The effects of parasitism on ewes for prime lamb production in western Victoria

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Abstract

Context. Internal parasites are estimated to cost the Australian sheep industry AUD436 million per annum (p.a.).

Aims. To assess the effects of parasitism in flocks producing prime lambs in the 500–700 mm p.a rainfall. area of Victoria.

Methods. Ewes on two farms that followed 'best practice' gastrointestinal parasite control programs (BP) and two farms that did not (regionally typical, TYP) were compared. Separate cohorts of ewes were monitored from pregnancy scanning to their subsequent joining each year for three consecutive seasons. Observations included worm egg count (WEC), bodyweight, condition score and presence of breech soiling (dag). These were compared between groups that were treated to suppress parasitism (SUP) and those treated according to the usual program used on that farm (NSUP). Data from individual ewes were analysed using a multivariable, mixed-effects regression model.

Key results. After adjusting for known confounders, SUP ewes were 1.2 (95% CI 0.80–1.6) kg heavier than NSUP ewes. Mature SUP ewes were significantly heavier than NSUP ewes at their next joining on 6 of 18 occasions, mostly following winters when ewes experienced nutritional stress. Ewe hoggets and Merino ewes were generally more susceptible to parasitism than mature non-Merino ewes; single-bearing ewes were less susceptible than those bearing twins. The effects of parasitism were reduced when peri-parturient ewes had an optimal condition score and grazed adequate pastures.

Conclusions. Ewes were more vulnerable to parasitism when immature, twin-bearing, or under nutritional stress. Some of the greatest differences between SUP and NSUP ewes occurred following periods of low feed availability and/or ewe condition score. The difference between the mean bodyweight of SUP and NSUP Merinos was not always greater than that of the non-Merinos. WECs are not a sole reliable indicator of the effects of parasitism in this class of sheep.

Implications. Immature or twin-bearing ewes, and those in suboptimal body condition, should be managed considering their increased vulnerability to parasitism, and WEC interpreted alongside other factors. Controlled release capsules were not cost effective in reducing production loss from gastrointestinal nematodes in most years but may be effective in reducing the effects of clinical parasitism in some cases.

Introduction

Prime lamb production has increased in Australia in recent years; the gross value of lamb production was AUD4 billion in 2017–2018 (ABARES 2019), having risen from AUD 0.5 billion in 1988 (CPI adjusted figure AUD1.1 billion) (ABS 2013). In contrast, over the same period, the value from wool production declined from AUD6 billion to AUD2.5 billion

in 2010 (Rowe 2010) but increased to AUD4.5 billion in 2018–2019 (ABARES 2019).

The southern part of western Victoria has a pasture growing season of 7–8 months, with an annual rainfall of 500–700 mm, most of which occurs in winter. This provides ideal conditions for prime lamb production. Indeed, some 44%, or 207 100 tonnes of Australian prime lamb were produced

in Victoria in 2012–2013 (Anon 2014*b*). To maximise the use of improved pasture species, the time of lambing for prime lamb flocks should be 6 months before pasture senescence if lambs are to be sold direct to abattoirs, or 5 months if lambs are to be sold as stores for further growth (Warn *et al.* 2006). Consequently, lambing in western Victoria typically occurs from June to August, which coincides with the peak availability on pastures of the infective stage of nematode parasites (Anderson 1972; Niven *et al.* 2002). The effects of parasitism acquired during winter and early spring on wool producing sheep have been reported; Anderson (1972) identified a 7% decrease in bodyweight of Merino ewes not receiving any anthelmintic treatment, compared with those treated fortnightly. Morris *et al.* (1977) found a significant difference between bodyweights of Merino ewes that were not treated with anthelmintic compared with those receiving fortnightly treatments (Anderson 1972; Morris *et al.* 1977). In total, internal parasites have been estimated to cost the Australian sheep industry AUD436 million per annum (Lane *et al.* 2015) and the total annual cost of gastrointestinal parasitism in Australian prime lamb flocks has been estimated to be over AUD90 000 (Sackett *et al.* 2006).

With this background, the aim of this study was to assess the effects of parasitism in flocks producing prime lambs in the 500–700 mm annual rainfall area of Victoria, by comparing production from ewes and lambs either treated according to the farm's usual practice for controlling nematode parasites or given successive long acting treatments of anthelmintic to suppress parasitism during the period of prime lamb production. Results obtained from measurements on the ewes are reported in this paper; those from lambs will be reported subsequently. This study was part of a project conducted in four regions as part of Meat & Livestock Australia Project B.AHE.0045. Other sites were the Northern Tablelands (Dever *et al.* 2017); Central Tablelands, and South-West Slopes of New South Wales.

Materials and methods

Study design

The effects of nematode parasitism in prime lamb flocks were assessed on each of four farms in south-western Victoria over three consecutive seasons (2012–2013, 2013–2014, 2014–2015). The source population comprised ewes on extensively managed sheep farms operational in south-western Victoria in January 2012. The experimental design was longitudinal, similar to that described by Dever *et al.* (2017), namely a $2 \times 2 \times 2$ factorial design (Fig. 1) where ewes from two mobs on each farm, on which one of two different types of gastrointestinal nematode control program was practiced, were assigned to one of two treatment groups.

Of the more than 30 flock managers that were contacted to take part in the study, four were chosen to participate. Two farms in each of two distinct areas of western Victoria (Mortlake and Winchelsea) were selected. One farm in each of the two areas was chosen because a 'best practice' (BP) program was used to control gastrointestinal nematodes. This program included: (1) one or two strategic anthelmintic treatments given in summer, with additional treatments based on season and worm egg counts (WEC); (2) regular use of WECs for decisions on treatment; (3) knowledge of resistance to anthelmintics in the nematode population, via worm egg count reduction test (WECRTs); and (4) the use of rams with Australian Sheep Breeding Values for WEC (Anon 2014*a*).

The second farm in each of the two areas was selected because a 'regionally typical' gastrointestinal nematode control program (TYP) was followed, including: (1) variable timing of strategic and tactical anthelmintic treatments; (2) irregular or no use of WECs to guide decision making for anthelmintic treatment; and (3) an absence of recent testing to detect anthelmintic resistance.

Two separate mobs of ewes on each of the four participant study farms were included in the study. Within each mob, ewes
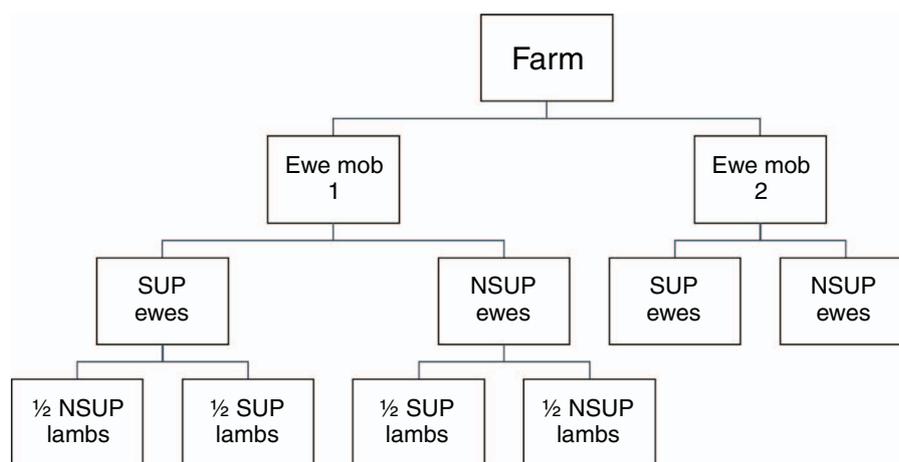

Fig. 1. Selection of groups and treatments given to ewes and lambs on each farm. Lambs of ewes in mob 2 were identified to ewe group and weighed at marking but then not monitored further. SUP, animals treated to suppress parasitism; NSUP, animals treated according to farm's usual worm control program.

were randomly allocated to treatment group and either treated according to the usual worm control practice for the farm (NSUP) or treated with long-acting anthelmintics (SUP) to suppress nematode infections (Fig. 1). Details of each of the four study farms are provided in Table 1. This study was conducted following approval from the University of Melbourne animal ethics committee (1212407).

