test because of unequal variances. A P-value of 0.05 was considered significant, with trends reported when $P < 0.10$. Results are presented as means ± s.e.m. Herbage availability was also analysed by linear mixed model by using time × fetal number × treatment as the fixed terms after transformation by natural logarithm to equalise variances, but with paddock as the random term. Geometric means ($e^{\text{mean ln}}$) are presented, and a least significant ratio (l.s.r = $e^{(\text{l.s.d.ln})}$) calculated using the maximum l.s.d. was used to compare means.

Results

Pastures and weather

The mean quantity of herbage available showed a significant ($P < 0.001$) interaction among time of sampling, fetal number and treatment, as shown in Fig. 1. The mean quantity of live herbage available in oat pastures was above 2300 kg DM/ha in all paddocks at all times of sampling. This was a higher quantity than in lucerne pastures at allocation and pre-lambing (800–1200 kg DM/ha; lucerne and lucerne to oats treatments), although the quantity was similar for single- and twin-bearing mobs within a pasture type. Post-lambing, the quantity of herbage grazed had increased for the lucerne to oats treatment because these ewes were then grazing oat pastures (2700–4500 kg DM/ha), whereas the lucerne ewes remaining on lucerne pastures grazed a lower quantity of herbage (1600 kg DM/ha).

Oat pastures were predominantly oat forage at allocation (78 ± 4.1%) and this dominance increased significantly ($P \leq 0.05$) by pre-lambing (85 ± 4.1%). Annual grasses, mainly annual ryegrass (*Lolium rigidum*), were the other major component. Lucerne pastures were dominated by lucerne and subclover (*Trifolium subterraneum*) at allocation, with 64 ± 11.9% in lucerne and 77 ± 11.9% in lucerne to oats treatments ($P > 0.05$). The percentage of legume declined approximately 20% by pre-lambing as the percentage of

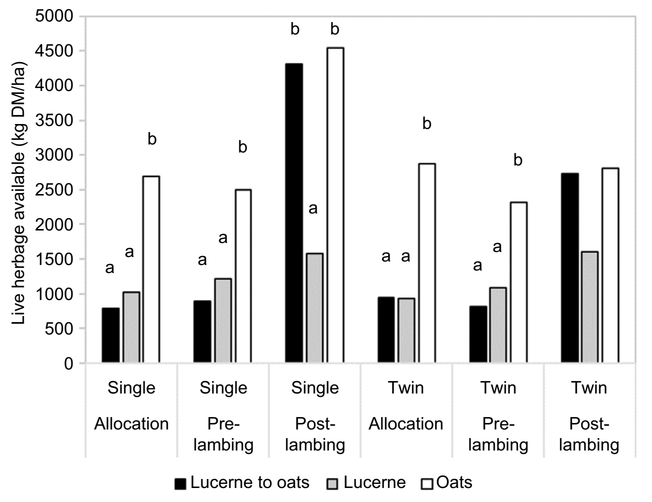

Fig. 1. Geometric mean quantity of live herbage available (kg DM/ha) for single- and twin-bearing ewes at allocation, pre-lambing and marking in the lucerne to oat (black columns), lucerne (grey columns) and oats (white columns) treatments. Different letters within each time × fetal class indicate that means differed significantly by using a l.s.r of 1.94.

annual grasses increased, although these changes were not significant.

The weather at the Wagga Wagga station was mild for winter during the period when ewes were on lambing paddocks. The average minimum daily temperature was 4.2 ± 0.49°C, with only 12% (7/57) of days having temperatures below 0°C. The mean maximum temperature was 14.9 ± 0.32°C, and rainfall of ≥5 mm occurred on 7 days. An average maximum wind gust of 34 ± 1.8 km/h was recorded, with only 13 days when wind speed at 0900 hours was <8 km/h. The average Donnelly chill index was 1038 ± 8.3 kJ/m^2.h, with an index of ≥1000 kJ/m^2.h occurring on 40 of 57 days.

