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Lifting the limits imposed by worms on sheep meat production

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Abstract

The impact of gastrointestinal nematode parasites (worms) represents the highest animal health cost to the Australian sheep industry but surprisingly little attention has been paid to worm control in sheep meat systems. The primary objective of the work conducted during this project was to develop and evaluate integrated worm control programs for meat sheep systems in four geographical regions of eastern Australia. The main feature to emerge from this project was identification that integrated worm control programs can almost completely remove the deleterious effects of worm infection and have benefit for drench resistance and therefore sustainability of worm control.

Executive summary

The impact of gastrointestinal nematode parasites (worms) represents the highest animal health cost to the Australian sheep industry. At the same time, the endemic nature of anthelmintic resistance and its increasing severity highlights future risks for the industry. Integrated regional worm control programs have been tested and developed for Merino sheep enterprises but surprisingly, little attention has been paid to worm control in sheep meat systems. The primary objective of the work conducted during this project was to develop and evaluate integrated worm control programs for meat sheep systems which delivered the following benefits:

- Improved animal welfare with reduced worm-related adult mortality.
- Increased sheep meat production as a result of reduced parasitism and mortality.
- Elimination of unnecessary drench treatments leading to a reduction in drench treatment frequency and reduced selection pressure for development of drench resistance.
- Increased annual gross margin returns

Development of the worm control programs occurred in four geographical regions of eastern Australia, from the Northern Tablelands, NSW to the winter rainfall zone in Victoria. The project covered the years 2012-2015 and was conducted on 17 commercial sheep properties. The experimental design allowed evaluation of integrated (Lifting the Limits; LTL) and regionally-typical (TYP) worm control programs by reference against the performance of worm suppressed twin-bearing ewes and prime lambs. Industry engagement was facilitated by formation of industry advisory groups within each region with the purpose of reviewing progress and improving industry adoption of project outcomes.

The conclusions from project activity were:

- Adoption of integrated LTL worm control resulted in lower worm egg count and was achieved with fewer treatments and less reliance on long-acting products with benefits most pronounced where Barber’s Pole worm was dominant. These changes should reduce selection pressure for drench resistance.
- Both LTL and typical worm control provided protection that was almost as good as year-long worm suppression, highlighting the effectiveness of management programs.
- Meat-breeds and crossbred genotypes in good condition and grazing improved pastures were very resilient to the impacts of worms with little effect on ewe and lamb live weight, fleece weight, reproduction and mortality.
- When lamb growth exceeded 200 g/day there was no benefit for weaning weight from drenches given to lambs before weaning.
- Apparent mortality (though unaffected by worm infection) of twin-bearing ewes was in the range 3.9–10.2% p.a., surpassing accepted benchmarks. Where cause of death was established, dystocia was the main cause.
- By itself, WEC was not a reliable indicator of production loss but is useful as a means of managing pasture infectivity and, in summer rainfall regions, for avoiding mortality.

Regional integrated worm control programs will be included in WormBoss (www.wormboss.com.au) reflecting differences from Merino enterprises. The key additional worm control practices for sheep meat production systems rely on:

- Ewes being maintained in good body condition (in the range 2.5–4.0; lowest at lamb marking and highest at mating).
- Prime lambs growing in excess of 200 g/day to weaning.
- Modification of strategic and tactical drenching to include:
    - Northern Tablelands, NSW
        - Strategic ewe treatments: mid-winter treatment
        - Preparation of low worm-risk weaning paddocks
    - Central Tablelands, NSW
        - Strategic ewe treatments: prelambing
    - South West Slopes, NSW
        - Strategic ewe treatments: prelambing with a short acting drench
    - Victoria
        - Tactical ewe treatments: monitor worm egg counts before the first summer drench and delay if counts are zero or very low.

Adoption of these practices will prevent production loss associated with worm infection and, where Barber's Pole worm is dominant, reduce worm egg count with fewer treatments and less reliance on long-acting products.

There were a number of R&D opportunities identified throughout the project and these are detailed within the report. Minimising the exposure of lambs to infective worm stages after weaning is identified as an important issue for post weaning growth across regions. Mitigating this effect, without recourse to blanket anthelmintic treatment, will require weaners to graze low worm-risk pastures. Further research is required to adapt smart grazing methods for use in prime lamb enterprises in southern and northern regions.

The main feature to emerge from this project was the identification that in sheep meat production systems only a small residual effect of worm infection remains with LTL and TYP worm control. Both approaches almost completely removed the deleterious effects of GIN infection but LTL will have benefit for drench resistance and therefore sustainability of worm control.

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1 Background

The impact of gastrointestinal nematode parasites (worms) represents the highest animal health cost to the Australian Sheep Industry. The total annual cost of lost production and control of GIN infection has most recently been estimated at $436M AUD (Lane et al. 2015) from an Australian sheep population (2011; excluding sheep in the pastoral zone) of 64M. These estimates represent an increasing per head annual total cost of GIN from $4.24 (Sacket et al. 2006) to $6.81. The increased cost of GIN has arisen for a number of reasons of which the greater value of sheep meat and hence lost production from GIN infection has been central. Increasing value of sheep and lamb brings into focus the importance of good GIN control. At the same time, the endemic nature of anthelmintic resistance and its increasing severity highlights the importance of control practices that minimise further selection for resistance.

Integrated worm control programs for Merino sheep enterprises were developed for many regions through the Integrated Parasite Management of Sheep project (IPMs). The programs integrated chemical and a non-chemical control options into a worm control program. Since then integrated control programs for all regions have been developed and are maintained through ParaBoss. These programs have proven efficacy with field work conducted in the New England region of NSW demonstrating reduced treatment frequency of 20% and an annual advantage of approx. $4.00 (AUD) per head over existing strategies (Kelly et al. 2010).

The extent that benefits of these programs will accrue similarly for sheep meat systems is uncertain. Sheep meat breeds are generally known to be more tolerant of GIN infection and sheep meat systems typically have a greater focus on nutrition which is known to confer benefit for resistance and resilience to GIN infection. Surprisingly, little attention had been paid to GIN control in sheep meat systems until Carmichael (2009) reported effects of GIN infection from southern Australia.

With the increasing focus on sheep meat production and the uncertainties surrounding the impact of GIN infection in these systems, it was timely to undertake a large-scale replicated field experiment to determine the production costs associated with GIN infection and develop regional integrated control programs.

2 Projective objectives

The primary objectives are the development of integrated worm control programs that lift the limits imposed by worm infection for sheep meat systems, and the adoption of these programs by a significant number of advisors and their clients. Adoption of these programs will significantly improve animal welfare, reduce turn-off times to the lamb supply chain, better deal with risks associated with worm infection and preserve drench efficacy.

Outcomes arising from adoption of an evidence-based Lifting the Limits worm control program will include:

a) Improved animal welfare with annual worm-related adult mortality reduced by 2-4% points (winter - summer rainfall).
b) Increased sheep meat production as a result of reduced parasitism and mortality.

c) Reduced time to turnoff by minimising the development of worm-related lighter lambs.
d) Elimination of unnecessary drench treatments leading to a reduction in drench treatment frequency of 20%.
e) Increased annual gross margin returns by $4-$6 per breeding ewe.
f) Reduced selection pressure for development of drench resistance.

3 Methodology

MLA is committed to investing in top quality scientific research, performed by suitably qualified, experienced and registered researchers and organisations. In experiments that involve livestock, MLA acknowledges that such research needs to be done under the auspices of a recognised Animal Care and Ethics Committee (AEC). The responsibility for obtaining AEC approval lies with the researcher. MLA has in the past not specifically asked for evidence that such AEC approval had indeed been obtained.

3.1 Overview

Development of the *Lifting the Limits* worm control programs occurred in four regions (Fig. A) of eastern Australia (500-700 mm winter rainfall zone in Victoria, south-west slopes NSW, central tablelands NSW and northern tablelands NSW) over the years 2012-2015. Seventeen commercial sheep properties were recruited across the four geographic regions and the project involved close collaboration between University of New England (lead organisation), Central Tablelands Local Land Services, Charles Sturt University and University of Melbourne, Mackinnon Project. The industry impact of the project occurred through regional advisory groups that provided linkage with animal health advisors (private and public) and agribusiness suppliers.

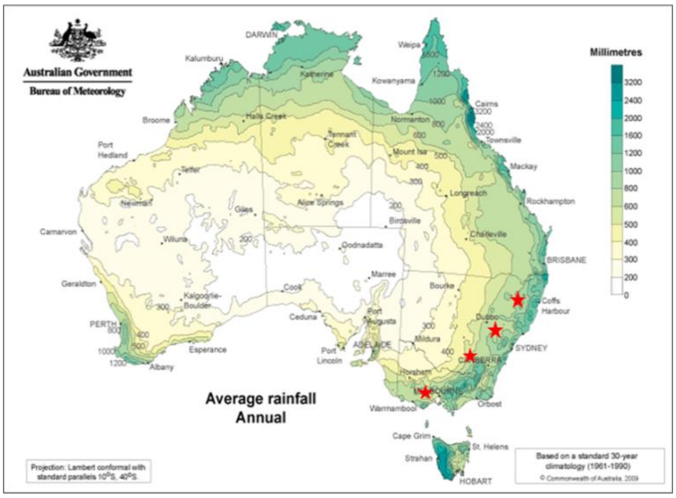


Fig A. Location of regions where farms were located.

3.2 Design and treatments

The project was designed to test the effects of nematode parasitism on ewes and lambs in prime lamb flocks in eastern Australia (Fig. B). Within each region the project was designed as a 2 x 2 x 2 x 2 factorial with two worm control programs (*Lifting the Limits* (LTL) and regionally-typical (TYP)), two worm treatments (suppression (SUP) and not suppressed (NSUP)), two mobs and 2–3 years of observation. Worm control programs occurred on separate properties with 2–3 LTL properties and 2 TYP properties in each region. Pairing of the location of LTL and TYP properties within each region was attempted. The strategies used within worm control programs are summarised in Table A and LTL properties received real-time information and recommendations. The choice of TYP properties was made to reflect typical worm control for each region. These properties did not receive any information or advice from project staff until after completion of this project. The purpose of TYP properties was to provide a point of comparison for the cost of worms on LTL properties.

Table A. Worm control strategies used by Lifting the Limits (LTL) and Regionally typical (TYP) properties.

Worm control strategies	LTL	TYP
Non chemical		
Select rams with negative WEC ASBV	Yes	Sometimes
Grazing management	Sometimes	No
Decisions made using evidence	Mostly	Seldom
Chemical		
WECRT within last 3 years	Yes	No
Regular WEC monitoring	Yes	No
Tactical drenching based on WEC and species thresholds	Yes	No
Strategic drenching to reduce worm contamination on pasture or protect susceptible stock	Yes	Yes
Use of effective combination drenches	Yes	Sometimes
Strategic use of drenches with persistent activity	Yes	No
Drench rotation	Yes	No

ASBV: Australian sheep breeding value; WECRT: worm egg count reduction test.

On each property twin-bearing ewes (Border Leicester x Merino or Coopworth) which had been joined to terminal (or Coopworth) sires were identified at pregnancy scanning and a total of 240 ewes selected and tagged. The ewes were then equally allocated to be grazed in 2 separate mobs. Within each mob, ewes were randomly allocated to receive worm suppression (n=60) or not (n=60). As far as possible, selected sheep grazed within a larger mob (minimum size = 200). A new selection of animals was made for each year of observation.

Year-long worm suppression of SUP ewes was achieved by serial treatment (70-110 d intervals) with short (monepantel (Zolvix; Novartis Animal Health) and long-acting anthelmintics which included either (i) moxidectin (Cydectin LA; Virbac Animal Health) + albendazole (Extender capsule; Merial Australia); or (ii) albendazole + abamectin (Dynamax capsules; Merial Australia); or (iii) ivermectin (Ivomec Maximiser; Merial Australia). Worm control of NSUP ewes was reflective of LTL or TYP management. The Extender and Dynamax capsules contained selenium and cobalt, and so NSUP ewes were treated with selenium and cobalt supplements at scanning (Permatrace Cobalt Pellets® and Permatrace Selenium Pellets® for sheep).

At 4-11 weeks after lambing, lambs were identified to their ewe treatment group by udder painting (Butler, 2004). Briefly, the udder and inguinal area of the ewe was painted with a mixture of one part vegetable oil to two parts Si-Ro-Mark® branding fluid. This marked the lamb's head with udder paint when it suckled overnight. The following day lambs were counted and their head colour, determined by their dam's treatment group, was recorded. Lambs whose head colour could not clearly be distinguished, or whose heads were not coloured, were counted but recorded as not identifiable to a dam treatment group.

Lambs were randomly allocated from within ewe worm treatment to receive either NSUP (i.e. farm worm control of LTL or TYP; n=60/mob) or SUP (n=60/mob) to create a 2 x 2 design with all combinations of ewe and lamb worm treatment. This occurred in one or both mobs of ewes depending on region. SUP treatment of lambs varied among regions for reasons mostly associated with expected age at sale and implication for choice of anthelmintic and export slaughter interval. SUP treatment comprised (see SUP description for ewes for active ingredients and company names) either (i) Cydectin LA + Zolvix at lamb marking; (ii) Weanerguard + Zolvix at marking followed by monthly treatment with short acting effective drenches; or (iii) Weanerguard + Zolvix at marking and four weeks later retreatment with Cydectin LA + Junior Extender Capsule + Zolvix.

3.3 Measurements

On a 2-monthly basis, ewes, starting at pregnancy scanning, were yarded to determine live weight, condition score (1-5 scale) and dag score (1-5 scale; not measured in all regions) and faeces sampled to determine worm egg count (1 egg = 15-60 epg depending on region) and contributing infective genera (morphological characteristics or based on DNA extraction (AusDiagnostics Pty Ltd)). In some regions (i.e. Northern Tablelands) all ewes were sampled while in other regions (i.e. Victoria) rectal faecal samples were collected from at least 20 ewes in each treatment group for individual worm egg counts (WECs). Selection of the ewes sampled was based on ear tag number, such that the same NSUP but different SUP ewes were sampled at each visit. Measurements occurred at pregnancy scanning, 2-4 weeks before lambing, lamb marking (4-11 weeks after the start of lambing), weaning, post weaning and before mating the following year. Presence and absence of ewes was recorded at each yarding to facilitate a survival analysis.

The number of lambs present at marking was determined and used to calculate marking rates. Live weight and dag score of lambs was determined at marking, one month later(in the Northern Tablelands), weaning and in some regions at monthly intervals post weaning depending on the sale of lambs. Faecal samples were collected at post lamb marking events to determine WEC (individually in some regions and bulked in other regions) and contributing infective genera.

At adult shearing, fleeces from one mob were individually weighed before a mid-side sample was collected and analysed for mean fibre diameter and yield in order to assign a dollar value to the fleece. Ewes were scanned by ultrasound to determine pregnancy and conception rates which marked the end of the year's activities. A formal worm egg count reduction test to determine anthelmintic efficacy was conducted early in year 1 on LTL properties and on all properties during year 3.

3.4 Statistical analysis

The statistical analysis was completed by three of the four regions at the time of preparing this final report. In essence, the analysis includes fixed (i.e. worm control program, worm treatment, year) and random (farm, mob within farm) effects and interactions appropriate for each region. Interest is principally for the interaction between worm control program and worm treatment to investigate if the production cost of worms differed between LTL and TYP properties.

3.5 Industry

Industry engagement was facilitated by formation of industry advisory groups within each region. The groups (7-10 people/group) were composed of veterinarians, consultants, agribusiness, ram breeders and collaborating LTL producers. The role of these groups was to provide a forum to assist with planning of project activity and review of progress.

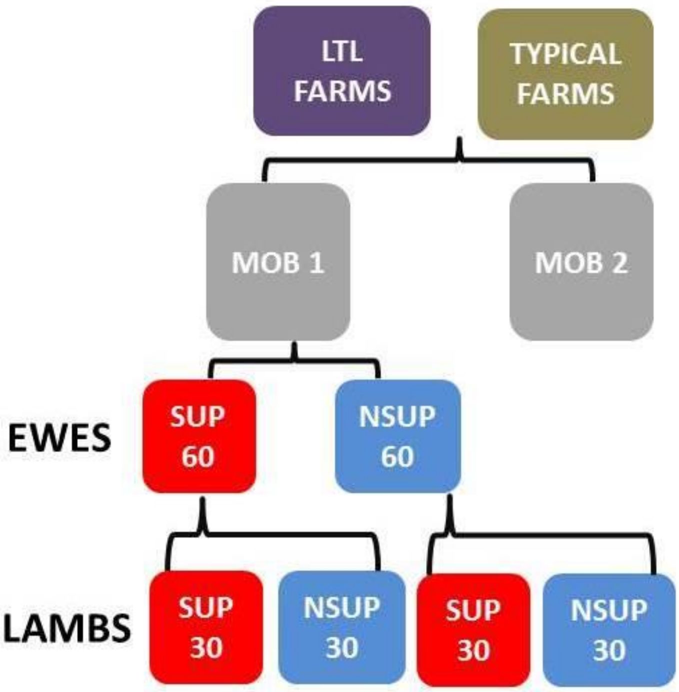


Fig. B. Experimental design implemented on LTL and TYP farms indicating the use of two mobs of twin-bearing ewes each containing animals treated to suppress worms (SUP) or not (NSUP) and the allocation of SUP and NSUP worm treatments to lambs from within each ewe treatment group. Numbers of ewes and lambs within each treatment are provided. Allocation occurred for both mobs but only one is displayed due to space limitations.

4 Results

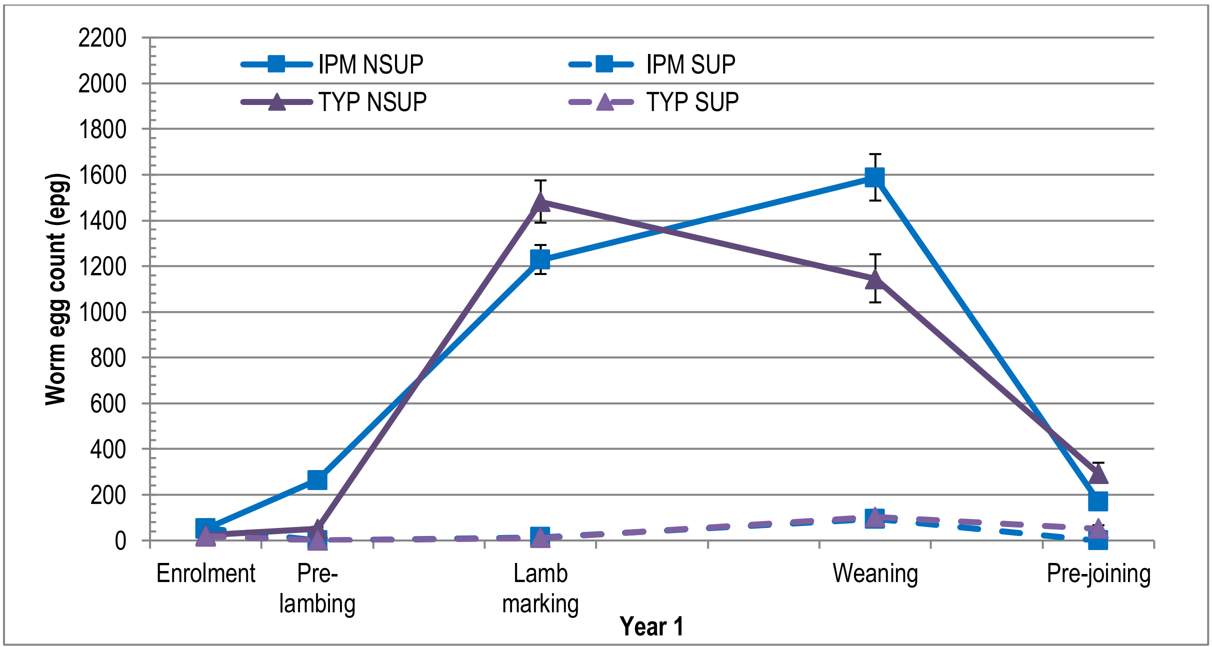
The results are provided separately for each of the four regions. LTL is referred to as IPM in the NSW Northern Tablelands section for consistency with previous work conducted with Merino flocks (Kelly et al. 2010).

4.1 NSW Northern Tablelands

4.1.1 Ewe faecal worm egg count and larval differentiation

WEC did not differ at enrolment (IPM 47 vs TYP 54 epg, p=0.498) but thereafter WEC of NSUP ewes were lower on IPM farms at pre-lambing (IPM 90 vs TYP 192 epg, p<0.0001), lamb marking (IPM 747 vs TYP 1029 epg, p<0.0001) and weaning (IPM 833 vs TYP 1496 epg, p<0.0001) but were higher at pre-joining (IPM 414 vs TYP 164 epg, p<0.0001). Overall mean WEC was lower with IPM (IPM 766 vs TYP 931 epg, p=0.004). As expected, GIN suppression was successful with WEC of SUP ewes being significantly lower (p<0.0001) than NSUP ewes at all times. Mean WEC of SUP ewes were negligible and in the range 0–16 epg with the exception of weaning when WEC were elevated (IPM 63 vs TYP 197). There was an effect of year, with WEC of NSUP ewes on IPM farms lower in Year 2 (p<0.0001) (Fig. 1).

H. contortus was the predominant GIN species present on both IPM (56%) and TYP (70%) farms with *Trichostrongylus* spp. (IPM 29% vs TYP 16%) and *T. circumcincta* (IPM 8% vs TYP 9%) also present (Table 1).



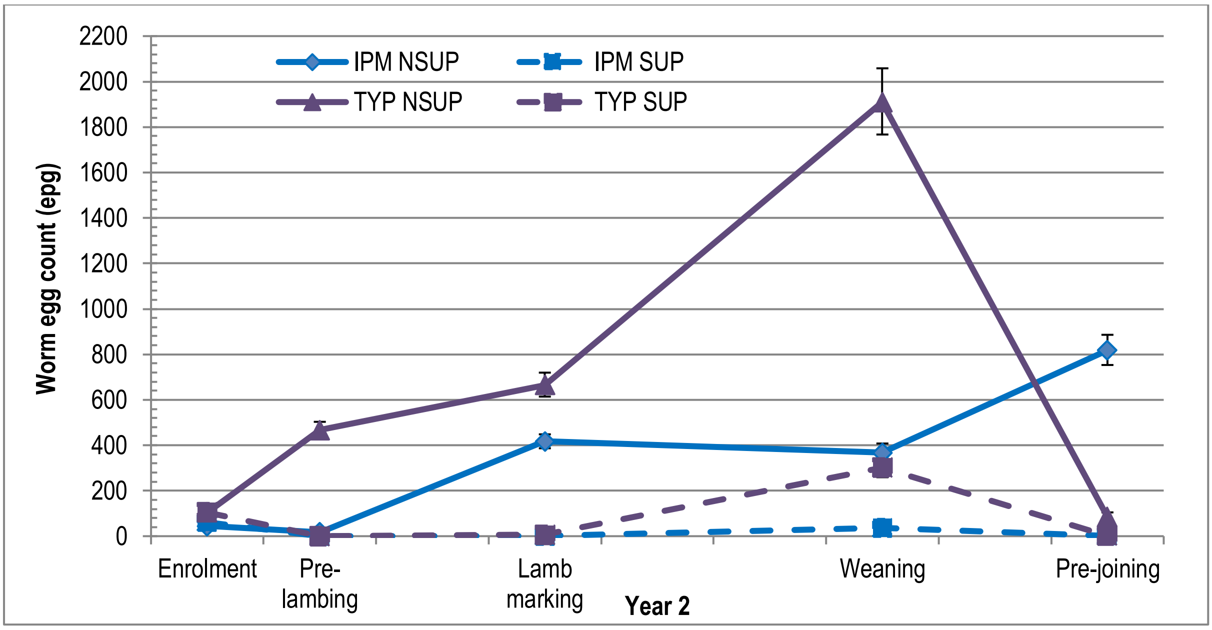


Fig. 1. Back-transformed least squares mean worm egg count (epg ± 68% c.i.) of ewes that were either GIN-suppressed (SUP) or not suppressed (NSUP) and managed with either IPM or TYP programs in Years 1 and 2.

4.1.2 Drench frequency and number of effective treatment days

There were a greater number of drenches administered annually on TYP compared with IPM farms (5.5 vs 4.5/yr). The largest difference was observed in the number of short-acting drenches with TYP farms administering 4.5 drenches and IPM farms 3 drenches annually. There were a greater number of sustained-action drenches administered on IPM than TYP farms (1.3 vs 0.8) and little difference in the number of long-acting drenches (TYP 0.3 vs IPM 0.2). The number of effective treatment days was lower for IPM farms (IPM 44 days vs TYP 47 days).

Table 1. Larval differentiation results (%) for NSUP ewes that were managed with IPM or TYP programs in Years 1 and 2.

GIN Management	GIN Species	Enrolment		Pre-lambing		Lamb marking		Weaning		Pre-joining	
		Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
IPM	*H. contortus*	18	47	43	47	64	39	82	54	74	90
	Trichostrongylus spp.	46	41	43	38	17	39	13	33	21	4
	T. circumcincta	4	2	7	13	14	18	4	13	5	5
	Other species*	32	10	7	2	5	4	1	0	0	1
TYP	*H. contortus*	77	59	68	73	78	68	53	80	50	92
	Trichostrongylus spp.	19	36	30	17	11	17	23	10	0	3
	T. circumcincta	4	4	2	10	11	15	24	10	0	5
	Other species*	0	1	0	0	0	0	0	0	50	0

* Other species includes: *Oesophagostomum* spp. and *Cooperia* spp

4.1.3 Liveweight, liveweight change and body condition score

NSUP ewes were lighter (p<0.0001) at all times. Ewes on TYP farms were heavier (p<0.0001) than ewes on IPM farms at all times but there was no interaction between GIN management and GIN ewe control. Ewes were heavier (p<0.0001) in Year 2 than in Year 1 (Fig. 2). There was no relationship between WEC and liveweight during the experiment.

