Sweeny, J.P.A. , Gardner, G.E. , Dobson, R.J. , Jacobson, C. and Bell, K. (2011) Associations between trichostrongylid worm egg count and productivity measures in Dorper lambs. Veterinary Parasitology, 180 (3-4). pp. 307-314.

Associations between trichostrongylid worm egg count and productivity measures in Dorper lambs

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Abstract

Two flocks of pure bred Dorper lambs were managed separately according to sex (283 ewe lambs and 212 ram lambs) in southern Western Australia. Faecal sample collection, weighing and body condition assessments were performed for each lamb on 2 occasions, specifically pre-weaning (approximately 14 weeks of age) and post-weaning (approximately 9 months of age). Body condition score (BCS) was assessed using a scale of 1 (very thin, emaciated) to 5 (excessively fat). Faecal worm egg counts (WECs) were measured using a modified McMaster technique and larval cultures were performed to identify trichostrongylid nematode genera present. Eye muscle and c-site fat depths were measured using ultrasound at post-weaning. Lambs received an abamectin anthelmintic treatment at weaning (18 weeks of age). Worm egg count data was assessed for normality of data distribution and homogeneity of variance. This data was transformed using $Log_{10}(WEC+25)$ to stabilise variances between groups prior to statistical analyses and general linear models were used to assess relationships between WEC and productivity measures. Mean WECs were 564 eggs per gram of faeces (EPG) and 514 EPG at pre- and post-weaning in the ewe flock and 552 EPG and 480 EPG at pre- and post-weaning in the ram flock. *Teladorsagia (Ostertagia) circumcincta, Trichostrongylus spp.* and *Oesophagostomum spp.* larvae were identified. No lambs with WEC<500 EPG pre-weaning had WEC>1000 EPG post-weaning. Ewe and ram lambs with WEC>1000 EPG at pre-weaning were 42 (12 – 145 95% CI) and 37 (9 – 153) times more likely to have WEC >1000 EPG at post-weaning than lambs with WEC 501 – 1000 EPG at pre-weaning. There were no significant relationships between WEC and live weight in the ram flock, while relationships between WEC and live weight were inconsistent in the ewe lamb flock. There was no relationship between WEC and eye muscle or c-site fat depth. Significant negative relationships between WEC and BCS were identified at pre- and post-weaning for both flocks. Lambs with WEC<500 EPG had 0.19 – 0.61 higher mean BCS than lambs with WEC>1000 EPG at pre- and post-weaning. In conclusion, high WEC was associated with lower body condition in Dorper lambs, however the relationship between WEC and live weight was inconsistent and there was no effect on eye muscle depth.

Keywords: Sheep; worm; trichostrongylid nematode; live weight; body condition; productivity.

1. Introduction

Gastrointestinal parasitism is widely regarded as the major disease problem of sheep, particularly in Australia (McLeod, 1995; Love and Coles, 2002; Sackett *et al.*, 2006) and increasing anthelmintic resistance threatens to undermine effective parasite control (Besier and Love, 2003; Coles *et al.*, 2006). The most economically significant trichostrongylid nematodes throughout southern Australia are *Trichostrongylus spp., Teladorsagia (Ostertagia) circumcincta* and *Haemonchus contortus* (Besier and Love, 2003; Woodgate and Besier, 2010). Trichostrongylid worm infections in sheep are characterised by sub-optimal productivity that can be broadly attributed to reduction in voluntary feed intake and the nutrient cost associated with establishing and maintaining an immune response against trichostrongylid worms (Colditz, 2008).

Dorper and White Dorper sheep are gaining increased adoption for sheep meat production by Australian farmers, mainly due to reduced management requirements compared to wool breeds (Curtis, 2009). Dorper sheep have been reported to demonstrate greater parasite resistance when compared to wool breeds in some environments (Wildeus, 1997; Burke and Miller, 2002, 2004), although other studies have reported Dorpers to be 'relatively susceptible' to trichostrongylid worm infections in higher-rainfall regions where the degree of parasite challenge is greater than in semi-arid regions (Baker *et al.*, 2003; Mugambi *et al.*, 2005). Evidence of large trichostrongylid worm burdens was found to be common in lambs consigned for slaughter from the medium and high rainfall areas of Western Australia (Jacobson *et al.*, 2009b), but the effects of trichostrongylid worm parasitism on the productivity of specialist meat sheep breeds (such as the Dorper) in the medium and high rainfall areas of southern Australia, are not well described in the scientific literature. This study aimed to investigate the relationship between WEC and production attributes of Dorper lambs, following a natural trichostrongylid worm challenge from pasture.