Farms

Phalaris aquatica and/or perennial ryegrass (*Lolium perenne*) and subterranean clover (*Trifolium subterraneum*) were the dominant pasture species on all farms. Cocksfoot (*Dactylis glomerata*) and lucerne (*Medicago sativa*) were also grazed on Farm 2. Grazing crops of plantain (*Plantago lanceolate*) and rape (*Brassica napus*) were sown on Farms 2 and 3, and millet (*Panicum miliaceum*) and rape (*B. napus*) on Farm 4, which also had extensive amounts of onion grass (*Romulae rosea*) on stony rises, indicative of lower soil fertility.

Farms 1 and 2 were enrolled into the study in October 2011. At the time of enrolment into the study, a WECRT was conducted on weaned lambs and samples for WECs were collected from ewes over that summer. Farms 3 and 4 were enrolled into the study in October 2012, but a WECRT was not conducted at this time and only two collections for WEC were made during the summer of 2012–2013. Only 1 year of data (in Year 2) was able to be collected on Farm 3.

Ewes and treatments

Ultrasound scanning was used to select pregnant ewes with single and multiple fetuses at around 60 to 80 days of gestation. Where possible, maiden ewes, ewes pregnant with twins, or ewes that had conceived early in the mating period were chosen for the study. Within a week of scanning, ewes were

identified using radio frequency identification ear tags and alternately allocated to NSUP and SUP treatment groups until there were at least 60 ewes in each group. Ewes for each year of the study were reselected randomly based on their ultrasound results.

At the time of allocation to treatment group, ewes in the SUP groups were given their first controlled release capsule (CRC) containing either albendazole and abamectin (Dynamax or ivermectin (Ivomec Maximiser (Merial Australia Pty, Ltd, Macquarie Park, NSW, Australia). A treatment of monepantel (Zolvix, Novartis Animal Health Australasia, North Ryde, NSW, Australia) was also given to remove nematodes resistant to the drugs in the capsules. These treatments were repeated twice after intervals of 80–100 days to maintain the suppressive effect on nematode numbers. The capsules also contained selenium and cobalt so ewes in the NSUP groups were treated with selenium and cobalt pellets that lasted for the duration of the study (Permatrace Pellets for Sheep, Coopers Animal Health, North Ryde, NSW, Australia).

Schedule of visits and measurements

Several visits were made to each farm each year. These coincided with management procedures that involved mustering and yarding of ewes, the timing and exact number of which varied between farms. The measurements, treatments and samples collected at these times are in Table 2. All measurements were collected by one of the first two authors.

Measures of parasitism

Faecal soiling on the breech of ewes (dag) was assessed at the time of each farm visit using a scale of 0–5; 0 for no soiling and 5 for soiling down the caudal and plantar surface of the hind legs (Larsen *et al*. 1994).

Table 1.   The location, type of farm, area, annual rainfall, breed and number of ewes, stocking rate and worm control program of the farms selected for the study

BP, farm following best practice gastrointestinal nematode control program; TYP, farm does not follow best practice gastrointestinal nematode control program; WEC, worm egg count; s.t., anthelmintic treatment in summer

Farm type and location	Area (ha)	Rainfall (mm)	Breed (number of ewes)	Stocking rate (DSE/ha)	Worm control program
Farm 1 (BP) Mortlake	1400	580	Coopworth (2000) Merino (2800)	16	s.t., December[A] s.t., February[B] Ewes pre lamb, July[C] Regular use of WECs
Farm 2 (BP) Winchelsea	150	620	Composite (800)	11	s.t., December[A] s.t., February[B] Regular use of WECs
Farm 3 (TYP) Mortlake	1720	580	Composite (7000)	13	s.t., January Ewes pre-lamb, June Hoggets, August Some use of WECs
Farm 4 (TYP) Birregurra	830	630	Border Leicester × Merino (BLM) (1200) Merino (1000)	12.5	s.t., January Ewes pre lamb, June Ewes marking. August No use of WECs

[A]Strategic treatment.
[B]Optional strategic treatment depending on WECs.
[C]Optional tactical treatment depending on WECs.

Table 2. The approximate timing of scheduled visits, measurements, treatments and samples collected from groups of ewes selected on each farm each year[A]

SUP, animals treated to suppress parasitism; NSUP, animals treated according to farm's usual worm control program; CRC, controlled release capsule; BWt, bodyweight; CS, condition score; DS, dag score; PDM, pasture dry matter (kg/ha); WEC, worm egg count; GFW, greasy fleece weight

Visit	Description and timing	Measurements	Treatments	Samples
Scanning	About 45 days after rams removed (April–June)	Ultrasound examination, tags applied, groups selected BWt, CS, DS, PDM	CRC+ Monepantel to SUP ewes Se/Co pellet to NSUP ewes	WEC
Pre-lamb	2–4 weeks before the start of lambing (June–August)	BWt, CS, DS, PDM	–	WEC
Lamb marking	4–8 weeks after the start of lambing (August–October)	BWt, CS, DS, count no. of lambs, PDM	CRC+ Monepantel to SUP ewes	WEC
Weaning	13–20 weeks after the start of lambing (September–December)	BWt, CS, DS, PDM	CRC+ Monepantel to SUP ewes	WEC
Sale of lambs	Varied between farms and seasons (November–December)	Nil	Nil	Nil
Pre-join	0–3 weeks before joining (January–March)	BWt, CS, DS, PDM	Nil	WEC
Shearing	According to farm schedule (December–January on Farms 1, 2 and 4; April on Farm 3)	GFW	Nil	Mid-side sample 33% of ewes in one mob[B]

[A]Timing varied slightly on some occasions; for example, only one year of data was collected on Farm 3; condition scores were not able to be obtained at pre-join on Farm 1 in Year 1 and for one mob in Year 2;
[B]To measure fibre diameter, yield, comfort factor and curvature.

Faecal samples were collected from the rectum of at least 20 ewes in each group at each visit. The same NSUP ewes were selected for individual WEC but samples from SUP ewes varied and a bulk count was made. A modification of the McMaster Slide method described by Anderson *et al*. (1991) was used for WEC, with each egg counted equivalent to 15 eggs per gram (epg) for individual counts or 10 epg for bulk counts.

WECRT was carried out at the start and end of the study on Farms 1 and 2, and at the end of the study on Farm 4, as described by Anderson *et al*. (1988). The anthelmintics tested were chosen after discussion with the flock managers, accounting for previous anthelmintic use and the results from any previous tests.

