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THE EFFECT OF DIFFERENT PROTEIN SUPPLEMENTS ON THE PRODUCTION ECONOMICS AND NEMATODE RESILIENCE OF MERINO EWES

by

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Submitted in partial fulfilment of the requirements for the degree of MMedVet (Caprov) in the Department of Production Animal Studies, Faculty of Veterinary Science, University of Pretoria, Pretoria

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I dedicate this to my parents

Martin and Susan Janse van Rensburg

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LIST OF ABBREVIATIONS

ADF = Acid detergent fibre

BCS = Body condition score

BW = Body weight

CP = Crude protein

CSO = Cottonseed oilcake

CV = Coefficient of variance of the fibre diameter

DM = Dry matter

DOM = Digestible organic matter

F1; F2 = Week 1 and 2 of flushing

FEC = Faecal egg count

g = Gram

G1; G2; G3 and G4 = Period 1 to 4 of late lactation

GIT = Gastrointestinal tract

IgG = Immunoglobulin G

h = Hour

ha = Hectare

Kg = Kilogram

ktex = Kilotex

L1; L2; L3 and L4 = Week 1 to 4 of lambing

ME = Metabolizable energy

MFD = Mean fibre diameter

mg = Milligram

MJ = Mega Joules

ml = Millilitre

NDF = Neutral detergent fibre

N = Newton

NPN = Non protein nitrogen

P1; P2; P3; P4; P5; P6 and P7 = Period 1 to 7 of gestation

R = Rand

R1; R2 = Period 1 and 2 of mating

RDP = Rumen degradable protein

RUP = Rumen undegradable protein

S1; S2; S3; S4; S5; S6; S7 and S8 = Week 1 to 8 of early lactation

Yield% = Percentage clean wool yield

µm = Micro-millimetre

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ABSTRACT

THE EFFECT OF DIFFERENT PROTEIN SUPPLEMENTS ON THE PRODUCTION ECONOMICS AND NEMATODE RESILIENCE OF MERINO EWES.

by

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Department: Production Animal Studies
Degree: MMedVet (Caprov)

Ninety Merino ewes, divided into three equal groups, were kept on natural highveld grazing for 42 weeks. Group M received a mineral supplement continuously, averaging 28 g per day. The other groups received commercial protein supplements, group RDP a mainly rumen degradable supplement and group RUP, a mainly rumen undegradable supplement. These supplements had crude protein (CP) levels of 29% and 28% respectively and were supplied at strategic times during the reproductive cycle, at 250 g per ewe per day for 14 days before mating, at 350 g per ewe per day for 42 days, starting 21 days before lambing and at 500 g per ewe per day for 56 days, starting 21 days after lambing. Grazing was randomized to minimize differences in nutrition and parasite challenge, and had an average CP of 8.8%. Lambing rates were: RUP 96%, RDP 89% and M 76%. Lamb survival rates at 11 and 17 weeks post lambing were 75% & 63% for RUP, 64% & 57% for RDP and 55% and 48% for M respectively ($P < 0.05$). Wool production parameters were similar for all groups, as were mean faecal egg counts: 685 (RUP), 371 (RDP) and 465 (M). Body weights, body condition scores and FAMACHA scores were also similar for all three groups. Income per ewe, calculated at 11 and 17 weeks post lambing, was highest for RUP at R147.80 & R132.87, lowest for M at

R117.86 & R111.13, and in between for RDP (R129.85 & R121.38). However, the gross margin was the highest for M at both points (R114.35 & R107.77) compared to RUP (R70.43 & R54.93 – $P < 0.03$ & $P < 0.008$ respectively), as well as RDP (R82.96 & R74.12). Strategic supplementation with protein improved performance but the additional income was not sufficient to cover feed costs under prevailing conditions and neither supplement could therefore be economically justified.

CHAPTER 1
INTRODUCTION

All types of sheep farming are dependent on a favourable production level for success but the operation must be cost effective for the farmer to make a good profit. Production is measured either by the amount of meat (lamb) produced per year or meat plus wool per year if the flock is a wool producing breed. The amounts of lamb and wool produced are calculated per unit with a unit usually being a breeding ewe or if the farms are comparable, per land surface area with a unit usually a hectare. Thus profit is usually calculated per breeding ewe or per hectare (Van Zyl *et al*. 2000).

The amount of lamb produced for sale is determined largely by the number of lambs weaned per ewe in a production cycle. The number of lambs weaned in turn, is determined by factors determining reproductive efficiency through the different phases of the reproduction cycle, from mating through gestation, lambing, lactation and finally weaning. The value of wool produced is determined by the amount and quality of wool shorn from each ewe and lamb during a year (Olivier, 2002; Van Zyl *et al.* 2000).

Nutrition is one of the biggest expenses for the sheep farmer, either directly or indirectly. Most of the direct expenses arise from the purchase of supplementary feeds or licks. Of these, protein is especially important since it forms a critical element in sheep nutrition: it affects ovulation rate, embryo survival, foetal growth, colostrum and milk production, body mass, lamb survival and growth as well as wool growth (O'Callaghan & Boland, 1999; Robinson *et al*. 1999).

Several studies have shown that protein also affects the sheep's resilience and resistance to gastrointestinal parasites, which can be a major constraint to production. Gastrointestinal parasites decrease production through depression of feed intake, blood and protein loss as well as using extra energy (Coop & Holmes, 1996; Sykes, 2000)

The theory of protein supplementation has been established in several carefully controlled laboratory experiments, but the practical application of this knowledge at farm level is not as well understood.

OBJECTIVES OF THIS STUDY

1. To determine the influence of strategic protein supplementation using commercially available products throughout a reproduction cycle from pre-mating to weaning in Merino ewes grazing natural vegetation.
2. To determine how strategic protein supplementation affects wool and lamb production as well as resilience to gastrointestinal parasites.
3. To determining what, if any, the economic benefits of strategic protein supplementation are and whether it is economically advisable using either rumen degradable or rumen undegradable protein sources.

HYPOTHESIS

Strategic protein supplementation improves production, increases gastrointestinal nematode resilience and is economically beneficial to ewes on natural grazing.

CHAPTER 2
LITERATURE REVIEW

In past years, most of the studies conducted on protein supplementation were focused on the amount or level of protein (% crude protein) in a diet, which is simply the calculated amount of protein based on the percentage of nitrogen in a feed multiplied by 6.25, the average conversion factor (Van Horn, 1999). Recently it has become evident that the source of protein is as important (Perry *et al*. 1999). In ruminants, dietary protein can occur in two forms – as rumen undegradable protein (RUP) or rumen degradable protein (RDP). Another form of protein used in ruminant nutrition is non-protein nitrogen (NPN) which is a RDP source of protein. (McDonald *et al*. 1995)

Rumen degradable protein is degraded in the rumen into amino acids, peptides and ammonia which are then used for microbial protein synthesis. The microbial protein subsequently goes to the abomasum and small intestine, where it is digested. NPN, which is most commonly used in the form of urea, also serves as a protein source for microbial protein synthesis in the rumen. Rumen undegradable protein, by contrast, is protein that is rumen protected or undegradable, which means that it is not digested in the rumen but moves unchanged through the rumen, reticulum and omasum into the abomasum and small intestine where it is digested into amino acids. This protection preserves the original biological value of the protein source. RUP protein is generally more expensive than RDP protein, with NPN being the least expensive source of RDP (Kellems & Church, 2002; McDonald *et al*. 1995). Most natural sources of protein contain a mixture of RDP and RUP but with varying proportions, thus some sources are classified as mainly RUP protein and others as mainly RDP protein. Most commercial supplementary feeds are a combination of RDP and RUP. Also, in commercial feeds, NPN is often a major part of the RDP, mainly because of the relatively high cost of natural protein, nevertheless some commercial feeds are formulated to contain high amounts of RUP because of the greater biological benefit of this form of protein. Table 2.1 contains a summary of protein sources.

Table 2.1 Crude protein, RUP and RDP levels of proteins sources

Protein	Average % CP	RUP % of CP	2002 market price Rand per ton	Quality of protein	Comments
Lupins	34	22-35	1400	Good but low methionine	Mainly RDP protein
Soya-beans	40-42	20-24	2600	Fair to good	Mainly RDP but treatment e.g. toasting can increase RUP% to 44%
Soya-bean oilcake meal	44-50	30-40	2400	Good	Can increase RUP% to 60% with treatment e.g. formaldehyde
Cotton seed	18-25	27-30	2600	Fair to good	Mainly RDP
Cotton seed oilcake meal	44-48	30-43	2400	Good	Can increase RUP% with treatment to 60%
Rapeseed meal (Canola)	37	29	1600	Good, high in methionine	Can increase RUP% to 70% with treatment
Sunflower seed	19	20	2700	Fair to good	Mainly RUP
Sunflower seed oilcake meal	37-44	25-27	2400	Good	Higher RUP than whole seed
Meat & bone meal	60	49	1900	Fair, high lysine, low methionine, tryptophan	RUP and RDP
Lucerne meal	16	30-48	1400	Good	RUP and RDP
Linseed meal	23	27-35	7600	Good, methionine and lysine lower than soya-beans, cottonseed	Mainly RDP
Fishmeal	73	57-78	5500	Excellent	Mainly RUP
Beet pulp	10	45-49	700	Low	RUP and RDP
Groundnut meal	52	26	2200	Fair, lower lysine, methionine	Mainly RDP
Maize	10-12	52-57	1600	Low, especially in methionine, lysine, tryptophan	Some RUP
Barley	11-13	20-34	1700	Low, especially lysine, but higher levels than maize	Some RDP
Oats	12-13	24	2050	Low, especially methionine, histidine, tryptophane but highest of all energy feeds	Some RDP
Peas	24	22-24	5500	Fair	RDP
Fresh grass	10	15		Variable	RDP and RUP
Molasses cane	4-5	10	750	Low	RDP
Urea	275	0	2400	Low	RDP only

Sources: Kellems & Church, (2002); McDonald *et al*. (1998); Perry *et al*. (1999); Van Horn (1991); Van Straalen & Tamminga, (1990); OTK, (2002); Grain SA, (2002); Schmidt seed and feeds, (2002).

Protein degradation can be manipulated by treatment e.g. heat, formaldehyde or formic acid (McDonald *et al.* 1998). This usually increases the RUP percentage of the protein. Quality of protein refers more to the amount of amino acids and especially essential amino acids in the protein.

2.1 Flushing

The term flushing, applied to sheep farming, means that the nutritional level of ewes is increased shortly before mating, which in turn stimulates ovulation. In the past, ewes were usually flushed for several weeks (± 6 weeks) with mainly an energy based supplement (Gunn *et al*. 1992a, 1992b).

Smith *et al*. (1983) flushed mature Coopworth ewes with an average weight of 45 kg, by offering them either 5.0 kg DM per ewe per day (H level) or 1.0 kg DM per ewe per day (L level) of a good quality grass at different time intervals over a six week period: the controls received six weeks of L while the others respectively were given: five weeks L and one week H; four weeks L and two weeks H; three weeks L and three weeks H; three H and three L; two L, three H, one L; one L, three H, two L; six H. Ewes were synchronised with 60 g medroxy-progesterone acetate intravaginal sponges, and then mated. The respective conception rates at the first cycle of mating were as follows: 81.1%, 71.9%, 71.4%, 64.9%, 80%, 85.4%, 87% and 75%. Thus the two L, three H, one L; and one L, three H, two L had the highest conception rates but this was not statistically significant. However, the lambing rates for the groups receiving three weeks flushing was significantly higher than groups flushed less than three weeks. Flushing for longer than three weeks did not improve lambing rates. The conclusion drawn was that flushing for three weeks was the most effective period.

Venter and Greyling (1994) used an energy based diet consisting of alkali-ionophore-treated whole maize containing 11.86 MJ per kg ME and 11.7 % CP at 600 g per ewe per day, to flush mature Merino ewes for different time intervals of two, three or four weeks. A control group received no supplements. The lambing percentages of the different groups were: control: 71.8%; two weeks: 79.5%, three weeks: 95% and four weeks: 65.1%. Flushing did not affect either the body weight or body condition score of the ewes. In this study it was shown again that three weeks is the most effective period. It was also shown that flushing for more than 3 weeks may have a negative effect.

In later studies it was shown that protein-based supplements are more effective than energy-based ones. Molle *et al*. (1995) flushed Sarda ewes grazing Italian ryegrass pastures with either 250 g per day whole corn grain (energy-rich supplement) or 270 g per day soya-bean meal (protein-rich supplement) starting two weeks before mating and continuing for the first three weeks of mating. The control group received no supplement. Supplements were iso-energetic with a CP intake of 232 g per day for the soya-bean group, 138 g per day for the corn group and 129 g per day for the control group. Ewes had been grazed on high, medium or low yield grazing for about ten weeks before flushing commenced. Ewes that came from the high yield grazing had a better BCS and had slightly higher body weights at the beginning of flushing compared to the medium and low yield groups. High, medium and low yield groups weighed 47.5 kg, 45.1 kg and 42.8 kg respectively. There was a significant difference in BCS between the supplemented groups at the end of mating, with the soya-bean and corn groups higher than the control group, 2.89 and 2.97 respectively vs. 2.70. The ovulation rate was the highest in the soya-bean group (1.67) compared to the corn (1.11) and control (1.25) groups. Ewes from a high yield grazing background also had higher ovulation rates (1.50) than ewes from a low yield (1.18) background. However the reproductive advantage of the soya-bean group was eroded due to embryo mortality since only 1.33 lambs were born per ewe compared to 1.11 in the corn group and 1.15 in the control group. In this study it was shown that supplementation could improve ovulation rate but that over-nutrition may have a negative effect.

