CHAPTER FIVE

A field experiment to determine the effect of supplementary feeding on responses to *Trichostrongylus spp.* and some production parameters in Merino weaners.

5.1 INTRODUCTION

The survey (Chapter 3) identified that sheep graziers indicated diarrhoea and nematode parasites in young Merino weaner sheep as their problem. It is speculated (Chapter 4) that this is due to *Trichostrongylus spp.* infections that develop in Merino sheep after weaning, and that nutritional status at this stage is a major contributing factor. Hall (1990) used field evidence to suggest that this was due to inadequate nutrition and argued it was because Merino weaners failed to develop satisfactory immunity prior to the winter.

There is a lack of pasture in the winter due to nil pasture growth in this period (Hilder 1956; Vickery 1972), and as demonstrated in Chapter 4 there is little to negative growth in Merino weaners over this period.

This field experiment was carried out to ascertain the effect of supplementary feeding Merino weaners over this period on the effects of natural infections of *Trichostrongylus spp.*, and monitor the long-term effect on the production parameters of body weight gain and annual wool production.

The paddocks available had the advantages that the pasture characteristics had been studied previously (Archer, Bell and Rose 1991) and hence supplementary feeding could be varied to produce predicated weight responses with some degree of accuracy.

5.2 MATERIALS AND METHODS

5.2.1 Sheep and Supplementary Feeding

150 Merino weaners (full description given in Appendix A2.3.2) were run from weaning in December 1991 until February 1993 on a 24 ha paddock south of Armidale, New South Wales. A description of the paddock is given in Appendix A1.2.3.1. This paddock was fenced in to two paddocks of equal size, and contained similar pasture characteristics. The pasture was primarily unimproved growing on basalt soils.

The sheep were randomly divided into two groups on a paired weight basis, and 25 of 75 selected from each group on a weight subset basis. One group was fed commercial 28% protein sheep nuts (details given in Appendix A2.3.5) when the feed in the paddock was not sufficient to maintain adequate growth rates. The weather details over the period are given in Appendix A2.3.3, the estimate on available pasture is given in Appendix A2.3.4, and the amount of supplementary feed is given in Appendix A2.3.6 The sheep were subsequently run as a single group on an adjoining paddock of similar pasture for 2 years and run as a group on another similar paddock until January 1998.

To equalise availability of pasture and parasite challenge the supplemented and non-supplemented groups were exchanged in paddocks weekly.

5.2.2 Field Monitoring

Each of the 25 sheep in each group were bled, weighed and faecal sampled every 4 weeks. Four sheep from each group had wool dyebands applied every 8 weeks. Three sheep selected on a weight basis (one average, one above and one below average) were selected from each group monthly for total worm counts. At shearing, fleeces of the 25 selected sheep in each sub-group were weighed and fleece measurements obtained.

Subsequently, body weights and faecal egg counts were monitored regularly. Fleece weights were measured each year at shearing, up to January 1998.

5.2.3 Laboratory Testing

Faecal egg counts (FECs) were conducted on the 25 selected sheep for each group every 4 weeks using a modified McMaster technique (Whitlock 1948), as outlined in Appendix A1.1. The parasite eggs were differentiated into trichostrongylid genera by larval culture of a bulk faecal sample from each group (Lyndal-Murphy 1993), as outlined in Appendix A1.2. *Ostertagia* and *Trichostrongylus spp.* numbers were calculated using the group arithmetic mean and percentage of larvae for each genus.

Total worm counts (TWCs) were conducted on three sheep from each group using the method described by Lyndal-Murphy (1993) every 4 weeks, as outlined in Appendix A1.3 and A1.4.

T. colubriformis antibody levels were measured on the 25 selected sheep from each group every 4 weeks using an enzyme linked immunosorbent assay (ELISA) described by Watson and Gill (1991), as outlined in Appendix A1.5.

5.2.4 Fleece Measurements

The sheep were shorn 12 months after the commencement of the experiment (on 15/12/92) and fleeces weighed of the 25 selected sheep from each group. A mid-side sample of 25-30 g was collected for micron and yield testing. This was conducted by an AWT certified commercial testing service (Walcha Wool Testing Service, 5 Hamilton Street, Walcha NSW 2354).

Fleeces from those sheep remaining were weighed at shearing each year until January 1998.

5.2.5 Statistical Analysis

The effects of nutrition on the changes in egg counts and antibody levels was assessed using transformed data and subjected to a multivariate analysis with repeated measures, using Genstat 5, Release 2.2, (1990), Lawes Agricultural Trust. The total worm count data was assessed using transformed data and subjected to analysis of variance. The effects of nutrition on fleece measurements was analysed using Students *t*- test.

5.3 RESULTS

5.3.1 Liveweights

Liveweights of the two groups of weaners are shown in Figure 5.1. The stocking rates were set so that the non-supplemented group should reach 25 kg prior to winter and that the supplemented group should be fed to reach 30 kg, a 5 kg difference. This figure had been suggested to be that required for weaners be maintained through the winter period (Macfarlane 1992) and is based on field results (see Chapter 4).

Supplemented weaners were given some feed from weaning as they had not been trained to feed pre-weaning. This feed was initially lucerne hay, with small amounts of nuts being gradually introduced. Significant weight differences did not develop until 27/5/92. Full supplementary feeding with commercial 28% by-pass protein sheep nuts was commenced on 29/4/92 as evaluation of paddock feed availability revealed that it was not sufficient to maintain growth rates. A 5 kg difference between the two groups was established during the first full feeding 4 week period. This difference was maintained by calculating the required amount of supplementary feed at least every 4 weeks (every 2 weeks in critical periods). This was achieved by estimating paddock feed availability and utilising GrazFeed (GrazFeed, CSIRO Version 1.1, 1990), a computer aided nutritional management system for grazing animals. This was used to calculate the amount of supplement required to maintain a desired growth rate level. The amount of feed required varied from 58 to 240 g/per head per day. Feeding ceased on 11/11/92, by which time pasture feed was adequate for full growth rate of both mobs. The established weight difference was maintained up to the first shearing (15/2/92). A detailed analysis for period of least feed is given in Appendix A2.3.7.

The increase in weights that commenced from 19/8/92 was due in part to the fact that pasture availability increased from this period (see Appendix A2.3.4). It is characteristic of New England that pasture production increases with increases in temperatures commencing in August (Hilder 1956; Vickery 1972). It was also due to drenching which removed resident parasitic burdens, the effect of which is decreased growth rates (Barger 1982).

The liveweight difference remained through the spring/summer period; that is, no compensatory growth occurred. This was not due to the effects of parasites as there was no difference from 13/10/92, but probably as a result of negligible clover or other high protein feed in the pasture during the animals growth phase leading up to maturity. This liveweight difference was maintained for the next 4 years.

After the first shearing, all remaining sheep were run together in one paddock as one mob. Regular weights were recorded until the third shearing. Although weights fell during periods of low pasture growth and availability, the significant weight difference was still evident on an annual basis until January 1998.