Ewe health and condition score

Only three ewes died (0.47%) during the study, two in lucerne to oats and one in the lucerne treatment, all twin-bearing and due to either dystocia or becoming cast after dystocia. A further eight ewes were assisted to either deliver lambs (5 ewes) or to stand when cast post-lambing (3 ewes), and these were distributed across treatments. No clinical metabolic disease was observed. The mineral supplement offered was readily consumed by ewes, with repeated refusals occurring only in one plot (singles, Lucerne) because of failure of ewes to consume before rain or ewes not grazing in proximity to the trough in large paddocks. That group refused 34% of the supplement offered during the last 5 weeks of the lambing period.

The mean condition score of ewes showed no interaction among fetal number, time and treatment (P = 0.767). The mean condition score of ewes was similar among forage treatments and fetal classes at allocation (3.1 ± 0.06) and increased ($P \le 0.05$) to 3.5 ± 0.06 by pre-lambing (Fig. 2). Condition score then declined in all treatments to the end of the experiment, when it was lower ($P \le 0.05$) in the lucerne to oats and oats ewes (3.2 or 3.3 ± 0.06 respectively) than in the lucerne ewes (3.4 ± 0.06). The change (loss) in condition score during the lambing period showed no interaction between fetal class and treatment. The loss was greater in twins than singles (–0.39 ± 0.069 vs −0.04 ± 0.070; P = 0.016), and greater in lucerne to oats than the lucerne ewes (Table 2). This was associated with a numerically greater loss in the lucerne to oats twin-bearing ewes.

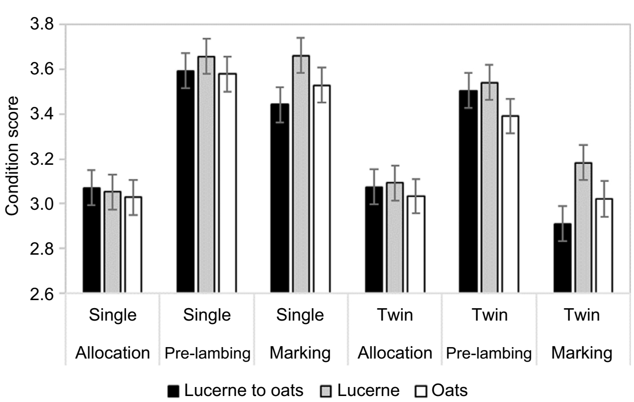

Fig. 2. Mean condition score (±s.e.m.) of twin- and single-bearing ewes at allocation, pre-lambing and marking in lucerne to oats (black columns), lucerne (grey columns) and oats (white columns) treatments. The interaction time × fetal number × treatment P = 0.767.

Reproductive performance

Mean lamb birthweight was similar among all forage treatments (Table 2), but was higher in males than females (5.1 ± 0.13 kg vs 4.8 ± 0.15 kg; P < 0.0001) and in singles than in twins (5.5 ± 0.18 kg vs 4.4 ± 0.16 kg; P = 0.049). The weight of lambs at marking was ≥2 kg higher ($P \le 0.05$) from ewes that grazed lucerne throughout late pregnancy and the lambing period than from those grazing oats or lucerne to oats.

For lamb survival to marking, there was no interaction between fetal class and forage treatment. Lamb survival to marking was higher (P = 0.022) in the lucerne than the lucerne to oats treatment, whereas that in the oats treatment was similar to both (Table 2). Survival was higher in singles than twins (93.4 ± 0.74% vs 62.4 ± 0.74%; P = 0.001). The percentage of lambs marked per ewe lambing was not reduced by grazing oats rather than lucerne throughout late pregnancy and lambing, or only during the lambing period, as shown in Table 2. However, the lucerne ewes had 5 kg per ewe more total weight of lambs marked than did lucerne to oat ewes because of the combined higher survival and heavier weights of lambs. Cause of perinatal death was determined from 53 post-mortems across all treatments. Dystocia (26%; n = 14/53) was diagnosed for 20–29% of cases within treatments, and starvation was the most frequent cause of death (40%, n = 21/53). Primary predation (13%; n = 7/53) was recorded only in twin-bearing paddocks but occurred across all treatments (1 for lucerne; 3 for oats; 3 for lucerne to oats). The remaining deaths were due to exposure (n = 4), *in utero* (n = 1) or were undiagnosed (n = 6).