2. Materials and Methods

2.1 Study site, animals and experimental protocol

The farm was located near Kojonup 250 – 300km south, south east of Perth, Western Australia. This region is characterised by a Mediterranean environment (hot, dry summers and cool, wet winters), with an average rainfall of 500-550mm per annum (Hill *et al.*, 2004; Moeller *et al.*, 2008). The paddocks used in the study had not been grazed by sheep over the previous summer/autumn prior to commencement of the experiment. This experiment was approved by the Murdoch University Animal Ethics Committee (permit R2236/09).

All lambs were pure-bred White Dorper or Dorper. The 283 ewe lambs included in the study were born in July and the 212 ram lambs were born in September. Both flocks were managed separately for the duration of this study. All lambs were individually identified using ear tags at 2 – 6 weeks of age. Lambs were weaned at approximately 16 weeks of age. All lambs were treated at weaning with 0.8mg (ewes) or 0.96mg (rams) abamectin given by oral liquid (Virbac First Mectin, Virbac Australia).

Faecal sample collection, live weight and body condition assessments were made for each lamb at pre-weaning (approximately 14 weeks of age) and post-weaning (approximately 8 months of age). Assessment of eye muscle depth and fat depth were made at post-weaning only.

Each lamb flock had access to only one annual pasture paddock, consisting primarily of annual rye-grass (*Lolium spp.*) and sub-terraneum clover (*Trifolium subterraneum)* throughout the duration of the study. Water was supplied *ad libitum* from a dam. Following weaning, both flocks were supplementary fed, with approximately 100g/head per day (ewes) or 150g/head/day (rams) of supplementary feed consisting of 35% pelleted sheep feed (11.0 megajoules metabolisable energy per kg dry matter and 14.5% crude protein: EasyOne Pellets, Milnes Feeds, Australia) and 65% oaten hay (6.9 megajoules metabolisable energy / kg dry matter and 3% crude protein).

2.2 Live weight, body condition, fat depth and eye muscle depth measurements

Lamb live weight and body condition score (BCS) were measured at the same time as pre- and post weaning faecal sample collection, using methods previously described (Sutherland *et al.* (2010). The BCS scale used ranged from 1 (very poor condition, emaciated) to 5 (excessively fat). Eye muscle depth and fat depth were recorded at post-weaning using methods previously described by Gilmour *et al.* (1994). Fat and eye muscle depth were measured with ultrasound and calculated from the average of three measurements taken from the c-site site (45mm from the midline over the 12th rib).

2.3 Parasitological measurements

All faecal samples were sampled directly from the rectum using fresh latex gloves and were placed in individually labelled, airtight 120ml containers. All faecal samples collected from the Dorper ewe and ram lambs, were then transported to the Department of Agriculture and Food, Animal Health Laboratories in Albany (for all ewe lamb samples) and South Perth (for all ram lamb samples) within 3 – 6 hours of their collection and were refrigerated at 2 – 4^{o}C. Faecal worm egg counts (WECs) were performed within two days of sample collection, by using a modified McMaster technique previously described in the

Australian Standard Diagnostic Techniques for Animal Diseases Manual (Lyndal-Murphy, 1993). The detection level for this method was 50 (i.e. 1 observed egg equated to 50 EPG). Larval culture and differentiations were performed using the method described in the Australian Standard Diagnostic Techniques for Animal Diseases Manual (Lyndal-Murphy, 1993), with equal amounts of faeces (1g) taken from each faecal sample collected.

2.4 Statistical Analysis

Statistical analysis was performed using SPSS Statistics 17.0 (Statistical Package for the Social Sciences) for Windows (SPSS inc. Chicago, USA). All data from ewe and ram flocks were analysed separately. Faecal worm egg count frequency distributions were tabulated for each at pre- and post-weaning. Faecal worm egg count data were assessed for normality of data distribution and homogeneity of variance. Faecal worm egg count data were transformed using $\log_{10}$(WEC+25) to stabilise variances between groups prior to statistical analysis (Torgerson *et al.*, 2005; Dobson *et al.*, 2009). Production data (live weight, liveweight gain between pre- and post-weaning, BCS, c-site fat and eye muscle depth) were not transformed for analyses, with means and ranges of these above measurements for each flock at pre- and post-weaning, shown in Table 2. Correlation between transformed WEC (independent variable) and each production attribute (live weight, liveweight gain, BCS, c-site fat and eye muscle depth as the dependent variable) were estimated by linear regression. Transformed pre-weaning WEC were used for correlation with pre-weaning production measurements and transformed mean WEC (mean of pre-weaning WEC plus post-weaning WEC) were used for correlation with post-weaning production measurements. Where significant relationships between WEC and production attributes were identified, the difference across the WEC range observed was calculated using the linear regression function and displayed in both Table 3.