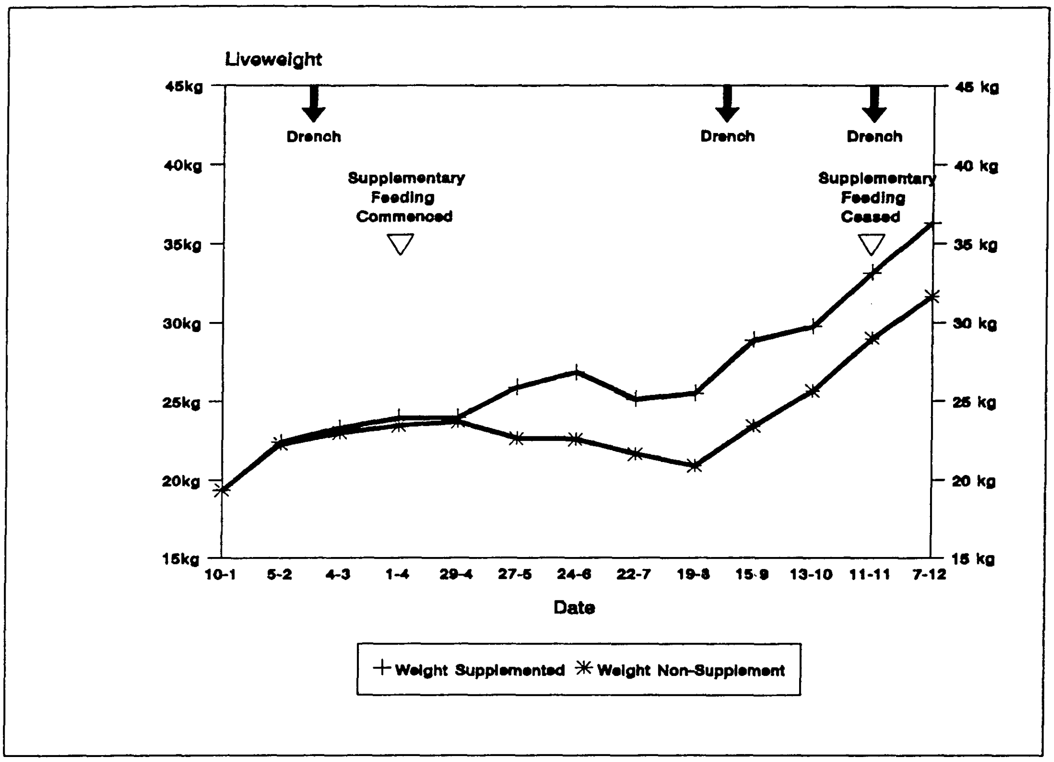

Figure 5.1 *Liveweights of the two groups of weaners from 10/1/92 to 7/12/92, ie, until first shearing.*

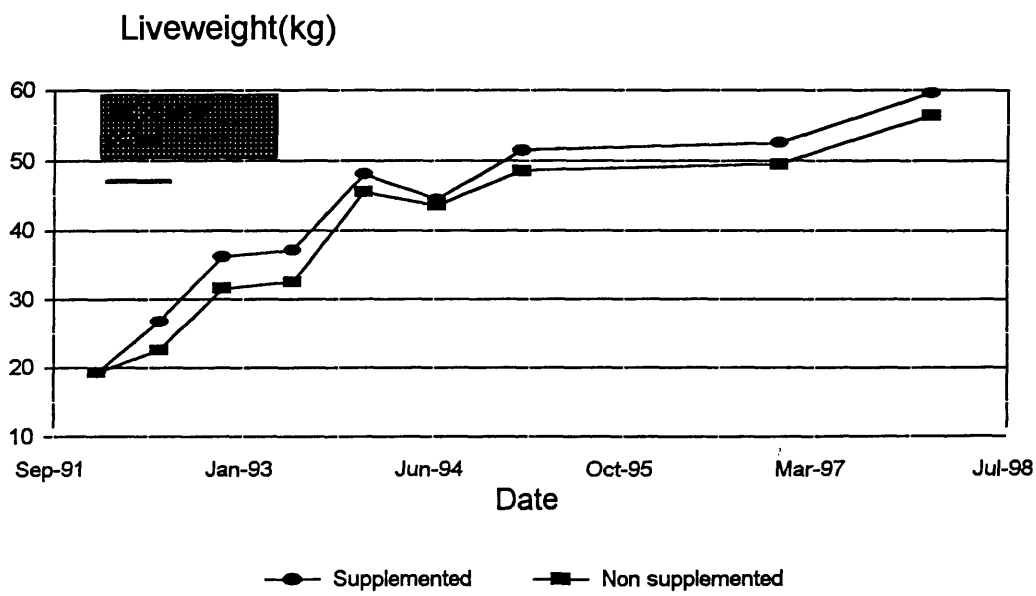

Figure 5.2 *Liveweights of sheep from 10/1/92 to 7/1/98 (ie, over a six year period). Supplement was only given in the period 1/4/92 - 11/11/92.*

5.3.2 Faecal Egg Counts

The estimated *Trichostrongylus spp.* faecal egg counts are shown in Figure 5.3. These are calculated from group differentials of bulk cultures applied to arithmetic means of individual faecal egg counts (eggs per gram of fresh faeces) for each group.

A significant difference had established by 1/4/92 and this was maintained until 19/8/92. Egg counts increased over this period, in all cases the differential count indicated that *Trichostrongylus spp.* was the major pathological species present (varying between 43% and 93%).The supplemented group were averaging below 500 (arithmetic mean epg), a count arbitrarily used as a point when tactical drenching is required (B Chick, *pers comm.*). On the other hand, the non-supplemented groups developed higher egg counts indicating that infection was affecting sheep. Indeed, suspect clinical effects of *Trichostrongylus spp.* had developed in some sheep in the non-supplemented group by 22/7/92, and some individuals had become clinically affected by 19/8/92. At this time, a decision was made on welfare grounds that drenching of the non-supplemented group was required as some individuals were judged to be unfit, in that they could not move with the mob over 250 m when worked with a dog. All sheep were drenched with a levamisole - benzimidazole combination drench (Scanda RTM, Pitman-Moore Australia) (72% effective by faecal egg count reduction test). There was a slight difference between groups in egg counts on 15/9/92, but thereafter there was no significant difference.

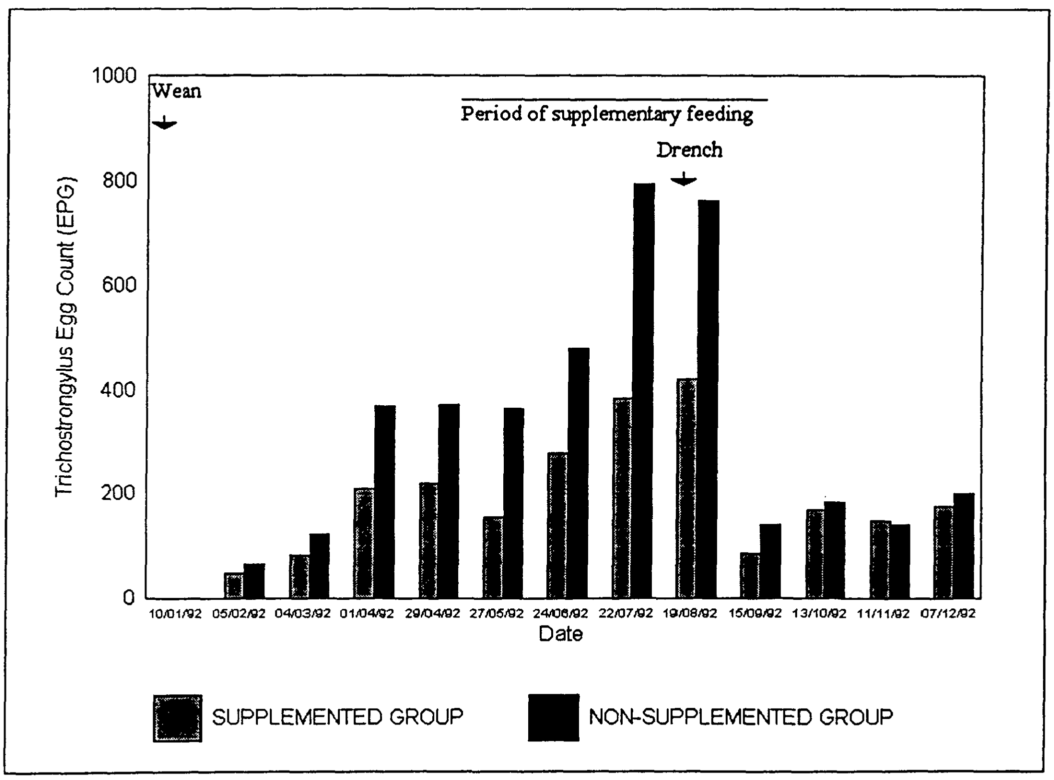

Figure 5.3 *Estimated Trichostrongylus spp. egg counts that developed as a result of continual exposure to field larvae in the two groups of Merino weaners from 10/1/92 until 7/12/92, ie, until first shearing.*

5.3.3 Total Worm Counts

Results of total worm counts of the 3 sheep slaughtered from each group at monthly intervals are shown in Table 5.1. These counts are averaged over 3 sheep and although there were mixed nematode infections, the majority were *Trichostrongylus spp.*, and the counts for that species are given.

Total worm counts were measured in three sheep from each group. The general trend was for *Trichostrongylus spp.* to mirror egg counts. The worm counts were very variable amongst the three sheep in each group; which given the range of natural genetic susceptibility/resistance to parasites is to be expected (Gray, Barger, Le Jambre and Douch 1992).