This led to a study in which Molle *et al*. (1997) used a similar protocol and protein supplement, but ewes were flushed for different intervals. Long term was five weeks, medium term was two weeks and short term was eight days. The control group had no supplement. No significant differences were found with regard to BW and BCS. However both the conception percentage and fecundity rate (lambs born per ewe mated) were higher for the medium term group compared to the others. Medium was 93% and 1.6; Long was 86% and 1.28; Short was 71% and 1.14 and Control was 86% and 1.14 for conception percentages and fecundity rates respectively. In this study the higher ovulation rate and thus conception of the medium group also led to a high percentage of lambs born. In the Long group some embryonal loss took place again and thus negated some of the advantage. This study showed that if a protein supplement is used for flushing, the most effective period is two weeks.

In a similar study Nottle *et al*. (1997) flushed Merino ewes groups grazing clover and grass pastures with 500 g lupins per ewe per day also for a period of two weeks. The control groups received no supplement. They found that lupin supplementation increased the ovulation rate by 20 ovulations per 100 ewes and increased weaning by 11 lambs per 100 ewes. In this study, flushing for two weeks using a protein-rich supplement was effective because the higher ovulation rate was reflected in the lambing rate. The protein used contained some RUP.

The above studies are summarised in Table 2.2. It shows that flushing ewes using a protein-based supplement is most effective for a time period of two weeks, while flushing with an energy-based supplement is usually most effective over three weeks. The loss of lambs or embryo mortality seen when long periods of flushing is used was explained by another study in which it was found that overfeeding during early pregnancy can lead to lower levels of peripheral progesterone and thus early embryonal death (Parr *et al.* 1987). Later studies (O'Callaghan & Boland, 1999; Robinson *et al*. 1999; Yaakub *et al*. 1997) have come to a similar conclusion.

2.2 Late pregnancy, colostrum production, milk production and lamb survival

The importance of milk production for lamb survival has been known for a long time (Brown, 1964). Gibb *et al*. (1981) showed that if grazing ewes had adequate milk production (fair body condition), lambs grew well and weaning could be done at about 12 to 14 weeks. If ewes did not have enough milk and their lambs had to be weaned earlier (eight weeks) because the ewes were losing condition, lambs growth rates were usually lower. In a later study Gibb and Treacher (1982) showed that provided ewes were in fair body condition in mid-pregnancy, they would be able to produce adequate milk if given good feed during lactation. In their study they had two groups of ewes: one group had an average BCS of 2.6 (T group) and the other group an average BCS of 3.3 (F group) at day 90 of pregnancy. Each group was then sub-divided into two groups with the TL and FL groups given insufficient feed so that they lost 150 g body weight per day while the TH and FH groups received enough feed (dried grass pellets) to maintain BW. This was continued for the last eight weeks of pregnancy. At lambing, the different BCS scores were TL: 1.9; TH: 2.9; FL: 2.8 and FH: 3.1. On day two after lambing all the ewes were moved to pastures with good grazing. They were then moved every week to a new pasture until week ten. There were no significant differences regarding milk yield per day and lamb growth rate although the differences in BCS of the ewes persisted until the end of the experiment. Thus although some ewes were receiving restricted feed they were still able to produce adequate milk for good lamb growth rates. Thus ewes can compensate for pre-lambing shortages if given enough food during lactation. No supplementation was used in this study, only good grazing which turned out to be adequate for milk production. Neither the CP content of the grazing nor the dried grass pellets were given. Lamb survival rates were also not given.

Cowan *et al*. (1982) supplemented mature Finnish Landrace X Dorset Horn ewes during pregnancy with hay and concentrates (CP of 139 g per kg, ME of 10 MJ). After lambing, the ewes suckling twins were divided into two groups: one was given a low protein diet *ad lib* (CP of 116 g per kg, ME of 9.2 MJ ME per kg) and the other one a high protein diet *ad lib* (CP of 143 g per kg, 9.1 MJ ME per kg). Supplements were given for 42 days and the main source of protein was fishmeal (high RUP). Milk yields and overall milk protein was significantly increased during week 4-6 for the high protein group. However lamb growth rates were similar for both groups. This agreed with the finding of Gibb and Treacher (1982) that ewes are able to produce adequate milk for growth of lambs even if they receive restricted feed. In this study even though a low level of CP was used for the low group, the quality of the protein was very good. This may indicate that low levels of protein can be fed as long as the quality is good and the ewes are in a fair to good body condition range.

Gonzalez *et al*. (1982) used twin suckling Finnish Landrace X Dorset Horn ewes to measure the effect of protein supplements on milk production. They gave them a basal diet of hay, barley, molasses and salt (75 g CP, 10 MJ per kg) during the last week of gestation. Then during the first week of lactation ewes were given the basal diet plus fishmeal at 60 g CP per day. From the second up to the eighth week, ewes received the basal diet plus one of the following supplements: urea, meat and bone meal, blood meal, groundnut, soya-bean meal, linseed and fishmeal. Urea was included at 43 g per kg while all the other were given at one of three levels: 34 g, 60 g or 86 g per kg. This ensured that daily CP intake was between 231 to 236 g, 285 to 297 g and 340 to 357 g per day for each level. CP intake for urea was about 254 g per day. All supplements except urea, led to higher levels of milk production at the low level of inclusion. This increase was even more significant at higher levels for soya-bean meal, blood meal and fishmeal but not for the others (all these contain medium to high levels of RUP). There was also a trend for milk solids to be increased with the supplements (except urea) but this was only statistically significant for soya-bean meal. This study showed that various sources of RDP and RUP, except urea, can improve milk production and that sources containing more RUP are better.

Gonzalez *et al*. (1984) decided to combine protein and energy supplements. They used three levels of CP: at 128 g per kg DM (low); 155 g per kg DM (medium) and 186 g per kg DM (high). The three different diets contained either 60, 100 or 140 g of fishmeal per kg DM. For each of the CP levels they also used three levels of energy at 19, 23 and 27

MJ ME per day, thus nine groups in total. All ewes were suckling twins and were individually penned. Supplements were given from the first week of lactation to the eighth week. Milk yields for the different groups were as follows: low CP: 2.32, 2.61, 2.53 kg per day; medium CP: 2.49, 2.28, 2.67; high CP: 2.52, 2.78, 3.09 kg per day for the three energy levels in ascending order. Both the different levels of protein and the different levels of ME were significant in increasing milk production. There were also significant differences regarding lamb growth rates. The different ME levels caused increases from 200 g per day to 238 g per day while the different CP levels caused increases from 214 g per day to 240 g per day. Thus the protein effect was more significant than the ME effect. The main protein source in this trial was fishmeal (RUP) which although of high quality, is a very expensive source of protein. DM intakes of ewes were between 2 and 2.8 kg per day, which would mean a fishmeal intake of between 120 g and 390 g per day. This is unlikely to be economically advantageous.

Penning *et al*. (1988) first supplemented housed Scottish Halfbred ewes given fresh-cut grass *ad libitum* with either no supplement or barley; barley and soya-bean meal; barley, soya-bean meal and fish meal; or barley and fish meal in weeks two to seven of lactation. All supplements provided 10 MJ ME per day and either 40 g (barley) or 240 g CP per day (the other three groups). All the groups received the soya-bean and fishmeal supplement for the first two weeks of lactation. Ewes on the protein supplements had higher milk volumes and solids yields than the no supplement and barley only groups. The lambs of the protein-supplemented groups also had higher growth rates than the other two groups. The researchers then supplemented Masham ewes grazing perennial ryegrass at either a low stocking rate (10 kg organic material per week) or high stocking rate (4 kg organic material per week). The last two weeks before lambing, all ewes received the soya-bean/ fishmeal supplement at 0.6 kg per day. Then after lambing the ewes and lambs were put out into their two groups and either got no supplement, barley or fishmeal. Lamb growth rates were better in the fishmeal group than for the no supplement or barley groups, and the high herbage groups compared to the low herbage groups. Loss of BCS was also significantly less in the fishmeal group during the first six weeks of lactation than the other two groups but during week six to twelve there were no differences between the groups. These studies showed that supplementation during lactation with a good protein source (RDP or RUP) increases milk volume and solids with the RUP protein having a more significant effect. They also showed that general nutrition is important in milk production because even with supplementation the high stocking rate group still had lower milk production than the low stocking rate group. However, there was no data on the cost-effectiveness of the supplements.

De Waal and Biel (1989a, 1989b) supplemented Merino and Dorper ewes suckling a single lamb on veld with both energy and protein. The supplements were provided via rumen fistulae to the ewes. The energy levels varied from 23 g per day DOM to 319 g per day DOM, while the protein levels varied from 9.3 g per day CP to 51 g per day CP. They studied the effect of supplementation on the daily herbage intake, body mass and general performance of ewes as well as lamb growth rates. They found no significant differences between the parameters of supplemented ewes and non-supplemented ewes although the lamb growth rates were higher for supplemented ewes. Merino lambs of non-supplemented ewes had an average growth rate of 96 g per day while the highest growth rate of supplemented ewes was 144 g per day. In the Dorper ewes, lamb growth rates varied from means of 163 g per day (control) to 259 g per day (CP of 51 g per day and 164 g per day DOM). In these trials the total level of crude protein intake was almost the same for the supplemented and non-supplemented groups because the crude protein content of the veld was higher than expected (CP of 12% first season and 17.3% second season). In this study it was shown that energy had a smaller influence than protein on lamb growth rates and thus milk production. It was also shown that if the quality of grazing was good, additional supplementation with either energy or protein did not increase growth rates. The main source of protein used was a commercial supplement called HPC 60 which consisted of mainly urea (NPN). No cost analysis was done in this trial.

Frey *et al.* (1991) supplemented Finn-Targhee ewes suckling twin lambs, grazing on improved pasture with 450 g per head per day of a 53.5% protein lick, three times a week. This provided 80 g of protein per head per day of which 40 g was RUP. The supplement was started 33 days post partum. Ewes had an initial BCS of 2.1. Milk production (quality and quantity) and lamb growth rate were measured at the end of each of four, three-week periods. Supplemented ewes had slightly better milk production during the second and fourth period. No other significant differences were found. The ewes grazed a high quality pasture (CP of 18% during the first period and 8% during the fourth period) during the summer period. The authors estimated that non-supplemented ewes had no energy or protein deficiency. Furthermore, supplementation only started 33 days post partum when ewes were already at peak lactation. This study showed again that ewes on good quality grazing benefit little from supplements, even if they contained high levels of RUP i.e. 50% as in this trial.

Kleemann *et al*. (1993) started supplementation earlier. They divided Merino ewes grazing mature pasture into two groups in mid-pregnancy (day 50 after mating). One group received supplements consisting of oat grain at 800 g per ewe per day plus pea grain at 200 g per ewe per day and hay at 350 g per ewe per day until day 100 (thus each received 1350 g supplement per day). The supplements contained 10.9 MJ, 12.8 MJ and 9.7 MJ of ME and 11.2%, 27% and 9.2% CP respectively. The other group received no supplements up to day 100. On day 100, all the ewes were moved to paddocks where both groups received the supplements. At two weeks before lambing each of the original groups were divided into two groups, thus there were four groups in total. One sub-group of each of the original groups then received lupin grain (13.6 MJ ME and 33.3% CP) at 700 g per ewe per day instead of oat grain. In this study nutrition during mid or late pregnancy did not influence lamb survival up to 12 weeks of age. The authors stated that no significant changes were found, probably because the CP of the supplements was mainly RDP. They also stated that the high stocking rate (about 70 ewes per 0.6 hectares) and high frequency of lambing (the ewes were synchronized for mating) led to a higher than normal lamb mortality. Thus lupin supplementation could not improve lamb survival in this intensive system which indicated that supplementation cannot always compensate for incorrect management. In addition, lupin grain fed at 700 g per day is unlikely to be financially viable.

Brand *et al*. (1997) also used lupin grain for supplementation. They synchronized South African Mutton Merinos grazing oat stubble and divided them into four groups: no supplement, 200 g, 400 g or 600 g lupin per ewe per day starting six weeks before lambing and continuing until the sixth week of lactation. The lupin had 355 g per kg CP and 911 g per kg DOM. Ewes were grazed at a stocking rate of 2.4 sheep per hectare. Grazing was evaluated using both samples from oesophageal fistulas and by hand samples. The pasture samples collected with the fistulas had a mean CP 71 g per kg and DOM of 501 g per kg while the hand samples had a mean CP of 23 g per kg and a DOM of 318 g per kg. They found no significant differences between any of the groups regarding lamb growth rates, clean wool production or fibre diameter. This study showed that sheep could select a high quality diet from pastures which may not appear to be of good quality provided that the stocking rate is correct. It also showed again that no supplements are necessary if adequate grazing is available.