The genus of nematodes present was assessed from the proportion of eggs that contained specific DNA as measured by robotic melting point analysis of DNA extracted from eggs (Bott *et al*. 2009). The method used was that described by the manufacturer of the Sheep Parasites 8Plex kit (AusDiagnostics Pty Ltd).

Measures of production

The availability of pasture expressed as the number of kilograms of dry matter per hectare (kg DM/ha) was estimated at each visit using 20 pasture stick measurements or by visual assessment using the methods described in the 2009 Prograze Victoria Manual (Bishop *et al*. 1995).

The body condition of each ewe was assessed by palpation of the spinous and transverse processes and the allocation of a score on a scale of 1–5; 1 indicating emaciation (bones easily felt with little tissue covering) and 5 indicating fatness (bones not felt or only after applying firm pressure) (Anon 2011*a*). At the same visit ewes were weighed using commercially available load bars and monitors.

At shearing, the fleece of each sheep was weighed to the nearest 0.1 kg and, from a third of the ewes in one monitor group, a mid-side sample of 25–35 g was collected for measurements of yield, staple strength, mean fibre diameter, coefficient of variation and comfort factor (AWTA Ltd, Kensington, Vic., Australia).

Statistical analyses

A total of 1984 ewes were enrolled into the study with bodyweight, condition score, dag score and WEC assessed on five occasions.

During the collation and validation of data, observations for individual ewes were removed from the dataset for the following reasons: (1) NSUP and SUP ewes that were not found to be lactating at the lamb marking visit (this included those ewes absent at the marking visit), $n = 200$ observations; (2) NSUP and SUP ewes that were ill at any visit (e.g. ewes with mastitis or metritis at lamb marking, $n = 5$ observations); and (3) SUP ewes with a WEC of >100 epg at any visit as they were assumed to have regurgitated their capsule, $n = 18$ observations. A ewe was assumed to have died if she was not present for two consecutive visits.

Continuously distributed variables, such as bodyweight and wool production (greasy fleece weight, yield and fibre diameter), were described in terms of a measures of central tendency (mean, median) and variability (standard deviation, quantiles). The purpose of the descriptive analyses was to identify outliers and implausible records and to identify the distributional form of each of the continuous variables.

Categorical variables, such as condition score and dag score, were tabulated and described as frequencies. To test the hypothesis that worm suppression had a statistically

significant effect on ewe condition score or dag score, scores of NSUP and SUP ewes were compared at each visit using the Mann–Whitney U (Wilcoxon rank-sum) test. Data within the categorical variables were divided into two groups based on whether the result was associated with a negative outcome. For example, a dag score of 2 or more has been associated with an increased risk of flystrike (Greeff *et al.* 2014; Tyrell *et al.* 2014), so dag score data were categorised into Category A (dag score ≤1, low dag) and Category B (dag score ≥2, moderate dag). The percentage of NSUP or SUP ewes in each of the two categories (associated with a negative outcome or not associated with a negative outcome) was then compared at each visit. This allowed comparison of results between treatment groups, visits and mob–farm–year combinations.

This was a repeated-measures dataset in which bodyweight measurements were made on individual ewes over time. These data were not independent because individual bodyweight measurements were clustered within ewes and ewes were clustered within farms. To account for lack of independence and confounding in the data, a mixed model approach was used including a random effect term for individual ewes and a random effect term for ewes within farms. An autocorrelation structure of order 1 was included in the model to account for autocorrelation in individual ewe bodyweights at adjacent observation dates and a smoothed spline term for each property fitted to account for the non-linear association between bodyweight and observation day. The general form of our model was as follows:

$$y_{ijk} = \beta_0 + s(\beta_{1k}x_{1ijk}) + \beta_2 x_{2ijk} \ldots + \beta_m x_{mijk} + P_k + E_{jk} + \varepsilon_{ijk} \quad (1)$$

In Eqn 1, y_{ijk} represents the ith bodyweight measurement made on the jth ewe from the kth farm. The term β_0 is an intercept term (representing average bodyweight across all ewes from all farms), $s(\beta_{1k}x_{1ijk})$ represents the smoothed spline term for observation day for each farm and $\beta_2 x_{2ijk} \ldots + \beta_m x_{mijk}$ the regression coefficients and covariate values for the fixed effects, which included study year (a categorical variable with three levels: 2012, 2013 and 2014), farm type (a categorical variable with two levels: BP and TYP), treatment group (a categorical variable with two levels: SUP and NSUP), breed (a categorical variable with four levels: composite, Coopworth, first cross and Merino) and the number of fetuses observed via ultrasound (a categorical variable with two levels: single and multiple).

In Eqn 1, the term P_k is a normally distributed, zero mean random effect term with variance σ^2_P representing the influence of the kth farm on ewe bodyweight. Similarly, parameter E_{jk} is a normally distributed, zero mean random effect term with variance σ^2_E representing the influence of the jth ewe from the kth farm on ewe bodyweight. ε_{ijk} represents the model error term.

Frequency histograms of the residuals from the multilevel model and plots of the residuals versus predicted values were constructed to check that the assumptions of normality and homogeneity of variance had been met.

Post hoc comparisons were carried out to quantify the combined effect of property management (BP or TYP) and treatment group (NSUP or SUP) on ewe bodyweight.

Contrast analyses were carried out to compare the effect of SUP treatment on ewe bodyweight on BP and TYP farms.

Descriptive analyses were carried out using Stata ver. 13 (StataCorp, 2013, Stata Statistical Software Release 13, StataCorp LP, College Station, TX, USA). The mixed-effects models were developed using the contributed lme4 (Bates *et al.* 2014) and gamm4 (Wood and Sheipl 2014) packages implemented in R version 3.1.2 (R Core Team 2014).

Results

Rainfall and pasture growth

After a drier than average start on Farm 1, rainfall for the 2012 growing season (March–November) was similar to average on both Farms 1 and 2. Pasture availability on Farm 1 was low during the winter, with only 600 kg DM/ha available to adult ewes at lamb marking in late August. Pasture availability then increased to 1200 kg DM/ha in early October and 3200 kg DM/ha in late November. On Farm 2, which had a lower stocking rate, there was ample pasture, with at least 1500 kg DM/ha available to the single-bearing ewes, and 2200 kg DM/ha available to the twin-bearing ewes at lamb marking, and over 3000 kg DM/ha available to both mobs at weaning.

In the first quarter of Year 2 (2013), rainfall was below average for Farms 1 and 3, and Farm 2 received 50% below the average rainfall. Rainfall that enabled significant pasture growth was not received until late May. This was followed by up to 25% higher than average rainfall during winter and spring. On Farm 4, heavy rainfall, particularly between June and November, caused waterlogging of many low-lying areas of the farm.

This rainfall pattern was again reflected in pasture availability. On Farms 1, 3 and 4, pasture availability for the adult ewes was again below optimum during winter (less than 1000 kg DM/ha before lambing, and at lamb marking for twin-bearing ewes) but increased during the spring to 1200–1600 kg DM/ha at weaning on Farms 1 and 3, although it was still only 1000 kg DM/ha on Farm 4. On Farm 2, single and twin-bearing ewes had 1400–1600 kg DM/ha pasture available at marking and again more than 2000 kg DM/ha at weaning. The hoggets on Farm 3, which lambed later, had 2000 kg DM/ha available at marking in October, and 1500 kg DM/ha available at weaning in November.