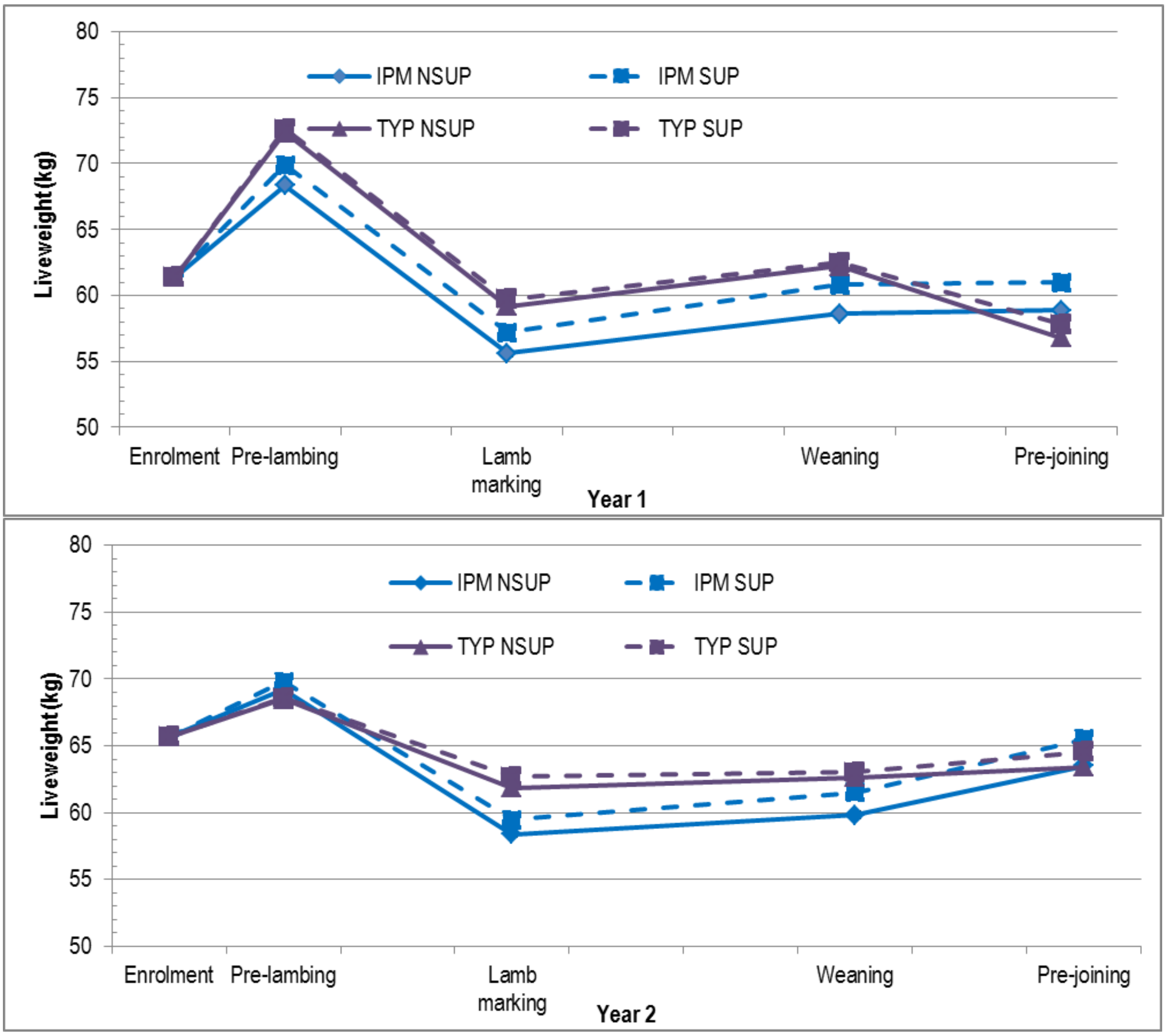


Fig 2. Mean liveweight (kg; least square means ± se) of SUP and NSUP ewes managed with either IPM or TYP GIN programs in Years 1 and 2. Liveweight at enrolment was fitted as a significant covariate.

GIN depressed liveweight change between enrolment and pre-joining by 1.6 kg (NSUP -2.9 kg vs SUP -1.3 kg, p<0.0001) and the difference was greater in the first year of the experiment (Year 1 -2.3 kg vs Year 2 -0.9 kg, p<0.0001). Within GIN management systems, the effect of GIN on ewe liveweight change on IPM farms was greatest between enrolment and pre-lambing (-1.1 kg, p<0.0001) and on TYP farms between weaning and pre-joining (-0.9 kg, p=0.0001). Comparison of the effects of GIN across GIN management system (Analysis 2) showed that the effect of GIN on liveweight change was greater (p =0.0006) for ewes on IPM farms (IPM -2.1 vs TYP -1.1 kg) (Table 2).

Table 2. Mean liveweight changes (kg; least squares mean ± s.e.) of SUP and NSUP ewes managed to IPM or TYP programs.

GIN management	Ewe GIN control	Enrolment – Pre-lambing	Pre-lambing – Lamb marking	Lamb marking – Weaning	Weaning – Pre-joining	Overall
Within ewe GIN control (analysis 1)						
	SUP	6.6[a] ± 0.2	-10.4 ± 0.2	2.2 ± 0.2	0.4[a] ± 0.2	-1.3[a] ± 0.2
	NSUP	6.0[b] ± 0.2	-10.8 ± 0.2	2.1 ± 0.2	-0.2[b] ± 0.2	-2.9[b] ± 0.2
		p<0.0001	p=0.071	p=0.664	p=0.0004	p<0.0001
Within GIN management (analysis 1)						
IPM	SUP	6.2[a] ± 0.1	-11.5 ± 0.2	2.8[a] ± 0.2	2.2 ± 0.2	-0.4[a] ± 0.2
	NSUP	5.2[b] ± 0.1	-11.9 ± 0.2	2.2[b] ± 0.2	1.9 ± 0.2	-2.4[b] ± 0.2
		p<0.0001	p=0.201	p=0.010	p=0.231	p<0.0001
TYP	SUP	7.0 ± 0.2	-9.2 ± 0.3	1.6 ± 0.3	-1.4[a] ± 0.2	-2.2[a] ± 0.3
	NSUP	6.8 ± 0.2	-9.7 ± 0.3	1.9 ± 0.3	-2.3[b] ± 0.2	-3.3[b] ± 0.3
		p=0.600	p=0.215	p=0.309	p=0.0001	p=0.014
Across GIN management (analysis 2)						
IPM		-1.1[b] ± 0.1	-0.3 ± 0.2	-0.6[b] ± 0.2	-0.3[a] ± 0.1	-2.1[b] ± 0.2
TYP		0.04[a] ± 0.1	-0.7 ± 0.3	0.4[a] ± 0.2	-0.9[b] ± 0.2	-1.1[a] ± 0.2
		p<0.0001	p=0.322	p=0.0007	p=0.004	p=0.0006

BCS was significantly higher (p<0.0001) for ewes on TYP farms between enrolment and weaning, however the difference in BCS between the two GIN management systems was less than 0.5 units at all time points. GIN reduced (p<0.002) ewe BCS although the differences between SUP and NSUP ewes were <0.2 BCS units at all time points. Ewe BCS was higher (p<0.0001) in Year 2 than Year 1.

4.1.4 Lamb marking percentage

Lamb marking percentages were not affected by ewe GIN control (NSUP 159% vs SUP 152%, p=0.233) or GIN management (IPM 157% vs TYP 155%, p=0.653). Across GIN management, there was no effect (p=0.969) of GIN on lamb marking percentages with both IPM and TYP having a 7% advantage for NSUP ewes.

4.1.5 Pregnancy scanning

Pregnancy scanning rates were unaffected by ewe GIN control (SUP 171% vs NSUP 168%, p=0.193), GIN management (IPM 170% vs TYP 170%, p=0.735) or year (2013 171% vs 2014 169%, p=0.621). The effect of GIN across GIN management system was greatest (p=0.043) for ewes on IPM farms, with GIN reducing pregnancy scanning rates by 7% on IPM farms with no effect of GIN on pregnancy rates of ewes on TYP farms.

4.1.6 Fleece traits

Greasy and clean fleece weights of NSUP ewes were lower than for SUP ewes but only on IPM farms ($p<0.006$). Ewe GIN control did not affect washing yield or mean fibre diameter. Across GIN management systems the effects of GIN on GFW and CFW were greater for ewes on IPM farms ($p<0.05$) (Table 3).

Table 3. Fibre diameter (µm), washing yield (%), greasy and clean fleece weights (kg) (least squares mean ± s.e.) for NSUP and SUP ewes that were managed to IPM or TYP programs.

GIN Management	Ewe GIN control	Fibre diameter (µm)	Yield (%)	Greasy fleece weight (kg)	Clean fleece weight (kg)
Within ewe GIN control (analysis 1)					
	SUP	26.5 ± 0.11	80.6 ± 0.19	3.89 ± 0.03	3.14 ± 0.03
	NSUP	26.4 ± 0.12	80.4 ± 0.21	3.83 ± 0.03	3.09 ± 0.02
		p = 0.728	p = 0.435	p = 0.121	p = 0.130
Within GIN management (analysis 1)					
IPM	SUP	27.0 ± 0.12	82.6 ± 0.24	4.01 ± 0.03	3.31 ± 0.03
	NSUP	27.0 ± 0.12	82.5 ± 0.23	3.88 ± 0.03	3.20 ± 0.03
		p = 0.960	p = 0.785	p = 0.002	p = 0.005
TYP	SUP	26.0 ± 0.23	78.7 ± 0.35	3.77 ± 0.05	2.98 ± 0.04
	NSUP	25.9 ± 0.22	78.4 ± 0.38	3.78 ± 0.05	2.98 ± 0.04
		p = 0.709	p = 0.463	p = 0.853	p = 0.898
Across GIN management (analysis 2)					
IPM		-0.01 ± 0.12	-0.08 ± 0.25	-0.13^{b} ± 0.03	-0.11^{b} ± 0.03
TYP		-0.13 ± 0.15	-0.21 ± 0.30	-0.02^{a} ± 0.04	-0.01^{a} ± 0.03
		p = 0.501	p = 0.733	p = 0.021	p = 0.030

4.1.7 Mortality

The annual rate of apparent ewe mortality (%) was similar for both GIN management systems (IPM 6.7% vs TYP 6.3%, p=0.334) and for both systems the incidence of mortality was highest between pre-lambing and lamb marking. There was no effect of ewe GIN control on mortality rates (SUP 6.4% vs NSUP 6.7%, p=0.786) on either IPM or TYP farms..

4.1.8 Lamb faecal worm egg count and larval differentiation

Lamb WEC were higher on TYP ($p<0.0001$) than IPM farms. One month after lamb marking, WEC were very low (<1 epg) for both GIN management systems but increased by weaning (IPM 159 epg vs TYP 322, $p<0.0001$). There was no effect of ewe GIN control, year or sex on lamb WEC and no meaningful interaction between the main effects of GIN management and ewe GIN control.

WEC were significantly higher ($p<0.0001$) in NSUP lambs one month after lamb marking and at weaning when mean WEC was 1170 epg (Fig. 3). WEC of male castrate lambs were higher (p=0.0005) at weaning (290 epg castrate male and 230 epg female) but there was no influence of year on WEC pre-weaning nor were there meaningful interactions between these main effects. Lambs were drenched at weaning which is reflected in lower WEC observed one month after weaning but nevertheless WEC remained higher (p<0.0001) in NSUP lambs at both measurements after weaning. WEC differed each year (p<0.0001) after weaning being highest in 2014 and WEC of male castrate lambs were higher (p<0.02) than females at two months after weaning (570 epg vs 455 epg respectively).

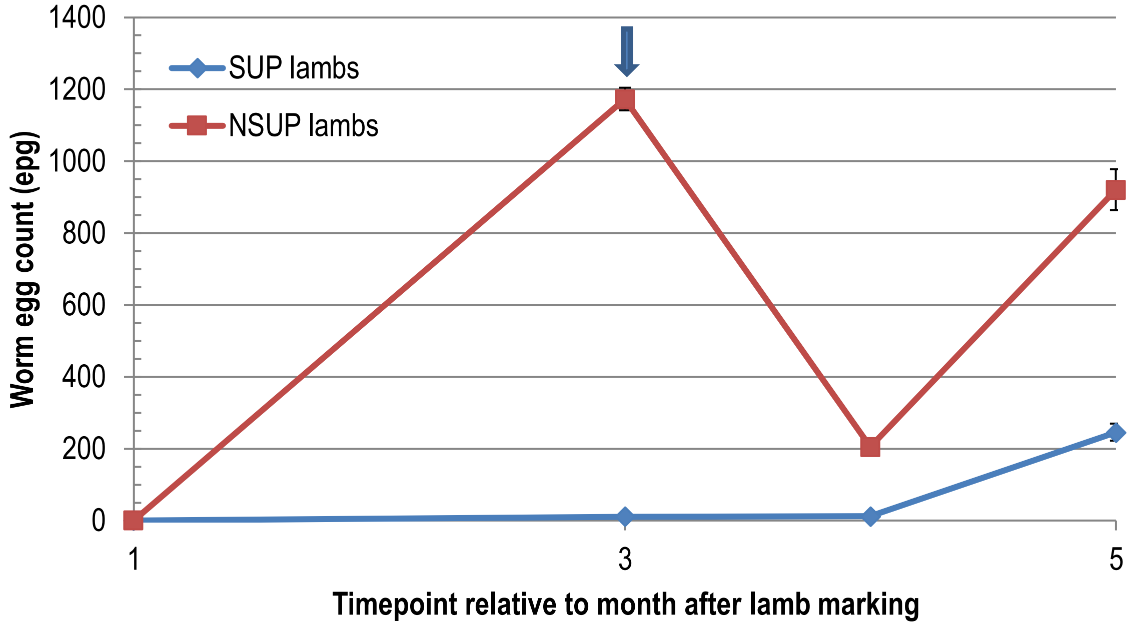


Fig 3. Back-transformed least squares mean worm egg counts (epg ± 68% c.i.) of lambs that were either GIN-suppressed (SUP) or non GIN-suppressed (NSUP). The arrow indicates when all lambs were drenched.

Overall, *H. contortus* was the predominant GIN species present (62%) in NSUP lambs with smaller contributions from *Trichostrongylus* spp. (30%) and *Teladorsagia* spp. (6%) (Table 4).

Table 4. Mean percentage (%) of gastrointestinal nematode species in NSUP lambs with timepoints relative to lamb marking.

	1 month	3 months (weaning)	4 months	5 months
Haemonchus contortus (%)	49	69	69	62
Trichostrongylus spp. (%)	42	24	17	37
Teladorsagia spp. (%)	5	6	12	1
Other species (%)	4	1	2	0

4.1.9 Liveweight, liveweight change and body condition score

Lambs on IPM farms were heavier ($p<0.0001$) than lambs on TYP farms from lamb marking. There was no liveweight advantage for lambs reared by SUP ewes until weaning and lambs were heavier ($p<0.0001$) at all time points in Year 2. Across GIN management system, differences in lamb liveweight due to ewe GIN control were greater ($p<0.0001$) on IPM farms at all time points (Table 5).

Table 5. Mean liveweight (kg; least squares mean ± s.e.) of lambs reared by either NSUP or SUP ewes and managed with IPM or TYP programs.

GIN management	Ewe GIN control	Lamb marking (October)	November	Weaning (January)
Within ewe GIN control (analysis 1)				
	SUP	13.8 ± 0.1	20.9 ± 0.1	32.3^{a} ± 0.1
	NSUP	13.7 ± 0.1	20.6 ± 0.1	31.8^{b} ± 0.1
		p = 0.124	p = 0.069	p = 0.014
Within GIN management (analysis 1)				
IPM	SUP	14.4^{a} ± 0.1	21.2^{a} ± 0.1	32.7^{a} ± 0.2
	NSUP	13.9^{b} ± 0.1	20.3^{c} ± 0.1	31.5^{c} ± 0.2
		p < 0.0001	p < 0.0001	p < 0.0001
TYP	SUP	13.2 ± 0.1	20.5 ± 0.2	31.9 ± 0.2
	NSUP	13.5 ± 0.1	20.8 ± 0.2	32.1 ± 0.2
		p = 0.222	p = 0.169	p = 0.459
Across GIN management (analysis 2)				
IPM		-0.6^{b} ± 0.1	-0.9^{b} ± 0.1	-1.1^{b} ± 0.2
TYP		0.2^{a} ± 0.1	0.3^{a} ± 0.1	0.2^{a} ± 0.2
		p < 0.0001	p < 0.0001	p < 0.0001

Liveweight of lambs, allocated to SUP and NSUP groups, did not differ at lamb marking (Fig. 4) and there was no effect of GIN control prior to weaning. Post weaning liveweight of NSUP lambs was lower ($p<0.01$) with the difference being 0.5 and 0.7 kg at 4 and 5 months post lamb marking. Male castrate lambs were consistently heavier than female lambs ($p<0.0005$) and at 3 (weaning) and 5 months were 0.6 and 0.8 kg heavier respectively. There were no meaningful interactions between main effects for pre and post weaning liveweight.

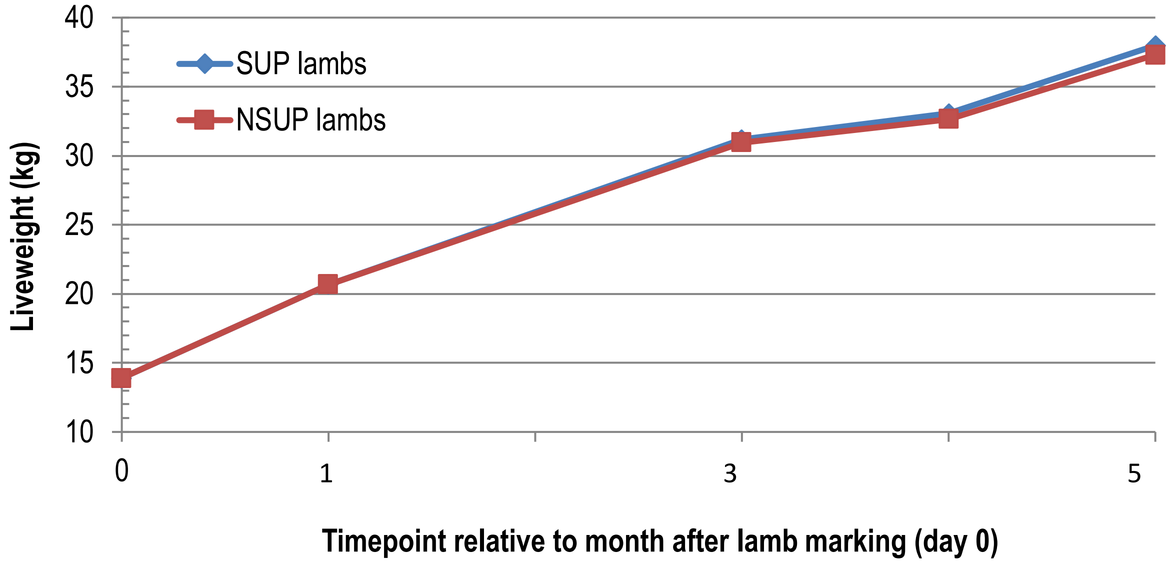


Fig 4. Least squares mean liveweight (kg ± s.e.) of SUP or NSUP lambs. Liveweight at lamb marking was fitted as a significant covariate.

There was no effect of GIN control on lamb growth in the month following lamb marking but thereafter growth of NSUP lambs was reduced up to weaning (Table 6). Over the entire pre-weaning period, there was no effect of GIN control on growth (SUP 17.2 kg vs NSUP 17.0 kg, p=0.093). In the month after weaning, lamb growth declined (exacerbated by the loss of fleece) with no difference between SUP and NSUP groups. Lamb growth increased in the final month of the experiment but was significantly lower (p=0.002) for NSUP lambs with the difference being 0.5 kg. Lamb growth was highest in castrate males during the pre-weaning period (p<0.0001; 17.4 kg castrate males and 16.8 kg female) with no significant differences post-weaning. There were no interactions between these main effects. Relationships between WEC and liveweight and WEC and growth were not significant during either period.

Table 6. Least squares mean growth (kg ± s.e.) for SUP and NSUP lambs and the number of lamb observations for each assessment. Timepoints are relative to lamb marking.

	Lamb GIN control		
Timepoint	SUP	NSUP	p-value
Lamb marking – 1 month	6.7 ± 0.06 n = 1510	6.7 ± 0.06 n = 1499	p=0.858
1 month – 3 months (weaning)	10.5 ± 0.06 n = 1458	10.3 ± 0.06 n = 1463	p=0.022
3 months (weaning) – 4 months	2.8 ± 0.08 n = 1067	2.6 ± 0.08 n = 1070	p=0.078
4 months – 5 months	7.1 ± 0.10 n = 516	6.6 ± 0.10 n = 510	p=0.002

There was no effect of lamb GIN control on BCS at weaning (SUP 2.97 and NSUP 2.98, p=0.802), however one month later BCS of SUP lambs was significantly (but not meaningfully) higher (SUP 3.22 and NSUP 3.19, p=0.032) and BCS did not differ between GIN control groups at the final assessment (SUP 3.75 and NSUP 3.72, p=0.1). There was no relationship between WEC and BCS.

4.1.10 Dag score

Dag scores were low in all animals, but significantly higher in NSUP lambs at weaning (NSUP 1.6 vs SUP 1.5, p<0.0001) and one month later (NSUP 1.3 and SUP 1.2, p=0.016). There was no relationship between WEC and dag score.

4.1.11 Mortality

Lamb apparent mortality averaged 2.8% between lamb marking and weaning and was unaffected by ewe GIN control (p=0.570) and GIN management (p=0.656). On IPM farms there was no difference (p=0.384) in lamb mortality for lambs reared by NSUP (3.2%) and SUP (2.7%) ewes, while on TYP farms, lamb mortality was surprisingly higher (p=0.045) for lambs reared by SUP (3.8%) than NSUP (1.5%) ewes.

4.1.12 Drench resistance

Drench efficacy was variable among farms with the number of effectives actives in the range 0–4 among a total of 6 actives tested (excluding monepantel and Startect). Despite this, the use of multi-active combinations provided effective control in many instances. The low number of effective treatments on IPM1 occurred because treatment recommendations were based on results completed prior to Year 1 and were expected to be >95% effective, however a change in efficacy of a number of actives occurred during the intervening period (Table 7).

Table 7. The number of drench actives effective against *H. contortus* or *Trichostrongylus* spp., and the percentage of anthelmintic treatments administered to ewes that were effective, on each of the IPM and TYP farms at the end of Year 2.

	IPM			TYP	
Farm	1	2*	3	4	5
No. actives effective against *H. contortus*	0/6	4/6	4/6	3/6	1/6
No. actives effective against *Trichostrongylus* spp.	2/5	2/5[a]	4/5	3/5	NA
Drenches used that were >95% effective (%)	33%	90%	100%	100%	57%
Drenches used that were >90% effective (%)	75%	100%	100%	100%	64%

Actives tested: albendazole, levamisole, abamectin, moxidectin, naphthalophos and closantel (*H. contortus* only). NA: Effectiveness of actives against *Trichostrongylus* spp. was unable to be established due to insufficient larval numbers recovered from coproculture. [a] Results from first WECRT prior to Year 1 as insufficient larval numbers recovered from coproculture to test effectiveness of actives against *Trichostrongylus* spp. in Year 2.

4.2 NSW Central Tablelands

4.2.1 Ewe faecal worm egg count and larval differentiation

The arithmetic mean WEC, measured at enrolment prior to SUP treatment, was 67 eggs per gram (epg). Across the subsequent 4 visits the mean WECs for SUP and NOSUP ewes were 0.05 ± 0.001 vs. 11.1 ± 0.001 epg (back-transformed; P<0.001), or 13 ± 5 vs. 100 ± 5 epg (arithmetic means) and this was consistent across both LTL and TYP flocks (arithmetic means 8.6 ± 7.2 vs. 85.7 ± 7.2 and 18.2 ± 7.4 vs. 114.6 ± 7.4 epg, respectively, P<0.01).

Within NOSUP ewes, mean WEC was not different (P=0.47) between LTL and TYP worm management groups (arithmetic means; 86 ± 13 and 122 ± 13 epg, respectively). There was no difference between years but there were differences between visits (Table 8).

Table 8. Mean (back-transformed and arithmetic ± s.e.) WEC data for NOSUP ewes managed by LTL and TYP procedures at four times averaged across Year and Flock.

Worm	Visit			
Management	1. Prelamb	2. Mark	3. Wean	4. Join
	Back transformed means			
LTL	1.8 ± 0.04^{a}	25.2 ± 0.04^{a}	26.4 ± 0.05^{a}	0.8 ± 0.05^{a}
TYP	58.7 ± 0.05^{b}	4.4 ± 0.04^{b}	29.5 ± 0.05^{a}	6.3 ± 0.05^{b}
mean	16.6 ± 0.02^{A}	11.9 ± 0.02^{A}	28.0 ± 0.02^{B}	2.6 ± 0.02^{C}
	Arithmetic means			
LTL	45 ± 16	148 ± 16	127 ± 17	26 ± 17
TYP	238 ± 18	59 ± 16	136 ± 17	56 ± 17
mean	141 ± 12	103 ± 12	131 ± 12	41 ± 12

Means with different lower case superscripts within columns are different (P<0.05). Means with different upper case superscripts within the “mean” row are different (P<0.05).