Worm Count *(Trichostrongylus spp.)*			
Date	**Supplemented Group**	**Non-Supplemented Group**	**Comments**
10/1/92	0	0	
5/2/92	33	200	
4/3/92	133	500	
1/4/92	133	500	Supplementary feeding commenced
29/4/92	367	300	
27/5/92	667	533	
24/6/92	1400	1533	
22/7/92	1633	1900	
19/8/92	1033	9367	Drench
15/9/92	100	333	
13/10/92	667	4833	
11/11/92	1600	1000	Supplementary feeding ceased

Table 5.1 *Trichostrongylus spp. worm counts (average of 3 sheep) that developed as a result of continual exposure to field larvae in the two groups of Merino weaners over a 12 month period from weaning, one of which was supplemented over a period of low pasture feed availability.*

5.3.4 Antibody Levels

The *T. colubriformis* antibody levels for each group were measured using an ELISA test, are shown in Figure 5.4.

T. colubriformis antibody levels rose in both groups indicating a good and continual antibody response due to continuing field challenge. However, despite lower egg counts in the supplementary feed group, there was no difference between the groups in antibody levels.

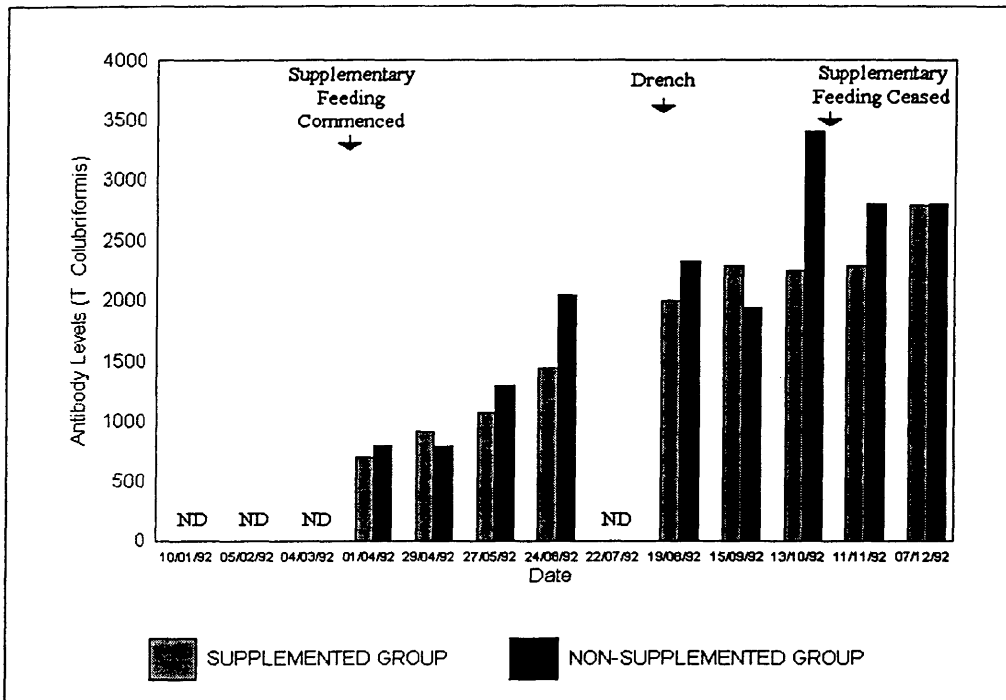

Figure 5.4 *T. colubriformis ELISA antibody levels that developed as a result of continual exposure to field larvae in the two groups of Merino weaners over a 12 month period from weaning, one of which was supplemented over a period of low pasture feed availability.*

5.3.5 Fleece Measurements

Specific wool measurements from 25 selected sheep from the two groups at their first shearing are shown in Table 5.2.

	Supplemented Group	Non-Supplemented Group
	Average ± SEM	Average ± SEM
Greasy Fleece Weight (kg)	3.04 ± 0.068 a1	2.59 ± 0.062 a1
Clean Fleece Weight (kg)	2.37 ± 0.059 a2	1.92 ± 0.049 a2
Fibre Diameter (micron)	16.96 ± 0.202 b	16.58 ± 0.234 b
Fibre Diameter Coefficient of Variation of %	20.11 ± 0.316 a3	21.42 ± 0.443 a3
Yield (16%)	78.10 ± 0.728 a4	74.26 ± 0.464 a4

a1, a1; a2, a2; a3, a3; a4, a4; significantly different p < .001
b, b: no significant difference

Table 5.2 Wool measurements of two groups of Merino weaners over a 12 month period from weaning, one of which was supplemented over a period of low pasture feed availability.

Greasy fleece wool weights were measured at each shearing and the results are given in Table 5.3. Significant differences in fleece weights (P > .001) were maintained for 5 years after supplementary feeding.

Shearing Date	16/12/92	05/01/94	25/01/95	15/11/95	13/1/97	8/1/98
Supplemented Group						
Av. Greasy Fleece Weight	3.04 kg a	3.56 kg b	3.86 kg c	3.96 kg d	4.06 kg e	3.93 kg f
SEM	0.12	0.25	0.27	0.18	0.25	0.18
Non-Supplemented Group						
Av. Greasy Fleece Weight	2.59 kg a	3.21 kg b	3.6 kg c	3.67 kg d	3.84 kg e	3.59 kg f
SEM	0.10	0.37	0.07	0.18	0.19	0.21

a, a; b, b; c, c; d, d; e, e; f, f; significantly different p < .001

Table 5.3 Fleece wool weights of the two groups of Merino weaners at shearings from 1992 - 1998.

In this experiment, supplemented weaners grew 0.45 kg more greasy wool (17.4% above the non-supplemented group) ($P < .001$) or 23.4% more clean wool in the first year. Although this would be expected with supplementary feeding, it could also be in part a consequence of reducing the effect of *Trichostrongylus spp.* These differences in wool weights, a pattern established in the 6 - 12 months age range, were maintained for the next 4 shearings, as shown in Table 5.3.

5.4 DISCUSSION

5.4.1 Liveweights

These results are in agreement with the general conclusions of Allden (1970), who reviewed the effects of variations in early nutrition of sheep on their subsequent growth and productivity. Allden's general conclusions were that effect of exposing sheep to under-nutrition was harder to overcome the earlier the under-nutrition was imposed - and sheep stressed under 6 months could only recover much more slowly compared with older sheep.

Early work in New Zealand (Coop and Clark 1955) had suggested that similar conditions apply to self-breeding flocks in New Zealand as to Australia in that breeding sheep are confined to the relatively infertile hill country and are severely nutritionally stressed in early life. In the trials of Coop and Clark (1955), body weights did not remain significantly different one year after the nutrition stress ceased. In their experiments, however, weaners were given good nutrition prior to maturity, and allowed for compensatory growth to occur, which meant liveweight differences were not significant after a further 12 months.

In Scotland, a similar pattern occurs with sheep grazed on poor hill pasture. Gunn (1977), in a series of field experiments in which low and high levels of nutrition were imposed up to 12 months of age, demonstrated liveweight differences that persisted for 5 years, but declined at variable rates depending on subsequent nutrition.

In America, a similar picture is portrayed with range sheep, with young sheep not making good growth in early life. Bradford, Weir and Torell (1961) tested the variation in nutrition imposed from weaning to first breeding on lifetime production of ewes. One trial involving Merino type sheep, pastured on natural conditions after the nutrition treatment had ceased, demonstrated a significant but decreasing weight difference for 3 years after the nutrition treatment.

In Australia, Giles (1968) looked at the effects of different levels of nutrition in Merinos from weaning to seventeen months of age over the life of the sheep. The weight difference established was 20 kgs vs 27 kgs after 2 months of nutrition treatment, and at the end of the treatment the difference was 34 kgs vs 45 kgs. Subsequent to the cessation of treatment, the weight difference was reduced to about 10 lbs and this difference was maintained for the life of the sheep (6 years); ie, in this experiment, nutrition treatment had a permanent effect in that sheep on low nutrition remained permanently stunted.

Reardon and Lambourne (1966) found a similar effect on ewe lambs run on either native pasture or improved pasture on the Northern Tablelands. Differences in liveweight diminished, but remained significantly different until 7 years of age.

Langlands, Donald and Paull (1984), in a trial involving Merino lambs treated with high and low planes of nutrition from weaning (3-4 months) until 15 months, showed that the weight differences declined in time. Both groups were thereafter run on a high plane and low plane of nutrition (low and high stocking rates). The weight differences fell, but were maintained in the groups on low planes of nutrition much longer (significant at 5½ years compared to 2½ years).