In Year 3 (2014), rain initiated good pasture growth in April. Rainfall was then similar to the long-term average until the end of September on Farms 1 and 2, and 25% above average rainfall was received on Farm 4 during autumn and winter. Rainfall during the spring and early summer was between 50% and 70% of the average rainfall for those seasons, and improved perennial pastures senesced about a month earlier than is usual for the area. Consequently, more pasture was available to ewes on Farm 1 before lambing and at lamb marking than in previous years (close to 1000 kg DM/ha, and around 1500 kg DM/ha, respectively). Pasture availability before lambing and at marking was again abundant on Farm 2; on Farm 4, both the twin and mixed single- and twin-bearing mobs had ~1000 kg DM/ha available before lambing and at lamb marking; however, quality and

quantity of pasture had declined markedly on all farms by late spring.

Measures of parasitism

Dag scores

There was little breech soiling during the study, and the proportion of ewes with moderate or severe dag (score ≥2), remained low. For example, on Farm 1, mean scores of NSUP ewes ranged between 0 and 1.7 for all visits during the 3 years of the study and were similar in both Coopworth and Merino ewes that grazed the same pasture. Ewes were generally crutched before lambing, and again before shearing and/or

joining. The highest dag scores were generally recorded at weaning.

WECs

The arithmetic mean WEC from NSUP groups, at each visit on Farm 1 for the years 2012, 2013 and 2014 are in Fig. 2, together with the times when treatments of anthelmintic were given. Both the pattern and mean counts from the groups on other farms were similar. At ultrasound scanning and pre-lambing, mean counts were generally about, or less than, 200 epg except for 2 of the 20 groups monitored: Merino ewes before lambing in Year 2 (570 epg) and single-bearing
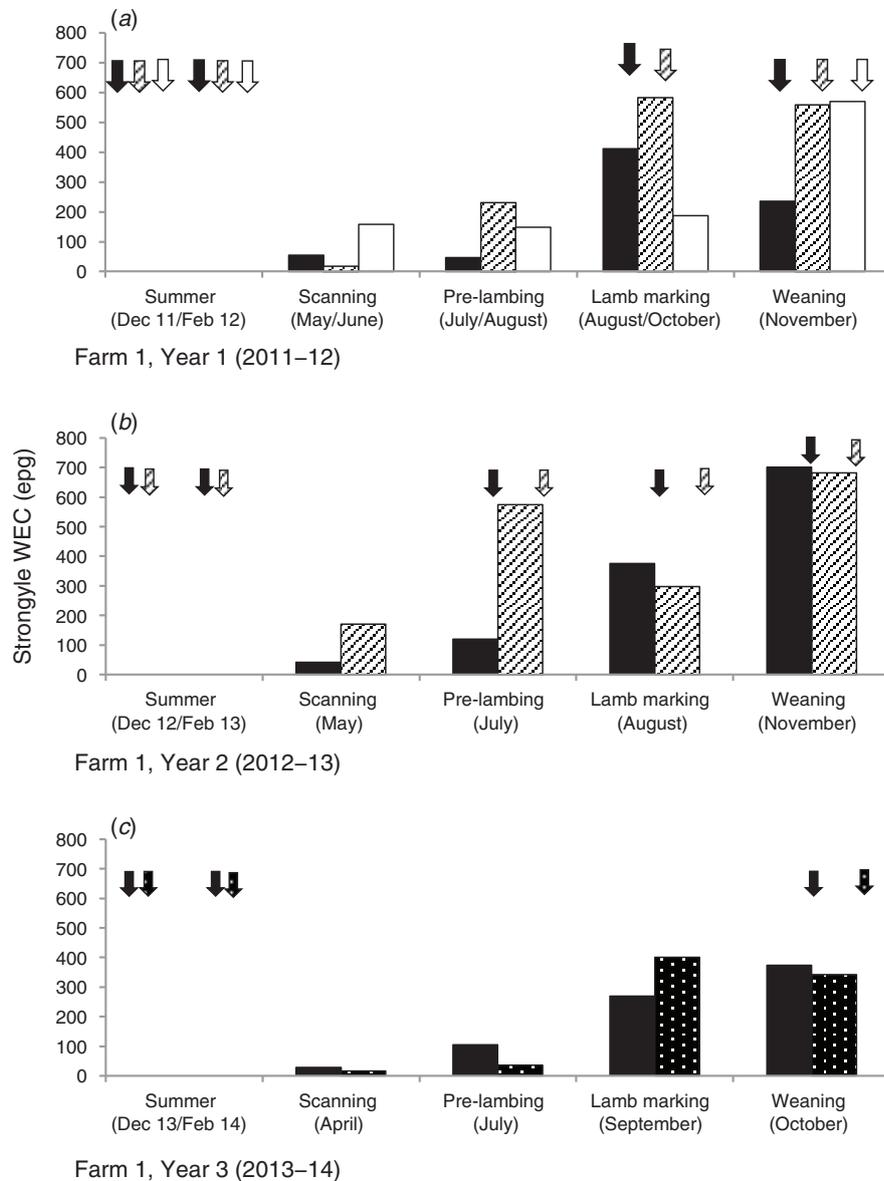

Fig. 2. Arithmetic mean worm egg counts from Coopworth ewes (solid bar, or dotted bar for mob 2 in Year 3), Merino ewes (striped bar) and Coopworth hoggets (clear bar) at each visit on Farm 1. (*a*) Year 1, (*b*) Year 2 and (*c*) Year 3. The timing of anthelmintic treatments to mobs is indicated by arrows of same pattern as the bar for each mob.

Composite ewes on Farm 2 at scanning in Year 2 (370 epg). Mean counts were generally 2–3 times higher at lamb marking and weaning than before lambing, indicating a post parturient rise in mean counts (Barger 1993). On most occasions, there was little difference between the mean counts from Coopworth, Composite or Merino ewes. Similarly, there were no consistent differences between counts from the single bearing or twin bearing ewes or between hogget and mature age Coopworth ewes.

Tactical treatments to adult Coopworth and Merino ewes on Farm 1 at lamb marking in Years 1 and 2, and pre-lambing in Year 2 were undertaken, because mean counts of 500 epg or more in the Coopworths, Merinos or both groups were associated with poor condition score of the ewes and low availability of pasture. All mobs on Farms 3 and 4 (TYP) were also treated at pre-lambing in Year 2 even though mean counts were only 0–75 epg.

Proportion of nematode genera

Teladorsagia, *Trichostrongylus* and the large bowel worms *Oesophagostomum* and *Chabertia* were predominant on Farms 1, 2 and 4 (the nematode genera on Farm 3 not having been tested). The proportion of each genus varied throughout the production year. *Haemonchus* spp. was present on Farms 2 and 4; this genus varied 2–25% of the eggs present on Farm 2, and was the predominant genus found in the twin-bearing ewes at marking (69%) and weaning (40%) on Farm 4.