Plasma metabolic and mineral analyses

The mean concentrations of metabolic and mineral variables are shown in Table 3. The mean plasma concentrations of beta hydroxybutyrate were similar among forage treatments and no other significant interactions occurred. The concentrations were lower in single- than in twin-bearing ewes (0.352 ± 0.0190 mmol/L vs 0.414 ± 0.0188 mmol/L; P = 0.010), associated with a low concentration in singles at allocation. Pre-lambing, the concentrations in single and twin-bearing ewes were similar. Mean plasma glucose concentrations were similar among treatments and fetal

Table 2. Mean (±s.e.m.) performance of lambs produced by ewes and loss in condition score of ewes during the lambing period in the lucerne to oats, lucerne and oats treatments.

Variable	Fetal class	Treatment			*P*-value		
		Lucerne to oats	Lucerne	Oats	Fetus	Treatment	Fetus × treatment
Number of ewes (*n*)		211	212	212			
Lambs marked (*n*)		208	253	232			
Lamb birthweight (kg) (*n*)	Singles	5.6 ± 0.22 (33)	5.3 ± 0.23 (25)	5.6 ± 0.29 (25)	0.049	0.326	0.292
	Twins	4.5 ± 0.19 (63)	4.4 ± 0.19 (48)	4.3 ± 0.18 (56)			
	Total	5.0 ± 0.14	4.8 ± 0.15	4.9 ± 0.17			
Lamb weight at marking (kg) (*n*)	Singles	14.4 ± 0.61 (92)	15.7 ± 0.59 (104)	13.3 ± 0.60 (101)	0.066	<0.001	0.029[A]
	Twins	10.5 ± 0.59 (116)	13.2 ± 0.57 (149)	11.1 ± 0.57 (131)			
	Total	12.5 ± 0.42a	14.5 ± 0.41b	12.2 ± 0.41a			
Lamb survival (%)	Singles	86.8 ± 2.36	98.1 ± 2.36	95.3 ± 2.36	0.001	0.022	0.617
	Twins	55.2 ± 2.36	70.3 ± 2.36	61.8 ± 2.36			
	Total	71.0 ± 1.94a	84.2 ± 1.94b	78.5 ± 1.94ab			
Median lambs marked per ewe lambing (%)		98.2	117.0	105.7	–	0.343	–
Weight of lamb marked per ewe lambing (kg)	Singles	12.5 ± 1.06	15.4 ± 1.06	12.7 ± 1.06	0.354	0.020	0.248
	Twins	11.5 ± 1.06	18.6 ± 1.06	13.8 ± 1.06			
	Total	12.0 ± 0.74a	17.0 ± 0.74b	13.3 ± 0.74ab			
Loss in ewe condition score	Singles	−0.08 ± 0.080	−0.04 ± 0.078	−0.07 ± 0.084	0.016	<0.001	0.114
	Twins	−0.55 ± 0.077	−0.28 ± 0.082	−0.35 ± 0.078			
	Total	−0.31 ± 0.070a	−0.12 ± 0.071b	−0.21 ± 0.073ab			

Values within a row with different letters differ significantly at $P = 0.05$.
[A]Using a Bonferroni correction, individual means were similar at $P = 0.05$.

Table 3. Mean (±s.e.m) plasma beta hydroxybutyrate, mineral and glucose concentrations at allocation and pre-lambing for ewes in the lucerne to oats, lucerne and oats treatments.

Variable	Time	Treatment			*P*-values			
		Lucerne to oats	Lucerne	Oats	Time	Fetus	Treatment	Time × treatment
Ca (mmol/L)	Allocation	2.41 ± 0.033	2.42 ± 0.033	2.41 ± 0.033	0.070	0.212	0.169	0.116
	Pre-lambing	2.33 ± 0.033	2.45 ± 0.033	2.33 ± 0.033				
K (mmol/L)	Allocation	4.74 ± 0.141	4.42 ± 0.141	4.62 ± 0.141	0.284	0.555	0.015	0.054
	Pre-lambing	4.73 ± 0.141	4.56 ± 0.141	4.18 ± 0.141				
Mg (mmol/L) (median)	Allocation	0.96	1.03	0.97	–	0.058	>0.050	–
	Pre-lambing	1.04b	0.93a	1.05b	–	0.714	≤0.005	–
Na (mmol/L)	Allocation	144.2 ± 0.48a	144.4 ± 0.48ab	144.9 ± 0.48ab	<0.001	0.661	0.003	0.003
	Pre-lambing	146.0 ± 0.48b	148.0 ± 0.48c	149.4 ± 0.48c				
Phosphate (mmol/L)	Allocation	1.24 ± 0.067ab	1.36 ± 0.067ab	1.15 ± 0.067a	0.022	0.190	0.011	0.008
	Pre-lambing	1.14 ± 0.067a	1.48 ± 0.067b	1.49 ± 0.067b				
Beta hydroxybutyrate (mmol/L)	Allocation	0.347 ± 0.028	0.372 ± 0.028	0.378 ± 0.028	0.154	0.010	0.444	0.065
	Pre-lambing	0.451 ± 0.028	0.402 ± 0.028	0.352 ± 0.028				
Glucose (mmol/L)	Allocation	3.11 ± 0.244	3.23 ± 0.250	3.38 ± 0.244	0.003	0.193	0.653	0.633
	Pre-lambing	3.65 ± 0.244	3.75 ± 0.250	3.89 ± 0.244				