Their work is comparable with this trial, as at no time were sheep running on a pasture of high nutritive value, ie, native pastures.

One suggested major effect of long-term body weight differences is the effect on fertility in ewes. It is well established that condition prior to joining is a major factor in determining fertility and fecundity of that joining (Lindsay 1983, Smith and Stewart 1990). However, the long-term effect of nutrition between weaning and puberty on subsequent fertility is unresolved, and like the effect of the liveweight, is probably influenced by the length and severity of nutritional stress, the age it is applied, and the subsequent nutrition.

Gunn (1977) found long-term reproductive effects (as measured by ovulation rates) due to low and high nutrition diets over the whole period of rearing (up to 12 months), but noted the critical development stage remained unidentified.

The effect of the body weight changes on fertility in ewes was variable in the trials of Langlands *et al.* (1984). In general, the fertility at first joining is dependent on how severe the nutritional stress was, and how long it was applied for.

5.4.2 *Trichostrongylus spp.* Faecal Egg Counts

Reduction in faecal egg output as demonstrated by faecal egg count has been shown to be one manifestation of developing immunity to parasites (McClure, Emery, Wagland and Jones 1992). In this experiment, egg counts were lower in supplemented sheep from the period of full supplementary feeding.

Reviewing previous experiments designed to test the effect of protein supply on the acquisition of resistance to nematode parasites in young sheep, it can be said that in general the effect of dietary protein supply is to enhance the ability of the host to develop both resilience and resistance to nematodes during the challenge.

Early studies to investigate the influence of protein intake on parasite establishment conducted by Bawden (1969) and Dobson and Bawden (1974) compared low and high protein diets in young sheep that were trickle infected with *Oesophagostomum columbianum*, and later post mortemed. FECs started earlier and were significantly higher in sheep on low protein diets. Post mortems showed that the high protein diet did not influence the number of incoming larvae becoming established, but did increase the rate of expulsion of adult worms. Worms in sheep on low protein diets developed more worms per adult female worm.

More recently, Abbott, Parkins and Holmes (1988) used trickle infections with *H. contortus* and observed differences in FECs in sheep given low and high protein diets despite similar feed intake. Sheep given low protein diets carried almost 3 times as many worms at the end of the experiment.

Bown *et al.* (1991), using trickle infections of *T. colubriformis*, used either protein (casein), or glucose asaline infused directly into the abomasum to determine the effects of protein and energy on the effect of worm establishment and worm diminution. After 12 weeks (but not 6 weeks), daily FECs and worm burdens were 50% lower in the sheep infused with protein compared with sheep infused with energy or controls. This was confirmed by Coop *et al.* (1995), in which a challenge dose of *O. circumcincta* was given following anthelmintic treatment following 9 weeks of trickle infection. Worm burdens 10 days later were 50% lower in casein infused sheep than controls, and a smaller proportion of worms developed beyond early L4 stage. The authors concluded protein accelerated the immunity to *O. circumcincta* in young sheep.

Kambara *et al.* (1993) trialed diets of low or high protein pellets and a trickle infection of *T. colubriformis* in young and older sheep. FEC and worm burdens were lower in sheep on high protein diets, indicating high protein diet sheep developed higher resistance. This effect was not apparent in older (12 month) sheep.

Roberts and Adams (1990) trickle infected 5 months old merino wethers, with *H. contortus* for 17 weeks, which were offered 600 g or 400 g of a pelleted diet (17% crude protein). Over this period, weaners on the higher diet gained significantly more weight and the low diet sheep had a FEC 3 times higher than the high diet sheep. The authors concluded that the weaners on the high diet were adequately nourished and the resistance developed against the parasite was due to the development of immunity. In this experiment, the FECs of the high diet sheep plateaued at 8 weeks and fell there after, whereas the low diet sheep FECs continued to rise throughout the experiment.

van Houtert *et al.* (1995b), using fish meal as a high protein supplement in Merino weaners, found that the rate of development of infective larvae was similar, but the high protein diet enhanced the worm expulsion.

There are a number of factors that may have contributed to the variation in egg counts between the two groups besides the effect of variation in immunity. These include variation in dietary intake, variation in faecal output, direct effect of nutritional supplements and the appetite suppressant effect of *Trichostrongylus spp.* infections.

Pasture intake of the supplemented group could be lower due to the substitution effect of the supplement. Grazfeed, for example, gives a maximum variation when supplement was being fed at 240 gms/day, ie, 0.72 gms/day intake of herbage (in kg DM) for the supplemented group compared to 0.83 gms/day in the non-supplemented group. It must be pointed out that the whole topic of sheep responses to supplements when feeding on roughage remains controversial (Leng 1993; Rowe, Tudor, Dixon and Egan 1991).

In some recent experiments (Dixon, Thomas, Thalen and Egan 1993), supplements based on cottonseed meal have not reduced roughage intake. These authors suggest increased digestibility on supplement diets allows increased total intake due to increased utilisation of the low quality feed in the pasture. Similar effects have been reported in developing countries using low quality feeds (Leng, Jessop and Kanjanapruthipong 1993).

The effect of variation in pasture intake is to vary the possible larval intake. However, as a high percentage of this diet was roughage (ie, dead material component of this pasture was long dry grass), a relatively small variation in roughage intake is not likely to have caused the large variation in egg counts that occurred.

Supplements of themselves form a part of faecal outputs, and hence will have a dilution effect on egg counts in faeces. Using the Grazfeed model again, at maximum supplementary levels, this effect would be to reduce egg counts by 22%.

The appetite suppressant effect of *Trichostrongylus spp.* infections is well documented (Symons 1985) and this probably occurred in July/August in this experiment. This would have the effect of concentrating eggs in faeces, as well as reducing the intake of infective larvae in the non-supplemented group.

Finally, certain supplements are known to contain ingredients that affect nematode parasite viability. For example, antioxidants in some cattle feeds have been shown to have an inhibitory effect on nematode larval development (Ciordia, Porter and Bizzell 1967). There are no known such contents in the pellets given, but that is not to say such were not present.

5.4.3 Total Worm Counts

The results indicate the supplemented group were generally more resistant than the non-supplemented group, in that they generally had lower worm burdens. However, the small number of sheep meant it was not possible to demonstrate a statistically significant difference between the groups, except for the 18/9/92, when there was a significant difference ($P = 0.006$ for adult *Trichostrongylus spp.*). There was a significant overall upward trend in counts over time ($P<0.001$).

5.4.4 *T. colubriformis* Antibody Levels

T. colubriformis antibody levels rose in both groups, indicating a good and continual antibody response due to continuing field challenge. However, despite lower egg counts in the supplementary feed group, there was no difference between the groups in antibody levels. Watson and Gill (1991) concluded that despite the fact that Merino weaners develop strong antibody responses, this is not related to the ability to suppress egg counts. This trial confirms that serum antibodies are not related to the effective immune response in the gastrointestinal tract, and are not a specific indicator of effective immunity to nematode parasites.

5.4.5 Wool Production

The effect of nutrition treatments post weaning to Merinos has given variable long-term effects. Giles (1968) demonstrated that at the end of the nutrition treatments, a significant difference of 1.5 kgs in greasy fleece weights had established, and that once sheep were run under a similar nutritional treatment, a significant but reduced difference remained (about 0.5 kg). This variation essentially mirrored the liveweights of that trial, as previously outlined.

Besides nutritional effects, wool production is reduced by the effect of *T. colubriformis* infections. In young grazing sheep, greasy fleece weight reductions of up to 31% have been measured (Barger 1982). In a summary of 12 experiments, Barger (1982) found the average fleece weight reduction was estimated at 19%, with a range from 9% to 31%.

There was no long-term effect on wool production on the other trials reported, and this is consistent with their findings that there was no long-term fleece weight differences (Coop and Clark 1955; Bradford *et al.* 1961; Langlands *et al.* 1984).

Allden (1970) suggested in his review that field trials in general have shown that the effects of low nutrition in early life do not persist as long for wool production as for body weight. The results indicate that the wool production per body weight is not affected, ie, in trials where a wool production difference persisted, it was of a similar magnitude to the body weight (eg, Giles 1968), and is probably a function of it.

As indicated in Table 5.3, this fleece weight difference was accompanied by a non-significant increase in fibre diameter (0.38 micron). The supplemented group produced wool with less variation in fibre diameter (coefficient of variations 20.11 v 21.42), and higher yield (78.09% v 74.26%). These factors were not measured at subsequent shearings.