Lambs in each flock were categorised into WEC categories for both pre- and post-weaning according to untransformed WEC at pre- and post-weaning respectively; low WEC (WEC≤500 EPG), moderate WEC (WEC 501-1000 EPG) and high WEC (WEC>1000 EPG). General linear model analysis was performed using WEC category as the independent variable (fixed factor) and each production attribute as the dependent variable. Post-hoc tests were performed using least squares differences test. Proportions of ewe and ram lambs in each WEC category at pre- and post-weaning were compared using Chi-square Pearson's exact two-sided test for significance. Risk and odds ratios were calculated for WEC categories at pre- and post-weaning.

3. Results

3.1 Nematode genera identified using larval culture

The nematode genera identified using larval differentiations are shown in Table 1. *Haemonchus contortus* was not detected in either the ewe or ram lamb flocks. The most prevalent nematode larvae genera identified pre-weaning were *Oesophagostomum spp.* (68%) in ewe lambs and *Trichostrongylus spp.* (92%) in the ram lambs. *T. circumcincta* larvae were most commonly identified in both ewe lambs (72%) and ram lambs (62%) at post-weaning (Table 1).

3.2 Worm egg counts

Mean WECs and WEC ranges for respective ewe and ram flocks at both pre- and post-weaning samplings are detailed in Table 1, with frequency distribution of WECs shown in Figure 1. Mean WECs at pre- and post-weaning were similar in both ewe and ram flocks (Table 1 and 2). In the ewe flock, the frequency distributions of WECs at both pre- and post-weaning resembled a negative binomial distribution skewed to the left (Fig

1). The frequency distribution of WECs in the ram flock at both pre and post-weaning more closely resembled a normal distribution than the ewe flock data (Fig 1).

In the ewe lamb flock, 49/283 (17.3%) and 43/283 (15.2%) lambs were categorised as high WEC at pre-weaning and post-weaning respectively (Table 4) and 39/49 (79.6%). ewe lambs that were categorised as high WEC at pre-weaning were also categorised as high WEC at post-weaning. Ewe lambs categorised as high WEC at pre-weaning were 42 times more likely to be categorised as high WEC at post weaning than lambs categorised as moderate WEC at pre-weaning (P<0.001, 95% confidence interval: 12.1 – 144.6). Similarly, 22/212 (10.4%) and 24/212 (11.3%) ram lambs were categorised as high WEC at pre-weaning and post-weaning respectively and 17/22 (77.3%) of the ram lambs categorised as high WEC at pre-weaning were also categorised as high WEC at post-weaning (Table 5). Ram lambs categorised as high WEC at pre-weaning were 37 times more likely to be categorised as high WEC at post-weaning than lambs categorised as moderate WEC at pre-weaning (P<0.001, 95% CI: 8.8 – 152.7). No ewe or ram lambs categorised as low WEC at pre-weaning were subsequently categorised as high WEC at post-weaning. Over 40% and 36% of the ewe and ram lambs respectively were categorised as either moderate WEC or high WEC at both pre- and post-weaning.

3.3 Associations between live weight, live weight change and WEC

The relationships between live weight, liveweight gain and WEC are shown in Table 3. The relationships between WEC category and live weight for ewe and ram lambs are shown in Tables 4 and 5 respectively. There were no significant relationships identified between WEC and live weight in the ram lamb flock (Table 3). In the ewe lamb flock, a significant negative relationship between WEC and live weight (P=0.001) was identified at pre-weaning, but there was no difference in live weight between lambs categorised as low

WEC or high WEC. Furthermore, ewe lambs categorised as moderate WEC had 2.3kg lower live weight compared to ewe lambs categorised as high WEC at pre-weaning (Table 4). At pre-weaning, ram lambs categorised as moderate WEC had 1.9kg and 3.8kg higher pre-weaning live weights compared with ram lambs categorised as low WEC or high WEC respectively (Table 5).