Larval differentiation showed that *H. contortus* was the predominant species during the summer and autumn months while during winter/spring months at marking and weaning the scour worms, *Teladorsagia* and *Trichostrongylus*, were predominant (Table 9)

4.2.2 Drench frequency

Drench frequency was not different between LTL and TYP farms in Year 1 (2 vs 2) but TYP flocks drenched more often than LTL flocks in Year 2 (3.0 vs 1.5). In addition long acting drenches represented 80% of treatments on TYP flocks compared with 29% in LTL flocks.

Table 9. Worm species contribution (% - dominant in bold) to worm egg count measured in LTL and TYP flocks across the production year.

Time	Worm management type	Worm species contribution (%)			
		H. contortus	*T. circumcincta*	*Trichostrongylus* spp.	*Chabertia/ Oesophagostomum*
Enrolment	LTL	**62**	19	6	13
	TYP	**66**	19	9	7
		65	19	7	9
Pre-lambing	LTL	**52**	13	14	22
	TYP	**61**	30	6	3
		56	20	10	14
Marking	LTL	31	**46**	16	7
	TYP	29	**46**	23	3
		30	**46**	20	5
Weaning	LTL	19	**44**	27	10
	TYP	7	**37**	36	20
		12	**40**	32	15
Joining	LTL	**57**	22	11	11
	TYP	20	**56**	16	9
		38	**39**	14	10
Total		**39**	34	17	10

Predominant species in bold type

4.2.3 Ewe live weight and condition score

The average LW of ewes at enrolment in autumn was 74.1 ± 0.2 kg and LW varied throughout the production year depending on stage of reproduction (Table 10). Overall, SUP ewes were heavier than NOSUP ewes (72.4 ± 1.0 vs. 71.9 ± 1.0 kg; P<0.001) but there was no LW difference between worm management treatments (71.9 ± 1.4 and 72.6 ± 1.4 kg; NS). In addition there was no significant interaction between Dam suppression and Worm management, or between these 2 variables and Visit. However at pre-lambing, SUP ewes in LTL flocks were heavier than both SUP and NOSUP in TYP flocks. While LTL ewes were heavier than TYP ewes at marking, TYP ewes were heavier at weaning but these differences had disappeared by joining.

Similarly, ewe CS varied across the production year but there was no difference between SUP and NOSUP ewes in either TYP or LTL flocks (Table 11).

Table 10. Mean live weight (kg) of ewes across Years and the live weight penalty (kg) in NOSUP ewes compared to SUP ewes for each worm management treatment.

Worm Mgt	Dam_Trt	Visit Pre Lamb	Mark	Weaning	Joining
LTL	NOSUP	80.8 ± 1.5 ^{ab}	62.2 ± 1.5 ^{a}	74.7 ± 1.5 ^{a}	66.2 ± 1.5 ^{a}
	SUP	81.8 ± 1.5 ^{a}	63.6 ± 1.5 ^{a}	76.3 ± 1.5 ^{a}	67.9 ± 1.5 ^{a}
TYP	NOSUP	77.9 ± 1.5 ^{b}	70.2 ± 1.5 ^{b}	73.0 ± 1.5 ^{b}	70.4 ± 1.5 ^{a}
	SUP	77.8 ± 1.5 ^{b}	68.9 ± 1.5 ^{b}	73.1 ± 1.5 ^{b}	69.9 ± 1.5 ^{a}
Penalty (NOSUP – SUP)					
LTL		-1.05	-1.01	-1.65	-1.7
TYP		0.06	1.28	-0.07	0.5

Within columns means with different superscripts are different (P<0.05)

Table 11. Mean condition score of ewes across Years and the condition score penalty in NOSUP ewes compared to SUP ewes for each worm management treatment.

Worm Mgt	Dam_Trt	Visit Pre Lamb	Mark	Weaning	Joining
LTL	NOSUP	3.7 ± 0.1 ^{a}	2.9 ± 0.1 ^{a}	3.4 ± 0.1 ^{a}	3.1 ± 0.1 ^{a}
	SUP	3.8 ± 0.1 ^{a}	2.9 ± 0.1 ^{a}	3.4 ± 0.1 ^{a}	3.2 ± 0.1 ^{a}
TYP	NOSUP	3.6 ± 0.1 ^{a}	3.2 ± 0.1 ^{b}	3.4 ± 0.1 ^{a}	3.2 ± 0.1 ^{a}
	SUP	3.6 ± 0.1 ^{a}	3.2 ± 0.1 ^{b}	3.4 ± 0.1 ^{a}	3.3 ± 0.1 ^{a}
Penalty (NOSUP – SUP)					
LTL		-0.05	0.03	-0.00	-0.08
TYP		-0.07	0.01	-0.03	-0.10

Within columns means with different superscripts are different (P<0.05)

4.2.4 Ewe live weight changes

LW change differed between season/reproductive stage (Table 12). Ewes gained 5.4 ± 0.3 kg over autumn between scanning and pre-lambing, lost 13.5 ± 0.3 kg in winter over the lambing period, gained 8.2 ± 0.2 kg during spring between marking and weaning and lost 5.7 ± 0.2 kg over the summer between weaning and joining, resulting in an overall loss of 5.5 ± 1.1 kg over the 9 months annual monitoring period. LW change was lower in SUP ewes compared to NOSUP ewes (-1.3 ± 0.3 vs. -1.5 ± 0.3 kg; P<0.05) but there was no difference between worm management treatments (-1.0 ± 0.4 and -1.8 ± 0.4 kg for TYP and LTL flocks respectively. NS).

Table 12. Annual and seasonal live weight changes of ewes across years for Worm Management and Ewe treatment groups.

Worm Mgt	DamTrt	Autumn	Winter	Spring	Summer	Annual
LTL	NOSUP	6.5 ± 0.5^{a}	-18.4 ± 0.5^{a}	12.4 ± 0.5^{a}	-8.6 ± 0.5^{a}	-7.8 ± 1.6^{a}
	SUP	7.4 ± 0.5^{a}	-18.6 ± 0.5^{a}	13.2 ± 0.5^{b}	-8.4 ± 0.5^{a}	-6.3 ± 1.6^{ab}
TYP	NOSUP	3.9 ± 0.5^{b}	-7.7 ± 0.5^{b}	2.8 ± 0.5^{c}	-2.7 ± 0.5^{b}	-3.7 ± 1.6^{b}
	SUP	3.6 ± 0.5^{b}	-9.0 ± 0.5^{b}	4.2 ± 0.5^{c}	-3.2 ± 0.5^{b}	-4.3 ± 1.6^{ab}

Means within columns with different superscripts are different (P<0.05)
The seasons represent LW changes in the order of Enrolment to Pre-lambing, Pre-lambing to marking, marking to weaning and weaning to joining, respectively.

4.2.5 Reproduction

Across all flock/years, 162 lambs were marked per 100 ewes present at marking. The mean marking percentage did not differ across dam treatment or worm management groups.

The number of foetuses per 100 ewes scanned was lower in Year 1 than in Year 2 (143 and 185, respectively (P<0.001). However there was no difference between dam treatment or worm management groups.

4.2.6 Wool production and quality

Greasy fleece weight was higher, yield lower and mean fibre diameter finer in Year 1 compared to Year 2 (3.89 ± 0.46 and 2.98 ± 0.46 kg, 71.4 ± 0.77 and 78.2 ± 0.75%, 31.2 ± 0.58 and 32.0 ± 0.56 um, respectively). However greasy fleece weight and fibre diameter were not different between SUP and NOSUP ewes, or between worm management treatments (Table 13).

Table 13. Quantity and quality of fleeces from ewes across years for Worm Management and dam treatment groups.

Worm management	Dam treatment	GFW (kg)	Yield (%)	CFW (kg)	FD (microns)
LTL	NOSUP	4.0 ± 0.6	74.7 ± 1.1	2.9 ± 0.5	32.1 ± 0.8
	SUP	4. 0 ± 0.6	74.3 ± 1.1	3.0 ± 0.5	32.7 ± 0.8
TYP	NOSUP	3.9 ± 0.6	74.7 ± 1.1	2.9 ± 0.5	30.8 ± 0.8
	SUP	3.9 ± 0.6	75.4 ± 1.1	2.9 ± 0.5	30.7 ± 0.8

Means within columns with different superscripts are different (P<0.05)

4.2.7 Apparent ewe mortality

The mean estimated apparent annual mortality rate for all ewes was 10.2% and this was not different between years, dam treatment or worm management groups.

4.2.8 Lamb worm egg count and larval differentiation

The arithmetic mean WEC at weaning for all lambs was 178 epg. Dam treatment had no effect on lamb WEC but NOSUP lambs had higher WEC than SUP lambs (4.2 ± 0.6 vs 2.4 ±0.6; P<0.001) and this difference was greater in TYP flocks than in LTL flocks because of lower WEC in SUP lambs (Table 14).

Table 14. Predicted mean worm egg counts (geometric, back-transformed and arithmetic means) measured at weaning for SUP and NOSUP lambs within TYP and LTL worm managed flocks.

Worm management	Lamb treatment (transformed means)		Lamb treatment (back transformed means)		Lamb treatment (arithmetic means)	
	NOSUP	SUP	NOSUP	SUP	NOSUP	SUP
LTL	4.7 ± 0.9^{a}	3.5 ± 0.9^{a}	101 ± 0.7	43 ± 0.7	212 ± 58	142 ± 58
TYP	3.7 ± 0.9^{a}	1.2 ± 0.9^{b}	52 ± 0.7	2 ± 0.7	144 ± 58	32 ± 58
mean	4.2 ± 0.6	2.4 ± 0.6	73.3 ± 0.2	13.2 ± 0.2	130 ± 41	135 ± 41

Transformed means with different superscripts are different (P<0.05)

Larval differentiation showed that *Teladorsagia* followed by *Trichostrongylus were* the predominant genera at weaning (52 and 27%, respectively) with *H. contortus* and Chabertia/Oesophagostomum making up only 14% and 6% of larvae present, respectively.

4.2.9 Lamb liveweight and condition score

The least square mean LW of lambs at marking and at weaning was 18.1 ± 0.9 and 40.4 ± 0.9 kg, respectively, representing a mean daily growth rate of 256 ± 6 g/day. Compared to ewe lambs, male lambs were heavier at marking (19.0 ± 0.9 vs. 17.1 ± 0.9 kg. P<0.01) and as wethers grew faster to weaning (263 ± 6 vs. 249 ± 6 g/day. P<0.01) were heavier at weaning (41.3 ± 0.9 vs. 39.5 ± 0.9 kg. P<0.01).

LW at marking and weaning was not different between lambs reared by SUP or NOSUP dams in either worm management group (Marking LW: 16.1 ± 1.3 vs. 15.6 ± 1.3 and 20.0 ± 1.3 vs. 20.6 ± 1.3 kg for SUP and NOSUP dams in LTL and TYP flocks, respectively; Weaning LW: 40.2 ± 1.3 vs. 39.4 ± 1.3 and 40.8 ± 1.3 vs. 41.2 ± 1.3 kg for SUP and NOSUP dams in LTL and TYP flocks, respectively). LW at weaning was not different between SUP and NOSUP lambs in either worm management treatment (39.1 ± 2.2 vs. 40.5 ± 2.2 and 41.3 ± 2.2 vs. 40.7 ± 2.2 kg for LTL and TYP groups, respectively; NS). Lamb CS at weaning averaged 3.0 ± 0.09 and this was not affected by worm treatment, dam or lamb suppression.

The mean growth rate of lambs between marking and weaning was not affected by dam treatment (255 ± 6 vs. 256 ± 6 g/day for NOSUP and SUP, respectively), lamb suppression treatment or worm management affected lamb growth (Table 15).

Table 15. Daily growth rates (ADG; least squares mean ±s.e.) between marking and weaning for SUP and NOSUP treated lambs managed by LTL or TYP procedures.

Worm management	Lamb suppression treatment	ADG to weaning (g/day)
LTL	NOSUP	264 ± 8 [a]
	SUP	273 ± 8 [a]
TYP	NOSUP	241 ± 8 [b]
	SUP	246 ± 8 [b]

Means with different superscripts are different (P<0.05)

4.2.10 Apparent lamb mortality

Overall, 81 of the 814 (10%) lambs enrolled were not present at weaning and this was greater in 2014 (54/402 – 13.4%) than in 2013 (27/412 – 6.6%). There was no effect of lamb or dam treatment or worm management on apparent lamb mortality.

4.2.11 Drench resistance testing

Faecal egg count reduction tests (FECRT) were conducted in all 4 flocks (Table 16) but the WEC in control animals in Flock TYP3 fell significantly between pre-FECRT screening (260 epg) and post-drenching sampling (18 epg) such that the precision of the results presented for this flock are low. All trial flocks had effective drenches available to treat infections with the three major species of GIN found in central NSW. Levamisole remains an option for *Haemonchus* control only, while benzimidazole was largely ineffective against all GINs. Of the macrocyclic lactones moxidectin remains an option for *Haemonchus* control in most flocks but its efficacy in *Teladorsagia* and *Trichostrongylus* was variable. Abamectin was effective on 2 farms against *Teladorsagia* and *Trichostrongylus* but not against *Haemonchus*. Closantel was effective against *Haemonchus* in 3 of 4 flocks. Naphthalophos and abamectin when given in combination with levamisole and benzimidazole was an effective option for the control of all three worm species.

Table 16. Percent reduction in worm egg count compared to undrenched controls for *Teladorsagia*, *Trichostrongylus* and *Haemonchus* in sheep drenched with various anthelmintics in LTL and TYP flocks (resistance indicated by red text).

GIN	**Control WEC* (epg)**	**Lev**	**BZ**	**IVM**	**Aba**	**Moxi**	**Clos**	**NAP**	**Nap combo**	**Aba combo**
Flock LTL 1										
Tel.	30	37	78	100	100	46		89	100	
Trich.	455	87	36	96	100	99		93	100	
Hc	985	100	96	6	24	74	99	100	100	
Flock LTL 2										
Tel.	43	0	0	81	90	100			93	100
Trich.	57	66	83	67	95	100			100	100
Hc	34	100	75	73	95	100	91		100	100
Flock TYP 3										
Tel.	6	56	100	34	89	100		76	100	100
Trich.	2	-3	100	67	100	100		36	100	100
Hc	5	100	100	33	37	100	100	100	100	100
Flock TYP 4										
Tel.	44	96	100	72	99	100	75	91	100	100
Trich.	31	41	62	98	96	100	82	68	100	100
Hc	23	100	69	-4	88	100	100	100	100	100

* WEC for control sheep at post drench sampling
Anthelmintic key: Lev = Levamisole; BZ = Benzimidazole; IVM = Ivermectin; Aba = Abamectin; Moxi = Moxidectin; Clos = Closantel; Nap = Naphthalophos; Aba combo = Aba + Lev + BZ; Nap combo = Nap + Lev + BZ

4.3 NSW South West Slopes

Details of sampling events and times are provided in Appendix 1.

4.3.1 Ewe faecal worm egg count and larval differentiation

Worm egg counts for most groups were low to moderate with values provided for worm management (Table 17) and individual farms (Fig. 5). Generally the worm suppressed groups had low or zero egg counts. On several occasions the counts in these capsuled sheep were positive as the interval between capsules slightly exceeded their payout period. Where low egg counts were recorded in capsuled sheep, it was often difficult to recover any larvae on faecal culture, suggesting the small numbers of eggs were not viable.

Worm egg counts in the non-suppressed groups (both the "best practice" (LTL) and the "typical" (TYP) mobs) were consistently higher over the lambing period (WEC2 to WEC3) and generally fell after weaning (WEC3 to WEC4) and during the summer before rising in the late summer /autumn (WEC5, 6). Averaged across Years 2-3, mean WEC of NSUP ewes were 257 epg and 197 epg on LTL and TYP farms respectively.

Table 17. Average worm egg counts (epg) for different sampling times averaged over farms.

Year	Farm type	Ewe treatment	WEC1	WEC2	WEC3	WEC4	WEC5	WEC6
1	LTL	NSUP	87	284	265	155	209	104
		SUP	111	50	24	6	28	30
2	LTL	NSUP		920	251	151	77	
		SUP		727	119	32	143	
	TYP	NSUP	217	208	186	139		
		SUP	233	117	52	54		
3	LTL	NSUP	181	138	337	78	59	374
		SUP	65	46	114	3	5	23
	TYP	NSUP		334	154	210	53	274
		SUP		279	8	3	1	71

The Riverina area is typically hot and reasonably dry over summer. Most worm problems are associated with *Teladorsagia* and *Trichostrongylus* spp. *Haemonchus contortus* is only seen very occasionally. However, the sometimes wet summers, early autumn breaks and milder winters during the "Lifting the Limits" trial period resulted in the regular detection of *Haemonchus* in larval cultures, particularly in Year 2 (Table 18).

Table 18. Mobs with *Haemonchus* spp recovered from coproculture.

	Mobs with larval culture (n)	Mobs (and % mobs) with *Haemonchus* as dominant spp
Year 1	9	1 (11%)
Year 2	16	10 (63%)
Year 3	17	6 (35%)

The presence of *Haemonchus* probably resulted in higher than normal worm egg counts being recorded in non-suppressed sheep during this trial. However, given the regular presence of *Haemonchus*, it is surprising that worm egg counts were generally below 600 epg in untreated sheep, and often well below this.

The worm egg count data probably reflects the fact that for most of the trial period, the sheep were in good to excellent condition, and pasture conditions were more favourable than expected. Thus, the level of worm challenge during the trial period was considered to be low to moderate. It was only in summer / autumn in Years 1 and 3 that sheep required any feed supplementation.

The WEC of the NIL treatment group in Year 1 remained relatively low (< 160 epg) until the ewes were under nutritional stress and losing weight post weaning. Counts rose to 300-350 epg during January to March. In contrast, in Year 3, the NIL treatment group WEC rose between lambing and lamb marking (100 epg to 375 epg) but then fell again to 140 epg at weaning and 50 epg pre-joining, before rising to 180 post joining in March. Despite these variations, it is reasonable to note that at all times these untreated sheep had relatively low egg counts, suggesting that with the possible exceptions of the January to March period in Year 1 and the lambing period in Year 3, worms were not a major issue for the sheep.

4.3.2 Ewe bodyweights

Ewe bodyweight data was collected for all mobs pre-lambing (BWT2), at lamb marking (BWT3) and at weaning or shortly afterwards (BWT4). Pre-joining (BWT5) and post-joining weights (BWT6) were recorded for all mobs in Year 3 and for two of the four mobs in Year 1. Post-scanning weights (BWT 1) were recorded for all mobs in Year 1 and on one farm (two mobs) in each of Years 2 and 3. Pre-joining weights (BWT5) were recorded on one farm (two mobs) in Year 2.

Overall, bodyweight differences between groups were relatively small, and not consistent. When averaged over the two years of comparison, NSUP ewes lost 1.1 kg (LTL) and 1.5 kg (TYP) more weight compared to SUP ewes. As expected, despite the overall background of only a low to moderate worm challenge, based on the WEC data and the favourable nutritional status and condition of the sheep, the worm suppressed ewes generally gained or maintained higher bodyweights than the non-suppressed ewes in the same mobs. Thus, for the 20 mob comparisons between worm suppressed and non-suppressed ewes, worm suppressed ewes were heavier by at least 0.5 kg in 13 mobs, while in only 3 mobs, non-suppressed ewes were heavier by at least 0.5 kg. (There was less than a 0.5 kg difference in 4 mobs). For 6 of the 13 mobs the weight advantage occurred over the lambing period and was then maintained for the remainder of the trial. For the remaining 7 flocks the gains were relatively small during the lambing period but accumulated over the duration of the trial.

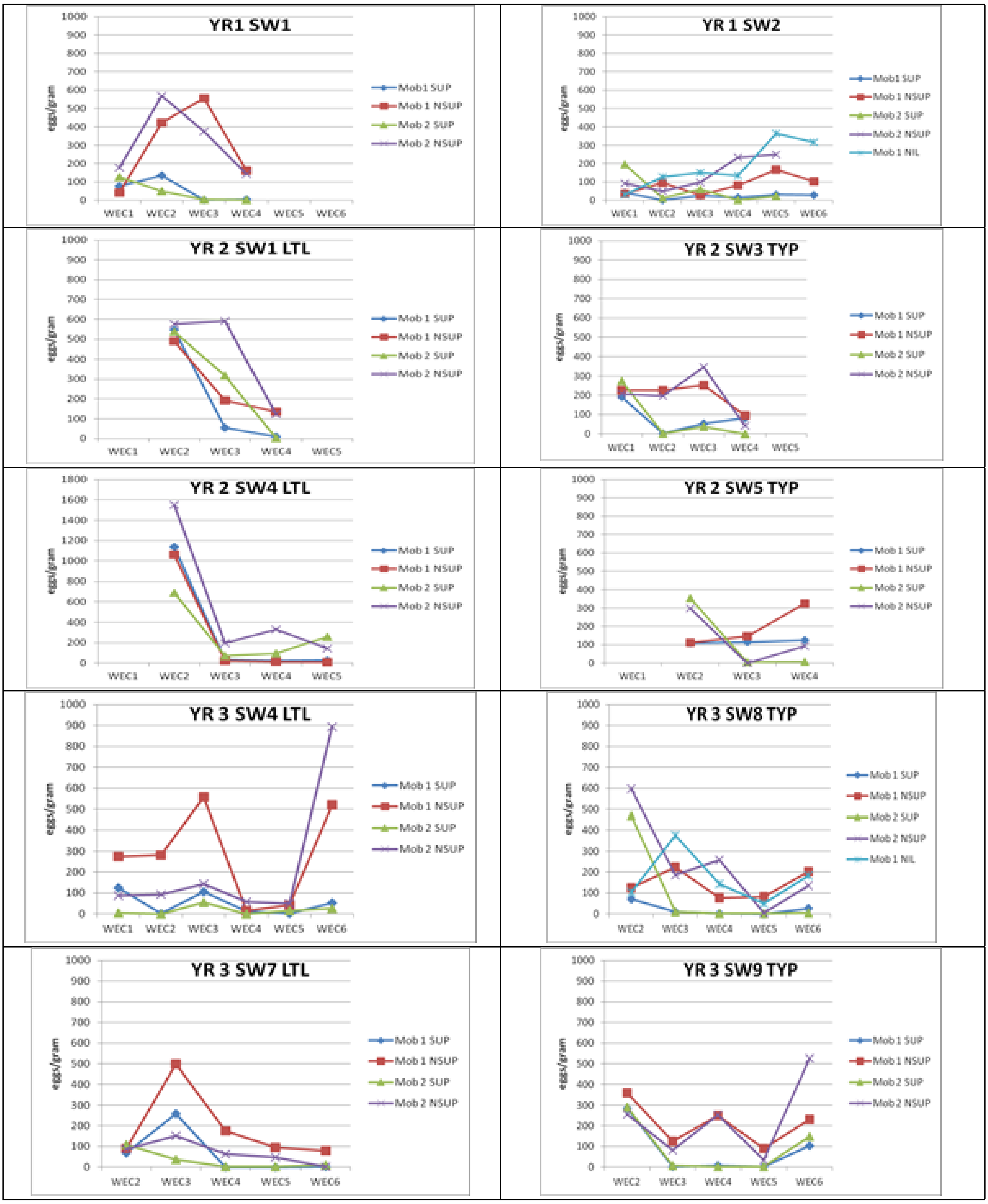


Fig 5. Worm egg counts (epg) of ewes from farms within LTL and TYP management across project years 1-3.

Weight differences between non-suppressed (NSUP) and suppressed (SUP) ewes for “best practice” and “typical” farms are shown in Table 19. This table highlights a small but consistent disadvantage in weight gain for NSUP ewes. In year 2 that difference was more marked on “typical” farms. In Year 3, differences were less and more variable. Year 3 was associated with an exceptional autumn and winter period, with abundant feed in both autumn and winter.

Table 19. Weight differences between non-suppressed (NSUP) and suppressed (SUP) ewes.

	Weight changes over lambing (kg)			Weight changes from initial to last weight (kg)		
	NSUP	SUP	Difference	NSUP	SUP	Difference
Year 1						
Best Practice (LTL)	-4.2	-2.3	-1.9	-9.0	-5.6	-3.4
Year 2						
Best Practice (LTL)	-9.3	-8.1	-1.2	0.7	2.0	-1.4
Typical (TYP)	-8.4	-6.0	-2.4	7.2	9.0	-1.8
Year 3						
Best Practice (LTL)	-7.4	-6.4	-1.0	-1.9	-1.1	-0.7
Typical (TYP)	-1.0	-1.6	0.6	-5.5	-4.4	-1.2

Weight differences between “best practice” and “typical” farms are summarised in Table 20. This table shows the advantage (if positive) or disadvantage (if negative) for “best practice” farms compared to “typical” farms. Thus in Year 2 in the low rainfall comparison, the weight differences between the suppressed and non-suppressed ewes on the “best practice” farm was 1.2 kg less than the weight differences between the suppressed and non-suppressed ewes on the “typical” farm.

Table 20. Weight differences between NSUP and SUP ewes on “best practice” and “typical” farms in low and high rainfall environments.

	Weight changes over lambing (kg)	Weight changes from initial to last weight (kg)
Year 2		
Low rainfall	1.2	-0.3
High rainfall	1.5	1.3
Year 3		
Low rainfall	2.8	2.4
High rainfall	-2.9	0.7

The fact that differences are relatively small and not always consistent is probably not surprising, given:

1. The worm challenge did not appear particularly high during the trial period
2. The ewes were generally in good condition
3. All farmers carried out similar treatments in their non-suppressed groups, irrespective of whether it was a “best practice” or “typical” farm, namely, a pre-lambing treatment.

The most consistent differences were in the low rainfall comparison, showing ewes were approximately 1-3 kg lighter at lamb marking on “typical” farms compared to “best practice” farms.

Interestingly, in Year 1 in the NIL treatment group, despite low worm egg counts, the NIL group lost considerable weight over the lambing period (BWT2 to BWT3), as shown in Fig. 6. Similarly in Year 3, the NIL group lost 3.8 kg over the lambing period, and at the end of the trial remained 3.8 kg lighter.