Tests for resistance to anthelmintics

The results of the WECRT showed that resistance was present on all farms. Generally, there was resistance to benzimidazole, levamisole, and combinations of these two anthelmintics (except to the combination on Farm 2 in 2011). Resistance to ivermectin occurred in some tests, a 45% reduction on Farm 4, and a 92% reduction on Farm 2. Abamectin and moxidectin were effective (>95% reduction in WEC) on all farms.

On farms where two WECRTs were conducted, the proportion of resistant worms detected on each farm did not change substantially, with the exception of a combination of benzimidazole and levamisole on Farm 2. Here, the efficacy of the combination decreased from 87% (95% CI 70%–94%) in Year 1, to 75% (95% CI 49%–88%) in Year 3 (of these resistant eggs, 74% were *Trichostrongylus*, and the remainder were *Teladorsagia*).

Measures of production

Bodyweight

Descriptive statistics of bodyweights of ewes on Farm 1 are in Table 3. Adult Coopworth and Merino ewes and Coopworth ewe hoggets showed a similar pattern within each year. Twin-bearing ewes on Farm 2 had a similar pattern but less significant differences than ewes on Farm 1. By comparison, there were fewer significant differences between SUP and NSUP single-bearing ewes on Farm 2, and these ewes gained weight between pre-lambing and lamb marking. There were significant differences between the weights of SUP and NSUP ewes at marking, weaning and pre-joining in both mobs on Farm 3. On Farm 4, there was a significant difference between the treatment groups at only one visit in the five mob–farm–year comparisons.

When inspecting the data from each property visit, the difference between the mean weights of the two treatment groups ranged from 0 to 6.6 kg. There was a significant difference between the two treatment groups at 28 out of a total of 99 visits, and 8 of 20 occasions at pre-joining. The greatest differences occurred on Farm 1 (5.9 kg in adult Coopworths at pre-joining in 2012; see Table 3) and Farm 3 (6.6 kg in Composite ewe hoggets at pre-joining in 2013). One significant difference was observed on Farm 4 (adult first-cross ewes at weaning in 2013).

Table 3. Mean (s.d.) bodyweight of ewes subjected to the usual worm control program (NSUP) and the difference in mean bodyweight of worm suppressed ewes (SUP) on Farm 1 in Years 1 (2012), 2 (2013) and 3 (2014)

SUP, animals treated to suppress parasitism; NSUP, animals treated according to farm's usual worm control program. *, $P < 0.05$; **, $P < 0.01$; ***, $P < 0.001$

Year	Ewe mob	Group	Bodyweight (kg) at Scanning	Pre-lamb	Marking	Weaning	Pre-join
1	Adult Coopworth	NSUP	67.3 (3.8)	78.5 (4.4)	61.6 (5.5)	74.8 (6.5)	60.5 (5.0)
		SUP	+0.5	+1.6	+3.9***	+4.7**	+5.9***
	Adult Merino	NSUP	54.9 (5.3)	63.6 (5.8)	53.9 (4.8)	61.6 (4.6)	50.4 (4.7)
		SUP	+0.7	+1.9	+4.3***	+4.7**	+3.6**
	Coopworth hogget	NSUP	46.8 (1.6)	61.8 (3.8)	60.5 (4.4)	61.1 (5.5)	46.6 (3.9)
		SUP	−0.2	−0.2	+2.2*	+3.9**	+2.5*
2	Adult Coopworth (twin lambs)	NSUP	56.9 (5.9)	69.0 (5.8)	58.2 (5.7)	73.6 (7.6)	66.5 (6.3)
		SUP	+0.5	+2.6*	+1.2	+2.1	+2.2
	Adult Merino (single and twin lambs)	NSUP	50.0 (4.1)	58.5 (4.7)	49.9 (4.0)	62.0 (5.7)	50.1 (4.5)
		SUP	−0.1	+1.5	+0.9	+1.3	+1.3
3	Coopworth Mob 1	NSUP	66.3 (6.4)	87.9 (7.4)	70.7 (6.7)	74.7 (7.2)	63.6 (6.2)
		SUP	−2.7*	−2.5	+1.1	+0.6	+0.3
	Coopworth Mob 2	NSUP	63.9 (6.7)	81 (8.4)	72.5 (8.6)	75.3 (8.3)	63.5 (7.3)
		SUP	−1.3	+0.1	+2.4	+4.1*	+1.7

Table 4. Estimated regression coefficients and s.e. from a mixed-effects linear regression model of factors influencing ewe bodyweight

TYP, farms following regionally typical gastrointestinal parasite control programs; BP, farm following best practice gastrointestinal parasite control programs; SUP, animals treated to suppress parasitism; NSUP, animals treated according to farm's usual worm control program

Variable	Coefficient (s.e.)	Confidence interval 95%	*t*-statistic	*P*-value
Intercept	61.58 (2.082)	57.5–65.7	29.6	<0.01
Year:				
2012	Reference	–	–	–
2013	–4.32 (0.262)	–4.8 to –3.8	–16.5	<0.01
2014	3.40 (0.288)	2.8–4.0	11.8	<0.01
Management type:				
TYP	Reference	–	–	–
BP	5.67 (2.390)[A]	1.0–10.4[A]	2.4	0.02
Treatment:				
NSUP	Reference	–	–	–
SUP	1.19 (0.201)	0.80–1.6	5.9	<0.01
Litter:				
Multiple-bearing	Reference	–	–	–
Single-bearing	–1.16 (0.266)	–1.7 to –0.64	–4.4	<0.01
Breed:				
Composite	Reference	–	–	–
Coopworth	1.94 (2.406)	–2.8–6.7	0.8	0.42
Merino	–8.85 (2.392)	–13.5 to –4.2	–3.7	<0.01
First-cross	1.39 (2.418)	–3.4 to 6.1	0.6	0.57
			F-statistic	*P*-value
Spline terms:				
Visit day Farm 1	–	–	1228.7	<0.01
Visit day Farm 2	–	–	306.0	<0.01
Visit day Farm 3	–	–	153.6	<0.01
Visit day Farm 4	–	–	364.5	<0.01
Random effects:	Variance			
Farm	5.40			
Ewe	31.64			
Residual	33.80			

[A]Interpretation: after controlling for the effect of study year, litter size, breed, visit day and lack of independence in the data arising from farm and individual ewe-level effects, ewes from BP farms were, on average, 5.7 (95% CI 1.0–10) kg heavier than ewes from TYP farms.

Our mixed-effects model identified statistically significant variation in bodyweight according to study year, farm management type, treatment group, the number of lambs born per ewe, and breed (Table 4). After adjusting for known confounders SUP ewes were 1.2 (95% CI 0.80–1.6) kg heavier than their NSUP flock mates. In contrast, ewes from BP farms were 5.7 (95% CI 1.0–10) kg heavier than ewes from TYP farms. Unmeasured farm-level factors accounted for 5.40 ÷ (5.40 + 31.64 + 33.80) = 8% of the unexplained variation in ewe bodyweight (Table 4). Unmeasured ewe-level factors accounted for 31.64 ÷ (5.40 + 31.64 + 33.80) = 45% of the unexplained variation in ewe bodyweight (Table 4).

Condition score

Generally, the condition scores reflected the bodyweights. Of greater interest was the proportion of ewes with a condition score of 2.5 or less at each visit. As an example, these proportions are in Fig. 3 for Farm 1 over the consecutive 3 years of the study, together with the mean condition score for each visit.