At post-weaning, there was a positive relationship between WEC and live weight (P=0.034) in the ewe lambs (Table 3), but there was no difference in live weight between ewe (Table 4) or ram (Table 5) lambs in any of the post-weaning WEC.

There were no significant relationships identified between WEC and liveweight gain in the ram lamb flock (Table 3). Significant positive relationships between WEC and liveweight gain expressed as kg change (P<0.001) and percentage change (P=0.022) were identified in ewe lambs. Ewe lambs categorised as moderate WEC at post-weaning had 3.9kg and categorised as high and low WEC respectively (Table 4), whereas ram lambs categorised as moderate WEC at post-weaning had 2.5kg and 3.2kg lower liveweight gains compared to ram lambs categorised as low WEC or high WEC respectively (Table 5).

3.4 Body condition score

The relationships between BCS and WEC are shown in Table 2. Significant negative relationships between WEC and BCS were identified in both ewes and lambs at pre- and post-weaning (Table 3). Ewe and ram lambs categorised as high WEC had lower BCS than lambs categorised as low WEC at both pre- and post-weaning (Tables 4 and 5). Lambs categorised as moderate WEC had lower BCS than lambs categorised as low WEC in the ram lambs at pre-weaning (Table 5) and the ewe lambs at post-weaning (Table 4).

3.5 C-site fat depth and eye muscle depth

The associations between WEC and both c-site fat depth and eye muscle depth are shown in Table 3. The associations between c-site fat depth, eye muscle depth and WEC category are shown in Table 4 (ewe lambs) and Table 5 (ram lambs). There was no effect of WEC (Table 3) or WEC category (Tables 3 and 4) on ultrasound eye muscle depth in either ewe or ram lamb flock. A trend towards a negative relationship between WEC and c-site fat depth was observed in the ram lambs (P=0.094), although the R^2 coefficient was low (R^2 ~0.07), suggesting that only 7% of the variation observed in c-site fat depth in ram lambs was attributable to WEC (Table 3). Ram lambs categorised as high WEC had lower c-site fat depth than ram lambs categorised as low or moderate WEC (Table 5). There was no relationship between c-site fat depth and WEC (Table 3) or WEC category (Table 4) in the ewe lambs.

4. Discussion

The key findings in this study were: animals observed in a WEC risk-category at weaning were generally found in the same category five months later despite anthelmintic treatment during the intervening period; increased WEC was associated with reduced BCS of lambs in both flocks; the relationship between WEC and other productivity measures for lambs were less clear. Although these findings are significant, it must be highlighted this study was conducted only on one farm in southern Western Australia. Larger scale studies (incorporating a greater number of farms or sheep breeds) are necessary to provide further information on associations between production attributes and trichostrongylid nematode infection, along with comparison of trichostrongylid nematode resistance between the Dorper and other wool and meat sheep breeds grazed in a extensive, broad-acre environment.

No lambs categorised as low WEC at pre-weaning were subsequently categorised as high WEC at post-weaning, and in both flocks the lambs categorised as high WEC at pre-weaning were approximately 40 times more likely to be categorised as high WEC at post-weaning. This finding suggests that WEC screening of lambs pre-weaning could be useful for predicting which lambs are likely to be in the highest WEC category in the post-weaning period. Early identification of lambs pre-disposed to high WEC would be helpful for sheep farmers using WEC as a selection tool to breed sheep resistant to nematode infections. Selection of sheep for breeding programmes usually occurs during the post-weaning period. For flocks where a high emphasis is placed on WEC in selection of sheep for breeding programmes, identifying lambs categorised as high WEC in the pre-weaning period and excluding these from further testing and measurement would reduce costs for unwarranted measurements where the lamb is likely to be excluded for high WEC. Identification of sheep pre-disposed to high WEC in the post-weaning period may also be beneficial for identifying young sheep that are suitable to be left untreated in refugia-based worm control strategies, aimed at maintaining a population of worms susceptible to anthelmintics (Waghorn *et al.*, 2008; 2010), although not entirely practicable.