Values within a row with different letters differ significantly at $P = 0.05$.
For lucerne to oats treatment, pre-lambing blood samples were collected when the lucerne to oats treatment ewes were still grazing lucerne pastures.

class with no interactions, but were higher ($P < 0.003$) pre-lambing (3.76 ± 0.164 mmol/L) than at allocation (3.24 ± 0.164 mmol/L).

Mean plasma concentrations of Ca showed no interactions and were similar among forage treatments, between single- or twin-bearing ewes and were maintained between allocation and pre-lambing. None of the sampled ewes was subclinically deficient in Ca (<2.0 mmol/L) (Suttle 2010). Median plasma concentrations of Mg were similar among treatments at allocation, although there was a trend ($P = 0.056$) for the values in the lucerne treatment to be higher than in the lucerne to oats treatment. Ewes carrying single fetuses also tended ($P = 0.058$) to have lower median Mg concentrations (0.97 mmol/L) than did those carrying twin fetuses (1.04 mmol/L). Pre-lambing, the mean Mg concentration of ewes in the lucerne treatment was lower ($P \leq 0.005$) than that in the lucerne to oats treatment (in which ewes were at that time also grazing lucerne) or oats treatment, but did not differ between ewes carrying single (1.02 mmol/L) or twin (1.03 mmol/L) fetuses. None of the sampled ewes was subclinically deficient in Mg (<0.74 mmol/L) (McCoy *et al.* 2001).

Mean plasma potassium (K) concentration for ewes in the oats treatment was lower ($P = 0.015$) than that for ewes in the lucerne to oats treatment. This was associated with a trend for concentrations to decline during late pregnancy in the oats treatment, but not in the other treatments, in both of which ewes were grazing lucerne pre-lambing. Concentrations of phosphate were similar among forage treatments at allocation but there was a significant ($P < 0.008$) interaction with time where concentrations were lower in the lucerne to oats treatment than other treatments pre-lambing, despite these ewes grazing lucerne pasture at this time of sampling. Sodium concentrations showed a significant ($P = 0.003$) interaction between forage treatment and time. These concentrations were similar among treatments at allocation, but had increased at pre-lambing at which time plasma in lucerne to oats treatment ewes contained a lower concentration of sodium than those in lucerne or oats treatments.

Discussion

To our knowledge, this is the first study to compare the perinatal survival of lambs when ewes graze cereal forage for different durations with that when ewes graze a legume-based pasture. Lamb survival was not reduced by extending grazing of oat forage through the lambing period in addition to during late pregnancy nor in comparison with a legume pasture throughout. These results directly contrast anecdotal perceptions that grazing of cereal forage through late pregnancy increases the rate of dystocia and reduces perinatal ewe and lamb survival (Holst and Killeen 1976; Masters *et al.* 2018*a*).