The most common pattern on all farms was similar to that in Fig. 3*a* (2012 on Farm 1), when ewes lost condition between scanning and lamb marking, with the highest proportion of NSUP ewes in condition score 2.5 or less occurring at marking. Body condition increased after marking. In most cases, there was no difference in the mean scores of NSUP and SUP ewes, or the proportion with scores of 2.5 or less.

When Merino ewes were included in the comparisons, they generally had similar condition scores at lamb marking to those of Coopworth or Composite ewes. On Farm 1 in Year 1, Merinos had a mean score of 2.0, with 97% of ewes in condition score ≤2.5, and Coopworths had a mean score of 1.9, with over 94% of ewes in condition score ≤2.5. On the same farm in Year 2, Merino ewes had a mean score of 2.1, with 98% of ewes in condition score ≤2.5, and Coopworths had a mean score of 2.2, with 93% of ewes in condition score ≤2.5 in Year 2 on Farm 1. On Farm 4 in Year 2, the mean score in both the Merinos and the first-cross ewes was 1.8, with 98%
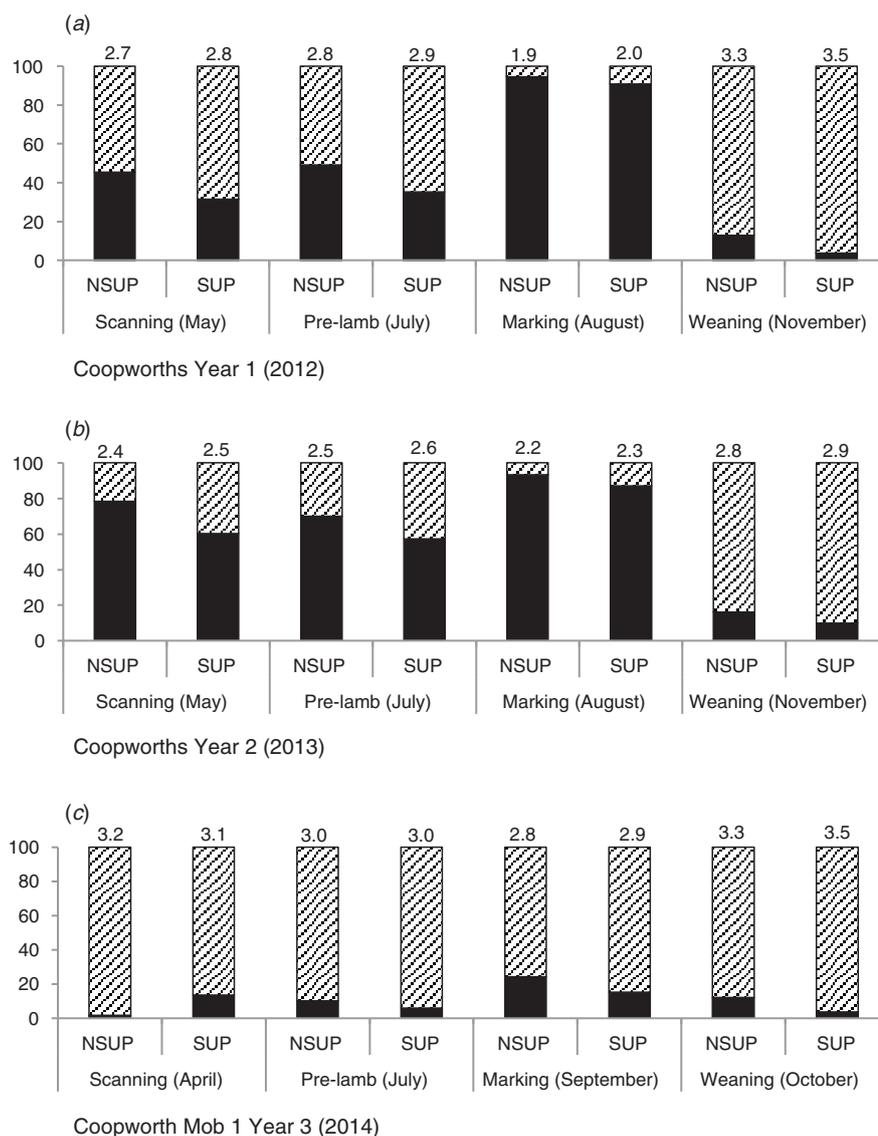
Fig. 3.   The percentage of Coopworth ewes at each visit on Farm 1 in with a condition score ≤2.5 (solid bar) and a condition score of ≥2.75 (striped bar) in (*a*) Year 1, (*b*) Year 2 and (*c*) Year 3. Mean condition scores are shown above each bar.

of Merinos, and 100% of first-cross ewes in condition score ≤2.5.

Wool production

Of the 16 mob–farm–year comparisons, there were only two occasions when there was a significant difference between the greasy fleece weight of SUP and NSUP ewes: the Coopworth ewes on Farm 1 in Year 1, and the Merino ewes on Farm 4 in Year 2. There was only one significant difference in each of fibre diameter and yield on the 11 occasions when these were measured.

Marking percentage

The number of lambs per number of ewes in each mob present at scanning and marking (marking percentage) was not analysed for statistical significance. Over all mobs on all farms, the number of lambs present at marking compared with the number of ewes present at marking was similar (within 5%) on 9 of 20 occasions. The marking percentage of SUP ewes was higher than 5% greater than that of NSUP ewes on 3 of 20 occasions, all of which occurred on Farm 1. On 8 of 20 occasions, the marking percentage of NSUP ewes was more than 5% greater than that of SUP ewes.

Discussion

The degree of parasitism in NSUP ewes during the study was generally low, with no ewe mortalities attributed directly to gastrointestinal parasites. WEC alone did not give a reliable indication of the magnitude of production loss attributable to parasitism; this is consistent with the findings of Dever *et al*.

(2017) in the summer rainfall area of the Northern Tablelands of NSW. For example, in our study, twin-bearing ewes on Farm 2 in Years 1 and 3 had a WEC of over 700 epg at marking, but the average bodyweight of NSUP ewes in this mob was only 3 kg lighter than the average bodyweight of SUP ewes before the next joining, early the following year (Kirk 2016). In contrast, ewes on Farm 3 in Year 2 had a relatively low WEC of 280 epg at marking, but the average bodyweight of NSUP ewes in this mob was 6.6 kg lighter than the SUP ewes at pre-joining the following year (Kirk 2016). This is also consistent with the findings of Larsen and Anderson (2009) where the WECs of Merino ewes in the highest or lowest bodyweight quartiles within the same mob were significantly different on only 3 of 28 occasions.

Bodyweight

Two best practice (BP) and two regionally typical (TYP) farms were selected based on the timing of strategic summer treatments, and whether they routinely used WECs or had tested for anthelmintic resistance. Our multivariable analyses showed that ewes on BP farms were 5.7 (95% CI 1.0–10) kg heavier than those on TYP farms. This contrasts with the findings of Dever *et al.* (2017) where ewes on TYP farms were heavier than those on best practice farms. The effect of suppression of parasitism in ewes was the same on both BP and TYP farms: SUP ewes were 1.2 (95% CI 0.80–1.6) kg heavier on both farm types. These results indicate that there were factors other than gastrointestinal parasitism that were responsible for the 5.7 kg difference observed in ewe bodyweights. The extent to which we can generalise these findings to other areas of the country remains in question. Replication of this study design, enrolling a greater number of farms, would provide the opportunity to investigate this issue further.