Measurement of BCS does not require sophisticated equipment and has been shown to be an effective measure of “nutritional wellbeing” and BCS reserves across ranges of genotypes and environments (van Burgel *et al.*, In Press). Body condition score is considered to be a more accurate measure of body reserves than live weight because unlike live weight, BCS is not confounded by factors such as gastrointestinal tract contents, sheep frame size, pregnancy and fleece weight (Russel *et al.*, 1969; Thompson *et al.*, 1987; Warriss *et al.*, 1987; Delfa *et al.*, 1989; Teixeira *et al.*, 1989; Sanson *et al.*, 1993; Frutos *et al.*, 1997; Oregui *et al.*, 1997; Caldeira *et al.*, 2007). The lambs in this study were not subjected to fasting before weighing, thus differences in live weight of gastrointestinal contents were likely to have increased the variability of live weight measurements. Furthermore, trichostrongylid nematode larval burden has been shown to impact gastrointestinal tract weight and the effects of larval challenge on lamb carcass productivity may be underestimated by live weight measurement (Jacobson *et al.*, 2009a).

The finding of higher BCSs in lambs with lower WECs are likely to have some impact on productivity of lambs, particularly the ewe lambs which may be joined at an early age. Body condition score of ewes at joining affects fertility with each additional 10kg in live weight (or one BCS) at joining, resulting in approximately 20 more lambs conceived per 100 ewes joined for Merino ewes across a range of environments within Australia (Thompson *et al.*, In Press; van Burgel *et al.*, In Press). Extrapolating these responses to the BCS differences observed in the Dorper lambs in this study, the difference of 0.2 BCS observed between high WEC and low WEC lambs at post-weaning represents a difference of 4 lambs conceived/100 ewes joined and the difference of 0.5 BCS observed across the WEC range observed at post-weaning represents a difference of 10 lambs conceived/100 ewes joined.

The relationships between WEC and both live weight and liveweight change were inconsistent across the two flocks. For the significant relationships between WEC and live weight or liveweight change that were observed in the ewe lambs, the R^2 values suggested that factors other than WEC were responsible for 80% or more of the variation observed. Such factors that may have contributed to the variation within and between flocks include genetics, nutrition and concurrent diseases. In this study, the two lamb flocks were managed separately in different paddocks and measurements of WEC, productivity measures were taken at similar ages but at different times of the year. As a consequence, no between-flock analysis was undertaken due to confounding factors including sex, diet quality and quantity, species of parasites and pattern of larval exposure (Arnold and Dudzinski, 1967; Arnold, 1975; Berggren-Thomas and Hohenboken, 1986; Dobson *et al.*, 1990; Lee *et al.*, 1995).

The phenotypic relationships between live weight and WEC in the ewe lambs observed in this study were different at pre-weaning (negative correlation) and post weaning (positive correlation). Greer (2008) reviewed the relationship between immunity to trichostrongylid nematodes and sheep productivity, showing inconsistent genetic and phenotypic correlations between WEC and live weight, suggesting that the timing of measurements relative to acquisition of immunity may affect the correlation observed. It was concluded that acquisition and maintenance of immunity comes at a nutritional cost, but any live weight advantages observed in high WEC sheep (susceptible to infection) relative to low WEC (resistant to infection) counterparts, can be a temporary phenomenon (Greer, 2008).

The average WECs at pre- and post-weaning were above or near the common anthelmintic treatment threshold in Western Australia of 500 EPG and was consistent with another study that found high WECs were common in lambs consigned for slaughter from farms throughout south-western Australia (Jacobson *et al.*, 2009b). This suggests that both flocks of Dorper lambs were susceptible to trichostrongylid nematode infections when grazed in an environment favouring high trichostrongylid worm challenge throughout winter and spring, although no direct comparison was made with other sheep breeds in the present study. Previous studies between the Dorper and wool breeds, have found conflicting results towards comparing their levels of resistance towards trichostrongylid nematode infections (measured by WEC), some studies finding the Dorper breed to have had greater resistance than wool breeds (Wildeus, 1997; Burke and Miller, 2002, 2004), while others reporting the Dorper to have less resistance to trichostrongylid nematode infection, compared to wool breeds (Baker *et al.*, 2003; Mugambi *et al.*, 2005).

Oesophagostomum spp. accounted for the largest proportion of larvae recovered from the ewe lamb flock at pre-weaning. Modern anthelmintics have been generally effective in controlling this trichostrongylid, and *Oesophagostomum spp.* are usually only identified at low proportions (1-10%) in larval cultures from flocks in this region (Besier and Love, 2003). However, a recent study utilising molecular PCR assay methods identified 75% and 37% lambs infected with *Oesophagostomum venulosum* on two sheep farms in south eastern Australia (Roeber *et al.*, In Press).