However, the survival of lambs was reduced by 13.2% when ewes grazed oats only during the lambing period relative to continuing to graze legume-based pasture. This contrasts earlier reports (Glover *et al.* 2008; Paganoni *et al.* 2008) where survival was similar, or where twin-lamb survival was increased (Oldham *et al.* 2008). In our study, the reduction in lamb survival for lucerne to oats treatment was associated with a larger loss in condition score over the lambing period, largely associated with twin-bearing ewes. The loss of condition occurred despite a higher quantity of live herbage being available in oat than lucerne paddocks, and may have been due to a lower nutritive value of the oat herbage as growth changed from vegetative to reproductive (Kilcher and Troelsen 1973), with stem elongation in August. Lower nutritional intake pre-lambing has been associated with a delay in colostrum secretion and the quantity produced (McCance and Alexander 1959), potentially reducing lamb survival. Nutritional changes a week prior to parturition can alter colostrum production (Mellor *et al.* 1987; Banchero *et al.* 2015). Hence, there was sufficient time for this mechanism to occur in our study, although colostrum production would have little impact on lamb survival if the nutritional restriction and loss of condition occurred after the majority of ewes had lambed. The trend for lower marking weights of lambs from ewes grazing oats and the loss of condition score of twin-bearing ewes, particularly in lucerne to oats, supports the possibility that lower nutritional intake may have contributed to the lower survival of lambs, despite the large quantity of herbage available.

However, if grazing forage oats during the lambing period restricted nutritional intake sufficiently to reduce lamb survival, it remains unclear why the survival of lambs was not also reduced by grazing oats throughout late pregnancy and lambing. The condition score of ewes pre-lambing and birthweights of lambs were similar in all treatments, indicating comparable nutritional intake during the medium term to late pregnancy. This was supported by similar glucose and beta hydroxybutyrate concentrations pre-lambing, suggesting that the ewes had adequate energy status as indicated by normal glucose and lower BHB concentrations. Beta hydroxybutyrate is a good indicator of fat mobilisation and this was well below the reference level for clinical or subclinical ketosis (normal <0.63 mmol/L; Radostits *et al.* 2007) in all treatments measured pre-lambing. The subsequent change from legume-based to oat forage may have caused behavioural changes that reduced forage intake (Villalba *et al.* 2015; Neave *et al.* 2018). The change may also have temporarily reduced digestive efficiency, because ruminal fermentation and the ruminal biome can also be altered by large changes in forage quality (Xie *et al.* 2018). It is possible that the recorded reduction in survival of lucerne to oats lambs relative to lucerne lambs was due to a greater loss in condition or among-paddock variability rather than the change in the type of forage, but the trend for lower survival across all replicates and fetal classes warrants further studies to confirm the result.

The larger size of lambing paddocks for ewes grazing lucerne than for those grazing oats is unlikely to have increased lamb survival. An impact of stocking rate is unclear for stocking rates of 1.7–10 ewes/ha (Kleemann *et al.* 2006; Lockwood *et al.* 2020). The small mob size used in this study would reduce any potential impact of stocking rate because there were expected to be fewer than 4.3 ewes lambing per day in a mob. This is the level at which minimal pedigree recording errors reportedly occur (Alexander *et al.* 1983), representing minimal among-ewe interference around parturition with a consequential low potential mortality owing to mismothering. A clear mechanism for the reduction in survival of lucerne to oats lambs was therefore not identified.

Forage oats have the potential to increase lamb survival by providing a more sheltered environment owing to their erect growth habit than do some pastures. However, previous reports when lambing occurred during mild weather have either shown no benefit (Glover *et al.* 2008; Paganoni *et al.* 2008) or only a benefit for twins (Oldham *et al.* 2008). Our study was not designed to provide different levels of shelter; however, both the lucerne and oat pastures in most paddocks would have provided some shelter (not measured but estimated as ≥25 cm) during the peak lambing period. The paddocks used contained either no trees or alternate shelter, a single tree or row of trees or undulating landscape, none of which would be expected to provide substantial shelter, nor which appeared to be used by the ewes. In our study, the height of pastures would have been the main source of shelter. Interestingly, the highest levels of lamb survival occurred in the lucerne paddocks with the least herbage (<1000 kg DM/ha) and height at the start of the lambing period, suggesting that the pasture height providing shelter was not the key factor influencing survival in our study. Differences in the proportion of lambs dying from exposure or other causes could not be established in our study because of the low number of post-mortem examinations.