5.4.6 Limitations of the Experimental Procedures

The development of immunity to parasites has been shown to be a complex procedure (McClure *et al.* 1992; Hohenhaus and Outteridge 1995) and it is only possible to estimate the development of immunity by measuring one or more of the manifestations of the immune process. A summary is given in Eady (1995).

In this experiment, faecal egg counts were measured and were essentially a means of estimating viable female parasites present. It is established that there is a good relationship between faecal egg counts and adult parasites in sheep for *Trichostrongylus spp.* (McKenna 1981 and Hall 1990). In this experiment, there were a number of confounding factors that a degree of uncertainty exists when comparing the two groups, as such discussed in 5.4.2.

Total worm counts were conducted to validate the faecal egg counts, however, the small number done per unit time, and the large variation between individuals meant it was not possible to get a statistical confirmation that the high egg count of non-supplemented group was due to high total adult worm burden.

Finally, specific ELISA antibody levels were measured, and although these indicated a response to infection, ELISA antibodies are not a critical part of the immune process in that they do not reflect a specific level of developed protective immunity.

Alternate methods that could have been employed to measure developing immunity are removal of parasites and then imposing an artificial challenge. Immunity at that time can then either be tested by faecal egg counts that develop as a result of the artificial infection (which will not be subject to confounding effects), or total worm counts conducted to determine the total number of worms that developed as a result of the artificial infection.

5.4.7 Limitations of the Experimental Design

For this experiment, the total effect of feeding is not assessed, as the experimental design is not based on a pasture. If a classical replicated split plot design had been used, then supplemented animals having lower FECs would have logically reduced contamination of pasture, and hence the full effect of supplementation could have been assessed (Gill 1987).

This was not done in this experiment because the experiment was designed to determine the effect of supplementation versus non-supplementation on parasite resistance given a similar natural field challenge. Secondly, split plot experiments using natural field challenges have had the problem that because of the replicates required, paddocks are usually small, and establishing initial equal natural field challenges has proved almost impossible to achieve and difficult to measure (D Gray, *pers comm.*).

5.5 CONCLUSION

In this experiment, supplementary feeding with a high protein diet had the effect of reducing the effects of *Trichostrongylus spp.* infections in Merino weaners at a time of critical feed shortage. There is evidence to suggest that the high protein diet allowed the development of an effective immunity against *Trichostrongylus spp.* This field trial confirms work previously conducted in pen trials.

The diet, selected to increase body weight, also increased wool production as expected. The effects of increased body weight and higher fleece weights were maintained throughout the life of the sheep. The effect of lower FECs did not persist, ie, FECs were similar once animals matured, suggesting that the non-supplemented group eventually developed a resistance similar to the supplemented group.

This experiment suggested a further trial using a supplementary feeding program that more realistically mirrors usual farm feeding practices. Secondly, it would be desirable to test sheep at the end of the feeding period to confirm supplemented sheep had developed a higher resistance to infection.

CHAPTER SIX

A field experiment to determine the effect of supplementary feeding on development of immunity to nematode parasites in Merino weaners and compare the effect between random-bred weaners, and those bred for nematode parasite resistance.

6.1 INTRODUCTION

6.1.1 General

The field trial previously reported (Chapter 5) indicated supplementary feeding assisted weaners in developing resistance to *Trichostrongylus spp*. It was not determined if the effect was mediated via increased development of immunity or by enhancing the ability of the sheep to withstand the pathophysiological consequences of infection, including ameliorating the effects of anorexia. These deficiencies are discussed in Chapter 5 as is the desirability of carrying out further trial work.

This field trial was established to run in a similar manner to the trial previously reported, with the difference that a live field method using artificial challenge of infective larvae to compare immunity of the groups was carried out at a time when significant egg counts had developed between the groups. Secondly, an opportunity arose to use Merino weaners from the University of New England flock in which some weaners were derived from rams known to be resistant to *H. contortus*. Hence, it was possible to compare the effect of supplementation both on random-bred and resistant-bred weaners.

6.1.2 Introductionary Remarks on Breeding Resistance to Nematode Parasites

The concept of breeding sheep resistant to parasites has a long-term appeal, and the subject has recently been reviewed Eady (1995) and Gray (1997). It is beyond the scope of this presentation to cover this subject, other than to summarise the situation as relates to Merino breeding on the New England Tablelands.

In breeding for resistance to nematode parasites, the initial quandary has been to decide what factor to select for. The difference between resistance (the ability of animals to resist infection by parasites) and resilience (the ability of animals to maintain production during infection) should be made, as the consequences for selection are somewhat different. There is in effect no single measure of either. As the two are genetically unrelated and as selection for resilience is at best difficult, the simplest and cheapest method has been used in Australia, ie, using the Faecal Egg Count (FEC) method (Woolaston and Eady 1995) as the basis for selection. Alternative selection criteria such as DNA makers, host antibody and parasite antigen assays are being developed but their use in the field has yet to be proven.

6.1.3 New England Resistant-Bred Flocks

Following confirmation that faecal egg counts (FECs) were heritable in Merinos (reviewed by Piper 1987), two projects were established in Armidale to study the potential of genetic selection for parasite control.

The CSIRO Haemonchus selected flock established at Chiswick Pastoral Centre, CSIRO Armidale, based on long-term selection of lines of Merinos, selected on FECs after artificial challenge with *H. contortus* larvae. Details are given by Woolaston, Barger and Piper (1990). The UNE 'Golden Ram' flock is based on the descendants of a ram whose progeny were found to be extremely resistant to *H. contortus* (ie, the 'Golden Ram') (Albers, Gray, Piper, Barker, Le Jambre and Barger 1987).

Subsequently, a third flock has been relocated to CSIRO Armidale. In this flock, lines of Merinos were selected with high and low responsiveness to vaccination with irradiated *Trichostrongylus colubriformis* larvae (Windon and Dineen 1984). A fourth nucleus flock based on resistant animals from all the above experimental flocks has also now been established in Armidale. Rams have been entered into commercial schemes for evaluation (Woolaston and Eady 1995).

It is interesting to note that comparisons for resistance to *H. contortus* and *T. colubriformis* are similar for sires from the lines selected for any one specific resistance, illustrating a cross selection of resistance exists (Gray 1995). Similar breeding programs occur in Victoria (Cummins, Thompson, Yong, Riffkin, Goddard, Callinan and Saunders 1991), Western Australia (Karlsson, MacLeod, Leelawardana, Sissoev and Simmons 1991), New Zealand (Morris, Watson, Bisset, Vlassoff and Douch 1995) and elsewhere (Gruner and Lantier 1995).

In New England, the breeding program "Nemesis" has been recently developed, promoted and adopted by commercial breeders in the New England and elsewhere (Eady, Woolaston, Ward, Gray, Karlsson and Greef 1997). It must be noted that whilst not all the consequences of these breeding programs have been established, the promoted benefits arise from the effects of having fewer worms. This leads to reduced impact on production, lower requirement for chemical control and a reduction of contamination of pasture by infective larvae. It is also suggested that selected sheep will be more responsive to vaccination and thus be better able to withstand stresses that cause productivity effects associated with parasite build up (Gray 1997).

6.2 MATERIALS AND METHODS

6.2.1 Genetic Background of Weaners

Eighty weaners were used in this trial, designated as either resistant- or random-bred. The resistant weaners (40) were offspring of 5 rams related to the founder ram of the UNE Resistance Flock, with whom the weaners had had a co-efficient of relationship of 50%. The random-bred weaners were unrelated to the founder ram, and therefore had a co-efficient of 0. Full details of the breeding is given in Albers *et al.* (1987). These sheep were sourced from Kirby, a UNE research farm.

6.2.2 Sheep Management and Supplementary Feeding

The 80 Merino weaners were run from weaning (January 1994) until shearing (October 1994) on the paddock described in Appendix A2.3.1. Each line of sheep was randomly divided into two groups on a paired weight basis, and one group from each line was selected at random for supplementary feeding. Supplementary feeding involved feed training all sheep together for one month, commencing with lucerne and lucerne based pellets, and gradually introducing lupins. Commencing 16/2/94, one group of each line was fed 150 gms lupins per day until 5/9/94. Due to severe drought, conditions all sheep received a survival ration of 100 gms oats per day from 7/7/94 until 31/8/94, in addition to the supplementary feeding.