Nottle *et al.* (1998) also used lupin grain as supplementary feed. This trial was done on two commercial Merino farms. The ewes grazed annual grass/clover pastures. Ewes were fed wheaten hay *ad lib* and 250 g oats per ewe per day from six weeks prior to lambing to meet their energy requirements as the grazing was considered of low quality and little nutritional value. Oats was fed three times a week. Ewes were then divided into two groups of which one received lupin three times a week at the equivalent of 500 g per ewe per day. Lupin supplementation started 12 days after the start of lambing which was designated day 150 of pregnancy, and continued for 14 days. Lupin supplementation increased lambs weaned by seven per 100 ewes. This was mostly due to better survival of twin lambs with the supplemented group having an 8% higher survival of twins and a 5% higher survival of singles. Weaning weights of the supplemented group were also 1.6 kg more than the control group. This study showed that lupin supplementation can have a significant benefit for ewes on poor grazing. The supplementation period was very short which would make this cost effective. However, no cost benefit analysis was done.

Hinch *et al*. (1996) divided Border Leicester X Merino ewes of mixed ages into two groups, supplemented and non-supplemented. Ewes were grazed on green pasture during pregnancy and early lactation. The supplemented group received pellets made up of 75% cottonseed meal, 18% bran and a small mixture of cereal grain and minerals. The pellets contained 31.5% CP of which only 15% was RDP and 9.7 MJ ME per kg. Ewes were supplemented at 80 g per ewe per day (fed in three batches three times a week) from day 50 to 100 of pregnancy and then from day 100 to 30 days post-partum according to litter size: 0 or 1 lamb – 80 g per day; 2 lambs – 160 g per day; 3 or more lambs – 220 g per day. Lamb survival rates were significantly different between the two groups with the supplemented group 72.7% compared to 57.8% of the non-supplemented group. There were no significant differences regarding lamb growth rates, lamb weaning weights or wool production. This study showed that supplementation can improve lamb survival by 15% but supplements were given for 130 days. No cost analysis was done but it is unlikely that it would be cost effective to give supplements for such a long period.

O'Doherty and Crosby (1997) penned Suffolk X Texel ewes either individually or in small groups from day 91 of pregnancy until lambing. They used soya-bean meal (516 g per kg CP and 20.1 MJ per kg ME) as supplementary protein source to two different basal diets, either formic acid treated grass silage (99.9 g per kg CP and 10.12 MJ per kg ME) or molasses sugar-beet pulp silage (112.3 g per kg CP and 10.03 MJ per kg ME). Basal diets were fed from day 91 to 125: formic acid treated grass silage *ad lib* (two groups); molasses sugar-beet pulp *ad lib* (two groups); formic acid treated grass silage *ad lib* with molasses sugar-beet pulp (two groups). A group in each of the different diets received soya-bean meal from day 126 of pregnancy at a level of 220 g CP per ewe per day. Groups supplemented with soya-bean meal had higher CP intakes (217.6 vs. 97 g per day) and higher ME intakes (12.61 vs. 8.98 MJ). Supplementation with soya-bean-meal increased overall colostrum yield at 1 h, 10 h and 18 h post lambing. However ewes receiving only the formic acid treated grass silage showed no response when supplemented with soya-bean meal. Furthermore although there was no significant effect of supplementation on IgG concentration in colostrum, the absorption of IgG was better in the lambs from protein supplemented ewes. In this study supplementation of soya-bean meal led to higher colostrum yield and better absorption of IgG which could increase lamb survival since mortality is usually highest during the first few days, often due to insufficient colostrum. However the study did not report on lamb survival up to weaning. Also no response was found in the formic acid treated grass silage group which indicated that supplementation may not have any effect if combined with some basal diets.

Dawson *et al.* (1999) measured colostrum production, lamb birth weight and lamb live weight from birth to weaning using different protein sources at different levels from six weeks before lambing up to lambing. Six iso-nitrogenous diets with different levels of soypass (xylose-treated soya-bean meal), fishmeal and urea were used. Urea levels ranged from 0 g per day to 15 g per day, soypass levels from 0 to 102 g per day and fishmeal was given at 50 g per day. Ewes of mixed breeds were kept on a basal diet of formic acid treated ryegrass silage. Diets provided 166 g CP per day with RUP levels varying from 16 g per day to 42 g per day and an energy level of 14.5 MJ ME. They found no significant difference between any of the groups and concluded that if ewes were in good body condition at six weeks prior to lambing, and fed good silage, then supplementation with protein will make no difference regardless of the level of RUP. Weaning percentage was not mentioned. This study showed again that ewes in good body condition could use their reserves during pregnancy if faced with restricted nutrition.

Frutos *et al*. (1998) synchronised mature Merino ewes grazing perennial ryegrass pastures (CP between 18% and 22%) and divided them into four groups on day 30 after the start of mating. Single-bearing ewes were used. Group GG grazed from day 30 to 140. Group GS grazed from day 30 to 90 and was then supplemented from day 91 to 140. Group SG grazed from day 30 to 140 but only received supplement from day 30 to 90. Group SS grazed and was supplemented from day 30 to 140. The supplement had 134 g per kg CP of which most was soya-bean meal and was given at 500 g per ewe per day. Supplement given during day 30 to 90 made no significant difference while supplement given during day 91 to 140 led to higher body weights and better BCS in the ewes. Ewes were slaughtered on day 141. No significant differences were found regarding the composition of the foetus or placenta and cotyledons. This study showed that ewes were able to mobilize sufficient reserves for normal foetal growth during periods of restricted nutrition.

El-Hag *et al.* (1998) flushed mature Sudan desert ewes with 150 g per ewe per day groundnut seed cake (25.7% CP, 11.8 MJ ME) for 45 days before mating and resumed supplementation for 45 days before lambing. Ewes grazed on natural vegetation, which consisted of a mixture of grasses and herbs with scattered shrub bushes. A control group received no supplement. They found significant differences between the supplemented ewes and non-supplemented ewes with higher conception (95% vs. 67%) and lambing rates (91% vs. 42%), higher lamb birth weights (3.9 kg versus 3.5 kg), lower ewe mortality (0 vs. 12.5%) and abortions (8.7% vs. 50%). They also did an economic analysis and found that supplementation was profitable with an increased income of 15 900 Sudanese pounds per ewe (about R124) under these circumstances. This study showed that protein supplementation could be economically beneficial under certain conditions.

Wilkinson *et al*. (2000) tested the response of lactating Friesland and Finn Dorset ewes on conventional grazing to various protein supplements. The researchers used three levels of RDP, low (L), medium (M) and high (H) and two levels of RUP, high (A) and low (B). Thus there were six supplements in total: LA, LB, MA, MB, HA and HB. The supplements consisted of wheat, oats, molasses sugar-beet pulp, soya-bean meal, fishmeal, fat prills, urea and minerals. They contained 180 g, 182 g, 229 g, 217 g, 247 g and 249 g of CP and 12.3, 12.4, 12.1, 12.1, 12.4 and 12.4 MJ ME per kg DM respectively. Supplements were started in week eight of lactation and were given for three periods of four weeks each. They were given at 1.2 kg per day. Grazing had a CP of 112 g, 174 g and 188 g respectively in period one, two and three. Milk yield increased with increased levels of protein, from L to H with the level of RUP making no difference. The same effect was seen regarding the lactose and milk fat concentrations. This study showed that high yielding dairy sheep responded to an increase supply of protein but that the level of RUP made no difference.

Hanford *et al*. (2000) supplemented Charollais X Lleyn, Charollais X Cambridge or Friesland X Lleyn twin-bearing ewes with five different sources of protein. These comprised of rapeseed meal, field beans, formaldehyde treated rapeseed; formaldehyde treated field beans or fishmeal. All diets contained approximately 206 g per kg DM CP and 13 MJ per kg DM. The basal diet was straw. Ewes were supplemented from six weeks pre-lambing at 0.9 kg per day to four weeks post-partum at 1.8 kg per day. In their trial, lambs from the fishmeal group had the lowest growth rates. They concluded that formaldehyde treatment increased the through flow of metabolizable protein from field beans and rapeseed sufficiently for it to be used as an alternative source of RUP protein. This could be a more cost-effective method of supplementation. No economic analysis was done.

In 2001 Hanford *et al*. did a similar trial using soya-bean meal, formaldehyde treated soya-bean meal, formaldehyde treated soya-bean meal plus added methionine or fishmeal. All diets consisted of a CP of 210 g per kg DM and 13.1 MJ per kg DM. Supplements were fed at 0.6 kg per day six weeks before lambing, increasing to 1.1 kg per day at lambing and then 1.6 kg per day from lambing until the fourth week of lactation. Again the lambs of the group receiving the fishmeal had the lowest growth rates. The diet providing additional methionine had the highest growth rates. No other differences were observed. This study showed that the level of RUP is not as important as the quality (amino acid composition).

The overall conclusion from all these investigations (summarised in Table 2.3) is that protein supplements seemed to increase milk production and thus indirectly lamb growth rates. In some studies RUP sources led to higher increases but RDP sources were also effective. It was shown that if ewes are in good condition at lambing they could produce adequate quantities of milk through mobilization of their body reserves and thus ensure fair lamb growth rates. These studies also showed that if the quality of grazing is adequate then supplementation with either RDP or RUP protein has little or no effect. Only one of the studies provided information on the costs and financial benefits.

2.3 Gastrointestinal parasites

Nematodes are specifically adapted to inhabit particular regions of the digestive tract. In ost parts of South Africa *Haemonchus contortus* is the most common nematode (Reinecke, 1964; Van Wyk, 1978). *H. contortus* inhabits the abomasum where it compromises abomasal functions causing changes in the endocrine and enzyme secretions, increasing the pH as well as causing serious blood loss due to its haematophagic activities (Coop & Kyriazakis, 1999; Sykes, 1994). The increase in cell turnover caused by nematode infections results in an increase in energy expenditure due to reduction in the efficiency of use of metabolizable energy and additional protein synthesis for maintenance (MacRae, 1993; Sykes. 1994). Another result of GIT nematode infections is the reduction in food intake (Poppi *et al*. 1990). This is especially a problem in young animals and lactating females (Coop & Kyriazakis, 1999). Furthermore, a reduction in mineral and trace element absorptions has also been shown. (Wilson & Field, 1983; Bang *et al*. 1990).

For many years it was thought that anthelmintics were the solution. During the 1970's and 1980's regular treatment with anthelmintics kept infections under control (Van Wyk *et al*. 1997). However the development of anthelmintic resistance made this an unsustainable method of nematode control. At present anthelmintic resistance is widespread throughout South Africa and the world (Van Wyk *et al*. 1997;Van Wyk *et al*. 1999; Waller, 1997). Other control strategies are therefore necessary.

The development of host resilience (being the ability of the host to maintain a reasonable level of productivity in the face of parasite challenge) and resistance (being the ability of the host to prevent establishment of/or limit the growth rate and/or persistence of the parasite) are two ways of helping to control nematodes. Both of these contain an environmental and genetic component (Coop & Holmes, 1996; Coop & Kyriazakis, 1999; Gray, 1987; Stear & Murray, 1994). Also it is well known that older or non-productive animals have better immunity against the establishment of infections (Coop & Holmes, 1996) while well nourished animals in a good body condition are usually more resilient against infections (Kyriazakis *et al*. 2002). Thus questions were raised, such as can the manipulation of nutrient supply contribute to the immunological development of resistance and improve animals' resilience to infections?

Abbott *et al.* (1985a, 1985b) showed that Scottish Blackface and Finn Dorset lambs on a high protein diet (CP of 170 g per kg DM compared to 88 g per kg consisting mainly of soya-bean meal) coped better with a single moderate *H. contortus* infection of 125 larvae per kg BW compared to lambs on a low protein diet. The lambs were given the respective diets from three months of age and were infected at four months of age. A control group for each breed was fed a similar diet but were not infected. The low protein diet supplied adequate energy but only about half the required protein while the high protein diet supplied about twice the necessary protein. The high protein diet did not appear to prevent the establishment of *H. contortus*, since lambs had similar faecal egg counts, but the lambs on the high protein diet showed less severe clinical signs. The Scottish Blackface lambs had lower FEC's than the Finn Dorset lambs. Scottish Blackface is considered a relatively *Haemonchus*-resistant breed and the Finn Dorset a susceptible breed. This study showed that breed differences do exist and that protein supplementation can increase both resistance, judged by lower FEC's and resilience, judged by less severe clinical signs.

In a later study, Abbott *et al*. (1986a, 1986b) used two groups of Finn Dorset X Dorset Horn lambs fed a similar high/low protein diet respectively from three months old and then infected them at four months but using a higher dose of *H. contortus* of 350 larvae per kg BW. Again lambs on the high protein diet were less affected by the pathogenic effects of *H. contortus*. The lambs on the low protein diet showed more adverse clinical signs i.e. anorexia, weight loss and oedema. They also had more severe anaemia, hypoproteinaemia and hypoalbuminaemia. Mortality was also higher in the low protein group. The establishment of the parasite was not affected since lambs of both groups had similar faecal egg counts and worm burdens, but the resilience of the high protein group was improved. In all these trials soya-bean meal was used as protein supplement, thus mainly a RUP source. However, soya-bean meal is considered a good quality protein compared to barley and sugar beet pulp, which is considered low to fair quality protein. Results indicated that protein supplementation can be beneficial but no cost analysis was done.