These observations, particularly with the NIL groups, suggest that despite low egg counts, first cross ewes, particularly twin bearing ewes, will benefit from pre-lambing drenching.

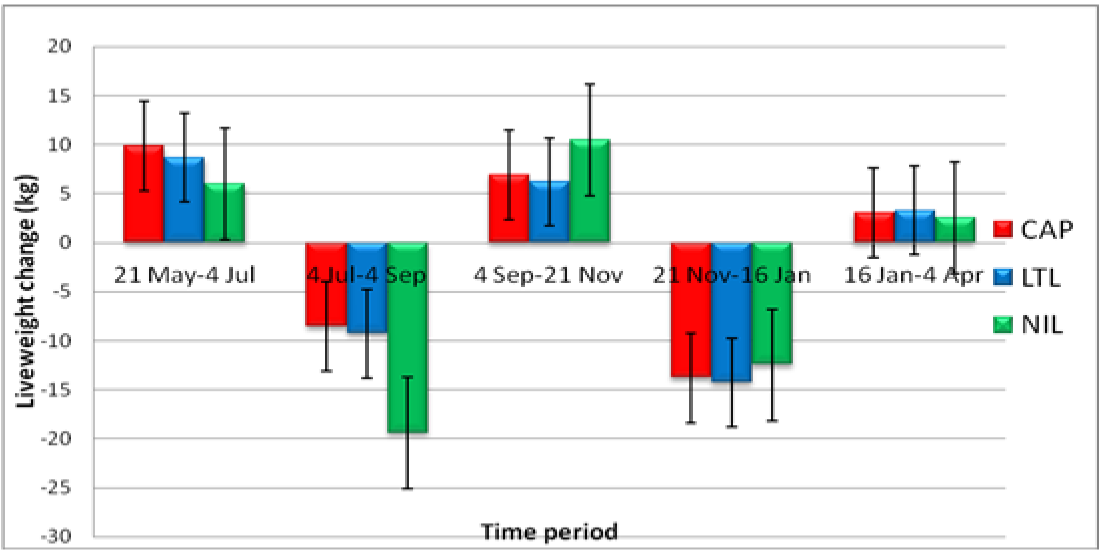


Fig 6. Weight changes in ewes that were worm suppressed (CAP) or not (LTL) or remained untreated (NIL) on LTL farms during Year 1. SW2. Graph from Emily Sims. Standard error bars shown.

4.3.3 Lamb bodyweights

Lambs born from the trial ewes were weighed at or shortly after lamb marking and again prior to the sale of the first draft of lambs on all but one of the farms (no lamb data was collected for SW9 in Year 3). At lamb marking, there was no clear advantage for lambs that were reared from worm suppressed ewes (capsule ewes) compared to those that had been reared from ewes that had received either no treatment or a short acting pre-lambing drench. For 13 comparisons available:

- for 6 mobs, lambs from worm suppressed ewes were greater than 0.5 kg heavier than lambs from non-worm suppressed ewes
- for 2 mobs, lambs from non-worm suppressed ewes were greater than 0.5 kg heavier than lambs from worm suppressed ewes
- for the remaining 5 mobs, differences in lamb weights were less than 0.5 kg.

NB. On two farms, mobs of non-worm suppressed ewes either received the same brand of capsule as the worm suppressed ewes (Yr 2 SW5) or a long acting moxidectin formulation (Yr 2 SW4). These 4 mobs were excluded from this comparison.

In terms of weight gain in lambs from marking to first sale, gains tended to be faster in lambs from non-worm suppressed ewes, with 7 mobs having superior weight gains (>0.5 kg) in lambs from non-worm suppressed ewes, while 1 mob had superior weight gains (>0.5 kg) in lambs from worm-suppressed ewes. There was little or no difference in weight gains in the remaining 6 mobs. Table 21 provides a summary of lamb weights by ewe treatment for all mobs.

Table 21. Summary of lamb weights by ewe treatment, for all mobs for all years.

Farm Type		Weight 1 (kg)*	Weight 2 (kg)*	Weight Gain (kg)
Best practice (LTL)	Lambs from worm-suppressed ewes	21.0	36.8	15.8
	Lambs from non-worm suppressed ewes	20.5	36.5	16.1
Typical (TYP)	Lambs from worm-suppressed ewes	21.4	39.2	17.8
	Lambs from non-worm suppressed ewes	20.7	39.5	18.8

*Weight 1 - lamb marking or 2-4 weeks post marking. Weight 2- immediately prior to first lambs being sold, approximately 8 weeks post weight 1.

For the two mobs where NIL treatment ewes were monitored, the comparisons are between lambs from capsule ewes, lambs from ewes drenched with an effective short acting drench pre-lambing and lambs from ewes which received no drench (see Table 22).

Table 22. Summary of lamb weights by ewe treatment with inclusion of NIL treatment mobs.

		Weight 1 (kg)	Weight 2 (kg)	Weight Gain (kg)
Year 1	Lambs from capsuled ewes	13.9	31.8	18.0
	Lambs from pre-lamb drenched ewes	13.4	31.3	17.9
	Lambs from NIL ewes	10.7	31.3	20.6
Year 3	Lambs from capsuled ewes	15.6	37.1	21.4
	Lambs from pre-lamb drenched ewes	15.9	38.1	22.1
	Lambs from NIL ewes	15.6	N/A	N/A

Overall, while there were sometimes advantages at or shortly after lamb marking from ewe treatment, any differences were largely negated by the time lambs were ready for sale.

Similarly, suppressive treatments of lambs from lamb marking until first sale (monthly drenching) had a small and variable effect on lamb weight gains. For 10 of the 17 mobs, there was little or no difference in lamb weight gain (<0.5 kg); in 6 mobs there was a small advantage in weight gain for worm suppressed lambs (0.7-2.2 kg) and in 1 mob, untreated lambs gained more weight. Overall the average weight gain was 16.6 kg for both monthly drenched lambs and undrenched lambs.

4.3.4 Drench Resistance Status

Drench efficacy was determined on 6 of the 8 farms either prior to the farm being involved in the trial, or as a result of the trial. A summary is provided in Table 23. Drench resistance status for worm species is given in Table 24. There were insufficient worm larvae recovered for SW2 and SW8 to provide this data.

Table 23. Drench Efficacy (% reduction in worm egg count) for Trial farms.

Farm	½ IVM	IVM	Mox	BZ+LEV	BZ+LEV +OP	BZ+LEV +IVM	LEV	Other	Description Other
SW1		84%		98%		98%		100%	Derq/ABA
SW2	32%	88%		71%	100%**		79%	48%	BZ
SW4*			62%				100%	69%	⅓ Closantel
SW7		83%	100%	93%	97%			100%	Derq/ABA
SW8	60%	84%		73%		100%	98%***		
SW9		49%		88%	92%			100%	Derq/ABA

* *Haemonchus* spp only, **BZ+OP and LEV+OP, ** *Lev x2

SW1 = LTL, SW2 = LTL, SW4 = LTL, SW7 = LTL, SW8 = TYP, SW9 = TYP

Table 24. Drench resistance status (% efficacy) for worm species for farms with larval culture results.

Farm	Spp	IVM	Mox	BZ+LEV	BZ+LEV +OP	BZ+LEV +IVM	LEV	Other	Description Other
SW1	Trich.	100 %		100%		100%		100 %	Derq/ABA
	Tela	97%		97%		95%		100 %	
	Haem.c.	67%		100%		100%		100 %	
SW4 *	Trich.								
	Tela								
	Haem.c.		62%				100 %	69%	⅓ Closantel
SW7	Trich.	59%	100 %		94%			100 %	Derq/ABA
	Tela	86%	100 %		96%			100 %	
	Haem.c.	91%	100 %		100%			100 %	
SW9	Trich.	100 %		83%		0%		100 %	Derq/ABA
	Tela	60%		48%		100%		100 %	
	Haem.c.	42%		100%		100%		100 %	

SW1 = LTL, SW4 = LTL, SW7 = LTL, SW9 = TYP

As can be seen from Tables 6 and 7, drench resistance is common on farms and the high prevalence of drench resistance has been well documented. It therefore reinforces the importance of individual farm tests to ascertain the range of effective drenches for that farm, to ensure that drenching when needed is effective.

It should be noted here that while there have been strong suggestions that summer drenching is likely to increase drench resistance due to the paucity of refugia at the time of drenching, this is unlikely to be the case with pre-lamb drenching.

4.3.5 Reproductive performance

There were insufficient data available to compare “best practice” and “typical” farms on subsequent reproduction performance (number of foetuses per 100 ewes). However, it was noted that for the 12 mobs where comparisons could be made between sheep that had received no capsules or a single capsule prior to lambing and those sheep that received multiple capsules for worm suppression during the year that in 6 cases the difference was greater than 10 lambs per 100 ewes and in 5 of those 6 cases, this was in favour of the “non-suppressed” ewes and in only one case was it in favour of the regularly capsule sheep. (In 6 of the 12 comparisons differences were less than 10 lambs /100 ewes).

This is a somewhat surprising result, given that in 17 out of 24 comparisons capsule sheep were at least 0.5 kg heavier than non-capsuled sheep and only in 3 cases did non-capsuled sheep have a weight advantage of over 0.5 kg. Therefore, given the small but generally consistent weight gains associated with sustained worm suppression, and the strong association between bodyweight and subsequent fertility, it would have been expected that reproductive performance would have been at least the same or higher in capsuled ewes.

While successive use of capsules is not recommended for worm control, and was only used in these trials to facilitate between farm comparisons, this preliminary data does suggest that further investigation on the reproductive effects of prolonged worm suppression using capsules is warranted if such strategies are considered in the future.

4.3.6 Wool production

Mobs were enrolled into the trial in April to June and the trials ended in the following April /May. All flocks enrolled shore sheep in late spring which meant that measurements at shearing only related to part of the trial period. Fleece measurements were collected from one mob in Year 1 and from 4 mobs in Year 2. No comparisons could be made in terms of wool production between “best practice” and “typical” flocks due to the lack of data. It was determined that it was not appropriate to assess wool production from the Riverina flocks due to the time of shearing in relation to the trial.

4.3.7 Ewe “mortality”

Ewe “mortality” was calculated for each group based on the number of ewes absent at the final weighing (out of the 60 ewes enrolled in each group). It is possible that a small number of tags were lost, which would mean ewe “mortality” was overestimated. It was also apparent on several farms that a number of trial ewes were either unexpectedly sold, or were inadvertently moved out of the trial mob. Therefore the numbers need to be treated with some caution.

For all mobs, the average number of ewes present at the trial completion was 46.4 and 47.0 for capsule and non-capsuled groups. For the 24 mobs analysed, 9 mobs had lost fewer ewes from the capsule groups and 12 mobs had lost fewer ewes from the non-capsule groups and 3 mobs had equal numbers.

Fifty five ewes or more were present in only 9 out of 42 groups of ewes, and 8 out of 9 of these were managed by the one farmer. Thus, even allowing for 1 or 2 ewes losing their tags, annual ewe “mortality” appeared to be higher than 5% in 80% of trial mobs.

4.4 Victoria (high winter rainfall)

Given the larger geographic area in this region, the location of properties is provided. Vic-1 was paired with Vic-3, both being located near Mortlake, 200 km west of Melbourne. Vic-2 (Winchelsea) was paired with Vic-4 (Birregurra), being located about 100 km southwest of Melbourne Details about farms are provided in Appendix 2. Measurements of rainfall and pasture are provided in Appendix 3.

4.4.1 Ewe worm egg counts, anthelmintic treatments and condition score

The arithmetic mean worm egg counts (WECs) and timing of treatments for NSUP ewes on each farm in each year are shown in Figs. 7-10. There were no consistent differences between the WECs of ewes on the LTL or TYP farms. The WECs of worm suppressed (SUP) ewes were always less than 75 epg, except in Year 2 when several ewes had counts of 100-700 epg, indicating that the controlled-release capsule had not been correctly administered. These ewes were also lighter than other ewes in the SUP group and so they were excluded from the analysis.

4.4.1.1 Farm Vic-1(LTL)

In Year 1, WECs remained relatively low until lamb marking when they increased to be 412 and 584 epg for the adult Coopworth and Merino ewes, respectively (Fig. 7). Ewes were treated with abamectin at this time because of their relatively low condition score (average CS = 1.9 for Coopworths, 2.0 for Merinos) and the low pasture availability (< 600 kg DM/ ha). No faecal samples were taken at pre-joining because ewes received their second summer drench 4 weeks before this visit. Coopworth hogget ewes had a WEC of 188 epg at lamb marking, and so were not treated, but were given their first strategic summer treatment with combination of abamectin, albendazole and levamisole (Aba+ABZ+Lev) at weaning in Dec. In Feb WECs were 495 epg when these ewes received their second summer drench.

In Year 2, both Coopworth and Merino NSUP ewes received additional anthelmintic treatments (ABZ and Lev combination) at the pre-lambing and marking visits because of their low body condition (CS = 2.2 and 2.1, respectively) and the short pasture.

In Year 3, both Coopworth mobs had low WECs at pregnancy scanning and pre-lambing (< 100 epg) and the peak was lower than in previous years (400 epg in Mob 2). NSUP ewes were not treated at lamb marking because they were in adequate body condition (CS = 2.8 & 2.6) and the first summer drench with a combination of Aba+ABZ+Lev was due at weaning within 4 weeks. The WEC at pre-joining was < 20 epg in both mobs and so ewes were not given a second summer treatment.

4.4.1.2 Farm Vic-2 (LTL)

In Year 1, WECs were below 80 epg in both the single and twin-bearing mobs at scanning and pre-lambing, and then peaked at 710 (twin-bearing) and 400 epg (single-bearing) at marking (Fig. 8). NSUP ewes were not treated with an anthelmintic at lamb marking because there was ample pasture and ewe condition score was satisfactory (average CS = 2.7 & 3.3 for twin- and single-bearing mobs, respectively). At weaning, counts were 480 and 280 epg and the ewes were given their first strategic summer treatment with Aba+ABZ+Lev. WECs before joining were zero and so a second summer drench was not needed.

In Year 2, WECs for twin-bearing ewes were lower than Year 1, peaking at around 250 epg at marking. Mean counts of the single-bearing ewes decreased from 365 epg at scanning to 100 epg at weaning. Both mobs of ewes were treated with an anthelmintic at weaning

(Aba+ABZ+Lev), their first summer drench, and no second summer treatment was needed (WEC < 100 epg).

In Year 3, WECs at marking in the twin- and single-bearing ewes peaked at 790 and 270 epg, respectively. NSUP ewes were not treated at this time because ewes were in good body condition (CS = 2.8) and pasture was adequate (1600 kg DM/ ha). WECs in both mobs decreased to around 140 epg at weaning, when ewes were given their first strategic summer treatment (Aba+ABZ+Lev). However, unlike previous years, counts were > 100 epg in Feb at pre-joining and so a second summer treatment was given (both Aba+ABZ+Lev).

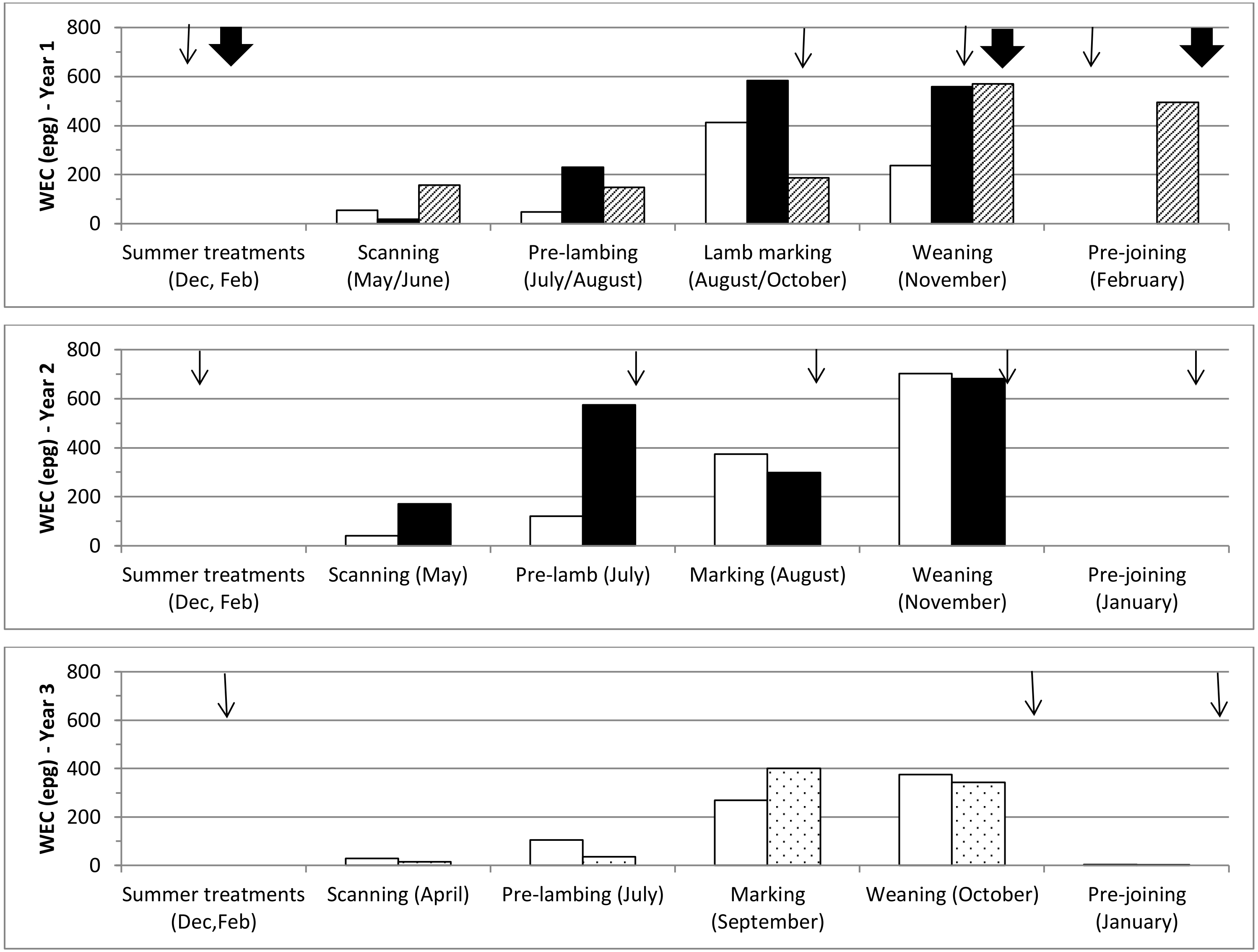


Fig 7. Arithmetic mean worm egg count (WEC) of Adult Coopworth (clear bars; dotted bar for Mob 2, Year 3) and Merino ewes (solid bar), and Coopworth hoggets (striped bar), at each visit on Farm Vic-1 in Years 1-3 (timing of anthelmintic treatments to adult ewes indicated by small arrows and to hoggets by broad arrows).

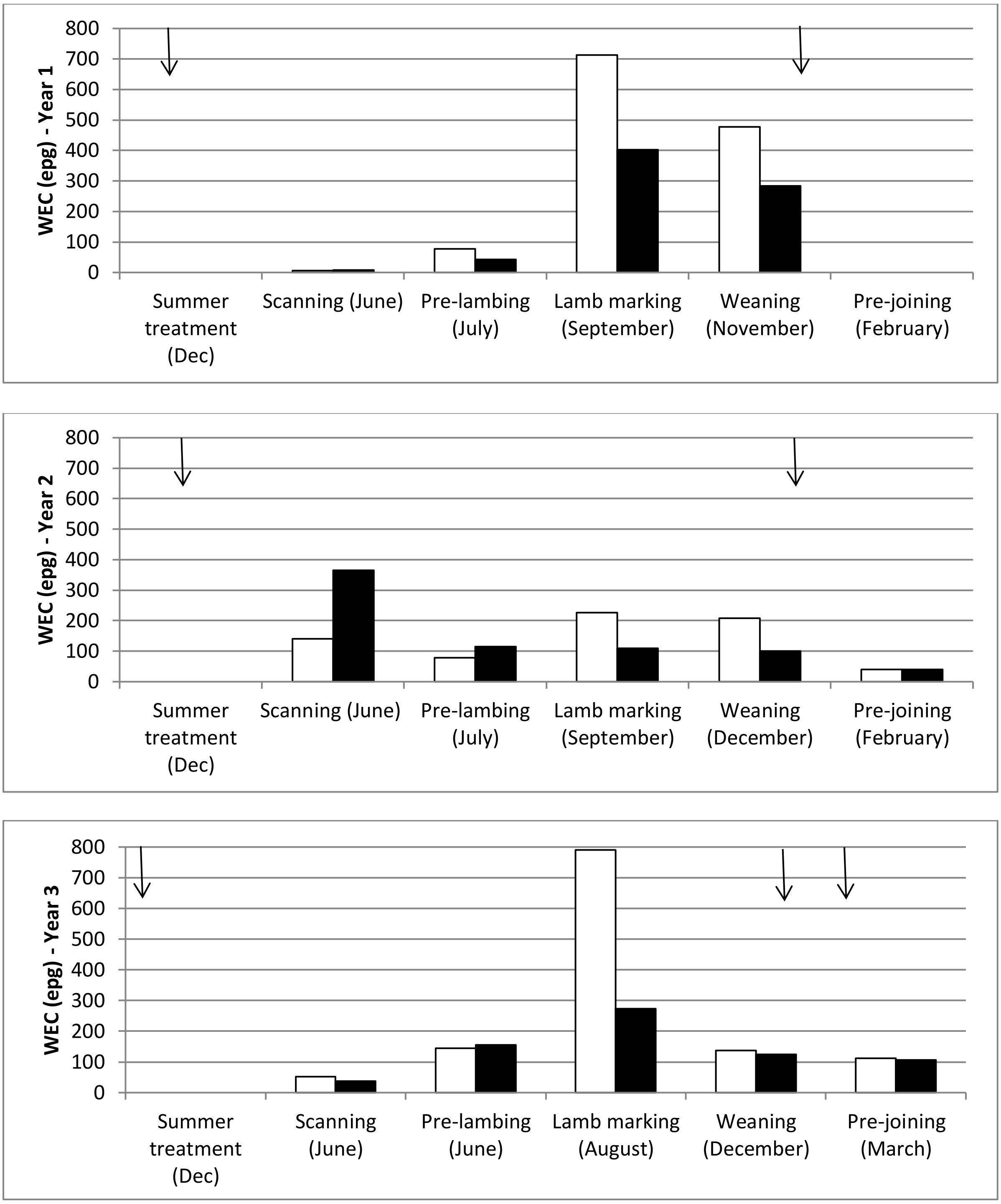


Fig 8. Arithmetic mean worm egg count of Composite twin-bearing (clear bar) and single-bearing ewes (solid bar) at each visit on Farm Vic-2 in Years 1-3 (timing of anthelmintic treatments to ewes indicated by arrows).

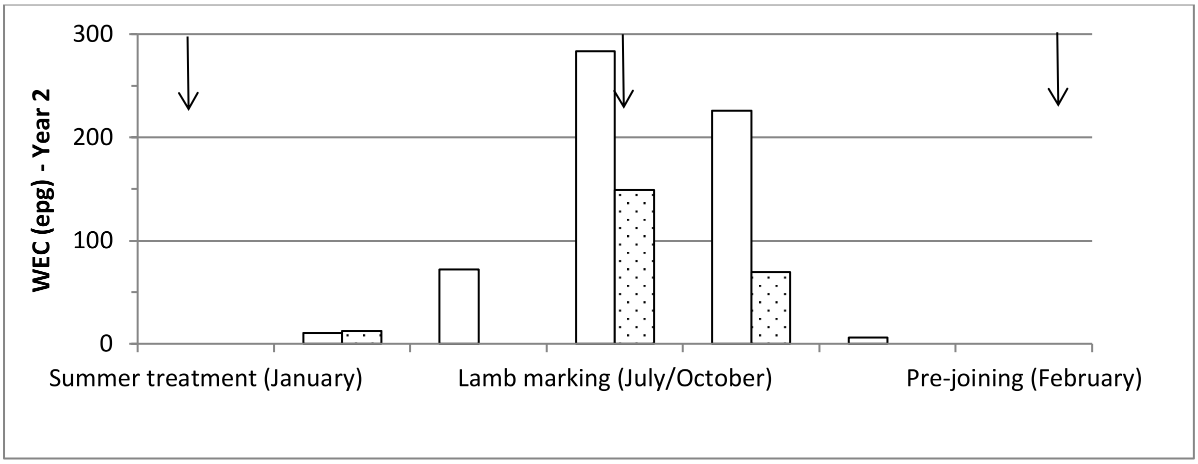


Fig 9. Arithmetic mean worm egg counts from Composite twin-bearing ewes (clear bar) and composite twin-bearing hoggets (dotted bar) at each visit on Farm Vic-3 in Year 2 (timing of anthelmintic treatments to ewes indicated by arrows).