As expected, the effect of SUP treatment on bodyweight was greater than the differences observed by Dever *et al.* (2017) in the *Haemonchus*-dominant Northern Tablelands of NSW. Our findings that SUP ewes were 1.2 kg heavier than NSUP ewes is surprisingly low, given both the intensive nature of the treatment, which successfully reduced WEC to near zero in the SUP ewes for around 9 months, and the differences observed on some farms on some occasions (up to 6.6 kg). This result is not dissimilar to that obtained by Miller *et al.* (2015), who found that prime lamb producing ewes in the Wairarapa region of New Zealand that had been treated with a CRC before lambing were 1.7 kg heavier than mineral-treated controls at pre-joining (*P* < 0.001). This difference in bodyweight was significant in 6 of the 14 trials in that study. However, West *et al.* (2009) found that ewes that had been treated with successive controlled release capsules for a period of 9 months, from January to weaning in November, were 3.6 kg heavier than untreated ewes at weaning (*P* < 0.05). In another study in western Victoria, Larsen *et al.* (1995) also found that Merino ewes on three farms that had been administered a controlled-release capsule 31–38 days before lambing had significantly greater weight gain than untreated ewes (1.7–3.7 kg).

Whilst statistically significant, a 1.2 kg difference in bodyweight is likely to have limited biological benefit. For example, an increase of 1 kg bodyweight in twin-bearing Merino ewes will increase ovulation by 2% (Morley *et al.* 1978), lambing by 1.5% and lamb survival by up to 1.2% (Caple 1994; Oldham *et al.* 2011). In contrast, in the study by West *et al.* (2009), ewes that were 2.7 kg heavier than untreated ewes at joining had 12.4 more fetuses per 100 ewes at pregnancy scanning; this equates to an extra 4.6% fetuses at scanning per kilogram of ewe bodyweight at joining. However, even this response would not be a cost-effective strategy given the cost of purchasing and administering the capsules (Larsen *et al.* 1995).

Most of the significant differences in bodyweight of SUP and NSUP ewes (27 of the 28 significant differences observed) occurred on Farms 1, 2 and 3; most of these differences occurred at marking, weaning or pre-joining (24 of 27 times when a difference was observed). Some of these significant differences occurred during or following a period when pasture availability or quality was low, and body condition of ewes was low, for example on Farm 1 in Year 1. This indicates that gastrointestinal nematodes can have a significant effect on ewe bodyweight when ewes are subjected to suboptimal nutrition. The exception to this was on Farm 3, when ewe and hogget nutrition and body condition was better than on Farm 1, but significant differences in bodyweights of SUP and NSUP ewes were still seen at marking, weaning and pre-joining in both monitored mobs. The reason for this is not clear, and unfortunately only 1 year of data could be collected on this farm. However, one possible explanation is that the nematode challenge on this farm was higher, due to a less well planned worm control program, and so a greater difference between bodyweights of treatment groups was observed despite reasonable nutrition.

Poor ewe nutrition and low bodyweight have a negative effect on production: poor nutrition of Merino ewes during pregnancy and lactation has been shown to decrease lamb marking percentage, particularly of twin-bearing ewes, and decrease progeny liveweight at weaning and 6 months of age (Behrendt *et al.* 2011). This is consistent with the observations in this study.

Furthermore, when a significant difference between bodyweights of SUP and NSUP ewes was seen at lamb marking or weaning, it was often detected at the subsequent visits (8 of 12 occasions). This is important because low bodyweight at weaning increases supplementary feeding requirements over the summer if ewes are to achieve optimal bodyweight before joining. In fact, adult ewes from the SUP group were significantly heavier than the NSUP ewes on 6 of 18 occasions before joining following sustained worm suppression; ewe weight and condition score at joining are strongly correlated with conception, and therefore the number of lambs marked and weaned (lamb production) the following year. Five of the occasions when a significant difference was seen at pre-joining were on Farms 1 and 2, reflecting below optimum nutrition in late pregnancy, early lactation and/or after weaning. Therefore, management of ewes to maintain or regain bodyweight as appropriate during or after lactation is important to prevent suboptimal bodyweight or condition at joining.

Implications for control programs

Although controlled release capsules and long-acting moxidectin were used in this study simply to suppress parasitism in ewes and lambs respectively, the results are of interest to the prime lamb industry in terms of the possible administration of long acting anthelmintics to ewes as part of a parasite control program. During discussions with prospective co-operators before the start of this study, it became apparent that long-acting anthelmintics were being routinely administered to non-Merino ewes in an attempt to suppress parasitism during lambing; a similar occurrence has been reported in New Zealand, where 50% of farmers treated non-Merino ewes with long-acting anthelmintics (Lawrence *et al.* 2007).

Farmers perceive that long acting anthelmintics given to ewes before lambing will prevent ewe deaths and increase lamb production (Miller *et al.* 2015). However, results from the present study suggest that production effects, if they occur, are small and so preventing them is unlikely to be cost effective. It has been shown that there is no significant difference between WEC or total worm counts of high and low bodyweight Merino ewes (Larsen and Anderson 2009). Furthermore, there is no evidence in this study to suggest that the benefits of using long acting anthelmintics that were observed in this study after sustained suppressive treatment (such as 1.2 kg increase in ewe bodyweight seen in the overall model, and up to a 1.8 kg increase in weight of lambs of hoggets at marking) would be realised with the use of only one CRC (100 days of worm suppression). Treatment of lambing Merino ewes in western Victoria with one capsule did result in up to a 3% increase in wool production and a decrease in dag score (Larsen *et al.* 1995), but these benefits were not considered cost effective by the authors of that study.

In New Zealand, Leathwick *et al.* (2006*a*) showed that anthelmintic resistance developed more rapidly when ewes were treated with a CRC pre-lambing, compared with ewes that were given a short acting anthelmintic at lamb marking, or left untreated. Furthermore, prime lamb producing ewes treated with a CRC had a temporary increase in WEC following the cessation of anthelmintic release, and the CRCs had no effect on lamb survival or weaning weights (Miller *et al.* 2015).

In addition, the mortality of NSUP ewes during this study was not substantially greater than mortality of SUP ewes (data not shown); this suggests that the use of long acting anthelmintics is unlikely to decrease ewe mortality.

These factors suggest that the routine treatment of whole mobs of ewes with long-acting anthelmintics should not be routinely used in gastrointestinal nematode control programs in prime lamb systems. However, in years when pasture availability and ewe condition score is lower than recommended, such as on Farm 1 in Year 1, anthelmintic treatment of ewes before lambing may be helpful to prevent deaths from clinical parasitism. In this case, a long acting anthelmintic is likely to be more effective in preventing deaths than a short acting treatment, although the merits of this strategy cannot be established from the present study. It should also be noted that the use of a long acting treatment is unlikely to result in epidemiological benefits, because a relatively large proportion of the larval population is found on pasture (rather than in the host) between June and October (Anderson 1972).