On 13/4/94, a number of weaners in the random-bred non-supplemented group failed to yard without assistance and clinical examination suggested trichostrongylosis was at least partially the cause. As a condition of the Welfare Approval, such weaners were to be treated, and as it was likely many would have to be treated with time, it was decided all weaners would be treated, and all sheep were drenched with a BZ - LV mixture drench (Scanda, Coopers Registered TM) and with the Closantel (Razar, Coopers Registered TM).

To equalise availability of pasture and parasite challenge, the supplemented and non-supplemented groups were rotated between paddocks regularly.

6.2.3 Field Monitoring

All sheep were weighed monthly, and 10 selected sheep from each group selected on a weight subset basis were faecal sampled for faecal egg counts. At the beginning of September, all sheep were tested for parasite resistance by (1) removing all parasites (by drenching) and moving to a worm-free paddock as one group, (2) drenched with 10000 *Haemonchus contortus* third-stage larvae; and (3) 21 days, 29 days and 35 days after challenge, all sheep were faecal sampled for a parasite egg count. A detailed description is given in Appendix A3.1.

6.2.4 Laboratory Testing

Faecal egg counts (FECs) were carried out as previously described in Appendix A1.1 and A1.2, that is, individual egg counts were carried out, and bulk culture carried out for each group.

6.2.5 Statistical Analysis

The results of FECs that developed during the period of supplementation were analysed using multivariate analysis with repeated measures of transformed data using Genstat computer program (Genstat 5 Release 2.2, 1990 Lawes Agricultural Trust). The results of FECs that developed after artificial challenge with infective *H. contortus* larvae were analysed using Statistix Analytical program on transformed data. Details described in Appendix A3.6.

6.3 RESULTS

6.3.1 Liveweights

Liveweights of the four groups, ie, supplemented random-bred, non-supplemented random-bred, non-supplemented resistant-bred and supplemented resistant-bred, from 18/1/94 until 31/8/94 are shown in Figure 6.1. Full details are given in Appendix A3.2. Feeding was constant throughout, although extra supplementary rations were necessary from July and both groups received 100 gms oats per day per head from 7/7/94 until 31/8/94.

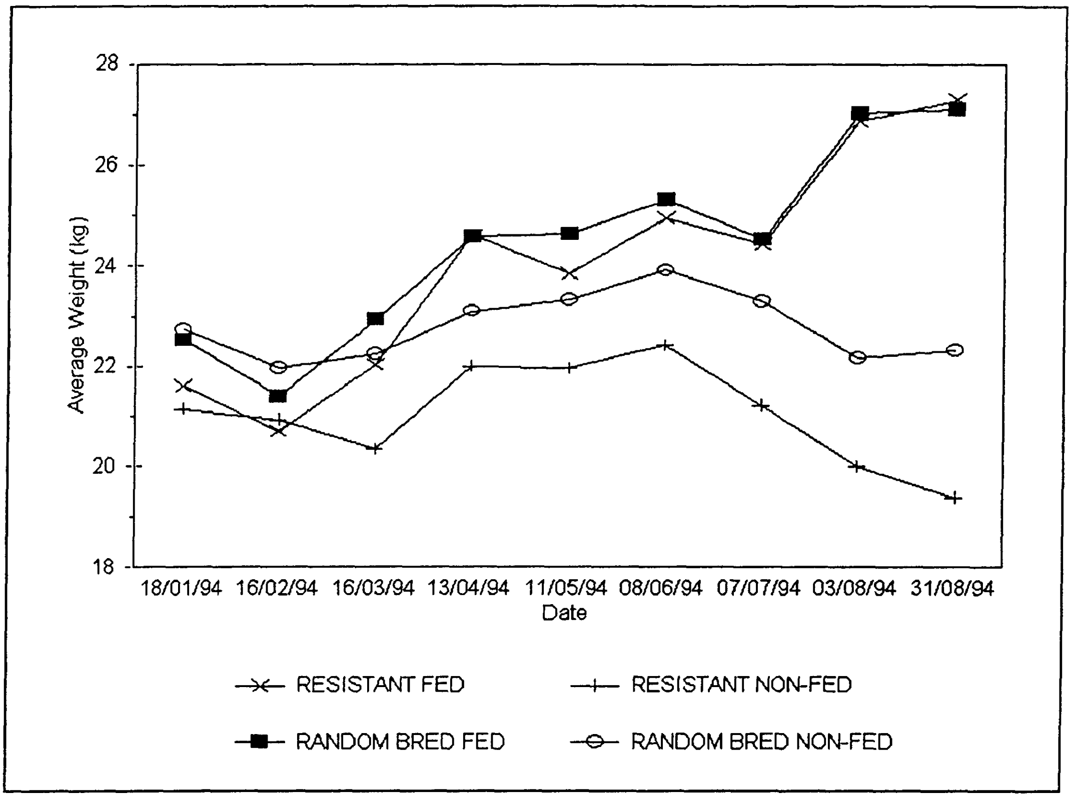

Figure 6.1 Mean body weights (kg) of the 4 groups of weaners over the period of supplementation.

6.3.2 Faecal Egg Counts During Supplementation

The faecal egg counts (in arithmetic means) for the period of supplementation for each of the 4 experimental groups is shown in Figure 6.2. Full details of faecal counts, including larval differentiation of bulk cultures are given in Appendix A3.3.

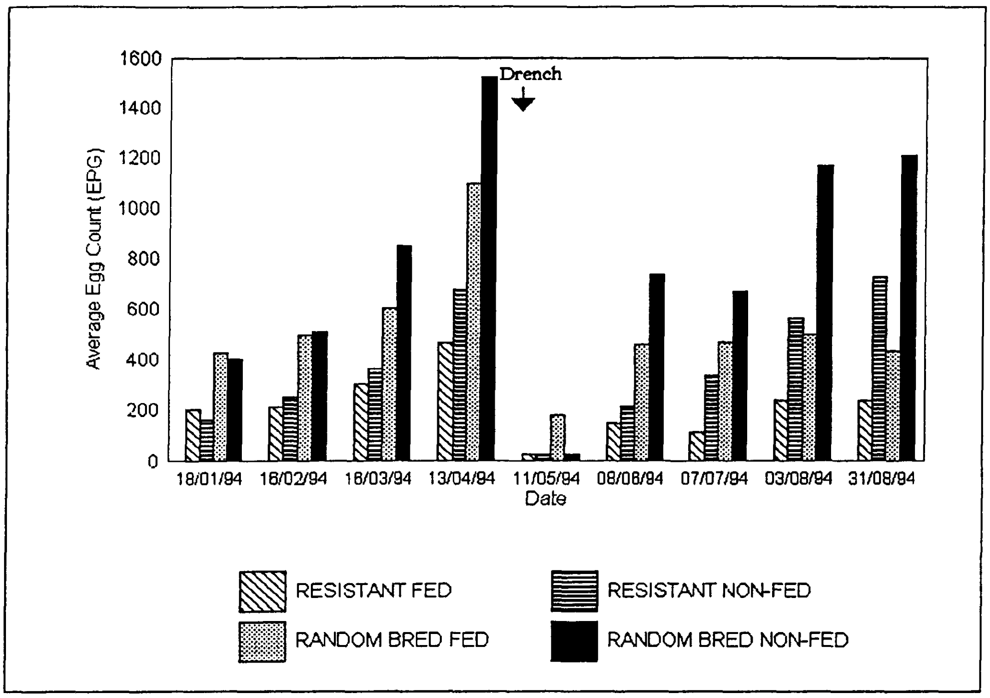

Figure 6.2 *Faecal egg counts that developed as a result of continual field exposure in the 4 groups of weaners over the record of supplementation.*

6.3.3 Egg Counts That Developed After Artificial Challenge

Faecal egg counts were conducted 21 days, 29 days and 35 days after artificial challenge with 10000 *Haemonchus contortus* third stage larvae. The results are shown in Figure 6.3.