5. Conclusion

High WEC was associated with lower BCSs in Dorper lambs. The relationships between WEC and live weight, liveweight gain and c-site fat depth were inconsistent across the two flocks. Most lambs categorised as high WEC pre-weaning remained in this category at post-weaning, therefore early identification of lambs pre-disposed to high WEC may be possible. Both of the Dorper lamb flocks in this study were susceptible to trichostrongylid nematode infection when grazing in an environment with high trichostrongylid worm challenge throughout winter and spring. Future studies of a larger scale are required to further compare associations between trichostrongylid nematode infection and production attributes in the Dorper, while also examining the level of nematode resistance of the Dorper compared to that of other sheep breeds, in extensive broad-acre grazing conditions.

Acknowledgements

We are grateful to the farmer Tamesha Gardner who cooperated with our research team for this study. Special thanks to the Albany and South Perth Animal Health Laboratories for assisting with the processing of faecal samples and performing faecal worm egg counts for the Dorper ewe and ram lambs respectively. Also, thank you to Aileen Elliot (Murdoch University Parasitology Laboratory) for her microscopy training and assistance with performing larval cultures.

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Table 1

Worm egg counts (WEC) and nematode genera identified by larval culture and differentiation for ewe and ram lamb flocks at pre- and post-weaning.

Flock	Lamb Age	WEC (EPG)		Larval differentiation (%)			
		Mean ± SEM	Range	*Haemonchus contortus*	*Tel. circumcincta*	*Trichostrongylus spp.*	*Oesophagostomum spp.*
Ewes							
Pre-weaning	4 months	565 ± 30	0 – 2700	0	7	25	68
Post-weaning	9 months	515 ± 31	0 – 3500	0	72	25	3
Rams							
Pre-weaning	4 months	553 ± 25	0 – 2000	0	5	92	3
Post-weaning	9 months	481 ± 26	0 – 1850	0	62	36	2

SEM = Standard error of the mean

Table 2

Mean and range worm egg count (WEC), live weight, body condition score (BCS), eye muscle depth and c-site fat depth measurements for ewe and ram lamb flocks at pre- and post-weaning.

Flock	Lamb Age	WEC (EPG)		Live weight (kg)		BCS		Eye muscle depth (mm)		C-site fat depth (mm)	
		Mean ± SE	Range	Mean ± SE	Range	Mean ± SE	Range	Mean ± SE	Range	Mean ± SE	Range
Ewes											
Pre-weaning	4 months	565 ± 30	0 – 2700	29.74 ± 0.33	18.0 – 46.5	2.62 ± 0.03	1 – 4	-	-	-	-
Post-weaning	9 months	515 ± 31	0 – 3500	42.51 ± 0.31	28.5 – 55.5	2.53 ± 0.04	1 – 4	25.30 ± 0.25	14 – 38	2.89 ± 0.04	1.5 – 5.0
Rams											
Pre-weaning	4 months	553 ± 25	0 – 2000	40.69 ± 0.55	22.5 – 64.0	3.39 ± 0.04	2 – 4.5	-	-	-	-
Post-weaning	9 months	481 ± 26	0 – 1850	52.64 ± 0.53	32.5 – 73.0	3.41 ± 0.05	2 – 4.5	28.15 ± 0.23	15 – 38	3.25 ± 0.05	2.0 – 6.0

SEM = Standard error of the mean.

Table 3

Correlation between log-transformed WEC and production attributes in Dorper ewe and ram lamb flocks.

	Live weight (kg)		Live weight gain (kg)[**]	Live weight gain (%)[***]	Body condition score (BCS)		Eye muscle depth (mm)[**]	C-site fat depth (mm)[**]
	Pre-weaning[*]	Post-weaning[**]			Pre-weaning[*]	Post-weaning[**]		
Ewes (n=283)								
Regression association	Negative	Positive	Positive	Positive	Negative	Negative	Nil	Nil
Difference across WEC range[†]	3 kg	3kg	9kg	4%	0.66 BCS	0.5 BCS	-	-
P-value	0.001	0.034	<0.001	0.022	<0.001	0.011	0.292	0.124
F-value	11.81	4.55	30.99	5.34	13.849	6.597	1.107	1.487
R^2 coefficient	0.204	0.183	0.205	0.207	0.204	0.146	0.056	0.061
Rams (n=212)								
Regression association	Nil	Nil	Nil	Nil	Negative	Negative	Nil	Negative
Difference across WEC range[†]	-	-	-	-	1 BCS	0.75 BCS	-	0.4mm
P-value	0.303	0.304	0.184	0.314	0.003	0.011	0.139	0.094
F-value	1.135	1.112	1.164	0.109	9.202	6.511	1.260	2.158
R^2 coefficient	0.148	0.202	0.214	0.221	0.181	0.219	0.047	0.071

* Pre-weaning WEC independent variable.