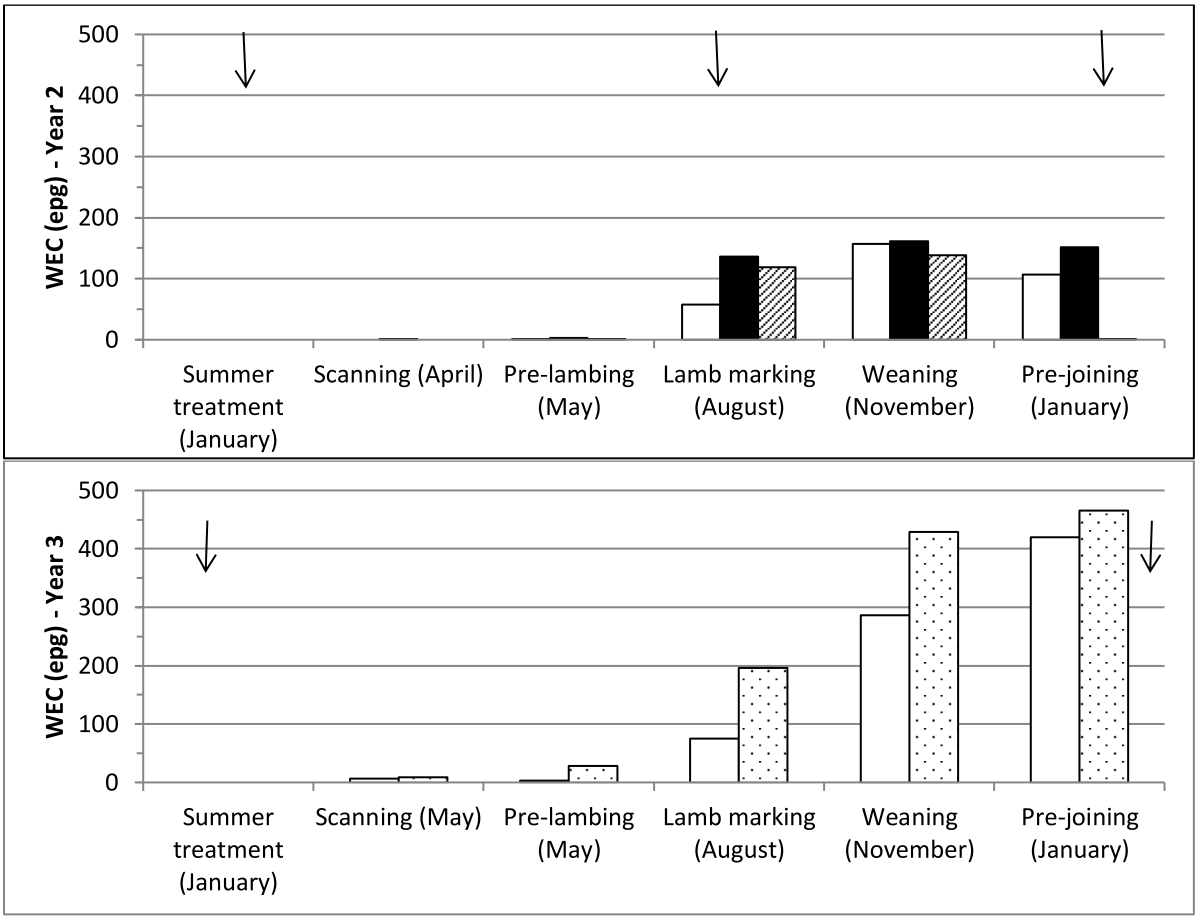


Fig 10. Arithmetic mean worm egg counts from adult First-cross ewes bearing twin lambs (clear bar), Merino ewes bearing mostly single lambs (solid bar), and maiden First-cross ewes bearing twin lambs (striped bar) at each visit on Farm 4 in Years 2 and 3 (timing of anthelmintic treatments to ewes indicated by arrows).

4.4.1.3 Farm Vic-3 (TYP)

The WEC remained relatively low in both adult and hogget ewes, with a peak in adult ewes of just under 300 epg at marking (Fig 9). Despite these low counts the manager decided to treat all NSUP adult ewes and hoggets with abamectin before lambing (CS = 2.7 and 2.9, respectively).

4.4.1.4 Farm Vic-4 (TYP)

In Year 2, WECs reached a maximum of 160 epg (Fig. 10). Despite these low WECs, the farm manager elected to treat all ewes before lambing because of the low pasture availability and low condition scores in the Merinos (CS = 2.4 and 2.9 for Merino and First-cross ewes, respectively). Counts in the Merinos remained above 120 epg from marking onwards, whereas those for the adult First-cross ewes peaked at 160 epg in November then declined to 105 epg at pre-joining. The WEC of maiden First-cross ewes was 140 epg in November. These ewes were treated with moxidectin before and adult Merino and First-cross ewes were treated with moxidectin immediately after the pre-joining visit.

During Year 3, the WECs of both ewe mobs increased steadily (Fig. 10). At lamb marking, the producer elected to treat ewes with moxidectin, a decision not based on the WEC or ewe condition score (CS = 2.7 and 2.5 for 4 y.o and 3 y.o ewes, respectively). Counts at this time were 75 epg in the twin-bearing and 195 epg in the mostly single-bearing ewes. Counts increased again during the spring and summer, and at pre-joining the twin- and mostly single-bearing ewes had WECs of over 450 and 400 epg, respectively. Ewes were treated with moxidectin at this time, which was routine practice on this farm.

4.4.2 Ewe breech soiling ('dag')

There was very little breech soiling on any farm during the study, hence the average dag scores and proportion of sheep with moderate or severe dag (a dag score ≥2) remained relatively low. Ewes were generally crutched before lambing, then again either before shearing or joining. Dag scores at weaning were generally the highest and so these were compared between the treatment groups using the Mann-Whitney test (Table 25).

Treatment with a controlled release capsule significantly reduced the average dag score and proportion of sheep with moderate or severe dag, with SUP ewes having significantly less dag at weaning than NSUP ewes on 12 of 20 occasions during the 3 years of the study (6 of 7 occasions on Farm 1, 5 of 6 occasions on Farm 2, but only 1 of 7 combined occasions for Farms 3 and 4). The degree of this protection varied, but was often less than for previous studies involving Merinos. For example, in Year 2 there was very little breech soiling on Farm 2 but the relative risk of moderate or severe dag in all NSUP ewes at weaning was 8.0 times that for SUP ewes (95% CL 1.0-62.9; 8 of 111 SUP ewes (7%) had a DS ≥2). On Farm 3 in the same year, the relative risk was 2.3 times (95% CL 1.2-4.3), with 23 of 59 NSUP ewes (42.4%) having a DS ≥2.

Table 25. Average dag scores at weaning of ewes in the NSUP and SUP groups on all farms in all years.[1]

Farm	Ewe mob (scanned with)	Year 1		Year 2		Year 3	
		NSUP	SUP	NSUP	SUP	NSUP	SUP
1	Adult Coopworth (twins)	1.6	0.6[b]	1.7	1.3[a]	1.4	0.7[b]
	Adult Merino (mostly twins)	1.5	0.5[b]	1.6	1.1[a]	-	- [3]
	Coopworth hogget (twins)	0.6	0.3	- [2]	-	-	-
2	Composite (twins)	0.5	0.1[c]	0.5	0.2	1.0	0.3[c]
	Composite (singles)	0.5	0.4[b]	0.5	0.3[a]	0.8	0.3[b]
3	Adult Composite (twins)	-	-	1.4	0.7[c]	-	-
	Hogget Composite (twins)	-	-	0.0	0.1	-	-
4	Merino (mostly twins)	-	-	0.4	0.3	-	-
	Adult First-cross[4]	-	-	0.3	0.2	0.1[6]	0.1
	Younger First-cross[5]	-	-	0.2	0.1	0.0[6]	0.0

[1] Highlighted cells denote significant difference between the treatment groups within each mob in each year: Mann-Whitney P < 0.05[a], < 0.01[b], < 0.001[c]; [2] a dash indicates this mob not included in that year of the study; [3] a second mob of adult Coopworths had average dag scores of 0.8 and 0.1 for NSUP and SUP ewes, respectively (P < 0.01); [4] mixed age in Year 2, 4 y.o in Year 3; [5] 2 y.o maidens with mostly twin lambs in Year 2, 3 y.o ewes with mostly single lambs in Year 3; [6] All ewes crutched prior to weaning and so scores for marking visit included

4.4.3 Ewe bodyweights

4.4.3.1 Farm Vic-1 (LTL; Coopworth and Merino ewes)

In Year 1, SUP ewes were significantly heavier than NSUP ewes at lamb marking, weaning and pre-joining in all three groups (Table 26). There was a 3.9-5.9 kg difference in the adult Coopworth, 3.6-4.7 kg difference in the adult Merino and 2.2-3.9 kg difference in the Coopworth hogget ewes.

In Year 2, adult Coopworths were 11.6 kg lighter, and Merinos 5 kg lighter at scanning compared to Year 1. The only significant difference in mean bodyweights during this year was when SUP Coopworths were 2.6 kg heavier than NSUP ewes before lambing.

In Year 3, two mobs of adult Coopworth ewes were monitored. In Mob 1, SUP ewes were significantly heavier on one occasion (weaning, 4.1 kg). In Mob 2, ewes averaged 65 kg at scanning, but the NSUP group was significantly heavier (2.7 kg) due to random error. Consequently, the change in bodyweight of each group was calculated and compared between the groups at each visit rather than the absolute bodyweight. This found a significant difference between the mean bodyweight change of the two treatment groups between pre-lambing and marking (2.3 kg; P<0.01).

4.4.3.2 Farm Vic-2 (LTL; Composite ewes)

In Year 1, twin-bearing SUP ewes were significantly heavier than N-SUP ewes at weaning (4.7 kg), whereas single-bearing SUP ewes were significantly heavier than N-SUP ewes at both weaning and pre-joining (3.8 and 3.4 kg, respectively; Table 27).

Table 26. Mean (standard deviation) bodyweight of ewes subjected to the usual worm control program (NSUP) and the mean difference in bodyweight of worm-suppressed ewes (SUP) on Farm Vic-1 (LTL).[1]

Year	Ewe age & breed	Group	Bodyweight (kg) at:				
			Scanning	Pre-lambing	Marking	Weaning	Pre-joining
1	Adult Coopworth (twin lambs)	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 [c]	+4.7[b]	+5.9[c]
	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[c]	+4.7[b]	+3.6[b]
	Hogget Coopworth	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[a]	+3.9[b]	+2.5[a]
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[a]	1.2	2.1	2.2
	Adult Merino (single & 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	Adult Coopworth–Mob 1 (twins)	NSUP	66.3 (6.4)	87.9 (7.4)	70.7 (6.7)	74.7 (7.2)	63.6 (6.2)
		SUP	-2.7[a]	-2.5	1.1	0.6	0.3
	Adult Coopworth–Mob 2 (twins)	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[a]	1.7

[1] Significant differences between groups are highlighted: [a]P<0.05; [b]P<0.01; [c]P<0.001

In Year 2, twin-bearing ewes were 8.8 kg lighter, and single-bearing ewes were 5.3 kg lighter at scanning compared to the corresponding mob in Year 1. Twin-bearing SUP ewes were significantly heavier than N-SUP ewes at pre-lambing, weaning and pre-joining (2.6-4.4 kg), but there were no significant differences between treatment groups in single-bearing ewes.

In Year 3, twin-bearing ewes were 6.4 kg heavier and single-bearing ewes 9.3 kg heavier at scanning compared to the corresponding mob in Year 1. Twin SUP ewes were significantly heavier than NSUP ewes at weaning and pre-joining, 4.4 kg and 3.0 kg, respectively, and single-bearing SUP ewes were significantly heavier than NSUP ewes at weaning (3.3 kg).

4.4.3.3 Farm Vic-3 (TYP; Composite ewes)

In Year 2 (2013), the only year the study was conducted on this farm, adult twin-bearing ewes were allocated to treatment groups at scanning whereas the twin-bearing hoggets were allocated at pre-lambing. SUP ewes in both age groups were significantly heavier than NSUP ewes at marking, weaning and pre-joining in the adult (3.2, 5.1 and 6.6 kg, respectively) and hogget ewes (3.0, 5.7 and 4.3 kg; Table 28).

Table 27. Mean (standard deviation) bodyweight of ewes subjected to the usual worm control program (NSUP) and the mean difference in bodyweight of worm-suppressed ewes (SUP) on Farm 2.[1]

Year	Ewe age & breed	Group	Bodyweight (kg) at:				
			Scanning	Pre-lambing	Marking	Weaning	Pre-joining
1	Adult Composite (multiple lambs)	NSUP	60 (7.2)	71.3 (7.7)	69.2 (7.9)	69.5 (9.0)	56.7 (5.8)
		SUP	-0.7	0.7	2.4	+4.7[b]	2.8
	Adult Composite (single lambs)	NSUP	56 (7.9)	65.7 (7.6)	72.1 (8.7)	74.5 (7.7)	57.2 (5.9)
		SUP	1.7	3.2	1.9	+3.8[a]	+3.4[a]
2	Adult Composite (multiple lambs)	NSUP	51.2 (5.3)	69.6 (5.7)	64.7 (5.9)	65.7 (7.0)	62.2 (5.5)
		SUP	0.5	+2.6[a]	1.6	+4.4[b]	+3.3[b]
	Adult Composite (single lambs)	NSUP	50.7 (7.7)	61.5 (7.7)	64.1 (7.5)	64.3 (7.8)	62.2 (7.8)
		SUP	-1.9	-0.1	0.4	2.1	0.5
3	Adult Composite (multiple lambs)	NSUP	66.4 (6.3)	71.2 (7.3)	64.8 (7.2)	65.6 (7.9)	58.6 (7.4)
		SUP	-1.2	-1.2	-0.1	+4.4[b]	+3.0[a]
	Adult Composite (single lambs)	NSUP	65.3 (7.1)	67.7 (7.8)	71.0 (7.5)	67.0 (6.9)	60.8 (8.2)
		SUP	-1.6	-0.7	0.7	+3.3[a]	0.1

[1] Significant differences between groups are highlighted: [a]$P<0.05$; [b]$P<0.01$; [c]$P<0.001$

Table 28. Mean (standard deviation) bodyweight of ewes subjected to the standard worm control program (NSUP) and the mean difference in bodyweight of worm-suppressed ewes (SUP) on Farms 3 and 4 in Years 2 and 3.[1]

Farm	Year	Ewe age & breed	Group	Bodyweight (kg) at: Scanning	Pre-lambing	Marking	Weaning	Pre-joining
3	2	Adult Composite (twin lambs)	NSUP	55.9 (5.4)	64.5 (5.1)	55.5 (5.6)	57.1 (6.1)	67.0 (6.6)
			SUP	0.5	0.7	+3.2[b]	+5.1[c]	+6.6[c]
		Hogget Composite (twin lambs)	NSUP	NM	54.1 (4.2)	60.6 (4.7)	60.8 (5.2)	66.6 (5.1)
			SUP	NM	0.4	+3.0[b]	+5.7[c]	+4.3[b]
4	2	First-cross (twin lambs)	NSUP	66.5 (5.7)	63.9 (5.9)	52.5 (5.5)	65.5 (6.0)	66.7 (5.7)
			SUP	-0.7	-0.5	-0.5	0	0.3
		2yo First-cross (maidens with twins)	NSUP	54.4 (6.1)	52 (4.9)	47.1 (5.6)	57.1 (5.4)	58.1 (5.6)
			SUP	-0.3	-0.4	0.7	0.6	2.1
		Merino (single & twin lambs)	NSUP	44.7 (5.1)	45.6 (5.5)	41.8 (5.4)	50.7 (5.5)	49.9 (4.9)
			SUP	1.5	1.1	1.6	+2.6[a]	1.8
	3	4yo First-cross (twin lambs)	NSUP	65.4 (7.3)	71.2 (7.4)	62.1 (7.3)	72.6 (7.6)	61.5 (6.6)
			SUP	1.3	1.6	1.4	0.9	1.5
		3yo First-cross (single and twin lambs)	NSUP	58.4 (6.3)	58.1 (5.7)	55.5 (5.5)	60.4 (5.4)	52.4 (4.8)
			SUP	0.1	0.8	0.1	0.6	1.6

[1] Significant differences between groups are highlighted: [a]P<0.05; [b]P<0.01; [c]P<0.001

4.4.3.4 Farm Vic-4 (TYP; First-cross & Merino ewes)

There were no significant differences between the two treatment groups in any of the First-cross ewes in either Year (Table 28). In Year 2, SUP Merino ewes were significantly heavier than NSUP Merino ewes at weaning (2.6 kg).

4.4.4 Multivariable analysis of ewe bodyweight

Data from all years on the four Victorian farms was aggregated and subjected to a multivariable analysis to determine the effect of several factors on ewe bodyweight (Table 29).

Overall, there was a significant effect of year, management type, treatment and litter size. The individual ewe effect is large, and because there are still significant associations between the fixed effects and outcomes after controlling for the effect of ewe, the model gives good assurance that these associations are real.

Table 29. Results from the multivariable model for ewe bodyweight showing the reference group (ref) and effect of each variable (year, management type, treatment group, litter size, breed, individual ewe and farm) on ewe bodyweight throughout the study.

Variable	**Categories**	**Beta**	**95% CL[2]**	**SE**	**t**	**Pr(>|t|)**
Intercept		60.9	56.0-65.7	2.47	24.69	<0.0001
Year (ref: 2012)	2013	-4.33	-5.0- -3.7	0.32	-13.45	<0.0001
	2014	2.53	1.9-3.2	0.33	7.71	<0.0001
Management type (ref: TYP)	LTL	5.81	0.3-11.3	2.83	2.06	<0.05
Treatment (ref: NSUP)	SUP	1.12	0.7-1.6	0.24	4.75	<0.0001
Litter (ref: single-bearing)	Multiple bearing	1.8	1.2-2.4	0.31	5.75	<0.0001
Breed (ref: Composite)	Coopworth	-0.53	-6.1-5.0	2.84	-0.19	0.852
	Merino	-10.16	-15.7- -4.6	2.83	-3.593	<0.001
	First-cross	0.053	-5.5- 5.6	2.85	0.02	0.985
Observation day (smoothed)		7.267	6.6-7.9	0.34	21.11	<0.001
Random effects:[1]	Ewe	6.03				
	Farm	2.78				
	Residual	6.42				

[1] Standard deviation of random effect term; [2] 95% confidence limit

The value of the intercept indicates that Composite ewes in the NSUP group on a TYP farm had a mean bodyweight of 60.9 kg throughout the study (standard error 2.5 kg, 95% CI 56.0-65.7 kg). Compared to 2012, ewes were significantly lighter in 2013 and significantly heavier in 2014 (4.3 and 2.5 kg, respectively).

Ewes on better practice (LTL) farms were significantly heavier than ewes on TYP farms (5.8 kg), worm suppressed (SUP ewes) were significantly heavier than NSUP ewes (1.1 kg) and multiple-bearing ewes were significantly heavier than single-bearing ewes (1.8 kg). Merinos were significantly lighter (10 kg) than the reference group (Composites), whereas the weights of Coopworth and First-cross ewes were similar to Composites.

The model was used to generate smoothed plots of mean ewe bodyweight in relation to the start of lambing (Fig. 11). These indicate that NSUP ewes on better practice (LTL) farms were about 5 kg heavier at lambing, and that minimum ewe weight, around day 75 after lambing, is about 5 kg heavier on LTL than on TYP farms.

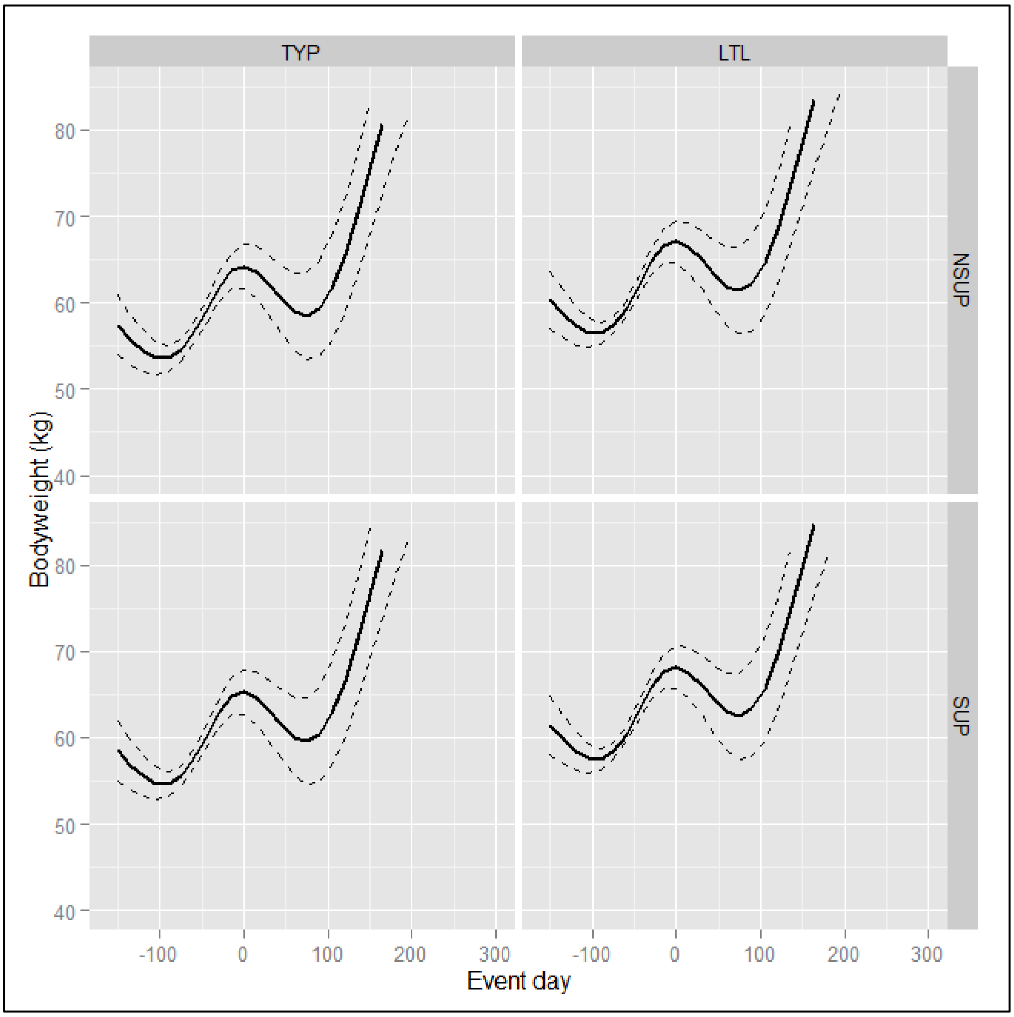


Fig11. Smoothed curve of mean (solid line) and upper and lower 95% confidence limits (dashed lines) of ewe bodyweights during the production year in relation to lambing start date (day 0). Management type (TYP or LTL) is plotted against treatment group (NSUP or SUP).

4.4.5 Wool production–ewes

The greasy fleece weight (GFW), yield and fibre diameter of adult ewe mobs on Farm Vic-1, Vic-2 and Vic-4 are shown in Tables 30-32. No measurements of wool production were collected on Farm Vic-3 as the time of shearing was changed during the study.

On Farm Vic-1 NSUP ewes had significantly higher GFW in Year 1. For the Coopworth hoggets there was no significant difference between the GFW of the SUP and NSUP groups in Year 1 (4.47 and 4.40 kg, respectively).

Table 30. Mean (SD) greasy fleece weight (GFW, kg), yield (Yld, %) and fibre diameter (FD, µm) of NSUP ewes, and differences between NSUP and SUP ewes (Farm 1, Years 1-3).[1]

Ewe mob	Group	Year 1 (2012)			Year 2 (2013)			Year 3 (Mob 1, 2014)		
		GFW	Yld	FD	GFW	Yld	FD	GFW	Yld	FD
Adult Coopworth	NSUP	3.9 (0.7)	76.2 (4.3)	37.6 (2.2)	4.2 (0.5)	81.2 (5.0)	37.1 (3.1)	4.7 (0.7)	75.8 (4.6)	38.7 (3.1)
	SUP	+0.45 [a]	+2.5	-0.2	+0.08	-1.1	+1	+0.1	-0.8	+0.4
Adult Merino	NSUP	4.3 (0.5)	80 (3.0)	19.1 (1.2)	4.6 (0.7)	81.1 (3.1)	20.4 (1.8)	- [2]	-	-
	SUP	+0.16	-1.1	-0.7	+0.09	-1.3	-0.27	-	-	-

[1] Significant differences between groups are highlighted: [a]P < 0.001; [2] Merinos not included in study in Year 3

Table 31. Mean (SD) greasy fleece weight (GFW, kg), yield (Yld, %) and fibre diameter (FD, µm) of NSUP ewes, and differences between NSUP and SUP ewes (Farm 2, Years 1-3).[1]

Ewe mob	Group	Year 1			Year 2			Year 3		
		GFW	Yld	FD	GFW	Yld	FD	GFW	Yld	FD
Adult Composite (twin lambs)	NSUP	4.0 (0.5)	75.9 (5.6)	35.2 (3.6)	3.6 (0.6)	73.1 (5.2)	33.4 (2.5)	3.8 (0.6)	73.7 (5.3)	35.3 (3.0)
	SUP	+0.02	+0.4	+0.9	+0.1	-2.7[a]	+0.6	+0.1	+0.3	+0.2
Adult Composite (single lambs)	NSUP	4.0 (0.6)	78.0 (4.3)	36.0 (2.8)	3.5 (0.6)	73.0 (4.4)	33.4 (3.3)	3.8 (0.6)	NM[2]	NM
	SUP	+0.1	+2.0	-0.54	+0.1	+1.4	+0.18	+0.1	NM	NM

[1] Significant differences between groups are highlighted: [a] P < 0.05; [2] NM = not measured

On Farm Vic-2, the only difference in the three years of the study was in the twin-bearing ewes in Year 2 when there was a significantly higher yield of wool from the NSUP ewes (P < 0.05). On Farm Vic-4, the only differences were a significantly higher GFW in the SUP Merino ewes in Year 2 and significantly lower fibre diameter in the 4-year-old SUP ewes in Year 3.