Preston & Allonby (1978) had done a similar study using four different breeds of sheep, Corriedale, Hampshire Down, Merino and Red Masai. They had two groups, one fed 3.5 g CP per kg BW (high protein) and the other group fed 1.5 g CP per kg BW. Experimental animals were 2 to 3 year old wethers. They also infected them with 350 *H. contortus* larvae per kg BW and performed FEC's twice weekly for 16 weeks. The trend of FEC numbers was similar for Red Masai, Merino and Hampshire Down sheep with all of them developing self-cure at 12-13 weeks. The Corriedales did not show self-cure by 14 weeks. However the FEC's showed a different picture with the Red Masai having the lowest counts, then the Merino, Corriedale and Hampshire Down. The trend of FEC numbers was similar for the sheep on the low protein diet except that the Red Masai was able to develop self-cure at nine weeks. All three other breeds still had high FEC's at 16 weeks. This study showed that breed differences could play a large role but that the resilience of susceptible breeds can be improved with high protein diets. The source of protein was not mentioned in this trial.

In a later trial Abbott *et al*. (1988) again used three month old Finn Dorset X Dorset Horn lambs fed the low/high protein diet used previously (Abbott *et al*. 1985a) for a month before infection. This time they used a trickle infection of *H. contortus*. Lambs were infected with 200 larvae each, three times a week for 17 weeks. Many of the lambs on the low protein diet developed severe clinical haemonchosis, severe macrocytic anaemia, hypoproteinaemia, loss of appetite and had reduced survival while many of the lambs on the high protein diet developed resistance to the continuing infections. These lambs had either low or negative faecal egg counts and worm burdens at slaughter. None of the lambs on the low protein diet developed any resistance to the continuing infections with *H. contortus*. These lambs had high faecal egg counts as well as high worm burdens at slaughter. Thus supplementing susceptible lambs with a good quality protein helps to improve their resistance against nematodes. However, again no cost analysis was done.

Roberts and Adams (1990) infected Merino lambs with a trickle infection of 500 *H. contortus* larvae three times a week for 17 weeks, more than twice the dose of Abbott *et al.* (1988). Lambs were fed either 400 g per head per day or 600 g per head per day of a lucerne-based pelleted diet containing 17% CP and 64.5% DOM. The lambs on the 400 g diet had both an energy and protein deficiency. Most of these lambs failed to develop an immune response to the continuous *H. contortus* infection while most of the lambs on the 600 g diet developed immunity against *H. contortus*. However one of the lambs in the 600 g diet group failed to develop immunity while 3 lambs on the 400 g diet developed adequate immune responses. They concluded that the innate resistance of sheep plays an important role in development of immunity against *H. contortus*, regardless of the level of nutrition. In this study both groups were on the same type of protein, lucerne, which is considered to have about 40% RUP and is a good quality protein. Thus the level of protein supplementation was varied instead of the type. This may indicate that the level may be as important as the type.

Wallace *et al.* (1995,1996) also performed similar trials using soya-bean meal as the supplementary protein source. They had a high protein group and a low protein group. The high protein group got 1.5 times the required level of metabolizable protein: 172 g CP per kg DM consisting mainly of soya-bean meal, while the low protein group got about 0.9 times the required level of metabolizable protein: 93 CP per kg DM, consisting of sugar beet pulp and barley. Energy levels were sufficient in both diets. The 1995 trial was done using Hampshire lambs while the 1996 trial was done with Scottish Blackface lambs. Lambs were dosed with a trickle infection of 200 *H. contortus* larvae three times a week for 10 weeks. In the trial with the Hampshire lambs, the high protein group had lower FEC's in the later stages of infection while with the Scottish Blackface lambs there were individual differences but no differences between groups. In both trials the supplemented groups had better growth rates as well as leaner carcasses (less fat deposition). They concluded that protein supplementation helped lambs to withstand the pathogenic effects of haemonchosis better as well as improved their growth rates. It also helped susceptible breeds like the Hampshire to develop better immunity but in naturally resistant breeds like Scottish Blackface, innate resistance masked the effects of protein supplementation. In this trial they used a similar diet to Abbott *et al*. (1985a). Thus both used different levels and qualities of protein, and although the resilience of the lambs was improved, there was no economic advantage as slaughter-out percentages and carcass weights were not different.

In the above studies mainly plant sources of RDP were used for supplementation. Therefore Wallace *et al*. (1999) used a similar study to see if urea supplementation (NPN protein) could increase resilience to gastrointestinal parasites. They used four groups of five month old Hampshire Down lambs. Two groups were offered 1.4 kg daily and the other two groups 1 kg daily of a urea-supplemented diet. Food was increased every two weeks to maintain a similar ratio of food to live weight gain in the four groups. The diet contained 89 g of metabolizable protein and 9.9 MJ of ME per kg DM. After ten days on the diets, lambs of two groups, one from the restricted and one from the non-restricted diet groups, were infected with 100 *H. contortus* larvae per kg BW. Subsequently these lambs were infected with 200 larvae three times a week for 10 weeks. All lambs were slaughtered at the end of the trial and worm burdens determined. FEC's were similar for the two infected groups. However during week eight, four of the six infected lambs in the restricted diet group developed severe anaemia and anorexia. They were all killed at the beginning of week nine. The difference in BW gain was 1.7 kg between the infected and uninfected lambs in the protein restricted group compared to 0.2 kg difference between the infected and uninfected lambs of the *ad lib.* groups. Worm numbers were similar between all the groups. Thus supplementing the diet with urea helped lambs to become more resilient against *H. contortus* infection. Again the source of protein was not as important as the level. In this study there was an indirect advantage in that supplementation lowered mortality. However no economic analysis was made.

Anindo *et al*. (1998) used five to seven month old Menz ram lambs (average BW of 15 kg and BCS of 1.5) grazing natural pasture and divided them into two main groups. One group had access to grazing only, while the other group was supplemented with molasses-urea-blocks at about 80 g per lamb per day for nine months using a NPN protein. The supplemented group had better growth rates with an average BW of 25.7 kg compared to 21.7 kg in the grazing only group at 12 months of age, as well as better BCS: 3.2 compared to 2.4 in the grazing only group. The semen quality of the supplemented group was also better than the control group. FEC counts were similar for all the groups. Thus supplementation with urea improved resilience in this trial. Feeding 80 g per day means that over the nine month period, the supplemented lambs received 21 kg of supplement but the BW advantage was only four kg. Thus it is unlikely that it would have be cost effective although no economic analysis was done.

Knox and Steel, (1996, 1999) also used urea as source of protein supplementation. In this trial four month old Merino lambs were either given a basal diet of oaten chaff containing about 5% CP supplemented by essential minerals, or they were given the same diet supplemented with 3% urea thus increasing the CP level to about 13% for 19 weeks. Lambs were infected with either 200 *H. contortus* larvae or 1000 *Trichostrongylus colubriformis* larvae, or both species (200+1000) three times a week, or remained uninfected. The uninfected lambs with the urea supplementation had better growth rates (54 g per day compared to 39 g per day) and wool production (5.4 g per day compared to 4.2 g per day) than the uninfected, no urea-supplementation group. The infected, urea-supplemented group had similar growth rates (40 to 43 g per day) to the uninfected, no urea-supplementation group (39 g per day). The no urea-supplement had the lowest growth rates (23-32 g per day). Initially the infected, urea-supplemented group produced more wool than the non-infected supplemented group but at the end of the trial the rates were similar. FEC's were similar for both infected groups. Both urea-supplemented groups had a higher level of feed intake than the no urea-supplementation groups. Thus they also concluded that urea supplementation can increase an animal's resilience and productivity. In this trial urea supplementation would probably have been cost effective because both resilience and productivity were improved with a low level of NPN supplementation. No economic analysis was made.

In other studies, Van Houtert *et al.* (1995a), Van Houtert *et al.* (1995b) and Coop *et al.* (1995) investigated the effects of dietary protein on other gastrointestinal parasites in young, growing sheep. These studies focused on infections with *Trichostrongylus,* *Nematodirus* and *Ostertagia*. Results were similar to studies on *H. contortus* infections. Van Houtert *et al*. (1995b) used fishmeal as supplementary source of protein. Fishmeal was supplemented at 50 g per head per day to one group, at 100 g per head per day to another group with the control group not receiving any supplement. The Merino lambs in this trial responded very well to the protein supplement especially at the 100 g per head per day level. These lambs had higher levels of weight gain, higher greasy wool production, higher rates of worm expulsion and thus lower FEC's. The 50 g per head per day group's response was not as good as the 100 g per head per day group. In this study they mainly used RUP protein, which led to good results. However the level of supplementation was high since 700 g per week for 20 weeks means 14 kg of an expensive supplement. This would be economically prohibitive and unlikely to be cost effective.

After showing that NPN, natural RDP and RUP protein all increased the resilience and resistance of sheep to gastrointestinal parasitism, the next question was, are all the types of protein equally effective? As mentioned before, RDP and especially NPN protein are generally less expensive than RUP protein.

Datta *et al*. (1998, 1999) used both urea and cottonseed meal as protein supplements. They supplemented five groups of cross-bred wethers with different levels of urea and cottonseed meal. The levels of CP were 10, 13, 16, 19 and 22 percent. The RUP component of each was 57, 68, 69, 68 and 63 percent respectively. Wethers were then infected twice weekly with 750 *H. contortus* larvae for nine weeks. In all the groups there were pair-fed controls. All diets were iso-energetic at 9 MJ per kg ME. The increase in CP level, increased feed intake by up to 19%. There was no difference between the 19% and 22% supplemented groups. Infected lambs of the 10%, 13% and 16% protein groups lost weight while the 19% and 22% gained weight. All controls gained weight. FEC's were significantly lower in the infected lambs with the higher protein content. After the nine weeks all the animals were treated with anthelmintics and grouped together again as a single group and monitored for 69 weeks on grazing. The ranking of the animals' BW in response to the nine weeks of supplementation remained similar throughout the whole period. The same happened with the FEC's. Lambs from the previously higher protein diet had lower FEC than the lower protein groups. Previously infected lambs were no different from non-infected ones. Wool weight and characteristics also improved with the increase in protein levels, but only up to 19%. There was a significant carry-over effect from protein supplementation. These studies showed that a combination of NPN and RUP was effective. It also showed that there is a maximum level for supplementation after which increasing the level of protein will not improve performance or resilience. This information can help to plan cost-effective supplements.

Haile *et al*. (2002) supplemented two breeds of lambs, Menz and Horro, with either 150 g per day molasses urea-blocks or 165 g per day cottonseed cake. The basal diet consisted of hay (58 g per kg DM CP) and wheat bran (175 g per kg DM CP). The molasses urea-block (MUB) had a CP of 390 g per kg DM and the cottonseed cake (CSC) 381 g per kg DM. Lambs were infected with 1000 *H. contortus* larvae three times a week for three weeks. Later the lambs were infected three times a week for 12 weeks with a mixture of 500 *H. contortus* larvae comprising 87% of the infective larvae, *Longistrongylus elongata* (10%) and *T. colubriformis* (3%). Menz lambs had lower FEC's than the Horro lambs as well as lower total adult worm burdens (slaughter trial). The effect of nutritional supplementation varied. With the Horro lambs, the CSC group had the highest FEC's followed by the basal and then MUB group. With the Menz lambs, the CSC group had the lowest FEC's, followed by the basal and then MUB group (highest FEC). Parameters also varied with regard to packed cell volumes and body weight gains. Thus in this study, the feeding of MUB or CSC was beneficial to infected lambs. It showed that breed differences are important and thus supplementation may not be cost-effective in some breeds.

All the above studies were done with either lambs, weaners or wethers which left some unanswered questions. One is, will the same principles apply to production ewes? It is well known that ewes experience a peri-parturient relaxation of immunity against gastrointestinal parasites (McAnulty *et al*. 1991). This happens at a time the ewe is most stressed for nutrients, the foetus is growing quickly and rumen fill is reduced due to the enlarging foetus (Gibbs & Barger, 1986; McAnulty *et al*. 1991). This is especially a problem in multiple bearing ewes. After parturition, lactation also puts huge demands on the ewe which leads to high nutritional stress. Again this is especially a problem in multiple suckling ewes (McAnulty *et al*. 1991).