Condition score

Assessing the body condition of ewes (condition scoring) is a time-efficient and accepted way of estimating the state of nutrition of ewes but is not as sensitive as measuring bodyweight (van Burgel *et al.* 2011). Consistent with this, and the differences in bodyweight, SUP ewes had significantly higher condition scores than NSUP ewes on 17 of 95 occasions. Most of these differences occurred at marking (5 of 20 occasions) and weaning (8 of 20 occasions). There were no occasions when the NSUP ewes had a significantly higher condition score than the SUP ewes. SUP ewes also had significantly higher condition scores on 3 of the 16 occasions that condition score was assessed at the pre-joining visit.

The pattern of bodyweights and condition scores showed that in most instances when the SUP ewes were significantly heavier before joining, ewe body condition score and pasture availability had been low during lambing. Significant differences in bodyweight or condition score also occurred in the two hogget mobs. This highlights the effect of pasture availability on ewe body condition and is consistent with the findings and recommendations of the Lifetime Wool Project (Behrendt *et al.* 2011; Trompf *et al.* 2011).

Two observations were made from the condition scores in this study: (1), a high proportion of ewes were in poor condition (condition score 2.5 or less) at marking on some farms in some years (particularly Coopworth and Merino ewes on Farm 1 in Years 1 and 2, and First Cross and Merino ewes on Farm 4 in Year 2), and up to 98% of ewes were in poor condition and pasture availability was very low during these years); (2) at the visits when this occurred, a similar proportion of SUP and NSUP ewes were in condition score 2.5 or less. These two observations are important because they indicate that ewe nutrition during late pregnancy and early lactation could be greatly improved, and that, in this study, suppression of gastrointestinal parasitism did not appear to influence the proportion of ewes in poor body condition.

Bodyweights of single- vs twin-bearing ewes

During this study, the mean bodyweight of the single-bearing NSUP ewes on Farm 2 increased by 2.6–6.4 kg between pre-lambing and marking. On these occasions, the pasture available exceeded the requirement of these ewes (Anon 2010). This shows that in years where pasture is limiting, there may be an opportunity to increase efficiency by reducing the amount of pasture offered to single-bearing ewes. More pasture may then be allocated to groups of ewes that require more energy during late pregnancy and early lactation, or are more susceptible to parasitism, such as twin-bearing ewes or lambing hoggets (Anon 2011*b*; Hocking Edwards *et al.* 2011; Mulvaney *et al.* 2012).

Timing of summer drenches on TYP farms and its effect on worm control

No overt signs of clinical parasitism were seen on any of the farms and this was reflected in the results from the

multivariable model. Thus, it can be concluded that the control of parasitism was reasonably effective on both BP and TYP farms during the 3 years of this study.

Despite this, it should be noted that the strategic summer treatments with anthelmintics may have been more effective on TYP farms if they had been better timed. The usual practice on both TYP farms was to give only one treatment in January, nearly 2 months after the average time of pasture senescence. In essence, this is only the second of the two summer treatments recommended by Anderson (1972), which meant that pastures would be more heavily contaminated with eggs from November and December, leading to higher larval contamination of pastures in the late summer and autumn.

Merinos

Merinos were included in 3 of the 20 mob–farm–year comparisons, allowing some comparison between the Merinos, and Composite or first-cross ewes that grazed the same pasture on these farms. The Merinos in this study tended to have higher WEC than non-Merino ewes (five of eight occasions on Farm 1, and all four occasions on Farm 4). This is consistent with the findings of Donald *et al*. (1982) who noted that, regardless of whether ewes had been treated with an anthelmintic before lambing, first-cross ewes had significantly fewer *Teladorsagia* spp. adult worms than Merinos ($P < 0.001$), and their WEC counts after lambing were also much lower.

However, the difference between the mean bodyweight of SUP and NSUP Merinos was not always greater than that of SUP and NSUP non-Merinos. On Farm 1 in Year 1, there were significant differences between the bodyweights of SUP and NSUP Merino and Coopworth ewes at marking, weaning and pre-joining. At marking and weaning the proportional difference between the treatment groups was greater in the Merinos than in the Coopworths; however, at pre-joining, the reverse was true. On Farm 4 in Year 2, the only significant difference between SUP and NSUP ewes in any of the three mobs was in the Merinos at weaning (53 kg vs 51 kg, respectively, or 5.1%; $P < 0.05$).

Furthermore, non-Merinos did not always have a higher condition score than Merinos. On Farm 1, and on two of five occasions on Farm 4, the condition scores of Merino ewes were similar (± 0.2) to those of non-Merino ewes. Nevertheless, the Merinos were 0.5–0.8 of a condition score lighter than the first-cross ewes on Farm 4 at scanning, pre-lambing and pre-joining. This implies that the bodyweight and condition score penalties imposed by nematodes are not always higher in non-Merinos than in Merinos. However, not all Merinos were twin-bearing, and had this been the case, the effects on bodyweight and condition score of this breed may have been higher.

The peri-parturient rise in WEC in ewes

WEC from NSUP ewes in most mobs on Farms 1, 2 and 3 (11 of 15 mobs) demonstrated a typical peri-parturient rise in WEC, peaking at marking and then decreasing in spring and early summer (Salisbury and Arundel 1970; Barger 1993; Beasley *et al*. 2010).

This rise did not appear to be influenced by anthelmintic treatments given before lambing or at lamb marking. A treatment was given to NSUP ewes before lambing on seven occasions. Subsequently, the WEC at the marking visit increased six times and decreased once (range between a decrease of 277 epg to an increase of 255 epg). At marking, the NSUP ewes were given a short-acting anthelmintic on nine occasions. Following this, and despite the natural decrease in WEC that occurs during the spring (Anderson 1972), the WEC at weaning increased five times (100–384 epg), decreased once (by 175 epg) and remained similar three times. Results similar to these have been reported in at least three other studies on ewes grazing contaminated pastures in areas with winter dominant or uniform rainfall (Arundel and Ford 1969; Donnelly *et al*. 1972; Donald *et al*. 1982). In a corresponding study in a summer rainfall environment, Dever *et al*. (2017) also reported a rise in ewe WECs between pre-lambing and weaning.

Conclusions

Overall, in the absence of severe clinical parasitism, our results show that WEC alone is not a reliable indicator of the degree of production loss in ewes. Within the limits of sample size, the large difference in bodyweights of ewes on BP and TYP farms could not be attributed to differences in gastrointestinal parasite control programs on these farms. The multivariable model showed that overall, the suppression of gastrointestinal parasitism increased ewe weight by only 1.2 (95% CI 0.80–1.6) kg. However, at individual visits, there were greater differences between SUP and NSUP ewes. Some of these occurred following periods of low feed availability and/or ewe condition score. Furthermore, a high proportion of both NSUP and SUP ewes were in body condition score 2.5 or less at marking (up to 98%, 50%, 40% and 100% on Farms 1, 2, 3 and 4, respectively).

The effect of suppression of parasitism was not always greater in Merinos than non-Merinos, and treatment of ewes with a short acting anthelmintic before lambing or at marking did not have a consistent effect on subsequent WEC of ewes. These observations indicate that providing adequate nutrition to ewes is critical to minimise loss of bodyweight and condition during late pregnancy and lactation. Furthermore, the use of controlled release capsules was not cost effective in reducing production loss from gastrointestinal nematodes in most years on most farms but may be effective in reducing the effects of clinical parasitism in some ewes in some years.

Conflicts of interest

The authors declare no conflict of interest.

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