Table 32. Mean (SD) greasy fleece weight (GFW, kg), yield (%) and fibre diameter (FD, µm) of NSUP ewes, and difference between NSUP and SUP ewes (Farm 4, Years 2-3).[1]

Ewe mob	Group	Year 2 (2013)			Year 3 (2014)		
		GFW	Yield	FD	GFW	Yield	FD
Adult First-cross[2]	NSUP	3.9 (0.5)	76.1 (5.2)	27.4 (1.8)	4.3 (0.6)	78.8 (4.4)	28.8 (2.0)
	SUP	-0.1	0.9	0.24	0	0.5	-1.4[b]
First-cross[3]	NSUP	3.8 (0.5)	79.0 (3.8)	24.6 (1.9)	4.4 (0.5)	NM[4]	NM
	SUP	0	0.4	0.43	0	NM	NM
Adult Merinos	NSUP	3.6 (0.6)	74.4 (5.8)	18.7 (1.4)	-[5]	-	-
	SUP	0.28[a]	1.6	0.08	-	-	-

[1] Significant differences between groups are highlighted ([a]P<0.05, [b]P<0.01); [2] In Year 2 these were mixed age ewes scanned with mostly twins, in Year 3 were 4 y.o ewes scanned with twins; [3] In Year 2 these were 2 y.o maiden ewes, in Year 3 were 3 y.o scanned with mainly single lambs; [4] NM = not measured; [5] Merinos not included in Year 3.

4.4.6 Ewe mortality

During the three years of the study on Farm 1, mortality of NSUP ewes exceeded a benchmark of 5% on 1 of 7 occasions (Coopworth Hoggets in Year 1, 15.3%). On three occasions mortality of SUP ewes was greater than for NSUP ewes (from 1.6-5.1%), it was less than NSUP ewes on two occasions (1.7 and 2.4%) and virtually identical twice.

During the three years of the study on Farm 2, mortality of NSUP ewes exceeded 5% on two of six occasions (10.8% and 13.6%). SUP ewes had a higher mortality than NSUP ewes on 4 occasions (from 2.1-4.5%) and a lower mortality twice (3.3 and 3.6%).

On Farm 3, the mortality rate of the NSUP ewes exceeded 5% in both mobs (6.5% in the adults and 15.6% in the hoggets, Year 2). On this farm the mortality rate was less for the SUP compared to the NSUP ewes (4.9% less in adults and 4.7% less in the hoggets).

During the two years of the study on Farm 4, mortality of NSUP ewes exceeded 5% on 2 of 5 occasions (7.9% and 8.2%). Mortality of SUP ewes was greater than for NSUP ewes on three occasions (from 1.6 to 3.4%) and less than NSUP ewes twice (2.9 and 4.8%).

Thus, over all years of the study there was a significant ewe mortality of NSUP ewes (>5%) in 7 of 20, or 35% of mobs. Overall, the SUP ewes had a greater mortality than NSUP on 10 of 20 occasions, and it was less on 8 occasions.

4.4.7 Marking percentages

The marking percentage (number of lambs at marking per ewe at scanning and at marking) of each treatment group is shown in Table 33. This data was not analysed for statistical significance.

In Year 1, the marking percentage was similar (+/- 5%) on 2 of 5 occasions, more lambs were marked from NSUP ewes on 2 occasions and more lambs were marked from SUP ewes on 1 occasion (Table 13). In Year 2, the marking percentage was similar (+/- 5%) on 3 of 9 occasions, more lambs were marked from NSUP ewes on 5 occasions (from 7-33%) and more lambs were marked from SUP on 1 occasion (32%). In Year 3, the marking percentage was similar (+/- 5%) on 4 of 6 occasions, more lambs were marked from NSUP ewes on 1 occasion (7.7%) and more lambs were marked from SUP ewes on 1 occasion (29%).

Thus, over all years lambing percentages were similar on 9 of 20 occasions, more lambs were marked from NSUP ewes on 8 occasions and from SUP ewes on 3 occasions.

4.4.8 Anthelmintic resistance

The efficacy of selected anthelmintic groups and combinations was assessed by a worm egg count reduction test (WECRT) on 12-16 week old lambs at the beginning and end of the study on Farms 1 and 2, and at the end of the study on Farm 4 (Table 34). The aim was to determine if anthelmintic resistance was present, which anthelmintics should be used for strategic and tactical treatments on the LTL farms and whether anthelmintic resistance changed during the three years of the study. The latter aim was restricted by the relative insensitivity of the WECRT, which only detects a reduced efficacy of a drench when at least 25% of alleles in a population of nematodes are resistant, hence the test is unable to detect small changes in resistance. In addition, on large farms test results can vary according to which subsets of the nematode population are sampled from various paddocks.

Table 33. Percentage of lambs marked per ewe at scanning and per ewe present at lamb marking in all years.

Year	Farm	Ewe mob	Group	Marking percentage as a proportion of ewes at:	
				Scanning	Marking
1	1	Adult Coopworth	NSUP	163.9	175.4
			SUP	+4.4	+8.2
		Adult Merino	NSUP	110.5	110.5
			SUP	+2.6	+2.6
		Coopworth hogget	NSUP	91.5	100.0
			SUP	-17.3	-13.2
	2	Composite (twin lambs)	NSUP	152.3	165.0
			SUP	-3.8	-9.4
		Composite (single lambs)	NSUP	126.8	126.8
			SUP	+1.8	+4.1
2	1	Adult Coopworth	NSUP	160.0	162.7
			SUP	+32.1	+32.4
		Adult Merino	NSUP	107.3	111.3
			SUP	-16.2	-18.6
	2	Composite (multiple lambs)	NSUP	153.0	187.0
			SUP	+10.3	-2.1
		Composite (single lambs)	NSUP	108.5	112.3
			SUP	-18.5	-15.9
	3	Adult Composite	NSUP	128.3	135.1
			SUP	-29.9	-33.4
		Hogget Composite	NSUP	95.3	117.3
			SUP	-12.5	-15.4
	4	Merino	NSUP	72.1	80.0
			SUP	+3.7	0
		Adult First-cross	NSUP	139.3	141.7
			SUP	-3.1	-3.1
		Maiden First-cross	NSUP	105.0	106.8
			SUP	-8.3	-6.8
3	1	Adult Coopworth (Mob 1)	NSUP	157.6	169.1
			SUP	-6.8	-7.7
		Adult Coopworth (Mob 2)	NSUP	149.2	151.7
			SUP	+15.8	+29.0
	2	Composite (multiple lambs)	NSUP	136.8	166.1
			SUP	-8.2	1.4
		Composite (single lambs)	NSUP	100.0	120.4
			SUP	-9.8	-3.4
	4	4yo First-cross (twin lambs)	NSUP	154.1	162.1
			SUP	-5.7	-1.1
		3yo First-cross (mostly single lambs)	NSUP	104.3	107.4
			SUP	+5.6	+2.5

Table 34. The efficacy of selected anthelmintics on prime lambs in Years 1 (2011) and 3 (2014) on the four farms (% reduction in WEC[1], 95% Confidence Limits in brackets).

Measure & anthelmintic tested	**Farm 1[2]**		**Farm 2**		**Farm 3[4]**	**Farm 4**
	2011	**2014**	**2011**	**2014**	**2012**	**2014**
Control WEC (epg)	181	434	789	632	480	96
Benzimidazole(BZ)	75 (15-93)	76 (53-88)	87 (70-94)	75 (49-88)	77	77 (39-91)
Levamisole (Lev)	89 (55-97)	99 (97-100)	81 (53-92)	86 (62-86)	51	86 (45-96)
BZ + Lev	96 (81-99)	-	98 (93-99)	73 (13-88)	87	-
Ivermectin	98 (75-100)	100	92 (77-97)	92 (74-97)	87[5]	45 (0-84)
Abamectin	99 (77-100)	100	84 (37-96)	100	88	-
Moxidectin	-	-	-		99	100
Naphthalophos	88 (71-95)	94 (83-98)	-	-	-	-
Other combinations	100[3]	100[3]	-	-	-	-

[1] Worm egg count; [2] similar results obtained in Merino lambs in Nov 2011 (BZ+Lev 97% (94-98), ivermectin 100%, naphthalophos 89% (73-96);[3] Combinations of BZ+Lev+Nap in 2011 & 2014, BZ+Lev+Abamectin in 2014; [4] Test undertaken by farm manager, no confidence limits available; [5] half-dose of ivermectin administered

4.4.9 Worm egg counts of lambs and genera of nematodes present

The WEC of lambs before or at anthelmintic treatment on all farms in all years is shown in Table 35. The counts for *Nematodirus* spp. typically ranged between 0-30 epg and were always less than 110 epg. These low counts were not considered important and were not analysed any further.

Table 35. The Worm Egg Count (WEC) of lambs and the predominant nematode genera before suppressive anthelmintic treatment on all farms during the study.

Farm	**Year**	**Breed**	**Age (wks)[1]**	**WEC (epg)[3]**	**Predominant genus (%)**
1	1	Coopworth	8[2]	175	*Teladorsagia* (96)
		Merino	8[2]	330	*Teladorsagia* (99)
	3	Coopworth	9	345	*Teladorsagia* (52)
		Coopworth	9	500	*Trichostrongylus* (63)
2	1	Composite	5	15	Not measured
	3	Composite	9	63	*Trichostrongylus* (98)
4	3	Second-cross	11	45	*Trichostrongylus* (90)
			21	16	*Teladorsagia* (60)
			24	64	*Haemonchus* (75)

[1]Weeks after the start of lambing; [2]WECs taken 5 weeks after start of lambing were 0 epg; [3]WECs similar between lambs of SUP and NSUP ewes

Strongyle eggs were recovered from faecal samples collected at or soon after marking and around weaning on Farm 1 (Years 1 and 3) and Farms 2 and 4 (Year 3). Nematode DNA was extracted and the proportion of nematode genera present assessed.

At marking on Farm 1, *Teladorsagia* was the predominant genus recovered from Coopworth and Merino lambs in Year 1, and present in a similar proportion to *Trichostrongylus* spp. in Coopworth lambs in Year 3 (Table 17, Fig. 12). *Trichostrongylus* spp. became predominant at weaning in both years (e.g. 74% and 77% in Coopworth and Merino samples in Year 1, respectively), then *Teladorsagia* was again predominant in the post-weaning samples collected in December of Year 3.

On Farm 2, *Trichostrongylus* was the predominant genus from marking until weaning, when a small proportion of *Haemonchus* was detected along with some *Oesophagostomum* and *Chabertia* spp. *Teladorsagia* was the only genus detected in the post-weaning samples in January, when the lambs were 23 weeks old.

On Farm 4, *Trichostrongylus* was the main genus at marking, but *Haemonchus* was predominant when lambs were 24 weeks old in early December. All lambs were treated with an anthelmintic 2 weeks before the second visit (21 wks) when the WEC of lambs from the NSUP and SUP ewes were 18 and 15 epg. Three weeks later these counts were 70 and 58 epg.

4.4.9.1 After suppressive anthelmintic treatment with moxidectin

Lambs were treated with a moxidectin preparation ('SUP' lambs) or left untreated ('NSUP' lambs) at the first (6 of 8 visits, Table 17) or second visits to record observations on the lambs. The WECs of the lamb groups following this treatment are shown in Tables 36-38.

Farm 1 – In Year 1, worm suppression with a long-acting moxidectin injection ('LA-Mox') was given to Coopworth lambs at 8 weeks old (w.o). This preparation prevents infection with *Trichostrongylus* spp. for up to 49 days and *Teladorsagia circumcincta* for at least 91 days. The treatment was no longer fully effective at weaning (18 w.o), when the average WEC of SUP and NSUP lambs was similar (550 vs. 657 epg; P=0.11). No further treatments were given to the SUP lambs and the mean WEC of a composite faecal sample in February was 290 epg. In contrast, the WEC of Merino lambs in the SUP group was still significantly lower than NSUP lambs at weaning (740 vs. 2100, P < 0.05).

In Year 2, treatment of SUP lambs at 4 weeks age was with a combined moxidectin and clostridial vaccine (Weanerguard™), which prevents infection with *Trichostrongylus* spp. for at least 7 days and *Teladorsagia circumcincta* for up to 21 days. Coopworth lambs in the SUP group had a significantly lower WEC than NSUP lambs at 11 weeks of age (300 vs. 641 epg; P<0.05), but counts were similar in 16 w.o lambs at weaning (507 vs. 627 epg; P=0.62). For the Merinos, there was no significant difference between the SUP and NSUP lambs at 11 w.o (415. vs 524 epg; P=0.5) or when they were weaned at 16 w.o (1217 vs. 1569 epg; P=0.43).

In Year 3, only the ewe lambs were treated with LA-Mox at 9 w.o. Subsequently, a valid comparison of the lamb treatment groups was not possible because samples from the untreated wether lambs were inadvertently pooled with samples from treated ewe lambs, but the values were 200 and 474 epg for the (mostly) SUP and NSUP pools, respectively. The wether portion of these lambs were then sold due to the dry spring and the ewe portion were treated with a short acting anthelmintic (Aba+BZ+Lev). Subsequently, the WEC of the ewe lambs at 19 w.o was 15 epg, with no difference between the lamb treatment groups.

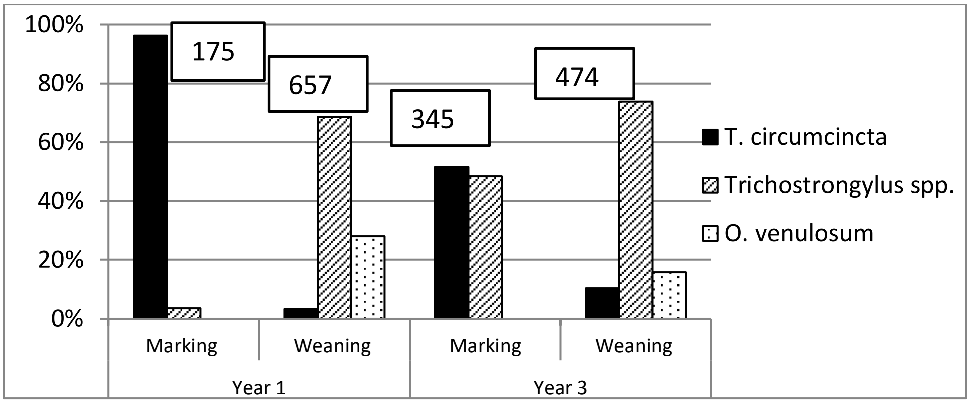


Fig 12. Proportion of nematode genera present in the faeces of Coopworth lambs at lamb marking and weaning on Farm 1 in Years 1 and 3 (average WECs shown in box)

Table 36. Worm Egg Count (WEC) and the predominant nematode genera present after suppressive anthelmintic treatment of lambs on Farm 1 (Years 1-3).[1]

Year	Breed	Lamb treatment group	Visit at 11-13 wks[2]		Visit at 13-19 wks[3]	
			Mean strongyle WEC (epg)	**Predominant nematode genus (%)**	**Mean strongyle WEC (epg)**	**Predominant nematode genus (%)**
1	Coopworth	NSUP	Treated	-	657	*Trich* (69)
		SUP	Treated	-	550	NM
	Merino	NSUP	Treated	-	21007[b]	*Trich* (77)
		SUP	Treated	-	740	NM
2	Coopworth	NSUP	641[a]	NM[4]	627	NM
		SUP	300	NM	507	NM
	Merino	NSUP	524	NM	1569	NM
		SUP	415	NM	1217	NM
3	Coopworth	NSUP	NM	*Trich*[5] (74)	11	*Teladorsagia* (50)
		SUP	NM	NM	20	NM

[1]Significant differences between lamb treatment groups highlighted: [a]P <0.05; [b]P <0.001; [2]Oldest lambs were 11 wks (Year 2) and 13 weeks (Year 3); [3]Oldest lambs were 18, 16 & 19 weeks in Years 1-3, respectively; [4]NM = not measured; [5]*Trichostrongylus* spp.

Table 37. The Worm Egg Count (WEC) and the predominant nematode genera present after suppressive anthelmintic treatment of composite lambs on Farm 2 (Years 1 & 3).[1]

Year	Lamb treatment group	Age of lambs:			
		14-17 weeks[2]		19-24 weeks[3]	
		WEC (epg)	**Predominant genus (%)**	**WEC (epg)**	**Predominant genus (%)**
1	NSUP	258	*Teladorsagia* (66)	45	NM
	SUP	226	-	0	-
3	NSUP	745[a]	*Trich*[4] (68)	275[a]	*Trich* (66)
	SUP	5	-	4	-

[1]Significant differences between lamb treatment groups highlighted: [a]P <0.05; [2]14 weeks (Year 1) & 17 weeks (Year 3); [3]24 weeks (Year 1) & 19 weeks (Year 3), faecal samples incorrectly bulked in Year 2

Farm 2 – In Year 1, SUP lambs were treated at 5 w.o using LA-Mox. There was no significant difference between the WEC of SUP and NSUP lambs at weaning (14 w.o), indicating that this treatment was no longer fully effective. No samples were taken at 18 weeks, because lambs had just been treated with a short acting anthelmintic, after which there were low WECs in in NSUP lambs at 24 weeks (Table 37).

In Year 2, SUP lambs were treated with LA-Mox at 6 w.o. Subsequently, there were no differences in the WEC of the 2 lamb treatment groups at 18 or 23 weeks when the average WECs were 338 and 198 epg, respectively (P=0.3 & 0.12). All lambs were treated with a combination of Aba+BZ+Lev at weaning (18 w.o).

No faecal samples were collected for WEC at the marking visit in Year 3 because lambs were only 4 w.o. Lambs were then treated with LA-Mox at 9 w.o when the WEC of lambs from NSUP and SUP ewes were 103 epg and 15 epg, respectively. The WEC of the SUP lambs was significantly less than for NSUP lambs at 17 and 19 weeks (weaning) (Table 37).

Farm 3 – SUP Lambs were treated with LA-Mox when 6 w.o (Year 2). There was a significant difference between the WECs of SUP and NSUP lambs when they were 14 w.o at weaning (50 and 1096 epg for SUP and NSUP, respectively), but no significant difference at weaning when the lambs were 19 w.o (Table 38).

Farm 4 – In Year 2, SUP lambs were treated with LA-Mox when 11 w.o. Subsequently, at 20 w.o the WEC of the second-cross SUP lambs was significantly lower than the NSUP group, but there was no difference in the groups of first-cross lambs (Table 38).

Lambs were not treated with LA-Mox in Year 3 because the producer was concerned about the relatively long withholding period and Export Slaughter Interval (91 and 133 days, respectively).

Table 38. The Worm Egg Count (WEC) of lambs after suppressive anthelmintic treatment in Year 2 on Farms 3 & 4.[1]

Farm	Breed	Lamb treatment	WEC (epg) of lambs at:	
			14-20 wks[2]	19-24 wks[3]
3	Composite	NSUP	1096[a]	497
		SUP	50	361
4	First-cross	NSUP	198	NM
		SUP	62	NM
	Second-cross	NSUP	217[a]	NM
		SUP	15	NM

[1]Significant differences between lamb treatment groups highlighted: [a]P <0.001; [2]14 (Farm 3) & 20 weeks (Farm 4) after the start of lambing; [3]19 (Farm 3) & 24 weeks (Farm 4) after the start of lambing

4.4.10 Lamb bodyweights

4.4.10.1 Results from the Multivariable Model

The bodyweight data from lambs on all farms in all years was collated and subjected to a multivariable analysis using a growth path model to determine the main effects and interactions of factors of interest on lamb bodyweight (Table 39, Fig.13). The interaction between dam and lamb treatment was not statistically significant (P>0.2) and so was excluded from the final model. The overall estimate of lamb birth weight (intercept value) was 3.8 kg.

Compared to 2012, lambs were significantly lighter in 2013 and 2014 (1.1 and 0.7kg, respectively). Coopworth, Merino, First-cross and second-cross lambs were significantly lighter than Composite lambs (from 4.2 to 6.4 kg; all P<0.0001), but lambs on the better practice (BP) farms were 5.9 kg heavier than lambs on typical (TYP) farms (P<0.01).

Suppression of worm infections in ewes (dam treatment group) or the lambs (lamb treatment group) had no significant effect on lamb bodyweight. However, the interaction between management type and dam treatment did have a significant effect, with lambs from worm suppressed ewes being 0.8 kg heavier on BP farms but not significantly different on TYP farms. Thus, overall there were significant effects on lamb bodyweight of year, breed, management type and the interaction between management type and dam treatment.

Table 39. Results from the multivariable model of lamb bodyweights showing the reference groups and effect of breed, management and worm suppression on lamb bodyweight.

Variable	**Categories**	**Beta (95% CL)**	**SE**	**DF**	**t**	**Pr(>|t|)**
Intercept	-	3.84 (2.9,4.8)	0.476	4368	8.099	<0.0001
tdsday	-	6.58 (5.2,8.0)	0.718	4368	9.181	<0.0001
Year (ref: 2012)	2013	-1.13 (-1.5,-0.7)	0.214	1835	-5.278	<0.0001
	2014	-0.74 (-1.2,-0.3)	0.236	1835	-3.146	<0.01
Breed (ref: Composite)	Coopworth	-4.21 (-4.9,-3.5)	0.361	1835	-11.66	<0.0001
	Merino	-6.41 (-7.2,-5.6)	0.412	1835	-15.560	<0.0001
	First-cross	-5.86 (-7.1,-4.6)	0.653	1835	-8.978	<0.0001
	Second-cross	-4.41 (-5.5,-3.4)	0.540	1835	-8.167	<0.0001
Management TYP (ref: TYP)	Best practice	5.92 (4.9,6.9)	0.512	2	11.475	<0.01
Worm suppression of:	Dam	0.15 (-0.5,0.8)	0.334	1835	0.447	0.655
	Lamb	-0.33 (-0.7,0.0)	0.168	1835	-1.937	0.053
Interaction between management & dam treatment	SUP dam BP mgt	0.76 (0.0,1.5)	0.383	1835	1.979	<0.05

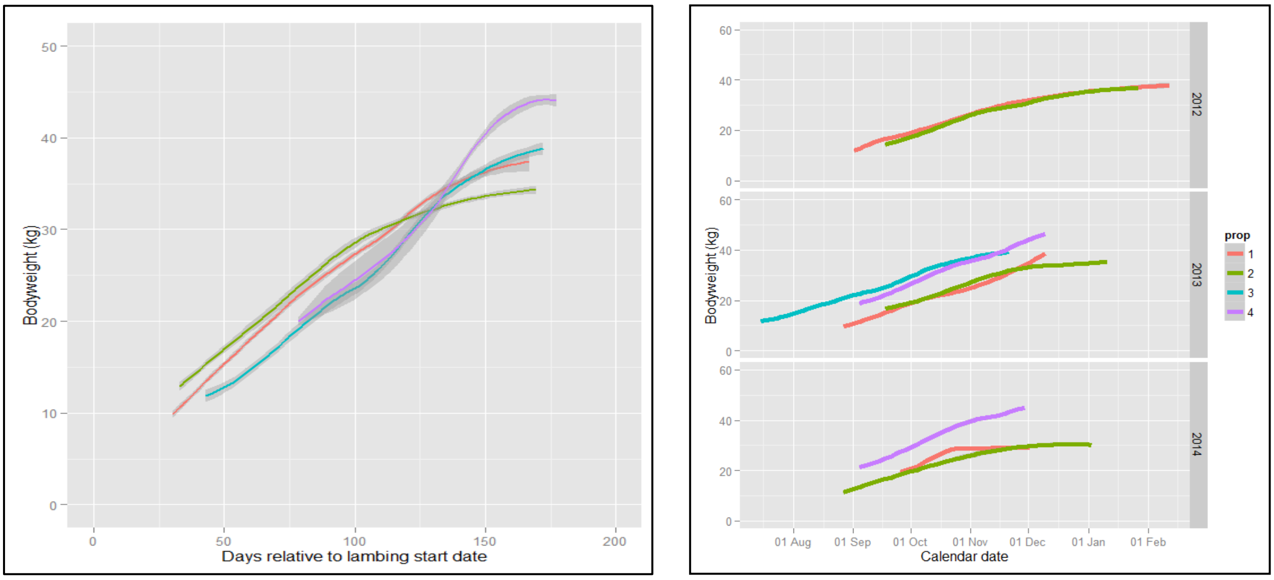


Fig 13. Average bodyweight of lambs (95% confidence limits in shaded area) fitted to the multivariable model on each farm relative to lambing start date (Day 0, left) and month (right).

4.4.10.2 Analysis of lamb bodyweights –by dam treatment group before lambs were treated

On Farm 1, lambs reared by SUP ewes were significantly heavier than those reared by NSUP on 4 of 7 occasions (0.8 to 1.8 kg), but there was no significant difference on any of the 6 occasions on Farm 2 (Table 40). On Farm 3, the lambs of the SUP hogget ewes were significantly heavier (1.5 kg) but there was no significant difference in the lambs of the adult mob, or in the lambs from the First-cross or Merino mobs on Farm 4 (Table 41).

Thus, over all farms, the weight of lambs from SUP ewes was from 0.6 lighter to 1.5kg heavier than lambs from NSUP ewes, with lambs from SUP ewes significantly heavier on only 5 of 19 occasions over three years.