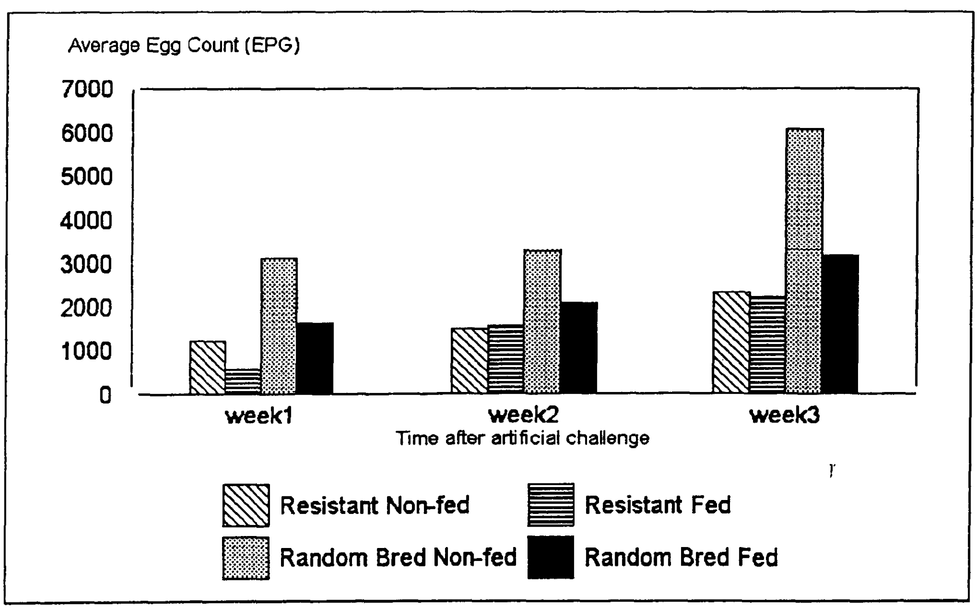

Figure 6.3 *Faecal egg counts (arithmetic means in eggs per gram) of the 4 groups of Merino weaners that developed after artificial challenge with 10000 infective larvae of Haemonchus contortus.*

6.3.4 Subsequent Measurements

No further measurements were obtained from these sheep by the author as they were returned to the University of New England flock for shearing and inclusion in future programs. However, their subsequent progress has been reported upon (Gray 1997).

6.4 DISCUSSION

6.4.1 Liveweights

In this experiment, liveweights of the supplemented group gradually increased so that there was a difference of 5 kg at the end of the supplementation period. This is in contrast to the previous experiment, in which a 5 kg difference was established initially and maintained.

The implications of supplementing in this manner is that it mirrors more accurately field experience where a constant ration is fed for purely practical reasons. The effect is that a gradual increase in body weight over a period of low feed availability occurs, in contrast to the previous experiment where both supplemented and non-supplemented groups could fall, and where both groups could lose weight during critical periods if there is a feed shortage. In effect, supplemented sheep received extra feed over and above the non supplemented sheep from the period 18/1/94 until 31/8/94.

6.4.2 Faecal Egg Counts During Period of Supplementation

6.4.2.1 Effect of Time

FECs increased in time with all groups, indicating that the trial paddock was contaminated with infective larvae. In all cases, the majority parasite was *Trichostronglyosis spp.*, with levels of *Ostertagia spp.* reaching 25% generally in times when overall counts were lower. This is consistent with the fact that *Ostertagia spp.* counts do not reflect worm burdens especially as FECs rise (Cole 1986). The fact that FECs continued to rise is an indication that sheep did not develop an immunity that was sufficient to overcome the ongoing larval challenge at any time (although it differed amongst groups see below). This is similar to findings in the previous experiment.

Some sheep were judged clinically to be infected to the point where drenching was considered essential, and hence all groups were drenched on 13/4/95. FECs had plateaued out by the end of the experiment. However, as it had turned dry, it is not possible to determine how much of this was due to reduced larval intake, although it is likely to be a major factor.

6.4.2.2 Effect of Supplementation

Pooled results of supplemented vs non-supplemented groups are given in Appendix A3.4.

The results of this trial are consistent with the previous trial (Chapter 5) and the implications of the results are covered in that discussion (5.4.2).

6.4.2.3 Effect of Breeding

Pooled results of resistant- and random-bred groups are given in Appendix A3.5. In general, resistant-bred animals maintained a FEC about half that of random-bred animals, which is consistent with reports on similar resistant-bred sheep (Gray *et al.* 1992).

The implications of this are discussed later.

6.4.2.4 Combined Effect of Breeding and Supplementation

The main effect that is noted on this part of the trial is that resistant-bred supplemented sheep developed significantly less FECs than the other groups, and that secondly, FECs did not rise beyond initial levels after drenching on 13/4, suggesting that a reasonable immunity had developed at that time. Weaners would be about 12 months old at this stage.

In contrast, the random-bred non-supplemented weaners developed significant FECs after the drench of 13/4/94 and this was increasing until the end of the trial, suggesting only a limited immunity had developed.

Resistant non-supplemented weaners, and resistant supplemented weaners appeared to perform about equally in between the other two, suggesting that the level of supplementation given had a similar effect on improving immunity compared to those bred for resistance in this trial.

6.4.3 Faecal Egg Counts that Developed as a Result of Artificial Infection

Firstly, it must be noted that supplementary feeding ceased on 31/8/94, after which all sheep were run together. Sheep were challenged with 10000 *H. contortus* infective larvae after anthelmintic administration. FECs were estimated 2, 3 and 4 weeks post-challenge.

The obvious result is that the random-bred non-supplemented sheep developed a high FEC, indicating that the least immunity developed in these sheep compared with all other groups. Both the supplemented and non-supplemented resistant-bred sheep developed lower FECs than supplemented random-bred sheep. It is also very significant that supplementation did not significantly affect the resistant-bred sheep. There is a non-significant indication that supplemented resistant sheep developed FECs a little slower.

6.4.4 General Discussion

In reviewing previous experiments, there appears to be no other work on the effects of nutrition and genotype on development of immunity in young Merino weaners.

Some breeds of sheep are known to be resistant to internal parasites (Gray 1995), and it is possible to extrapolate from various Scottish studies, in which various breeds were, or can be, compared with the Scottish Blackface which has been shown to be less susceptible to haemonchosis (Altaif and Dargie, 1978).

For example, it is possible to compare two experiments in which low protein and high protein diets were compared using a single dose of *H. contortus*. Initially, these experiments were carried out using Finn Dorsets (Abbott, Parkins and Holmes 1985a), and repeated using the more resistant Scottish Blackface (Abbott, Parkins and Holmes 1985b). Essentially, the results indicate that the low protein diet did not compromise the superiority of the resistant genotype of Scottish Blackface.

Subsequent studies in Scotland using similar low and high protein diets have investigated the nutrition/genotype interaction in larger groups of sheep and using heavier parasite challenges. In a study using pedigree Hampshire lambs, a breed known to be relatively susceptible to haemonchosis (Preston and Allonby, 1979), an initial infecting dose of 100 *H. contortus* larvae/kg body weight was given and followed by a trickle-infection of 200 larvae 3 times per week for 10 weeks (Wallace, Bairden, Duncan, Fishwick, Gill, Holmes, McKellar, Murray, Parkins and Stear 1995). This infection regimen was designed to provide moderate establishment and a continuous low level exposure to parasites, leading to a sub-clinical infection.

A similar study using lambs of a relatively resistant breed, Scottish Blackface, was conducted in parallel using an identical protocol (Wallace, Bawden, Duncan, Fishwick, Gill, Holmes, McKellar, Murray, Parkins and Stear 1996). As anticipated, the Scottish Blackface lambs had lower worm burdens (1367 vs 1795) and lower faecal egg counts (6000 vs 22000 epg at day 35) than the Hampshire lambs. The number of eggs per female worm were also lower. However, within the Scottish Blackface lambs, diet did not influence these parasitological parameters; whilst in the Hampshire lambs, the higher protein diet did reduce the faecal egg count between 20 and 70 days post-infection. The severity of the clinical and pathophysiological changes were also influenced by the breed with the Scottish Blackface lambs showing less anaemia than the Hampshire lambs on the same diets. However, within each breed, diet did influence these parameters with animals on the lower protein diet being more anaemic, hypoproteinaemic and hypoalbuminaemic than animals receiving the higher protein diet. These dietary influences were more pronounced in the Hampshire lambs.

These results, and the earlier ones of Abbott *et al.* (1985a, b), clearly show that protein supplemented diets can significantly reduce the pathophysiological changes associated with haemonchosis in genetically susceptible and genetically resistant animals. However, these effects are more pronounced in the former breeds and less critical in the latter breeds. This indicates that the benefits of a superior genotype are not lost on a low protein diet whilst a high protein diet can help overcome the disadvantages of an inferior genotype.

This experiment gave similar results with supplementation reducing FECs in random-bred sheep, whilst resistant-bred sheep were superior despite supplementation. It must be noted that in this trial, the field challenge was mostly due to *Trichostrongylus spp.*, whereas the challenge was by *H. contortus*, where as only *H. contortus* was involved in the previous trials mentioned.