Donaldson *et al*. (1997) looked at the effect of supplementing peri-parturient ewes with protein. They used four groups of single and twin bearing Coopworth ewes which were mated after synchronization. The ewes were dewormed and then housed individually from nine weeks before lambing. From seven weeks before lambing all ewes were infected with 10 000 *Teladorsagia circumcincta* larvae and 7 000 *Trichostrongylus colubriformis* larvae, three times a week until lambing. The four diets were formulated to consist of either low/high energy (70% lucerne hay & 30% barley or 70% barley & 30% lucerne hay) and/or low and high protein (0% or 8% fishmeal). The low energy diet supplied 10.7 and 12.9 MJ ME per day to single and twin ewes respectively during pregnancy and 19.3 and 28 MJ ME during lactation. The high energy diet supplied 13.2 and 15.4 MJ ME during pregnancy and 23.6 and 32 MJ ME during lactation for single and twin-bearing ewes respectively. The low and high protein diets supplied 94 g and 113 g or 110 g and 133 g metabolizable protein to single and twin ewes during pregnancy and 170 g and 248 g or 200 and 290 g metabolizable protein per day during lactation. All ewes were slaughtered three weeks after lambing and worm burdens determined. There were no significant changes in BW and BCS in any of the groups. In the high protein groups FEC's were suppressed from 21 day before lambing until the end of the study. This was especially significant from seven days before lambing until the end of the study. Energy supplementation had only a short suppressing effect on FEC's. The high energy diet had a significant effect only during the last seven days before lambing. FEC's from twin bearing ewes were significantly higher than those of single bearing ewes from lambing until day 14 of lactation. Worm burdens were also significantly different between the protein groups and the single and twin groups. The low protein groups had a mean of 12 020 worms per ewe compared to 1 540 in the high protein groups and 2 290 in the single bearing ewes compared to 8 090 in the twin bearing ewes. Thus protein supplementation was more effective in improving resilience than energy supplements and twin-bearing ewes were less resistant than single-bearing ewes. No comments were made on lamb survival.

Donaldson *et al*. (1998) did another two trials using twin-bearing Coopworth ewes. In the first trial they had two groups, a high and low nutrition group. For three weeks (nine to seven weeks before lambing) they were grazed on ryegrass/white clover pastures and given 500 g of lucerne hay daily (525 g DOM, 239 g CP, 9 MJ). The ewes also received pelleted barley concentrate (818 g DOM, 124 g CP and 11.5 MJ), at either 400 g (high) or 200 g (low) levels. Ewes were then housed at seven weeks prior to lambing. In-house they received meadow hay (553 g DOM, 168 g CP, 8 MJ) and increasing amounts of concentrate. From 15 to 21 weeks of gestation, the high group received 11.9 up to 24 MJ per day and the low group, 7.4 up to 13.6 MJ per day. After parturition all ewes received 2.5 kg concentrate and 400 g hay per day (28 MJ per day). From five weeks prior to lambing all ewes were trickle infected with 4 000 *T. circumcincta* larvae per day. Trickle infection was ceased either on the day of parturition, day ten of lactation or day 31 of lactation. After day 31, all ewes were treated with an anthelmintic and then dosed with 25 000 *T. circumcincta* larvae. All ewes were slaughtered 21 days later. There were significant differences in BW and BCS between the two groups, with the high nutrition group weighing on average 12 kg more pre-partum and 11 kg more post-partum. BCS differed 0.4 points pre-partum in favour of the high nutrition group. FEC's in the low groups were also significantly higher from one week before lambing. However no significant differences were found in worm burdens after the single challenge infection. This study showed that protein supplementation improves BW and BCS as well as resilience of ewes to nematodes pre-partum. Again no mention was made of lamb survival.

In the second trial they also had high and low nutrition groups. For three weeks (week 12 to 9 before parturition) ewes were grazed on ryegrass/white clover pastures. The high group was on a high yield pasture (800 kg DM per ha) and the low group on a low yield pasture (400-600 kg DM per ha). Both groups received 200 g concentrate per day (883 g DOM, 144 g CP, 10.2 MJ per kg DM). Nine weeks prior to lambing they were moved in-house and fed lucerne hay (488 g DOM, 168 g CP, 8 MJ/kg DM) and concentrate. The high group received 1 kg hay and 200 g concentrate per day increased to 1 kg per day at lambing (8.6 MJ to 15.7 MJ) and the low group 500 g hay increased to 600 g and 200 g concentrate per day increased to 700 g per day (5.2 MJ to 10.3 MJ). Ewes in the high group were infected with 10 000 *T. circumcincta* larvae daily until parturition while the low group were divided into three sub-groups, each infected with either 5 000, 10 000 or 20 000 larvae daily up to parturition. All ewes were slaughtered at parturition. BW and BCS were significantly different between the high and low groups. There were no significant differences between the three low sub-groups. The high group weighed between six and eight kg more than the low groups and scored 0.7 to 1 BCS more. Although there was a trend for the high group to have lower FEC's than the low groups, the difference was not statistically significant. The same happened in the three low sub-groups. Worm burdens were also the same for all groups although the high group tended to be lower and the three sub-groups tended to increase with increased level of infection. In these studies, results were significant with fishmeal supplement but not with the concentrate. Although the concentrate provided higher protein levels, the quality was not very good. This could indicate that if protein is going to be supplemented, it has to be good quality but other studies (mentioned previously) have proved that NPN has an effect. Thus there may be other limiting factors. In none of these studies was lamb survival mentioned and since this is one of the main determining factors of whether supplementation is cost-effective, no economic deduction could be made.

Houdijk *et al*. (2000a) used 3-4 year old twin-bearing Greyface ewes. They supplemented them with three different diets: the LL diet supplied 0.7 times the metabolizable protein and metabolizable energy required. The HL diet supplied 1.2 times the protein and 0.8 times the energy while the HH diet supplied 1.3 times the protein and 1.2 times the energy required. They fed the ewes for 42 days and infected them with 10 000 *T. circumcincta* larvae per day, three times a week. Ewes were 86 days pregnant when the experiment started. The results showed that FEC's of the HL and HH groups stayed low while the FEC's of the LL group increased rapidly from day 28 of the experiment. The body condition scores of the three groups as well as the muscle and backfat depths were significantly different. The LL group's BCS was 0.6 lower and the muscle and backfat depths 2 mm less. Thus in this study protein supplementation was more effective than energy supplementation. It improved the ewes' resilience to nematodes as well as carcass quality. The source of protein is not mentioned and thus no economic conclusions could be made.

Houdijk *et al*. (2000b) supplemented single and twin-bearing mature Dorset Finn ewes from three weeks before the expected lambing date until 35 days after lambing with three iso-energetic diets (12 MJ ME per kg DM). The diets contained 87, 105 or 130 g per kg metabolizable protein, providing either 80%, 100% or 120% of the requirements for single-rearing ewes producing 2.5 kg milk per day and twin-rearing ewes producing 3.5 kg milk per day. The ewes were infected with 10 000 *T. circumcincta* larvae per day three times a week from 42 days before lambing till 35 days after lambing. There was no significant difference between the three groups regarding body weight and BCS. However the FEC's of the 100% and 120% metabolizable protein groups were lower than the 80% group from day 23 of lactation. The 100% group was the lowest from about 14 days before lambing up to day 12 of lactation. FEC's of single-rearing ewes were also significantly lower than twin-rearing ewes from day 12 of lactation. In this study neither the source of protein nor the lamb survival rate was mentioned. Thus no other conclusion could be made.

Houdijk *et al*. (2001) supplemented twin-bearing ewes with three different feeds. LL group had low protein (less than maintenance), HP group had high protein but restricted energy intake, and group HH was given enough protein and energy to maintain body weight. These diets were used from day 65 to day 21 before lambing. Then from day 20 before lambing to day 42 of lactation, ten ewes in each of the groups received either a LP (low protein but adequate energy) or HH diets. Ewes were also infected with 10 000 *T. circumcincta* larvae per day three times per week from day 65 before lambing to the end of the experiment. Lambs of the LP group had weaker growth rates and the ewes had higher FEC's than the HP and HH groups. As in the study above neither lamb survival rate nor the source of protein is mentioned. Thus it is difficult to draw any conclusions but the study does show that the protein reserve of an ewe is more important than the energy reserve with regard to resilience against nematodes.

Houdijk *et al*. (2002) then supplemented twin-bearing Greyface ewes with increasing levels of metabolizable protein during the first four weeks of lactation. During pregnancy, the ewes received 0.8 times the recommended metabolizable protein requirements. During lactation, metabolizable protein was supplemented at 0.65, 0.8, 0.95, 1.10 and 1.25 times the requirements. They infected the ewes with 10 000 *T. circumcincta* larvae three times a week from day 46 before parturition. They found that FEC's were inversely lower as protein levels were increased. Protein supplementation also affected worm burdens but the effect was far less pronounced and not statistically significant (P = 0.054). The response in milk production was higher, which suggests that the immune responses that regulate the size of the worm burdens may be less sensitive towards changes in protein supply then those regulating fecundity. Again neither the source of protein nor the lamb survival rate was mentioned.

Thus from these studies it can be deducted that protein supplementation can improve sheep's resistance and resilience to gastrointestinal parasites. Also it seems as if RUP proteins are usually more effective than RDP proteins. However, breed resistance and reproductive status can sometimes mask the effects of protein supplementation. All the above data are summarised in Table 2.4.

2.4 Wool production and characteristics

In dual breeds like the Merino, wool is an important part of the farmer's income. In the past few years the price of wool has risen by more than 70%, thus increased production of good quality wool can increase income (Van Zyl, 2000). Wool growth is very dependent on protein supply since sulphur-containing amino acids are essential for wool growth (Reis *et al*. 1992; Mata *et al*. 1995). Several studies have been done on the role of protein nutrition in the production of wool (Williams & Winston, 1965; Boyazoglu, 1999). With wool production, quantity as well as quality is important. Due to newer technology and free markets all wool sold is now measured in term of its length (mm), strength (Newton/ktex), fibre diameter in microns, coefficient of variance of the fibre diameter (CV), clean fleece yield, point of break measured in percentage with as low a percentage as possible being required and the comfort factor (softness).

Cronje and Weites (1990) supplemented South African Mutton Merino wether lambs on a diet of wheat straw and urea with either maize (M) or cottonseed oilcake meal (CSO) at different levels (0, 100 or 200 g per day.) Both M and CSO supplements improved growth rates but CSO was almost double that of M. Lambs supplemented with M had a much higher percentage of body fat (28%) than lambs supplemented with CSO. Wool growth rates were higher for lambs supplemented with the CSO (89% higher for the 100 g and 226% for the 200 g) than with the M supplement (wool growth improved with 46% for the 100 g and 96% for the 200 g group). Staple length and fibre diameter were also higher with CSO (35 and 28 mm for the 100 g and 200 g respectively, as well as 21.4 and 18.9 microns) compared to the M supplement (31 and 30 mm for the 100 g and 200 g respectively, as well as 19.7 and 19.1 microns). In this study they showed that both energy and protein improve wool production with the effect of protein supplementation better for wool growth in lambs but negative for fibre diameter with an increase of more than two microns.

Reis *et al*. (1992) infused casein, whole milk, glucose and glycerol directly into the abomasum of mature Merino wethers. They used various combinations, milk; casein; milk and casein at low or high levels; milk, casein, glycerol and glucose at low or high levels; milk, glucose and glycerol at high or low levels. The basal diet was 200 g hay per day. They found that increasing the protein level from 53 to 99 g per day caused substantial increases in fibre diameter (22.5 to 24.6 microns), length (328 to 374 µm per day), mass (7.2 to 10.4 g per day) and volume (136 to 185 μm^3 per day) of growth. Increasing the protein level from 99 to 145 g per day had much smaller effects (25.3 microns, 390 µm per day, 10.5 g per day, 206 μm^3 per day). In contrast, supplying energy made no difference to any of the wool growth parameters. In this study they showed that RUP protein supplementation had a significant effect on wool production in wethers.

However, this method of supplementation is obviously not practical.

Coombe (1992) supplemented Merino wethers with either urea at 14% or different levels of formaldehyde treated rapeseed meal (from 819 g to 980 g per kg DM) for 20 weeks. The basal diet was straw. The urea diet increased wool production by 5 g per day while the different levels formaldehyde-treated rapeseed meal increased it between 4.7 (at 819 g) and 11 g (at 980 g). Fibre diameter was also increased by both supplements, the urea group to 20.3 micron while the different rapeseed groups were between 19.8 to 23 microns. An economic analysis at the end concluded that supplementing with urea was cost-effective but not with rapeseed meal. They used fibre diameter and mass in calculating wool income.

Masters *et al.* (1998) monitored wool growth, staple strength and fibre diameter in Merino weaner wethers supplemented with either lupins (253 g per kg DM, 164 g per kg CP, 9.4 MJ ME) or canola meal (251 g per kg DM, 162 g per kg CP, 9.1 MJ ME). Two groups of weaners were used. The one group was given good nutrition previously with an average BW of 33 kg while the other group received restricted feed previously with an average BW of 25 kg. Each group was then divided into two sub-groups. One sub-group was fed with each of the diets to maintain BW while the other sub-group was fed to first lose BW at 100 g per day for 28 days (0.6 maintenance) and then to regain weight for 28 days (1.6 maintenance). The basal diet consisted of hay (717 g per kg DM, 8.5 MJ ME), urea (10 g per kg DM) and minerals (20 g per kg DM). Groups receiving the canola supplement grew more wool and had a higher yield of clean wool (74.9% vs. 72.4%) than the lupin supplemented groups. The heavier group also grew more wool (1.8 g per day), had higher clean fleece yields (1.8 kg vs. 1.4 kg), staple strength (37 vs. 27.4 N/ktex), fibre diameter (18 vs. 17.4 microns) and longer staple length (61.8 vs. 58.6 mm) than the lighter group. The only difference between the groups fed the maintenance diets compared to the groups first underfed and then overfed, was the staple strength (35.8 vs. 28.6 N/ktex). In this study the canola group was slightly better than the lupin group but the biggest differences were between the previously restricted group and the previously good nutrition group. This indicates that growth during the early stages of life is very important and that protein supplementation later on cannot fully compensate for previously reduced growth. No economic analysis was done for this study.