Table 40. Average bodyweight (95% Confidence Limit (CL)) of lambs from ewes subjected to the farm's usual treatment schedule (NSUP) or ewes treated with controlled-release anthelmintic capsules to suppress parasitism (SUP) on Farms 1 and 2, Years 1-3.[1]

Farm	Year	Ewe: Age, breed & class	Ewe: Treatment	Lamb: Age (wks)[2]	Lamb: No.	Lamb: BWt (kg)	Lamb: 95% CL	Lamb: Difference (SUP-NSUP)
1	1	Adult Coopworth	NSUP	5	100	11.5	11,12	+0.8[a]
			SUP		101	12.3	11,13	
		Adult Merino	NSUP	5	42	11.0	10,12	+1.0
			SUP		43	12.0	11,13	
		Hogget Coopworth	NSUP	5	54	8.8	8,10	+1.8[c]
			SUP		46	10.6	9,12	
	2	Adult Coopworth	NSUP	4	96	9.3	8,10	+1.3[a]
			SUP		121	10.6	9,11	
		Adult Merino	NSUP	4	59	8.6	8,10	+1.2[b]
			SUP		51	9.8	9,11	
	3	Adult Coopworth (Mob 1)	NSUP	9	88	19.2	18,20	+0.2
			SUP		94	19.4	18,21	
		Adult Coopworth (Mob 2)	NSUP	9	93	20.6	19,22	+0.4
			SUP		92	21.0	20,22	
2	1	Adult composite (twin-bearing)	NSUP	5	99	13.9	13,15	+0.4
			SUP		98	14.3	13,15	
		Adult composite (single-bearing)	NSUP	5	71	14.1	13,15	+0.2
			SUP		72	14.3	13,16	
	2	Adult composite (twin-bearing)	NSUP	6	101	16.5	15,17	+0.8
			SUP		98	17.3	16,18	
		Adult composite (single-bearing)	NSUP	6	64	17.0	16,18	+0.6
			SUP		54	17.6	16,18	
	3	Adult composite (twin-bearing)	NSUP	4	93	10.7	10,12	+0.5
			SUP		72	11.2	10,12	
		Adult composite (single-bearing)	NSUP	4	59	12.0	11,13	+0.1
			SUP		55	12.1	11,13	

[1] Shaded cells highlight a significant difference between lambs of SUP and NSUP ewes: [a]P<0.05; [b]P<0.01; [c]P<0.001; [2]Weeks after the start of lambing

Table 41. Average bodyweight (95% Confidence Limit (CL)) of lambs from ewes subjected to the farm's usual treatment schedule (NSUP) or ewes treated with controlled-release anthelmintic capsules to suppress parasitism (SUP) on Farms 3 and 4, Years 2 and 3.[1]

Farm	Year	Ewe		Lamb				
		Age, breed & class	**Treatment**	**Age (wks)[2]**	**No.**	**BWt (kg)**	**95% CL**	**Difference (SUP-NSUP)**
3	2	Adult Composite (twin-bearing)	NSUP	6	77	11.6	11,13	+0.5
			SUP		61	12.1	11,13	
		Hogget Composite (twin-bearing)	NSUP	8	61	15.6	14,17	+1.5a
			SUP		53	17.1	16,19	
4	2	5-6 y.o First-cross	NSUP	11	85	18.7	17,20	+0.2
			SUP		79	18.9	18,20	
		Adult Merino (single lambs)	NSUP	11	44	17.8	16,19	+1.1
			SUP		44	18.9	17,20	
		2 y.o First-cross	NSUP	11	63	16.8	16,18	-0.1
			SUP		58	16.7	15,18	
	3	4 y.o First-cross (twin lambs)	NSUP	11	94	21.6	21,23	-0.7
			SUP		95	20.9	20,22	
		3 y.o First-cross (singles & twins)	NSUP	11	73	21.6	20,23	+0.6
			SUP		78	21.0	21,23	

[1] Shaded cell highlights a significant difference: [a]$P<0.05$; [2]Weeks after the start of lambing

4.4.10.3 Analysis of lamb bodyweights on each farm – by dam and lamb treatment group after lambs were treated

The mean weights of the lamb treatment groups on each farm, and the differences between them, are shown in Tables 42 and 43.

In Year 2 there were significant differences between the bodyweight of Coopworth lambs on Farm 1 (NN and SS, and NS and SS groups, at both 11 and 16 weeks after the start of lambing), and between the NN and SN groups of composite lambs, at both 18 and 23 weeks after the start of lambing, on Farm 2 (Table 42). There were no significant differences at any other times on any farm (Tables 42 and 43).

Thus, over all farm-year combinations there were significant differences on only 4 of 17 occasions; between the NN and SS group and the NS and SS group in one mob; and the NN and SN group in another mob (range 2.2-3.3 kg). If a significant difference was observed at the first visit after treatment, this difference remained at the next visit.

Table 42. Number of lambs (n), average bodyweight (BWt) and upper and lower 95% confidence limits (CL) of untreated (NSUP) and treated (SUP) lambs reared by ewes subjected to the standard worm control program (NSUP) or worm-suppressed ewes (SUP) on Farms 1 (Coopworth) and 2 (composites).[1]

Farm	Year	Dam treatment group	Lamb				
			Treatment group (n)	Visit A[2]		Visit B[3]	
				BWt (kg)	95% CL	BWt (kg)	95% CL
1	1	NSUP	NSUP (39)	Tr[4]	-	32.7	22,43
			SUP (41)	Tr	-	33.5	22,45
		SUP	NSUP (40)	Tr	-	34.4	22,47
			SUP (36)	Tr	-	34.0	23,45
	2	NSUP	NSUP (49)	22.8[a]	15,30	30.6[a]	21,41
			SUP (47)	22.4[a]	15,30	30.6[a]	21,40
		SUP	NSUP (61)	23.5[a,b]	16,31	32.0[a,b]	23,41
			SUP (60)	25.0[b]	18,32	33.9[b]	26,42
	3	NSUP	NSUP (68)	28.7	20,37	28.8	19,38
			SUP (20)	28.1	19,37	28.9	19,39
		SUP	NSUP (69)	29.4	20,38	30.0	18,42
			SUP (25)	28.4	21,35	29.0	20,38
2	1	NSUP	NSUP (48)	28.5	19,38	33.7	24,44
			SUP (52)	28.2	18,39	33.0	22,44
		SUP	NSUP (52)	30.2	21,39	34.7	25,45
			SUP (46)	29.7	18,41	33.8	22,45
	2	NSUP	NSUP (64)	32.1[a]	23,41	33.5[a]	24,43
			SUP (37)	33.9[a,b]	25,43	36.0[a,b]	26,46
		SUP	NSUP (61)	34.9[b]	26,44	36.8[b]	27,47
			SUP (37)	34.3[a,b]	26,43	34.9[a,b]	26,44
	3	NSUP	NSUP (49)	28.0	18,38	29.6	20,39
			SUP (48)	28.9	18,39	30.5	20,41
		SUP	NSUP (36)	28.1	16,40	29.8	17,43
			SUP (35)	29.2	19,40	30.4	20,41

[1] cells within each farm-year row with different superscripts are significantly different ($P<0.05$; shaded cells highlight groups with significant differences); [2] On Farm 1 this visit was 11 (Year 1) & 13 wks (Year 2), on Farm 2 it was 14, 18 & 17 wks after the start of lambing in Years 1-3, respectively, on Farm; [3]On Farm 1 this visit was 18, 16 & 19 wks, and on Farm 2 it was 18, 23 & 19 wks after the start of lambing in Years 1 to 3, respectively; [4]SUP lambs treated with moxidectin at this visit

Table 43. Number of lambs (n), average bodyweight (BWt) and upper and lower 95% confidence limits (CL) of untreated (NSUP) and treated (SUP) lambs reared by ewes subjected to the standard worm control program (NSUP) or worm-suppressed ewes (SUP) on Farms 3 & 4, Year 2.

Farm	Dam		Lamb				
	Breed	Treatment group	Treatment (n)	Visit A[1]		Visit B[2]	
				Mean BWt (kg)	95% CL	Mean BWt (kg)	95% CL
3	Composite	NSUP	NSUP (40)	23.5	16,31	34.3	26,43
			SUP (37)	23.3	15,32	33.4	24,43
		SUP	NSUP (30)	23.9	17,31	34.2	26,42
			SUP (31)	23.9	14,33	34.2	22,46
4	Second-cross	NSUP	NSUP (41)	36.3	25,48	47.1	37,57
			SUP (44)	37.8	27,49	49.1	38,60
		SUP	NSUP (39)	36.9	24,49	47.8	35,61
			SUP (40)	37.7	24,51	49.5	34,65
	First-cross	NSUP	NSUP (23)	34.1	27,42	44.6	36,53
			SUP (22)	35.0	26,44	45.4	35,56
		SUP	NSUP (22)	33.7	24,43	44.0	34,54
			SUP (22)	35.2	25,45	45.5	35,56

[1]14weeks (Farm 3) & 20 weeks (Farm 4) after the start of lambing; [2]19 weeks (Farm 3) & 24 weeks (Farm 4) after the start of lambing

5 Discussion

The discussion has been organised to directly address each of the six project objectives which were:

- Improved animal welfare with annual worm-related adult mortality reduced by 2-4% points (winter - summer rainfall).
- Increased sheep meat production as a result of reduced parasitism and mortality.
- Reduced time to turnoff by minimising the development of worm-related lighter lambs.
- Elimination of unnecessary drench treatments leading to a reduction in drench treatment frequency of 20%.
- Increased annual gross margin returns by $4-$6 per breeding ewe.
- Reduced selection pressure for development of drench resistance.

The experimental design utilized two types of GIN management (LTL and TYP), ewe GIN suppression (SUP) or not (NSUP) and lamb GIN SUP and NSUP. Using this design, the difference in production between NSUP and SUP reflects the residual production cost of GIN after either LTL or TYP management. It is necessary to keep in mind that the comparison of NSUP ewes on LTL and TYP farms is with a “largely” worm-free (SUP) control. Therefore, where there is no difference between NSUP and SUP, this reflects that LTL or TYP GIN management was as good as worm suppression. It is also timely to comment that the worm suppression methodology was for experimental purposes only and because of cost and consequences for drench resistance is not proposed as an alternative treatment regimen. The experimental design permitted comment on the two principle interests which were (i) the differences between NSUP and SUP to reflect the various residual costs of GIN infection; and (ii) the relative NSUP-SUP difference on LTL and TYP farms, which test the question of which gave superior GIN control after accounting for non-worm related differences between LTL and TYP farms.

5.1 Improved animal welfare with reduced worm-related adult mortality

In the context of this project, animal welfare is inferred from ewe WEC and mortality. Ewe WEC was lower on LTL farms in the two northern regions (Northern and Central Tablelands, NSW) but was unaffected by worm management program in the two southern regions (South West Slopes, NSW and Victoria). There are a number of reasons that likely account for these regional differences.

The prevalence and severity of *H. contortus* infections increased from southern to northern regions and the epidemiology of infection of this parasite is more susceptible to pasture and grazing management and interaction with rainfall events (O'Connor et al. 2006; Bailey et al. 2009). Development of *H. contortus* eggs to infective larvae (L3) is more dependent on rainfall occurring close to the time of deposition than is the case for *Trichostrongylus* spp or *T. circumcincta*. Whereas the L3 of *Trichostrongylus* spp and *T. circumcincta* can delay exposure to hostile environmental conditions —by residing within the faecal pellet for periods of weeks to months— this strategy is not used by *H. contortus* L3 and this shortens the period of pasture infectivity. LTL programs made better use of grazing management and strategically-timed anthelmintics which translated into lower ewe WEC where *H. contortus* was dominant.

Not only was LTL management able to reduce ewe WEC (where *H. contortus* was dominant) it achieved this with fewer treatments and less reliance on persistent products which is likely to have benefit for slowing development of drench resistance (discussed in Section 5.6). Similar results were reported by Kelly et al. (2010) where IPM control programs were found to reduce WEC of Merino ewes, in the Northern Tablelands NSW, with fewer treatments and days of active product.

In addition to differences in infective species, the ineffectiveness of LTL programs to reduce ewe WEC (in relation to TYP) in southern regions was also likely to have been accounted by greater host resistance of the meat-breeds of sheep used in this project. Ewe WEC was low on most occasions in the South West Slopes NSW, even where no treatment of ewes was provided and the low WEC reduces the sensitivity of detecting differences between worm control programs. Comparison of Merino and Coopworth ewes (in Victoria) indicated lower WEC for Coopworth ewes at many of the sampling occasions which is supportive of earlier publications (Donald et al. 1982) which indicated Border Leicester x Merino ewes to have lower worm burdens than Merino ewes.

Annual rates of apparent mortality of ewes were in the range 3.9–10.2% and exceeded industry benchmark values of 2–3% in all regions. It is possible that these values overestimate the true mortality rate because of the effects of tag loss (though sheep carried two tags) and temporary absenteeism but there is no reason why any overestimation would bias the comparison between SUP and NSUP treatments. Apparent ewe mortality was unaffected by ewe GIN control and the majority of deaths occurred during lambing suggesting that dystocia was a likely cause. The higher rates of mortality also reflect that they apply only to twin-bearing ewes rather than to all ewes regardless of pregnancy status. That GIN control on LTL and TYP farms eliminated worm-related ewe mortality is a pleasing result and contrasts sharply from the situation reported for Merino ewes (Kelly et al. 2010) where integrated control programs reduced annual worm-related mortality on TYP farms from 5.4 to 1.0%.

These results indicate an improvement in the welfare of these meat-type sheep as evidenced by lower WEC and fewer treatments, which was most pronounced in the northern regions. The objective of reducing worm-related ewe mortality by 2–4% p.a. through implementation of LTL programs was not met because there was no worm-related ewe mortality recorded across the regions. This indicates that the GIN management of these types of sheep being managed in productive systems was sufficient and that these meat-type breeds are highly resilient to GIN infection.

5.2 Increased sheep meat production as a result of reduced parasitism and mortality

The difference in ewe live weight change between NSUP and SUP ewes (i.e. the difference between LTL and TYP from respective worm suppressed groups) over the annual period ranged from -0.5 to -1.7 kg. This indicates that NSUP ewes had more loss and/or less gain than for SUP ewes (loss and gain varied among the regions) and reflects the “cost” of GIN infection. This cost was similar for LTL and TYP management in the three southern regions but on the Northern Tablelands NSW, the effect of GIN infection on ewe live weight was unexpectedly 1.0 kg greater on LTL farms; despite LTL having lower WEC. Nevertheless, these data indicate that there is only a small residual cost of GIN infection with LTL and TYP management. This contrasts with the situation with Merino ewes (Kelly et al. 2010) where GIN infection was reported to account for a loss of 2.8 kg/year.

Lamb marking rates from the twin-bearing ewes were in the range 156–162% and were unaffected by GIN except on the Northern Tablelands where rates were unexpectedly 7% higher for NSUP ewes. Pregnancy rates confirmed by ultrasound at the end of the annual experimental period were in the range 148–170% and were unaffected by GIN except on the Northern Tablelands where pregnancy rates of NSUP ewes were 7% lower than for SUP ewes on LTL farms but there was no difference between NSUP and SUP on TYP farms.

Wool accounts for 10–15% of gross income in meat-type enterprises. Greasy fleece weight of ewes was in the range 3.9–4.0 kg, with mean fibre diameter of 26.5–37.6 µm (higher in southern regions) and washing yield of 74.7–80.5% (lower in southern regions). Over all regions, GIN infection reduced fleece weight by 0.1 kg/head but without effects on fibre diameter or yield.

Weaning weights of lambs were in the range 32–40 kg (highest for Central Tablelands, NSW) and were lower (0.3–0.5 kg) for lambs reared by NSUP ewes in Victoria and the Northern Tablelands; but this difference was greatest on LTL farms. Weaning weights of lambs reared by NSUP ewes in Victoria and the Northern Tablelands were 0.7–1.1 kg (respectively) lower than for lambs reared by SUP ewes on LTL farms but there was no difference between ewe groups on TYP farms. Effects of lamb worm control on weaning weights were small in all regions except Victoria where NSUP lambs were on average 0.9 kg lighter at weaning on TYP farms but unaffected on LTL farms.

When these results are considered together the main feature is the small residual effect of GIN infection indicating that both LTL and TYP GIN management had almost completely removed the deleterious effects of GIN infection. It is likely that this impressive feature was aided by meat-type breeds that were highly resilient to GIN infection while being managed in productive systems.

5.3 Elimination of unnecessary drench treatments leading to a reduction in drench treatment frequency of 20% and reduced selection pressure for development of drench resistance.

The number of drenches given to NSUP ewes was in the range 1.8–5.5/year being lowest in the Central Tablelands and highest in the Northern Tablelands. The number of drenches to ewes was lower on LTL farms in the Central Tablelands (by 0.7 drench/year) and Northern Tablelands (by 1 drench/year). In addition, long-acting products accounted for 80% of treatments on TYP farms in the Central Tablelands and the number of days of active drench was 6% more on TYP farms in the Northern Tablelands. Averaged across the regions, the number of drench treatments given to ewes on LTL farms was 14% fewer than on TYP farms. Adoption of integrated GIN programs precludes clear identification of any one component as the basis for the reduction in treatment frequency but the adoption of regular monitoring of WEC as the basis for tactical drench decisions contributed to the reduction.

Reduced treatment frequency (within a given environment) will reduce selection for drench resistance as will the use of effective multi-active rather than single-active treatments (Barnes et al. 1995) and limiting the use of long-acting treatments (Le Jambre et al. 1999). GIN management on LTL farms reduced these risks and it is likely this resulted in reduced selection pressure for drench resistance. A more definitive comment on drench resistance is not possible because of the short time frame of the comparison (two years) and the insensitivity of the drench test.

5.4 Increased annual gross margin returns by $4-$6 per breeding ewe.

There have been numerous estimates of the financial cost of GIN infection (McLeod, 1995, Sacket et al. 2006, Lane et al. 2015) which have been based on reviews of the literature and the opinions of leading animal health advisors and researchers Each successive report has concluded a higher cost of GIN infection, no doubt reflecting a relative increase in the price of sheep, lamb and wool without reduction in the productive consequences of infection. Empirical measurement of the cost of GIN infection for a Merino breeding enterprise, in the Northern Tablelands, NSW, managed with best practice or regionally typical GIN control was provided by Kelly (2011) by maintaining NSUP and SUP ewes under these different GIN programs. While the total annual cost of GIN on TYP farms was $11.09/ewe it was reduced to $5.82/ewe on best practice farms. The main factor for the increased cost of worms under TYP management was an increased rate of ewe mortality, which was largely attributed to haemonchosis. These empirically derived cost estimates exceeded those reported by Sacket et al. (2006) by 40–50% who suggested an annual cost of $7.13/ewe (poor control) and

$4.13/ewe (good control) with increases in commodity prices suggested as the main reason for the difference.

Of relevance for this current project was the estimated annual cost of GIN for prime lamb enterprises which was reported (Sacket et al. 2006) to be in the range of $5.00 (good control) to $12.00 (poor control). At the start of this project, it was uncertain if the cost of GIN in meat production systems would be greater —because of the higher value of lamb leading to a greater value of lost production— or lower —because of higher resilience to GIN infection arising from the influence of British-type breeds and better quality pastures— than for Merino enterprises. The estimates of Sacket et al. (2006) suggested that the difference in the cost from GIN infection between good and poor GIN control is greater for prime lambs than it is for other sheep enterprises.

Given the small differences in the production consequences of GIN infection between LTL and TYP management it is unlikely that financial analysis will yield the same compelling case as for LTL in a Merino ewe enterprise ($5.27/ewe reduction; Kelly, 2011). Nevertheless, a formal gross margin analysis was conducted from the data collected in the Northern Tablelands, NSW using the following inputs obtained from Wool Cheque (http://www.woolcheque.awex.com.au), Auctions Plus (www.auctionsplus.com.au), Meat and Livestock Australia (www.mla.com.au) and commercial prices.

- Cast for age ewes ($2.00/kg liveweight)
- Replacement ewes ($198/head)
- Rams ($900/head)
- Weaners ($3.40/kg liveweight)
- Drenches at $0.55/head for short and sustained activity and $1.65/head for long-acting products
- Labour at $200/day to muster and drench 1000 sheep
- Worm test at $70/sample
- Drench test at $1000

The annual cost of GIN averaged across LTL and TYP management was $5.92 per ewe. This is less than the annual figure calculated from Lane et al. (2015) and for Merino ewes (Kelly et al. 2010) based on 2010 values, providing further evidence of the resilience of these sheep types and production systems to GIN infection. GIN was more costly for ewes on LTL than on TYP farms ($1.11/ewe per year; Table 44) because (i) NSUP ewes had lighter fleece weights than SUP ewes but only on LTL farms (accounting for 81% of difference in the cost of GIN); and (ii) there was a larger difference between NSUP and SUP ewes in the weight of cast for age ewes on LTL farms (accounting for 17% of the difference). The financial benefit from fewer drenches with reduced costs of labour with LTL was almost perfectly matched by the increased cost of monitoring and WECRT. The gross margin of twin-bearing NSUP ewes on LTL and TYP farms was $120.56/ewe and $120.14/ewe respectively, indicating that with a higher stocking rate (+1.7 DSE/ha), the gross margin per hectare is likely to be greater with LTL. Higher stocking rates and better animal production from LTL farms was also recorded from other regions.

Table 44. Gross margin analysis from using best practice (LTL) and regionally typical (TYP) programs in the control of gastrointestinal nematodes for meat-breed lamb production systems on the Northern Tablelands, NSW.

	$/ewe		
Item	**LTL**	**TYP**	**LTL - TYP**
NSUP-SUP income	-$1.63	-$0.41	-$1.23
NSUP-SUP costs	$0.22	$0.28	-$0.06
Drench inc. labour	$3.60	$4.51	-$0.91
Monitor and WECRT	$1.04	$0.18	$0.86
Gross margin	-$6.48	-$5.37	-$1.11

WECRT: worm egg count reduction test (drench test).

Despite the higher cost of GIN on LTL farms, reducing the number of drench treatments, will inevitably slow development of drench resistance over the long term. Overtime, the cost of GIN on LTL farms is likely to decline, as the compounded benefits arising from the adoption of LTL components will continue to reduce pasture larval challenge. Conversely, the cost of GIN is expected to increase on TYP farms, due to increased production losses associated with declining efficacy of drench actives. The cost of treatment is also likely to increase, as farms with few drenching options (due to a high incidence of drench resistance) will have greater reliance on the two recently released drench actives (monepantel and derquantel (+ abamectin)), which are also the most costly short-acting drenches commercially available.

5.5 Regional advisory groups

The industry impact of the project occurred through regional advisory groups that provided linkage with animal health advisors (private and public), veterinarians, consultants (in some regions these managed up to 15 flocks) and agribusiness suppliers. These groups were established to communicate results during the project and to facilitate industry adoption of project outcomes. Meetings were held annually within each region.

5.6 Communication activities and publication

Presentations, conference and journal publications arising from the project are provided in Table 45. More publications are expected following the completion of this project.

Table 45. Presentations, conference and journal publications arising from the project.

Activity	Details
District farming consultant group presentations	Presentation of consultancy farmer members including the owner of one trial site. June 2015
	Four producer presentations were given at the Graham Centre and SW Slopes region, and a further presentation at the 2016 Graham Centre sheep day is planned. The four presentations were at the Graham Centre Field Day (2014), Temora, Mangoplah and Holbrook. Further producer days are planned.
	Mortlake, Victoria Bestwool/ Bestlamb Group (Nov 2011)
Conferences	

8th International Sheep Veterinary Congress, Rotorua, New Zealand	B Kirk, J Larsen & N Anderson (2013): Evaluating the efficacy of current parasite management practice on two prime lamb producing flocks in western Victoria. p 106.
Australian Sheep Veterinarians Conference, Albany, Western Australia	Dever, M. & Kahn, L.P. (2013) Removal of tapeworm (Moniezia spp) did not increase growth rate of prime lambs on the Northern Tablelands, NSW. pp. 33-37.
	Kahn, L.P., Allworth, B., Crawford, K., Dever, M.L., Doyle, E.K., Eppleston, J., Kirk, B., Larsen, J., Scrivener, C., Watt, B. & Walkden-Brown, S.W. (2013). Lifting the limits imposed by worms on sheep meat production. pp. 29-32.
Australian Sheep & Cattle Veterinarians Annual Conference, Hobart, Tasmania	Kirk B, Larsen J, & Anderson N (2015). Nematode parasitism and prime lamb production in Western Victoria.',187-192.
24th International Conference of the World Association for the Advancement of Veterinary Parasitology, Perth, Australia	Dever, M., Kahn, L.P. & Bowers, S. (2013) Ewe but not lamb worm control increases weaning weight of prime lambs.
	Kahn, L.P., Dever, M. & Bowers, S. (2013) Lower worm egg counts associated with higher ewe body condition score.
	Dever, M., Kahn, L.P. & Bowers, S. (2013) A decrease in the efficacy of worm suppressive treatments observed during lactation in ewes.
Lambex conference, Adelaide (Jul 2014)	Kirk B, Larsen J, & Anderson N (2015). Worms and prime lamb production.
Australian Society of Animal Production conference Canberra	Eppleston J, Watt B, Crawford K & Kahn L. (2014). Production loss from nematode infection in sheep meat flocks adopting integrated management strategies: preliminary findings. P017.
Australian Society for Parasitology conference, Canberra	Dever, M. L., Kahn, L. P., Doyle, E. K. & Walkden-Brown, S.W. (2014) Worm egg counts in lambs decreased after administration of long acting anthelmintics to ewes.
25th International Conference of the World Association for the Advancement of Veterinary Parasitology, Liverpool, UK.	Kahn, L.P. & Dever, M. (2015) Ewe body condition score is a useful trait for refugia-based treatment strategies.
	Dever, M. & Kahn, L.P. (2015) Partitioning production loss due to Trichostrongylus colubriformis into direct and immune-mediated components in grazing meat-breed lambs.
Journals	
Veterinary Parasitology	Dever, M. L., Kahn, L. P., & Doyle, E. K. (2015). Removal of tapeworm (Moniezia spp .) did not increase growth rates of meat-breed lambs in the Northern Tablelands of NSW. Veterinary Parasitology, 1–5. doi:10.1016/j.vetpar.2015.01.016
	Dever, M. L., & Kahn, L. P. (2015). Decline in faecal worm egg counts in lambs suckling ewes treated with lipophilic anthelmintics: Implications for hastening development of anthelmintic resistance. Veterinary Parasitology, 209 (3-4), 229–234. doi:10.1016/j.vetpar.2015.02.018
	Dever, M. L., Kahn, L. P., & Doyle, E. K. (2015). Persistent challenge with Trichostrongylus colubriformis and Haemonchus contortus larvae does not affect growth of meat-breed lambs suppressively treated with anthelmintics when grazing.