** Average WEC independent variable.

***Live weight gain between pre- and post-weaning expressed as % of pre-weaning live weight.

[†]Change in production attributes across entire WEC range recorded at each sampling occasion (Table 1).

Table 4

Effect of WEC category on production attributes of ewe lambs (general linear model).

WEC Category	Live weight (kg)		Live weight gain (kg)	Body condition score		Eye muscle depth (mm)**	c-site fat depth (mm)**
	Pre-weaning*	Post-weaning**		Pre-weaning*	Post-weaning**		
Low WEC (0-500 EPG)							
Lambs (n)	168	165	165	168	65	165	165
Mean ± SEM	30.8 ± 0.41^{A}	42.3 ± 0.40	11.4 ± 0.45^{A}	2.69 ± 0.04^{A}	2.60 ± 0.04^{A}	25.40 ± 0.31	2.89 ± 0.05
Moderate WEC (501-1000 EPG)							
Lambs (n)	66	75	75	66	75	75	75
Mean ± SEM	27.2 ± 0.66^{B}	43.5 ± 0.67	16.1 ± 0.49^{B}	2.57 ± 0.06^{AB}	2.42 ± 0.07^{B}	25.71 ± 0.54	2.89 ± 0.07
High WEC (≥1000 EPG)							
Lambs (n)	49	43	43	49	43	43	43
Mean ± SEM	29.5 ± 0.76^{A}	42.3 ± 0.80	12.2 ± 0.60^{A}	2.44 ± 0.07^{B}	2.41 ± 0.08^{B}	24.40 ± 0.60	2.91± 0.08
P-value	<0.001	0.369	<0.001	0.027	0.046	0.269	0.954
F-value	10.711	1.001	21.775	3.644	3.110	1.320	0.047

* Mean for pre-weaning productivity measures for lambs categorised using pre-weaning WEC.

** Mean for post-weaning productivity measures for lambs categorised using post-weaning WEC.

^{ABC} Values in columns with different superscripts are significantly different (P<0.05).

SEM = Standard error of the mean.

Table 5

Effect of WEC category on production attributes of ram lambs (general linear model).

WEC Category	Live weight (kg)		Live weight gain (kg)	Body condition score		Eye muscle depth (mm)**	c-site fat depth (mm)**
	Pre-weaning*	Post-weaning**		Pre-weaning*	Post-weaning**		
Low WEC (0-500 EPG)							
Lambs (n)	136	124	124	136	124	124	124
Mean ± SEM	40.4 ± 0.46^{AB}	52.3 ± 0.66	12.6 ± 0.64^{A}	3.53 ± 0.06^{A}	3.46 ± 0.05^{A}	28.35 ± 0.29	3.25 ± 0.07^{A}
Moderate WEC (501-1000 EPG)							
Lambs (n)	54	64	64	54	64	64	64
Mean ± SEM	42.3 ± 0.45^{A}	53.8 ± 1.05	10.1 ± 0.67^{B}	3.31 ± 0.08^{B}	3.50 ± 0.08^{A}	28.10 ± 0.45	3.40 ± 0.09^{A}
High WEC (≥1000 EPG)							
Lambs (n)	22	24	24	22	24	24	24
Mean ± SEM	38.5 ± 0.72^{B}	51.6 ± 1.42	13.3 ± 0.87^{A}	2.92 ± 0.12^{C}	3.02 ± 0.14^{B}	27.17 ± 0.82	2.91 ± 0.14^{B}
P-value	0.098	0.369	0.048	<0.001	0.011	0.342	0.027
F-value	2.339	1.002	3.143	8.422	4.582	1.080	3.683

* Mean for pre-weaning productivity measures for lambs categorised using pre-weaning WEC.

** Mean for post-weaning productivity measures for lambs categorised using post-weaning WEC.

SEM = Standard error of the mean.

^{ABC} Values in columns with different superscripts are significantly different (P<0.05).

Figure 1. Frequency distribution of WECs in both pre- and post-weaning Dorper lambs.