6.5 CONCLUSION

The results of this experiment demonstrate that protein supplementation can assist random-bred sheep in developing immunity to internal parasites, but the use of supplementation needs to be re-assessed when used in resistant-bred sheep.

Most importantly, resistant-bred sheep do not lose their superiority when fed low protein diets under grazing conditions. Finally, these effects are not immediate effects related to the diet being fed at the time, as the final challenge was conducted 5 weeks after supplementation had ceased. Unfortunately, it was not possible to determine how long this effect lasted after supplementation ceased.

CHAPTER SEVEN

GENERAL DISCUSSION

7.1 INTRODUCTION

There remains the need for economic analysis to quantify these ideas, for whilst some of the findings of this research are included in parasite control strategies, the productivity gains of supplementary feeding used in association with selection for itnernal parasite resistance need to be demonstrated to be economically sound, as well as sustainable in the long-term, before they are incorporated into whole-farm management programs.

Internal parasites have always been a major problem on the New England Tablelands (Seddon 1950) and *H. contortus* the major parasitic problem. With the introduction of the Wormkill program effective control of *H. contortus* was achieved, and with the reduction of broad spectrum anthelmintic treatments, *Trichostrongylus spp*. emerged as a parasite causing major field problems.

One major problem was the chronic illthrift and diarrhoea that occurred in Merino weaners over that first winter. The initial response was to increase anthelmintic treatments to this class of sheep, however, this is not sustainable as drench resistance was emerging as a significant problem and no new alternate anthelmintics appeared likely to be released in the immediate future (Rolfe 1997).

It was becoming apparent that nutritional stress was a major contributing factor (Hall 1990) and recommendations were put into place to overcome or at least help in preventing the problem (Hall *et al.* 1990).

The work in this thesis along with other work (summarised by van Houtert and Sykes 1996) assisted in demonstrating that improving nutritional status by supplementary feeding had the potential to greatly assist in preventing the clinical effects of trichostronglyosis, as well as breaking the parasitic build up on pastures that readily compromises a delicate situation.

7.2 OVERALL RESULTS OF TRIALS

The results of these trials demonstrate that supplementing feeding can either ameliorate or overcome the affects of trichostrongylosis in Merino weaners in times of nutritional stress.

The production affects of trichostrongylosis have been shown to be increased mortality, anorexia and lowered liveweight gains and lowered wool production (Barger 1982) and effective parasite control to benefit productivity in lambs and weaners (MacLeod *et al.* 1992). The clinical effect of diarrhoea whilst of its self may not be significant, but it has been shown to have severe productivity effects including the need for increased crutching, reduction in crutch wool values, increased breech fly strike, and increased management input (Watts *et al.* 1978).

Johnstone *et al.* (1979) have attempted to put economic figures on various productivity effects of parasitism in weaners with mortalities and wool production being major factors. More recently, Larsen *et al.* (1995b), considering the productivity affects of diarrhoea, noted that the calculations are very sensitive to wool prices, relative price premiums for fine wool and productivity responses to treatment. This has been more complicated recently by variations in wool price of similar quality including micron caused by variations in strength and length (R Marchant, *pers comm.*).

The affect on nutrition on young sheep has recently been assessed (summarised by Gherardi 1997). Wool price fluctuations have always made wool productivity difficult to assess, and nutritional benefits of increased wool growth can be offset or even disadvantaged by lower mean fibre diameter. As indicated, wool staple strength has become a major factor in wool quality. Allden (1979) had shown that wool growth is not only related to the rate of change of liveweight but also to liveweight *per se*, that is larger weaners should grow more wool with a higher staple strength. Gherardi, Doyle, Woodgate, Plaisted and Ellis (1996), feeding lupins, demonstrated that increased intake by lupins by young sheep increased staple strength and mean fibre length. This was a linear relationship although the actual liveweight change required to produce a suitable non-tender wool (over 25N/Ktex) varied with genotype and other environmental factors. The use of lupins in maintaining staple strength has been demonstrated (Masters, Gherardi, Mata and Greef 1997).

So, although it would be nice to put some economic figures together in terms of nutritional supplement costs versus productivity gains, this would seem to be only practical by developing an economic *cum* nutrition computer model. The difficulty of such an economic assessment has been compounded by the large range in feed supplement prices, not to mention variation in seasonal conditions affecting sheep values.

7.3 OVERALL RELEVANCE OF TRIAL RESULTS

These field trials confirm previous trials that sheep on low protein diets developed higher FECs, and higher worm burdens. This effect is most pronounced in Merino weaners as this is an important time in development of parasite immunity (Dobson *et al.* 1990b). Nutritional status is critical at this time as in the New England Tablelands available field nutrition is at its lowest (Vickery 1972).

More broadly, it is important to note that Merino weaners being physiologically immature have limited reserves of body fat and proteins, are at a growing phase requiring extra protein to lay down new body tissue especially when their weight is below 25 kg (Gherardi *et al.* 1996). Consequently, they have a poor ability to respond to seasonal variation in nutrient intake.

These trials confirm previous studies (outlined in Chapter 5) that show long-term nutritional stress over this period confers life-long productivity affects including permanent lower body weights and fleece weights.

Studies on long-term affect of lower body weights on fecundity indicates a reduction in life-long fertility (Lindsay 1983; Farquharson 1989, and Smith and Stewart 1990), although this affect is moderated by numerous other factors.

7.4 LONG-TERM BENEFITS

The long-term sustainability of the sheep industry in the New England Tablelands is now being questioned (Webster, *pers comm.).* The basis of this questioning is the assumption that the sheep industry relies on anthelmintics for internal parasite control, and that ever-increasing anthelmintic resistance will ensure such program must fail (Rolfe 1997; Chick *et al.* 1998 and Love *et al.* 1998).

Barger (1997), in summarising the alternatives to anthelmintic treatments for parasite control, points out how vaccines of relatively low effectiveness can be surprisingly effective. This is because of the compounding effect of the infection - contamination - reinfection cycle. As Barger (1997) also notes, there is a secondary affect because most outbreaks in older stock are the result of high pasture contamination from parasite eggs deposited by young stock.

The results of these trials indicate supplementary feeding can reduce FECs in weaner sheep at a critical stage. Like vaccines, the domino effect of this on the infection - contamination - reinfection cycle indicates the potential for overall parasite control in Merino weaners using supplementary feeding. It was apparent in trials as described in Chapter 5 that supplemented weaners would not need to be drenched over the winter period and FECs were being maintained at a low level. As indicated above, this also reduces contamination of pasture reducing parasitic problems that arise in adult sheep.

Looking at the more broader context, nutritional supplement to Merino weaners is being increasingly adopted as a major sheep management tool. This has been stimulated by the development and promotion of Prograze, an integrated nutritional plan for use on farms using nutritional assessment of pastures and fodder budgeting. Parasite control and weaner growth rates are built into the program such that grazing management and weaner nutrition are considered in an overall scheme, and parasite control programs are an integral part of that scheme.

Results of field trials run in this and similar research projects lend credibility to the program as they demonstrate how nutritional supplements interact to enhance parasite control programs and improve weaner production. On-farm monitoring, as introduced in these trials, is now used to modify or correct faults in those programs (Marchant, *pers comm.*).

Trials in Chapter 6 indicate that sheep bred for resistance maintain this resistance when nutrition is compromised, and hence it is apparent that in sheep bred for worm resistance the need for nutritional supplements will be lower and therefore be more economically viable. With the introduction of commercial breeding programs such as Nemesis, used in combination with on-farm nutritional programs such as Prograze, long-term sustainable control of internal parasites in Merino weaners may yet be possible despite the development of broadscale anthelmintic resistance.

7.5 CONCLUSION

These trials were set up to help solve problems seen in the field as Merino weaner illthrift. It was apparent the problem was related to nutrition and parasites, and these trials were designed to determine the effect of nutrition on parasites (rather than the other way round), and the flow on effects on productivity.

Some of the findings have been incorporated as changes to the current Wormkill Program, some have been adapted to the Prograze program and some await further evaluation before they be utilised in whole farm programs.

Still pertinent are the comments of Morley and Donald (1980) on the economic impact of farm management and systems of helminth control. *"Management decisions aimed at helminth control cannot be considered in isolation from their effects on other parts of the enterprise, since they compete for labour, finance, land, skills and other resources."* The incorporation of some of these results of this work into the Prograze farm management system is one step towards achieving this integration.