	Veterinary Parasitology, 209 (1-2), 76–83. doi:10.1016/j.vetpar.2015.02.009
	Dever, M. L., Kahn, L. P., Doyle, E. K. & Walkden-Brown, S.W. (accepted pending revision). Immune-mediated responses account for the majority of production loss for grazing meat-breed lambs during Trichostrongylus colubriformis infection. Veterinary Parasitology
Postgraduate and undergraduate projects	Three final year Animal Science students at CSU were involved in aspects of the program - Elise Walker, Emily Sims and Rebecca Mayne. Emily Sims and Rebecca Mayne successfully completed their Honours, and Elise Walker completed a research project. Emily Sims' project involved the NIL treatment group in Year 1.
	Beata Kirk, MVSc thesis (due Mar 2016) *The effect of Internal Parasites on Profit and Production in Prime Lamb flocks in Western Victoria*, University of Melbourne.
	Michelle Dever, PhD thesis (2015) *Improving the effectiveness of gastrointestinal nematode control for meat-breed lamb production systems on the Northern Tablelands, New South Wales*, University of New England.

6 Conclusions/recommendations

6.1 Practical application of the project's insights and implications to the red meat industry

The key conclusions of this project conducted over two years with over 7,500 ewes managed on 16 properties in four regions of eastern Australia are as follows:

- Adoption of best practice GIN management in the form of LTL resulted in lower WEC achieved with fewer treatments and less reliance on long-acting products. These changes should reduce selection pressure for drench resistance and make LTL programs a sustainable option.
- Both LTL and TYP GIN management provided protection which was almost as good as year-long worm suppression, highlighting the effectiveness of management programs.
- Meat-breeds and crossbred genotypes in good condition and grazing improved pastures were very resilient to the impacts of GIN with little effect on ewe and lamb live weight, fleece weight, reproduction and mortality.
- More attention to GIN control will be warranted when ewes are in below target body condition and when pastures are limiting.
- When lamb growth exceeded 200 g/day there was almost no benefit for weaning weight from drenches given to lambs before weaning.
- A pre-lambing drench could be considered a strategic rather than tactical treatment in the Central and Northern Tablelands, NSW.
- In the SW Slopes of NSW a single short acting pre-lamb drench is a recommended strategy, especially in higher rainfall areas where longer acting products will be unnecessary in prime lamb ewes in good body condition. Conversely, producers in

lower rainfall areas may be undertreating ewes by not giving a pre-lambing drench, especially in poorer seasons.

- Sheep were heavier on LTL farms in Victoria with the advantage being 5.8 kg for ewes and 6.3 kg for lambs at weaning.
- Ewe mortality (though unaffected by GIN infection) was in the range 3.9–10.2% p.a., surpassing accepted benchmarks, though partly because it related only to twin-bearing ewes. Where cause of death was established, dystocia was the main cause.
- By itself, WEC is not a reliable indicator of production loss but is useful as a means of managing pasture infectivity and, in summer rainfall regions, for avoiding mortality.

6.2 Future R&D

Large scale field experiments such as those conducted in this project provide an ideal opportunity to identify future R&D opportunities which are described:

- The consistent presence of *H. contortus* on farms in the winter dominant rainfall region of the SW Slopes, NSW may indicate adaption to cooler climates and warrants further investigation.
- Managing ewes in low condition score at pre-lambing/marking is a consistent challenge for prime lamb producers, in Western Victoria and other areas. The following are some relevant issues:
    - When is a ‘disaster’ imminent and what are the best strategies to avert such a disaster? These occur in the form of low ewe condition score, often compromising reproduction the following season, poor lamb growth rates and unacceptably high mortalities of ewes and lambs. This occurs when internal parasites compound the effects of under-nutrition in a ‘tight’ season.
    - Most structured studies of short-acting treatments given to ewes before lambing and/ or at marking have failed to demonstrate any benefit unless ewes are moved to pastures with of lower ‘infectivity’ (reduced populations of infective larvae) after the treatment. Nevertheless, these treatments are often given in this area, especially during tight seasonal conditions (e.g. a late autumn break, cold wet winter, sub-optimal spring, or a combination of these conditions). In effect, treatments provide ewes a ‘worm-free day’, but the benefit (if any) on ewe and lamb production, and mortality, is difficult to quantify.
    - The evidence from this study is that capsules will not be cost-effective in most prime lamb flocks in Victoria. It is however acknowledged that they do have a role in preventing ‘worm disasters’.
- Single-bearing ewes are very resilient. Where ewes are routinely scanned for pregnancy there is the opportunity to run this cohort at higher stocking rates or on poorer pastures, freeing up better pastures or more protected paddocks for multiple-bearing ewes.
- Use of lipophilic long-acting products during lactation will lead to milk transfer of the active at sub-therapeutic levels to the lamb and presents as a significant risk for drench resistance. This requires further investigation and careful consideration of an extension message.
- There is an impact of GIN infection on lambs after weaning but it is not predicted from WEC (i.e. similar effect with low and high WEC). Mitigating this effect, without recourse to blanket anthelmintic treatment, will require weaners to graze low worm-risk pastures.

Further research is required to adapt smart grazing methods for use in prime lamb enterprises in southern and northern regions.

- There is potential to adopt partial flock treatment, as part of targeted selective treatment in meat-breed enterprises, but comprehensive trials would be required to confirm effects on production and especially in regions where *H. contortus* is dominant.
- SUP ewes had lower lamb marking results on a number of occasions and on the Northern Tablelands were 7% lower than for NSUP ewes. This suggests a possible negative influence of SUP treatment and/or application and would benefit from further investigation.

6.3 Development and adoption activities which would ensure the red meat industry achieves full value from the project's findings.

The project findings should be incorporated into WormBoss to provide information specific for prime lamb production. This may mean modification of programs, decision guides and other information. Each partner organisation will address producer groups directly or through the media to inform of the key recommendations. In addition to these actions, MLA should take responsibility for the transfer of key conclusions into extension materials aimed at advisors and producers.

7 Key messages

These key additional practices relate to meat-type genotypes:

- Ewes maintained in good body condition (in the range 2.5–4.0; lowest at lamb marking and highest at mating) will be highly resilient to the effects of worm.
- Prime lambs growing in excess of 200 g/day will be highly resilient to the effects of worms until weaning.
- Regional LTL programs will be included in WormBoss (www.wormboss.com.au) reflecting differences from Merino enterprises. In the interim the key additional (or of greater importance) practices for each region include:
    - Northern Tablelands, NSW
        - Strategic ewe treatments: mid-winter treatment
        - Preparation of low worm-risk weaning paddocks
    - Central Tablelands, NSW
        - Strategic ewe treatments: prelambing
    - South West Slopes, NSW
        - Strategic ewe treatments: prelambing with a short acting drench
    - Victoria
        - Tactical ewe treatments: monitor worm egg counts before the first summer drench and delay if counts are zero.
        - WEC as a decision point for treatment needs to be interpreted with condition score and pasture availability

Adoption of these practices as part of a regional LTL program will protect against production loss associated with worm infection and, where Barber's Pole worm is dominant, will reduce WEC; achieved with fewer treatments and less reliance on long-acting products.

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9 Appendix

9.1 Appendix 1: Sampling details for South West Slopes, NSW

Table A2. Sampling details for South West Slopes, NSW.

			Visit 1 Post Scan		Visit 2 Pre-lamb		Visit 3 Lamb mark		Visit 4 Weaning		Visit 5 Pre-join		Visit 6 Post join		Scan
Year	Farm	Mob	WEC 1	BWT1/CS 1	WEC 2	BWT2/CS 2	WEC 3	BWT3/CS 3	WEC 4	BWT4/CS 4	WEC 5	BWT5/CS 5	WEC 6	BWT6/CS 6	
1	SW1	1	✓	✓	✓	✓	✓	✓	✓	✓	X	X	X	X	X
1	SW1	2	✓	✓	✓	X	✓	✓	✓	✓	X	X	X	X	X
1	SW2	1	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
1	SW2	2	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
2	SW1	1	X	X	✓	✓	✓	✓	✓	✓	X	X	X	X	X
2	SW1	2	X	X	✓	✓	✓	✓	✓	✓	X	X	X	X	X
2	SW3	1	✓	✓	✓	✓	✓	✓	✓	✓	X	X	X	X	X
2	SW3	2	✓	✓	✓	✓	✓	✓	✓	✓	X	X	X	X	X
2	SW4	1	X	X	✓	✓	✓	✓	✓	✓	✓	✓	X	X	X
2	SW4	2	X	X	✓	✓	✓	✓	✓	✓	✓	✓	X	X	X
2	SW5	1	X	X	✓	✓	✓	✓	✓	✓	X	X	X	X	X
2	SW5	2	X	X	✓	✓	✓	✓	✓	✓	X	X	X	X	X
3	SW4	1	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
3	SW4	2	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
3	SW7	1	X	X	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
3	SW7	2	X	X	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
3	SW8	1	X	X	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
3	SW8	2	X	X	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
3	SW9	1	X	X	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
3	SW9	2	X	X	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

9.2 Appendix 2: Farm details for Victoria

The main features of the four farms are summarised in Tables A2 and A3.

9.2.1 Farm Vic-1

This farm, 15 km north-west of Mortlake, has a typical pasture growing season of about 8 months. Rams for the commercial self-replacing Coopworth flock are bred on the farm, with ram traits recorded and used to calculate ASBVs. Joining occurs for 5 weeks, starting in late January, and ewes lamb in July. Hogget ewes are mated in some years, depending on their bodyweight and seasonal conditions. Ewes are joined for about six weeks, scanned for pregnancy about 45 days after ram removal and drafted into mobs according to their predicted date of lambing and number of lambs.

The self-replacing Merino flock on this farm had 2,500 commercial ewes producing 4kg greasy of 18 micron diameter wool. These were mated at a similar time as the Coopworth ewes, but this enterprise was discontinued at the start of the third year of the study. There is also an autumn-calving vealer enterprise, with 200 Friesian cross breeding cows mated to Simmental bulls. The cattle are not used to prepare pastures of reduced worm risk for the sheep.

The standard practice is to give a first summer drench to all sheep at or shortly after weaning (in late November), then conduct WECs in early February to determine whether a second summer treatment is required. The WEC of weaned lambs are monitored at 4-6 weekly intervals after the autumn 'break' and ewes are monitored before lambing.

Table A2. Location and characteristics of the four farms in Western Victoria.

Farm (start year) & location	Rainfall (mm)	Area (ha)	Stocking Rate (DSE/ha)[1]	Breed (no.) of ewes
Vic-1 (2011); Mortlake	580	1400	16	Coopworth (2000) Merino (2800)
Vic-2 (2011); Winchelsea	620	150	11	Composite (800)
Vic-3 (2013); Mortlake	580	1720	13	Composite (7000)
Vic-4 (2013); Birregurra	630	830	12.5	Merino (1000) Border Leicester x Merino (1200)

[1] dry sheep equivalents/ ha

Table A3. Summary of the worm control program, pastures and fodder crops of 4 farms in Western Victoria.

Farm	Worm control program[1]	Most recent drench resistance test[2]	Pastures (grazing of crops)
Vic-1	SD1–December SD2–February Ewes before lambing–July Regular monitoring of WECs (> 15 yrs)	2008	Perennial ryegrass, phalaris & sub-clover (None)
Vic-2	SD1 – December SD2 – February (if needed) Regular monitoring of WECs (> 10 yrs)	2008	Perennial ryegrass, phalaris, cocksfoot, fescue & sub-clover (plantain & rape)
Vic-3	SD1 – January Some monitoring of WECs (began 2011)	2012	Phalaris & sub-clover (rape)
Vic-4	SD1 – January Ewes pre lamb – June Ewes marking – August No monitoring of WECs	2003	Improved – Perennial ryegrass & clover Unimproved – native grasses & broadleaf weeds (millet & rape)

[1] SD = strategic summer drench; [2] Worm egg count reduction test (WECRT)

Records of drench efficacy testing were available since 1990 and are shown in Table A4, with the macrocyclic lactones and a combination of benzimidazole and levamisole remaining effective. However, production losses due to gastrointestinal nematodes are a consistent problem on this farm due to the relatively high stocking rate and its location.

Table A4. Drench resistance tests on Farm Vic-1 (% reduction in WEC; 95% confidence intervals in brackets).

Year	Anthelmintic group or combination[1]				
	BZ	Lev	BZ + Lev	Ivermectin	Moxidectin
1990	71 (45,85)	77 (40,91)	98 (94,99)	100 (100,100)	-
1992	50 (5,73)	90 (78,95)	99 (97,100)	100 (100,100)	100 (100,100)
1994	56 (3,80)	100 (98,100)	89 (49,98)	-	100 (100,100)
1998	62 (16,83)	81 (47,93)	99 (98,100)	-	-
2001	-	-	92 (73,98)	-	-
2002	78 (32,93)	98 (94,99)	97 (81,100)	100 (100,100)	-
2005	-	-	99 (98,100)	99 (97,100)	-
2008	-	-	97 (89,99)	100 (100,100)	-

[1] BZ = benzimidazole; Lev = levamisole

9.2.2 Farm Vic-2

This farm is 10 km south-east of Winchelsea and has a pasture growing season of 8-9 months. Although a winter rainfall area, consistent rain falls in summer (35-45 mm each month during the summer months) and *Haemonchus contortus* is regularly detected in this district.

Composite and Coopworth breed rams are joined with adult composite ewes. The rams are selected on the basis of ASBVs, with a preference for those in the top 20% of the Maternal Index. Maiden ewes are joined with Southdown rams to decrease the risk of dystocia. Adult and maiden ewes are joined for six weeks, with adults joined in mid-March to lamb in mid-August and maidens joined 4 weeks later. Lambs are marked 6 weeks after lambing starts and weaned in late November or early December.

About 20% of lambs are finished for meat production with the remaining 80% sold as stores. The timing of sales is determined by the season and lamb weights, with the first draft usually sold in mid-December.

Ewes are shorn in January and crutched 4-6 weeks before lambing. They are rotationally grazed as one mob for most of the year, except during lambing when they are set stocked in mobs of 100-150 ewes.

The first summer treatment is given from mid- to late-December, with a second summer treatment generally not required. WECs are monitored regularly to determine the need for additional treatments; they typically remain low and ewes do not need a pre-lambing anthelmintic treatment in most years. Occasionally ewes have been drenched at lamb marking from concern that warm, wet conditions could lead to production loss or deaths from gastrointestinal nematodes, including *Haemonchus*.

9.2.3 Farm Vic-3

This farm is 12 km north of Mortlake with a typical pasture growing season of around 8 months. There are 7000 Composite ewes (6000 adults and 1000 hoggets), derived from Coopworth ewes, and 140 Dorset and Composite rams. Adult ewes are joined for 5 weeks to lamb in June, whereas hogget ewes are joined for 6 weeks to lamb in August. The time of shearing was changed from November to April when the study started on this farm in 2013.
Ewes are pregnancy scanned to identify early- and late-lambing ewes, and those bearing single or multiple lambs. They are lambed in mobs of around 200, depending on paddock size. About 500 lambs are sold each month between November and April, with from 80-90% sold as finished lambs and the remainder sold as stores.

A strategic summer anthelmintic treatment is given to most sheep in January, and ewes are often drenched before lambing. WEC monitoring commenced in 2011 and additional anthelmintic treatments are based on these results. A WECRT was conducted by the farm manager in 2012.

Cattle are traded in some years, but the timing and number of purchases and sales varies depending upon seasonal conditions.

9.2.4 Farm Vic-4

This farm is 17 km west of Winchelsea. There are 1000 Merino ewes, 30% of which are joined to Border Leicester rams to produce First-cross ewes, and 1200 First-cross ewes (Merino x Border Leicester, ‘XB’) joined to White Suffolk and Poll Dorset rams. Maiden ewes are joined at 17 months-old to lamb at 2 years of age. Mating begins in mid-January and, although ewes are scanned for pregnancy in April, rams are left with the ewes until mid-May (a 17 week joining). Ewes are set-stocked in paddocks of 25-40ha and start lambing in mid-to late-June in mobs of around 200. Lambs may be sold finished or as stores between November & February, but are occasionally kept until the following autumn, depending on the season.

Pastures are older varieties of Perennial Ryegrass and sub-clover, with significant amounts of unimproved or degraded pasture although some areas being re-sown to newer pasture varieties. Lambs are often finished on summer fodder crops, such as millet and rape, with occasional opportunity feedlotting. There are 250 Angus & Charolais cows with a split-calving pattern, often co-grazed with the sheep.

The worm control program consists of a macrocyclic lactone, typically moxidectin, given before joining in mid-January, and a combination drench (typically BZ/ Lev) given before lambing or at marking. There is no worm egg count monitoring and the last anthelmintic resistance test was in 2003.

9.3 Appendix 3: Rainfall and pasture details for Victorian farms

9.3.1 Rainfall

Rainfall was taken from the Bureau of Meteorology (BoM) recording station closest to each site; Mortlake Racecourse (BoM site 90176; 15 km south-east and 12 km south of Vic-1 and Vic-3, respectively), Wurdibolic Reservoir (BoM site 87126; 5 km south-west of Vic-3) and Birregurra Post Office (BoM site 090008, 10 km south of Vic-4).

9.3.1.1 Farms Vic-1 & Vic-3

In Year 1 (2012), Mortlake was drier than average during January and February, receiving 50% and 10% of average rainfall for January and February, respectively. Subsequently, rainfall for the 2012 growing season (March to November) was 20 mm above the average.
In Year 2 (2013) the summer was dry and rainfall promoting good pasture growth was not received until late May. This was followed by 25% higher than average rainfall during winter and spring.

In Year 3 (2014), the autumn break initiated good pasture growth in April and then rainfall was similar to the long term average until the end of September. Subsequently, rainfall from Oct to Dec was less than half the average, hence improved perennial pastures senesced about 1 month earlier than usual for this area.

9.3.1.2 Farm Vic-2 (Winchelsea south)

This area received close to average rainfall during the growing season of Year 1 (March to November 2012). The beginning of the following year (Jan-Mar 2013) was dry, with less than 50% of the average rainfall, followed by 25% above average rainfall between June and November. In Year 3 (2014) the autumn break rains initiated good pasture growth in April and average rain fell until June. Subsequently, rainfall between July and December of 2014 was 70% of the average for those 6 months and so pastures senesced at least 1 month earlier than usual.

9.3.1.3 Farm Vic-4 (Birregurra)

The initial part of 2013 (the first year of observations on this farm) was very dry, followed by 20% above average rainfall between March and November. Heavy rains, particularly between June and November, caused waterlogging of many low-lying areas of this farm and decreased pasture growth.

In 2014, 25% above average rainfall was received between March and July. This was followed by a dry spring, with less than two thirds of the average rainfall from August to December and reduced pasture growth.

9.3.2 Pasture availability

9.3.2.1 Farm Vic-1

In Year 1 (2012), pasture availability for the mixed mob of adult Coopworth and Merino ewes was below optimum, with only 575 kg of green dry matter per hectare (kg DM/ ha) available at lamb marking in late August. This increased to 720 kg DM/ ha by mid-September, 1155 kg DM/ ha in early October (Fig. A1), and over 3200 kg DM/ ha at weaning in late November. At this time pasture quality had decreased, with a mixed pasture sample having 60.4% digestibility and 8.8 MJ of metabolisable energy (ME)/ kg DM (compared with a typical spring pasture of 70% digestibility and 12 MJ/ kg DM). For the Coopworth hogget ewes, pasture availability was 650 kg DM/ ha two weeks before lambing, in mid-August 2012. This increased to 1350 kg DM/ ha at lamb marking in early October and over 3200 kg DM/ ha at weaning in late November. Similar to the reduced quality of pasture grazed by adult ewes at this time, the digestibility was 61.9% and ME 9 MJ/ kg DM.

In Year 2 (2013), adult ewes grazed the same paddocks as in Year 1. Pasture availability was again below optimum, being 600 kg DM/ ha before lambing in mid-July, 950 kg DM/ ha at lamb marking in late August, 1400 kg in mid-October, and 1600 kg DM/ ha at weaning in mid-November. Hoggets were not mated in Year 2.

In Year 3 (2014), Coopworth ewes in Mob 1 evenly grazed a pasture of around 900 kg DM/ ha during winter (average height < 3 cm). This mob was moved to a paddock with good quality phalaris and sub-clover before lambing (Fig. A2), and at lamb marking was grazing 1400 kg DM/ ha (5 cm). Mob 2 selectively grazed clumped pastures of 600-800 kg DM/ ha during winter, then were moved to pastures of 1000-1200 kg DM/ ha of a similar composition, but poorer quality than the pastures grazed by Mob 1. The two mobs were combined after lamb marking and were grazing 1500 kg dead DM/ ha and 600 kg green DM/ ha at weaning in late November.

Fig A1. Pastures grazed by adult ewes (left) and hoggets (right) at lamb marking in October on Farm Vic-1 in Year 1 (2012).

Fig A2. Pastures grazed by Mob 1 (left) and Mob 2 (right) before lambing on Farm Vic-1 in Year 3 (2014).

9.3.2.2 Farm Vic-2

This farm used a rotational grazing system for much of the year except for set stocking of small mobs during lambing. This aimed to maximise pasture utilisation, although sometimes pastures were grazed to as little as 400 kg DM/ ha (1cm) before ewes were moved to another paddock.

In Year 1 (2012), 4weeks before lambing, the single and twin-bearing ewes were grazing very short pastures (280 kg DM/ ha, <1cm) before being moved to a paddock with abundant pasture (1290 kg DM/ ha or 4.5 cm). Shortly afterwards the single- and twin-bearing ewes were separated to provide better nutrition for the twin-bearing mob.

At lamb marking, four weeks after the start of lambing, the mob of single-bearing ewes was moved from a paddock with 1500 kg DM/ ha to one with 1700 kg DM/ ha. Subsequently, at weaning in November this mob was grazing a pasture of over 3000 kg DM/ ha (14cm) and of reduced quality (65.7% digestibility and 9.7 MJ of ME/ kg DM). At this time in Year 1, the twin-bearing ewes grazed pastures of over 2200 kg DM/ ha (10cm) which consisted of cocksfoot, subterranean clover and some annual grasses. Pasture height had increased to well over 14 cm (3200 kg DM/ ha) by weaning when a sample of perennial ryegrass, barley grass, brome and subterranean clover had 66.5% DMD and 9.8 MJ ME/ kg DM.

Fig A3. Pastures grazed by single- (left) and twin-bearing (right) ewes at lamb marking on Farm Vic-2 in Year 3 (2014).

Fig A4. Pasture grazed by ewes and lambs before weaning on Farm Vic-2 in Year 3 (2014).

At pregnancy scanning in Year 2 (2013), ewes were grazing 900 kg DM/ ha of a mixed sward of cocksfoot, perennial ryegrass and sub-clover. At lamb marking, this increased to 1400 kg DM/ ha of cocksfoot, perennial ryegrass and sub-clover for the single-bearing ewes and 2000 kg DM/ ha of fescue and sub-clover for the twin-bearing ewes. At weaning, in early December, both ewe mobs were grazing the same paddock with 2000 kg DM/ ha (average height 8.5 cm).

At pregnancy scanning in Year 3 (2014), ewes were grazing a mixed sward of cocksfoot, perennial ryegrass and sub-clover of around 800 kg DM/ ha. At lamb marking this increased to 1600 kg DM/ ha (6 cm) for the single-bearing ewes and 2200 kg DM/ ha for twin-bearing ewes (Fig. A3). At this time the mobs were combined and grazed pastures with around 3000 kg DM/ ha which had senesced by weaning in December (Fig. A4).

9.3.2.3 Farm Vic-3

At marking in July 2013, adult composite ewes were grazing phalaris and sub-clover pastures of around 900 kg DM/ ha. At weaning in September, these ewes were moved from this paddock, which had 1200 kg DM/ ha, to one of a similar composition with 1500 kg DM/ ha (5.5cm).

Ewe hoggets grazed pastures of a similar composition and around 2000 kg DM/ ha at lamb marking in October, decreasing to 1500 kg DM/ ha at weaning in late November.

9.3.2.4 Farm Vic-4

At pregnancy scanning in mid-April of Year 2 (2013), both ewe mobs were grazing short, dry pasture (< 400 kg DM/ ha). At the pre-lambing visit, on 30 May, pastures were green but short (< 500 kg DM/ ha). Pasture availability was still below optimum at lamb marking in August (~600 kg DM/ ha, or 1.5cm), but had increased to around 1000 kg DM/ ha in late November.

In Year 3 (2014), the twin- and mixed twin- and single-bearing ewes were set stocked and each mob remained in its respective paddock from pregnancy scanning until joining in 2015. Twin-bearing ewes were grazing 400 kg DM/ ha at pregnancy scanning which increased to 1200 kg DM/ ha 2 weeks before lambing. Pasture then remained at a similar height for the remainder of the year, with 1100kg green DM/ ha at lamb marking in August (Fig. A5), and 1000kg green DM/ ha in November. In early December pasture had dried off considerably and consisted of 1000kg green and 1500 dead DM/ ha.

The paddock grazed by the mixed twin- and single-bearing ewes was of poorer quality, consisting of a mixture of perennial ryegrass and annual pastures. Ewes were grazing 1100 kg DM/ ha at pregnancy scanning; this height was maintained until lambing but decreased to 900 kg DM/ ha at lamb marking in August. Pastures had begun to senesce in November (1000 kg DM/ ha) and in December sheep were grazing poor quality pasture of 500 kg/ha green and 1200 kg dead DM/ha (Fig. A5).


Fig A5. Paddocks on Farm 4 grazed by twin-bearing and mixed twin- and single-bearing ewes at lamb marking (left & right paddocks of left photo) and in early December 2013 (right photo).