In another experiment Masters *et al*. (1999) used five month old Merino wethers. They used the same lupin and canola diets mentioned above but also an oats-barley diet (497 oaten hay, 379 oats, 100 barley, 10 urea g/kg). One group was only fed the oats-barley diet, one the lupin diet and one the canola diet. Two other groups were fed alternately in two week periods on either the lupin/canola or the barley-oats diet. The experiment lasted two months. They found that the weaners fed the canola meal grew 11% more wool than the lupin supplemented group with a 0.6 increase in microns. It made no difference whether the supplement was fed continuously or alternated with oats-barley in a two weekly rotations. All other wool parameters were similar. They concluded that canola was better for wool growth than lupins. However there was no carry-over effect, which means that it was only effective when supplements were given every two weeks. No economic analysis was done. The canola was probably better because it contained more methionine than lupins.

Thompson & Hynd (1998) used two groups of Merino wethers, 5-6 months old. The one group (+SS) came from a line selected for staple strength (mean strength of 43 N/ktex) and one group (-SS) from a line selected for low staple strength (mean strength of 11.5 N/ktex). They fed them according to the following patterns: BW maintenance throughout; BW loss for 112 days, BW gain for 112 days, BW maintenance for 63 days at either 50 g or 100 g BW loss or gain per day. The trial was done over 343 days. The diet for maintenance or gain consisted of 75% oat based pellets & 25% lucerne chaff while the diet for BW loss consisted of 75% oat based pellets & 25% low quality wheaten chaff. Oat-based pellets had 13% CP, wheaten chaff, 8.2% CP and lucerne chaff, 21.8% CP. Wool growth rates increased when BW increased and decreased when BW decreased. Wethers from the +SS group had higher wool growth rates, yield and mass throughout the trial compared to the –SS group. Wool from the group fed to maintain BW throughout had the highest staple strength, length as well as lowest point of break. This study showed that nutrition influenced along-fibre diameter changes, in contrast to genetic selection, which determines between-fibre diameter changes. Thus nutrition can help to reduce incidences of tender wool by decreasing along-fibre diameter variations. The above data, summarised in Table 2.5 shows that protein supplementation, especially with RUP sources, can improve wool production both with regard to quantity and quality.

2.5 Summary

Protein supplementation can improve production of both lambs and wool. It can also improve sheep's resilience and resistance to gastrointestinal parasites. In general RUP is more effective than RDP, although RDP sources including NPN can be effective. Sometimes the effects of protein supplementation are not clear due to inherent individual differences as well as breed differences. Also, sometimes the effects are not very good because basal diets supply sufficient nutrients. The effects are usually more obvious in high producing animals like multiple bearing ewes. The lack of economic analysis in most of the studies limits their practical usefulness.

Table 2.2 Summary of flushing references

Breed	Supplement	Type of protein	Period flushed	Results	Reference
Coopworth ewes, mature	High (H) or low (L) levels of good quality pasture	Mainly RDP	6L; 5L, 1H; 4L, 2H; 3L, 3H; 2L, 3H, 1L; 1L, 3H, 2L; 3H, 3L; 6H	3 weeks of H had highest conception rate, highest lambing rate	Smith *et al*. 1983
Merino ewes	Alkali-ionophore-treated whole maize	RDP	0, 2, 3 or 4 weeks	3 weeks had highest conception	Venter & Greyling, 1994
Sarda ewes	250 g whole corn 270 g soya-bean meal No supplement	Mainly RDP	From 2 weeks before mating and first 3 weeks of mating	Soya bean meal highest ovulation rate	Molle *et al*. 1995
Sarda ewes	270 g soya-bean meal No supplement	Mainly RDP	5 weeks; 2 weeks; 8 days; 0 days	2 weeks led to highest conception rate	Molle *et al*. 1997
Merino ewes	500 g lupins per day	Mainly RDP	0 or 2 weeks	Improved ovulation rate	Nottle *et al*. 1997

Table 2.3 Summary of late pregnancy, colostrum production, milk production and lamb survival references

Breed	Supplement	Type of protein	Time period	Results	Reference
Scottish Blackface ewes, 2-3 years old, twin-bearing	Mid-pregnancy: to achieve BCS of either 2.5 or 3.5 Last 7 weeks: dried grass pellets to either maintain BW or lose 150 g per day Lactation: good quality pastures	RDP	Mid-pregnancy: either high or low nutrition Last 7 weeks: either high or low nutrition	Similar milk production and lamb growth rates	Gibb & Treacher, 1982
Finnish Landrace x Dorset Horn, mature, twin-bearing	Either low or high level of protein *ad lib* Used fish meal as protein supplement	RUP	From lambing till day 42 of lactation	Improved milk yields and total milk solids. Lamb growth rates similar	Cowan *et al*. 1982
Finnish Landrace x Dorset Horn, mature, twin-bearing	Used basal diet of hay, barley, molasses & salt Supplemented with urea at 43 g per kg; meat and bone meal; blood meal; groundnut; soya-bean meal; linseed; fish meal at 34, 60 or 86 g per kg	Urea (NPN), RDP, RUP	From second to eighth week of lactation	Urea had no effect. Other supplements all improved milk production at low CP levels. Soya bean meal, blood meal, fish meal had increased milk production with increased level of CP	Gonzalez *et al*. 1982
Finnish Landrace x Dorset Horn, mature, twin-bearing	Either low, medium or high protein with low, medium or high energy. Fishmeal was used as protein source	RUP	From second to eighth week of lactation	Improved lamb growth rates, protein better than energy	Gonzalez *et al*. 1984
Scottish Halfbred, 2-4 years old	Fresh-cut perennial ryegrass; with barley & maize; barley and soya-bean meal; barley, soya-bean meal & fish meal; barley & fish meal	RDP and RUP	Week 2 to 7 of lactation	Improved milk volume and solids, lamb growth rates	Penning *et al*. 1988

Table 2.3 (cont) Summary of late pregnancy, colostrum production, milk production and lamb survival references

Breed	Supplement	Type of protein	Time period	Results	Reference
Masham ewes, 4 years old	Perennial ryegrass at high or low-level; with barley or barley and fishmeal	RDP and RUP	From lambing till week 10 of lactation	Protein improved lamb growth rates	Penning *et al*. 1988
Mature Merino & Dorper ewes with single lambs	Control: no supplement Energy: 100 or 200 g maize meal Protein: 60 g of protein concentrate with urea as main protein, added to each maize group. All supplements given via rumen fistulae	Urea (NPN), RDP	From lambing till day 63 of lactation	Improved lamb growth rates	De Waal & Biel, 1989a, 1989b
Finn-Targhee ewes, 2-5 years old with twin lambs	Concentrate containing dehydrated beet pulp, blood meal, corn gluten meal, molasses and salt CP of 53.5 % given at 80 g per day of which 40 g RUP	RDP & RUP	From 33 day post-partum for 12 weeks	Slight improvement in milk production	Frey *et al*. 1991
Merino ewes	Oat grain, pea grain and hay. CP of 11.2%, 27% and 9.2% for first supplement Lupin grain with CP of 33.3%	Mainly RDP with bit of RUP	From day 50 of pregnancy till day 100 only 1/2, then all ewes until 2 weeks before lambing then 1/4 and 1/4 lupin grain	No significant findings	Kleeman *et al*. 1993
South African Mutton Merino ewes	Lupin grain at 0, 200 g, 400 g or 600 g per day	RDP with some RUP	From 6 weeks before lambing till week 6 of lactation	No significant findings	Brand *et al*. 1997

Table 2.3 (cont) Summary of late pregnancy, colostrum production, milk production and lamb survival references

Breed	Supplement	Type of protein	Time period	Results	Reference
Merino ewes, 3.5 years old	All ewes oats at 250 g per day from 6 weeks prior to lambing Lupin at 0 or 500 g per day for 14 days	RDP with some RUP	Oats from 6 weeks before lambing Lupin from day 12 after lambing	Improved lamb survival by 7 lambs per 100 ewes especially significant in twins Improved lamb weaning weights	Nottle *et al*. 1998
Border Leicester X Merino ewes, mixed ages	Pellets consisting of 75% cottonseed meal, 18% bran, some mineral and cereals. CP of 31.5% with 15%RUP	RDP with 15% RUP	From day 50 of pregnancy till 30 days post-partum	Improved lamb survival	Hinch *et al*. 1996
Suffolk X Texel mature ewes	Soya bean meal with CP of 51% Various levels aiming to achieve 220 g CP per ewe per day	RDP with some RUP	From day 126 of pregnancy till lambing	Increased overall colostrum yield at 1, 10 and 18 hours post – lambing	O'Doherty & Crosby, 1997
Merino ewes, 3-4 years old, single bearing	Concentrate of barley, soya-bean meal & minerals with a CP of 13.4%	Mainly RDP	From day 30 to 140 of pregnancy. Different groups at different intervals	Improved BW and BCS of ewes but no differences found regarding the development of the foetus	Frutos *et al*. 1998
Mature ewes of mixed breeds, single bearing	Soypass, fishmeal and urea at different ranges	Urea (NPN), RDP and RUP	From 6 weeks before lambing untill lambing	No significant findings	Dawson *et al*. 1999
Sudan desert ewes, 2-4 years old, single bearing	Groudnut seed cake, CP of 14.8%	Mainly RDP	For 45 days before mating and 45 days before lambing	Improved conception, lambing rate, lamb birth weights. Decreased ewe mortality and abortions. Increased income by R120 per ewe	El-Hag *et al*. 1998

Table 2.3 (cont) Summary of late pregnancy, colostrum production, milk production and lamb survival references

Breed	Supplement	Type of protein	Time period	Results	Reference
Friesland and Finn Dorset ewes, mature	Three level of RDP combined with either a high or low level of RUP CP ranges from 180 g to 247 g per kg DM. Used urea, soya-bean meal and fishmeal.	RDP and RUP	From week 8 of lactation till week 21	Increased milk yield with increased level of protein with RUP level having no effect	Wilkinson *et al*. 2000
Charollais X Lleyn; Charollais X Cambridge; Friesland X Lleyn ewes, twin-bearing	Rapeseed meal, formaldehyde treated rapeseed meal; formaldehyde treated field beans, fish meal	Both RDP and RUP	From 6 weeks before lambing till 4 weeks post-partum	Improved lamb growth rates	Handford *et al*. 2000
Charollais X Lleyn; Charollais X Cambridge; Friesland X Lleyn ewes, Suffolk X Mule twin-bearing	Soya-bean meal, formaldehyde treated soya-bean meal, formaldehyde treated soya-bean meal with added methionine, or fishmeal	RDP and RUP	From 6 weeks before lambing till the fourth week of lactation.	Improved lamb growth rates with added methionine having biggest effect	Handford *et al*. 2001

Table 2.4 Summary of gastrointestinal parasite references

Breed, age, ♂♀	**Supplement**	**RDP or RUP**	**Nematode infection**	**Results**	**Reference**
Masai, Merino, Hampshire Down, Corriedale, 2-3 years, wethers	3.5 g CP per kg BW or 1.5 g CP per kg BW	Unknown	*H.contortus*. 350 larvae per kg BW once	Self-cure in high CP Not Corriedales. Improved susceptibility but breed differences	Preston & Allonby, 1978
Finn Dorset, Scottish Blackface, 4 month old lambs	Low: 8.8% CP, sugar beet pulp & barley High: 17% CP, soya-bean meal	Mainly RDP	*H.contortus* 125 larvae per kg BW once	Similar FEC but high CP less clinical disease especially Hampshire Down lambs Breed differences	Abbott *et al*. 1985a, 1985b
Finn Dorset X Dorset Horn, 4 month old lambs	Low: 8.8% CP, sugar beet pulp & barley High: 17% CP, soya-bean meal	Mainly RDP	*H. contortus* 350 larvae per kg BW once	Similar FEC but high CP less clinical disease	Abbott *et al*. 1986a, 1986b
Finn Dorset X Dorset Horn, 4 month old lambs.	Low: 8.8% CP, sugar beet pulp & barley High: 17% CP, soya-bean meal	Mainly RDP	*H. contortus* 200 larvae, 3 x week for 17 weeks	Low CP had severe clinical disease Similar FEC but at slaughter high CP less worms	Abbott *et al*. 1988
Merino, 5 month old lambs	Low: 400 g; High: 600 g of lucerne based pellets CP of 17%	40% RUP both groups	*H. contortus* 500 larvae, 3 x week for 17 weeks	Differences in resilience due to supplement & genetics Low: 6/9 no immunity; high: 1/9 no immunity	Roberts & Adams, 1990
Hampshire Down, Scottish Blackface, 7 month old lambs	Low: 9.8% CP, barley & sugar beet pulp High: 17.3% CP, soya-bean meal.	Mainly RDP	*H. contortus* 200 larvae, 3 x week for 10 weeks	Increase growth rate, leaner carcasses but same slaughter out % and slaughter weight	Wallace *et al*. 1995, 1996
Hampshire Down, 5 month old lambs	Molassed-sugar beet pulp, barley, urea, 9% CP Restricted or *ad lib*	Urea (NPN), RDP	*H. contortus* 200 larvae, 3 x week for 10 weeks	Improved resilience and maintained growth during infection	Wallace *et al*. 1999