The target intake of mineral supplement was achieved in all but one paddock, with ewes frequently observed to consume the supplement immediately when offered. This behaviour differed from previously observed refusals of supplement (Robertson *et al.* 2022), and indicated that the lime/causmag/salt form of supplement can be highly palatable even when abundant live forage is available. None of the sampled ewes was found to be subclinically deficient in Ca, Mg or phosphate pre-lambing, making it unlikely that subclinical deficiencies contributed to the lower survival for lambs grazed on oats only during the lambing period. Subclinical deficiencies of Ca are commonly detected in the plasma of ewes grazing legume-based pastures in southern Australia (Hocking Edwards *et al.* 2018), despite plasma concentrations being under hormonal control and resistant to fluctuation (for review, see Friend *et al.* 2020). The property owner reported clinical deficiencies of Ca and Mg occurring historically in non-supplemented ewes, indicating a risk in the present study if ewes had not been supplemented. Soils with high K concentrations have been correlated with risk of Ca and Mg deficiency in plasma (Masters *et al.* 2018*a*), inferring long-term risk on a property as a result of soil type. The small differences in Mg, K, Na and phosphate that occurred pre-lambing between ewes in lucerne and those in lucerne to oats treatments may represent differences among paddocks, or variation in mineral-supplement intake pre-sampling, because ewes in both treatments were grazing lucerne-based pastures at the time of sampling.

The rate of ewe mortality (0.47%) was well below the mean of 2–2.5% reported for periparturient mortality in a survey of 40 non-Merino flocks across southern Australia (McQuillan *et al.* 2021). Additionally, the rate of ewes requiring assistance at or immediately after parturition (1.3%) was relatively low. A similarly closely monitored Australian study with 24,652 Merino or crossbred lamb records reported that 7.3% of lambs were assisted for delivery, with an average of 4.9% of ewes assisted to deliver at the first lambing (Horton *et al.* 2018). Much higher rates of intervention (30.1%) have been reported in Britain for Suffolk and Scottish Blackface ewes (Dwyer and Lawrence 2005). The levels of ewe mortality and assistance in our study do not indicate a high nor elevated risk of dystocia as a result of grazing of cereal forage.

The effects of pasture type and grazing duration of oats on lamb survival reported here may not occur in all situations because the relative quantities of herbage available in different species may differ. Grazing cereals may have higher live biomass in some months, and may also promote weight gain at a lower availability than do alternate pastures (see review by Masters and Thompson 2016). The mean lamb birthweight was similar among treatments in our study; however, if the relative nutrient intake on cereals were higher than that on alternative pasture, a longer period of above-maintenance intake during late pregnancy would be expected to result in high birthweights and overfat ewes. Such increases in the proportion of lambs with birthweights above the breed average are expected to reduce survival of ewes and lambs at parturition (Hatcher *et al.* 2009). Gains of 0.5 condition score during late pregnancy have previously been reported as reducing lamb survival (Behrendt *et al.* 2019), although in our study this level of gain occurred in all treatments seemingly without a high level of dystocia. Lamb survival need not be reduced if nutrition is restricted to allow maintenance of condition rather than gain during late pregnancy (Kenyon *et al.* 2012). Monitoring of gain in condition during late pregnancy is recommended regardless of pasture type, to reduce the risk of over- or under-nutrition.

Conclusions

Grazing ewes on oat forage rather than on a legume-based pasture throughout late pregnancy and lactation did not result in a reduced perinatal lamb survival or increased birthweights. Lamb survival was reduced relative to grazing legume pasture by grazing of oat forage only during the lambing period. The reason for the reduced survival is unclear and requires further evaluation, but the abrupt change in forage type was associated with a greater loss of condition in ewes. The study indicated that ewes may be grazed on cereal forage continuously during late pregnancy and lambing without reducing lamb survival when a Ca, Mg and salt supplement is offered, although taking care to avoid excess gains in ewe condition is recommended.

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Data availability. The data that support this study will be shared upon reasonable request to the corresponding author.

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Author affiliations

[A]Gulbali Institute, Charles Sturt University, Locked Bag 588, Wagga Wagga, NSW 2678, Australia.

[B]School of Agricultural, Environmental and Veterinary Sciences, Charles Sturt University, Locked Bag 588, Wagga Wagga, NSW 2678, Australia.

[C]Office of the Pro Vice-Chancellor (Research and Innovation) Charles Sturt University, Locked Bag 588, Wagga Wagga, NSW 2678, Australia.

[D]Fred Morley Centre, Charles Sturt University, Locked Bag 588, Wagga Wagga, NSW 2678, Australia.