Table 2.4 (cont) Summary of gastrointestinal parasite references

Breed, age, ♂♀	**Supplement**	**RDP or RUP**	**Nematode infection**	**Results**	**Reference**
Menz, 5-7 month old, ram lambs	Molasses-urea at 80 g per lamb	Urea (NPN), RDP	Natural	Improved growth rates, BCS, semen quality	Anindo *et al.* 1998
Merino wether lambs, 5 months old	Oaten chaff, minerals, 3% urea	Urea (NPN), RDP	*H. contortus* 200 larvae, or 1000 *T. colubriformis* larvae or both 3 x week for 17 weeks	Improved growth rates, wool production	Knox & Steel, 1996, 1999
Merino wether lambs, 4 months old	Grazing & concentrate of 25% lucerne & 75% sunflower meal, treated with formaldehyde or untreated	RDP and RUP	Natural	Improved wool production, nematode resilience	Van Houtert *et al.* 1995a
Merino wether lambs, 4 months old	Oaten chaff, 5% urea, 50 g lucerne, 0, 50 or 100 g fishmeal per day	Mainly RUP	*H. contortus* 1000 larvae 3 x week for 20 weeks	Improved wool production, growth rates, nematode resistance	Van Houtert *et al.* 1995b
Suffolk lambs, 4.5 months old	Abomasal infusion of sodium caseinate 45 g per day	RUP	*T. circumcincta* 2000 larvae per day for 8 weeks	Improved resilience	Coop *et al.* 1995
Crossbred weaner lambs	Oaten chaff, barley, cottonseed meal, urea different combination for CP levels of 10%, 13%, 16%, 19%, 22%.	RUP and RDP	*H. contortus* 750 larvae twice a week for 9 weeks	Improved resilience, carry-over for improved wool production and growth rates	Datta *et al.* 1998, 1999

Table 2.4 (cont) Summary of gastrointestinal parasite references

Breed, age, ♂♀	Supplement	RDP or RUP	Nematode infection	Results	Reference
Horro and Menz lambs, 4 months old	Hay, 200 g wheat bran or hay &150 g molasses urea block & 80 g wheat bran; or hay & 165 g cottonseed cake	Urea (NPN), RDP and RUP	Initially *H. contortus* 1000 larvae 3 x week for 3 weeks; then 500 *H. contortus* larvae (87%), *Longistrongylus elongata* (10%) & *T. colubroformis* (3%)	Varied depending on breed. Improved resilience, growth rates	Haile *et al*. 2002
Coopworth ewes, single & twin bearing, mixed age Starting 9 weeks before lambing	Energy: 70% lucerne & 30% barley or reverse Protein: 0 & 8% fishmeal	RDP and RUP	From 7 weeks before lambing: 10 000 *T. circumcincta* larvae & 7000 *T. colubriformis* 3 x week till lambing	Improved resilience	Donaldson *et al*. 1997
Coopworth ewes, twin bearing, mixed age Starting 7 weeks before lambing	Hay, barley based pelleted concentrate at either low or high levels	RDP	*T. circumcincta* 4000 larvae daily for 5 weeks before lambing, until lambing or day 10 or day 31 of lactation	Improved body weight and BCS Improved resilience pre-partum	Donaldson *et al*. 1998
Coopworth ewes, twin-bearing, mixed age Starting 9 weeks before lambing	High: 1 kg lucerne hay with 200-1000 g concentrate Low: 500-600 g lucerne hay with 200-700 g concentrate (bran, barley, molasses, minerals)	RDP and RUP	From 8 weeks before lambing: *T. circumcincta* larvae High: 10 000 per day Low: 5000 or 10 000 or 20 000 per day	Improved BW and BCS before lambing	Donaldson *et al*. 1998
Greyface ewes, 3-4 year old, from day 70 of pregnancy	Low energy/protein: 0.7 of required level CP & ME High protein/low energy: 1.2 x CP. 0.8 x ME High: 1.3 x CP, 1.2 x ME	Unknown	From day 86 of pregnancy: 10 000 *T. circumcincta* larvae 3 x week for 42 days	Improved backfat & muscle depth Improved resilience to nematodes	Houdijk *et al*. 2000a

Table 2.4 (cont) Summary of gastrointestinal parasites references

Breed, age, ♂♀	**Supplement**	**RDP or RUP**	**Nematode infection**	**Results**	**Reference**
Dorset-Finn ewes, 2-6 years old, single and twin-bearing From 6 weeks before lambing	Level of protein either 80%, 100% or 120% of required MP	Unknown	From 6 weeks before lambing: 10 000 *T. circumcincta* larvae 3 x week until day 35 of lactation	Improved resilience to nematodes	Houdijk *et al* 2000b
Twin-bearing ewes from 65 days before lambing	Low energy & protein; high protein/low energy; high protein & energy day 65 to 21 before lambing then either low protein or high protein	Unknown	From 65 days before lambing until day 42 of lactation: 10 000 *T. circumcincta* larvae 3 x week	Improved lamb growth rates and resilience of ewes to nematodes	Houdijk *et al*. 2001
Greyface ewes, twin-bearing, from 46 days before lambing	Late pregnancy: 0.8 of required MP; First 4 weeks of lactation either 0.65, 0.80, 0.95, 1.10 or 1.25 times MP requirement	Unknown	From 46 day before lambing until day 28 of lactation: 10 000 *T. circumcincta* larvae 3 x week	Improved resilience to nematodes and improved milk production	Houdijk *et al*. 2002

Table 2.5 Summary of wool production references

Breed, age, ♀♂	**Supplement**	**Source**	**Results**	**Reference**
South African Mutton Merino wethers lambs Trial of 5 months	0, 100, 200 g per day cotton seed cake with either 0, 100, 200 g per day whole maize Basal diet of wheat straw & 5% urea *ad lib*	RDP and RUP	Improved growth rates, wool growth rates, staple length and fibre diameter	Cronje & Weites, 1990
Mature Merino wethers 3 x 3 weeks trial	200 g hay, abomasal infusions of milk; casein; milk & casein at low or high levels; milk, casein, glycerol & glucose at low or high levels; milk, glucose & glycerol at high or low levels	RUP	Initial increase of protein improved wool growth rate, length, fibre diameter, volume but no effect at different energy levels	Reis *et al*. 1992
Merino wethers, 2 years old 20 week trial	Basal diet of wheat straw; formaldehyde treated rapeseed meal at 819 g to 980 g per kg DM; urea 14%	Urea (NPN), RDP and RUP	Urea and RUP improved wool growth rates as well as increased fibre diameter Only urea economically advantageous	Coombe, 1992
Merino weaner wethers 12 weeks trial	Canola meal or lupin seed with hay, urea & minerals One group maintenance throughout trial and one group first to loose weight (0.6 maintenance) and then regain (1.6 maintenance) for each supplement	Urea (NPN), RDP and RUP	Canola better than lupin Improved wool growth, yield% and point of break	Masters *et al*. 1998
Merino wethers, 5 months old 2 month trial	Lupin, hay, urea, mineral; or canola, hay, urea, minerals; or barley, hay, urea & minerals. Either lupin/canola continuously or at 2 week intervals with barley	Urea (NPN), RDP and RUP	Canola improved wool growth 11% more than lupins No carry over effect	Masters *et al*. 1999
Merino wethers, 5-6 months old 49 weeks trial	Fed according to patterns: BW maintenance throughout; BW loss for 112 days, BW gain for 112 days, BW maintenance for 63 days at either 50 or 100 g per day 75% oat based pellets & 25% lucerne chaff for maintenance or gain; 75% oat based pellets & 25% low quality wheaten chaff for loss of BW	Mainly RDP	Wool growth rate decreases with BW loss, increases with BW gain Less variation if BW maintained Fibre diameter decreases with BW loss and increases with BW gain. Nutrition influences along-fibre diameter	Thompson & Hynd, 1998

CHAPTER 3
MATERIAL AND METHODS

3.1 Experimental Animals

Ninety fine wool Merino ewes, selected from the Mistbelt Study Group sheep flock, were randomly divided into three groups of 30 each. Ewes were stratified for body weight, body condition score and age. All ewes were breeding sound at the beginning of the project. Each ewe included in the trial had been examined to determine that she had a functional udder, sound teeth and no previous foot problems. Multiparous ewes included had lambed at each previous mating opportunity.

Individual faecal egg samples were taken at the start of the experiment from each ewe. These samples were individually analysed and no significant differences were found between the groups. All ewes were shorn four weeks before the start of the experiment and were kept together as one group for a four week adaptation period. All ewes were injected subcutaneously with 1 ml of a multi-mineral combination of Mg 20 mg, Zn 20 mg and Se 1 mg per ml (Multimin+Se for Sheep and Goats, Virbac) the day after shearing. Ewes had been routinely vaccinated previously with Enterotoxaemia, Blue Tongue and Tetanus vaccines (Onderstepoort Biological Products).

3.2 Experimental Area

The experiment was conducted on the farm Goedehoop (30° 5' S; 26° 5' E) in the Carolina district of Mpumalanga, South Africa. Ewes were kept on natural grazing which is classified as sourveld (Acocks, 1988) throughout the project. Grazing is considered good to excellent from late spring, towards the end of September, to early autumn, at the end of March. After light frost, usually early in April, the quality of the grazing is considered to be only moderate. After moderate to severe frost, the grazing is considered to be of poor quality, from May to August, but as environmental temperatures rise and the rainy season starts during late September, the quality of the grazing improves again (Barnes, 1992; Kirkman & Moore, 1995). Six camps were used during the experiment. Three camps were used when the ewes were kept as one group and were designated Camps A, B and C. A further three camps were used when the ewes were divided into three groups and were designated Camps D, E and F. Camp A was approximately 30 hectares, camp B 25 hectares, camp C 28 hectares, camp D 12 hectares, camp E 18 hectares and camp F 15 hectares. Camps D, E and F were adjacent to each other with a central handling facility. Camps D, E and F were considered to be of fairly similar grazing quality.

The stocking rates used were: Camp A – 3 ewes per hectare; Camp B – 3.6 ewes per hectare; Camp C – 3.2 ewe per hectare; Camp D – 2.4, 2.3 and 2.0 ewes per hectare for the Mineral, RUP and RDP groups respectively; Camp E – 1.6, 1.56 and 1.3 ewes per hectare for the Mineral, RUP and RDP groups respectively; and Camp F – 1.93, 1.87 and 1.6 ewes per hectare for the Mineral, RUP and RDP groups respectively. The stocking rates differed because there were 29 ewes in the Mineral group, 24 in the RUP group and 28 in the RDP at the start of the second supplementary period (see 4.5 Animal health management procedures and ewe losses). The grazing in camps D, E and F was sampled on 22 March 2002. This was approximately half way through the second period of supplementation. Samples of 10 cm X 10 cm were hand cut every metre in a W pattern through each camp. In camp D, 35.2 points per hectare were sampled, in camp E 35.6 points per hectare and in camp F 35.3 point per hectare. All grasses inside the sampling square were cut with hand shears to a level of about 1.5 cm. All samples were collected on the same day (‘T Mannetje and Jones, 2000). The samples were then sun dried for three days, thoroughly mixed and taken for analysis by conventional methods to the Nutritional Laboratory at the Department of Animal and Wildlife Science, University of Pretoria (Van Soest, 1964).

3.3 Supplements

One group, designated the Mineral group, received a mineral supplement throughout the project. The other two groups received a protein supplement at strategic times. The group designated RUP received a protein supplement of which more than 30% of the protein was rumen undegradable protein. The group designated RDP received a protein supplement of which less than 5% of the protein was rumen undegradable protein. Both protein supplements were mixed from commercially available products. The RUP supplement consisted of Procon 33 (Voermol), Maxiwol (Voermol), molasses, salt and lime. The RDP supplement was made up of urea, molasses, maize, salt and dicalcium phosphate. The mineral supplement was a 50:50 mix of salt and dicalcium phosphate. Formulations of supplements are summarised in Table 3.1.

Table 3.1 Composition of supplements

	Mineral	RUP	RDP
Salt	50%	2.6%	5%
Dicalcium phosphate 14	50%		5%
Maxiwol (Voermol)		42.5%	
Procon 33 (Voermol)		54.1%	
Molasses		0.6%	58%
Lime		0.2%	
Urea			8.5%
Maize grade 2			23.5%

Supplements were given three times a week in the morning. Any remaining supplements were removed and weighed just before new supplements were put out. Two double-sided feed troughs, each 1.5 m long were used for each group. The mineral supplement was available *ad lib* throughout the experiment either to all the ewes, when they were in one group, or to the Mineral group only, during the times they were in three groups. The protein supplements were given at three different levels. During the first period of supplementation, which lasted 14 days, protein supplements were given at 500 g per ewe on Mondays and Wednesdays, and 750 g per ewe on Fridays, a daily calculated average of 250 g per ewe per day. During the second period of supplementation, protein supplements were given at 700 g per ewe on Mondays and Wednesdays and 1050 g per ewe on Fridays for the first 42 days, starting 21 days before lambing, and then at 1000 g per ewe on Mondays and Wednesdays and 1500 g per ewe on Fridays for the next 56 days. Thus, during the second period of supplementation, protein supplements were initially given at a daily calculated average of 350 g per ewe per day and then at 500 g per ewe per day. At the beginning of the second period of supplementation, supplements were given at 100 g per ewe per day on day three before the start of the second supplementation period and at 200 g per ewe per day for day two and day one before the start of supplementation. The average calculated intake of the mineral lick was 28 g per ewe per day throughout the experiment.

3.4 Periods of supplementation

3.4.1 Flushing

A period of two weeks was selected on the basis of information obtained from the literature as this seemed the most effective time period (Molle *et al*. 1997; Nottle *et al.* 1997).

3.4.2 Pre-Lambing to Suckling

Starting supplementation three weeks before lambing was again decided upon the basis of available literature (Frutos *et al*. 1998; Kleeman *et al*. 1993; O'Doherty & Crosby, 1997). It was also the recommendation of the local feed companies (Coetzee, personal communication 2001). Continuing supplementation until eight weeks after lambing was done on the basis of literature reports and recommendations of feed companies (Brand *et al*. 1997; Coetzee, personal communication 2001; Handford *et al.* 2001; Hinch *et al*. 1996). It is also customary farm practice in this area. Whether farmers believe that this is the most cost-effective way of providing supplements or do so because they often are short of supplements was not very clear. However, the literature states that supplements have a carry-over effect (El-Hag *et al.* 1998; Nottle *et al*. 1998). Thus the decision was made to continue without the supplements for a further period to see if there was any carry-over effect. The type, time period given and amount of supplement given are summarised are Table 3.2

Table 3.2 Summary of type, time period given and amount of supplement given

Groups	**Stage of trial**	**Supplement**	**Average daily rate**
Three: Mineral RUP RDP	Flushing 2 weeks	Mineral RUP RDP	*Ad lib* 250 g per ewe 250 g per ewe
One	Mating 6 weeks	Mineral	*Ad lib*
One	Gestation 13 weeks	Mineral	*Ad lib*
Three: Mineral RUP RDP	Pre-lambing & lambing 6 weeks	Mineral RUP RDP	*Ad lib* 350 g per ewe 350 g per ewe
Three: Mineral RUP RDP	Early lactation 8 weeks	Mineral RUP RDP	*Ad lib* 500 g per ewe 500 g per ewe
One	Late lactation 6 weeks	Mineral	*Ad lib*

3.5 Cost of supplements

All supplements were obtained from commercial sources and costs reflect current, actual prices at the time of the trial. The costs are summarised in Table 3.3.

Table 3.3 Cost of supplements

	Mineral	**RUP**	**RDP**
Rand per kilogram supplement	1.20	1.63	0.98
Rand per ewe per day: Total Flushing Pre-lambing & lambing Suckling	 0.03	 0.67 0.41 0.57 0.81	 0.40 0.24 0.34 0.49
Total per ewe	3.75	75.11	45.07

As can be seen from Table 3.3, the cost per kilogram of the supplements was comparable. However, when the costs were calculated per ewe per day or per ewe for the whole period, the differences became substantial. The cost of the RUP supplement was nearly double that of the RDP supplement, while the cost of the mineral supplement was less than five percent of the RUP supplement cost.

3.6 Data recording

A code was allocated to each data collection according to the stage of the experiment as follows: Flushing: F1 and F2; Breeding: R1 and R2; Pregnancy: P1 to P7; Pre-lambing: PL1 and PL2; Lambing L1 to L4; Suckling (receiving supplements): S1 to S8; Suckling (but not receiving supplements, the growth period for the lambs): G1 to G4.
During Flushing, Pre-Lambing, Lambing and Suckling (with supplements), a data collection point represents one week, e.g. F1 to F2 indicates one week. During Breeding, Pregnancy and Suckling (with no supplements), a data collection point represents two weeks, e.g. P2 to P3 indicates two weeks.

Live body weight (BW) using a Tal-Tec cage scale, body condition score (BCS) (Russel, 1984) and FAMACHA score (Bath & Van Wyk, 2001) were recorded for each ewe every two weeks during periods that the ewes were kept in one group, and weekly during periods they were in separate groups.

Faecal egg samples were collected monthly during the periods ewes were kept as one group and every two weeks during periods they were kept separately. Ewes were divided into three sub-groups within their groups for the collection of bulk faecal egg samples. Faecal samples were kept in a cooler bag and transported within six hours or stored in a fridge and then transported within 24 h to the Ermelo Provincial Veterinary Laboratory for faecal egg counts using the Modified McMaster technique (Reinecke, 1973). Table 3.4 contains a summary of how and when data for the ewes were collected.

Table 3.4 Summary of data recording of ewes

Groups	Stage of trial	Parameters recorded	Interval of data recording
Three	Flushing (F1& F2) 2 weeks	BW, BCS, FAMACHA FEC	Weekly Every two weeks
Single	Mating (R1 & R2) 6 weeks	BW, BCS, FAMACHA FEC	Every two weeks Monthly
Single	Gestation (P1 to P7) 13 weeks	BW, BCS, FAMACHA FEC	Every two weeks Monthly
Three	Pre- Lambing (PL1 & PL2) 3 weeks	BW, BCS, FAMACHA FEC	Weekly Every two weeks
Three	Lambing (L1 to L4) 4 weeks	BW, BCS, FAMACHA FEC	Weekly Every two weeks
Three	Early Lactation (S1 to S8) 8 weeks	BW, BCS, FAMACHA FEC	Weekly Every two weeks
Single	Late lactation (G1 to G4) 6 weeks	BW, BCS, FAMACHA FEC	Every two weeks Monthly

Birth of lambs was recorded as follows: the date (the farmer recorded new births in the morning and evening), the dam (each lamb was identified and this identification was correlated to the correct ewe), parity (the number of lambs born per ewe), type (live, weak or stillbirth).

Body weight, body condition score and FAMACHA score was recorded for each lamb weekly, starting the week after the end of the lambing period and continuing until the end of the second supplementary period. Parameters were then recorded every two weeks until the end of the experiment. Table 3.5 summarises the data recording of the lambs.

Table 3.5 Summary of data recording of lambs

Groups	Stage of trial	Parameters recorded	Interval of data recording
Three	Early Lactation (S1 to S8) 8 weeks	BW, BCS, FAMACHA	Weekly
Single	Late lactation (G1 to G4) 6 weeks	BW, BCS, FAMACHA	Every two weeks

Lamb mortalities were recorded and classified into the following categories: still birth, mismothering, gastrointestinal parasites or predators (Kelly, 1992; Rook *et al*. 1990).

All ewes were shorn on 11 April 2002 and the weight of the greasy fleece recorded. A midrib fleece sample of approximately 50 g was then taken from the shorn fleece of each ewe and sent to the Wool Testing Bureau of South Africa, Summerstrand, Port Elizabeth. Each sample was analysed for fibre diameter (micron measurement), staple length, staple strength, coefficiency of variance of the fibre diameter, clean fleece yield and point of breakage.

3.7 Management of project

After an adaptation period of four weeks from 20 July 2001 to 16 August 2001, the ewes were separated into three groups for flush feeding, designated periods F1 & F2. The mineral group received its supplement *ad lib* while the protein groups received supplements at a calculated rate of 250 g per ewe per day. Ewes were flushed for two weeks. During the flushing period, from 17 to 30 August 2001, the ewe groups were kept in camps D, E and F. The three groups were randomly rotated between the three camps on Mondays, Wednesdays and Fridays before new supplements were put out. After flushing, the ewes were brought together into a single group again and mated to four rams for six weeks while grazing camp B from 31 August 2001 to 11 October 2001 designated periods R1 & R2. The rams were certified breeding sound by a veterinarian (Dr. P Schoeman, Hendrina Veterinary Clinic) two weeks before mating. After mating, the rams were removed and the ewes kept as a single group until three weeks before lambing was due to start, for the gestation period from 12 October 2001 to 10 January 2002, thus a total of 13 weeks, designated as P1 to P7. The start of lambing was set as day 150 from the first day of breeding. During the gestation period, the ewes grazed first camp C for four weeks from 12 October 2001 to 8 November 2001, then camp A for two weeks from 9 November 2001 to 22 November 2001, then camp B for three weeks from 23 November 2001 to 13 December 2001, then camp C for two weeks from 14 December to 27 December 2001 and again camp A for two weeks from 28 December 2001 to 10 January 2002. During mating and gestation all the ewes received the mineral lick *ad lib*. Three weeks before lambing was due to start, the ewes were separated into three groups for the Pre-lambing period, designated PL1 and PL2 from 11 to 30 January 2002. The respective protein supplements were given to the RUP and RDP groups as outlined above (Table 3.2) and the mineral mixture to the Mineral group *ad lib* throughout the whole period. The first ewe lambed on 31 January 2002 and the last on 28 February 2002. This period was then designated the lambing period (L1 to L4). Supplements were given until 18 April 2002 and thus the period 1 March 2002 until 18 April 2002, was called early lactation (S1 to S8). During the periods that the ewes were separated, they were randomly rotated between camps D, E and F every Monday, Wednesday and Friday before new supplements were put out. The ewes were rotated to eliminate any differences regarding quality and quantity of grazing as well as differences in the exposure to infective nematode larvae on the grazing. Ewe groups were then combined again and kept as a single group for six weeks from 19 April 2002 to 31 May 2002. This was called late lactation (G1 to G4). During this period they grazed camps B and C for three weeks each. The project outline is summarised in Table 3.6.

Table 3.6 Project outline

Stage of Experiment	**Number of weeks**	**Code**	**Calendar Date**
Adaptation	4	None	20 July 2002 – 16 August 2001
Flushing	*2*	*F1 & F2*	*17 – 30 August 2001*
Breeding	6	R1 & R2	31 August 2001 – 11 October 2001
Gestation	13	P1 to P7	12 October 2001 – 10 January 2002
Pre-Lambing	*3*	*PL1 & PL2*	*11 – 30 January 2002*
Lambing	*4*	*L1 to L4*	*31 January 2002 – 28 February 2002*
Early Lactation	*8*	*S1 to S8*	*1 March 2002 – 18 April 2002*
Late Lactation	6	G1 to G4	19 April 2002 – 31 May 2002

Periods in italics represent periods of supplementation.

3.8 Environmental observations

The farmer recorded daily rainfall and temperatures using a conventional rain gauge and a maximum-minimum thermometer, throughout the experiment. The daily maximum temperature was recorded around 13h00 each day and the daily minimum, each morning at around 05h00 in his dairy during the trail.

3.9 Animal management procedures

Ewes were scanned for pregnancy using ultrasound (Aloka 500, 7.5 MHz) on 11 December 2001. All ewes were vaccinated with Enterotoxaemia and Tetanus vaccines (Onderstepoort Biological Products) on 7 January 2002 (about 3 weeks before lambing) according to the manufacturer's specifications.

Ewes and lambs were monitored on a daily basis by the farmer and his staff. Any untoward incidents were reported to the researcher who then decided on a course of action in accordance with the project protocols.

Animals numbers were recorded by the farmer weekly and the cause of all changes noted. Whenever animals died they were examined at post-mortem by either the researcher or the local consulting private veterinarian to determine the cause of death, and this was then recorded.

3.10 Anthelmintic treatments

The main gastrointestinal parasite in the area of the experiment is *Haemonchus contortus* (Horak, 1978). Thus the FAMACHA© system was used to determine when individual sheep needed anthelmintic treatment. Ewes and lambs were only drenched for helminths if they had a FAMACHA score of three or more, which means the sheep were moderately to severely anaemic with estimated haematocrits of 20% to 10% (Bath *et al.* 2001; Bath & Van Wyk, 2001). The different remedies and routes of treatment used were recorded weekly during periods the ewes were divided into three groups and every two weeks when they were in a single group. The data are summarised in Table 3.7. All ewes were treated for *Oestrus ovis* on 15 October 2001 with rafoxanide 3% m/v (Ranox, Pfizer).

Table 3.7 Anthelmintic treatment record for ewes and lambs

Period	Remedy	Route	Trade name	Mineral	Mineral lambs	RUP	RUP lambs	RDP	RDP lambs
D1	Rafoxanide 3% m/v	Orally	Ranox (Pfizer)	29/29 100%		24/24 100%		28/28 100%	
L1	Albendazole 1.9% m/v	Orally	Valbazen (Pfizer)	1/29 3%		0/24 0%		0/28 0%	
L2	Albendazole 1.9% m/v	Orally	Valbazen (Pfizer)	2/29 7%		1/24 4%		1/28 4%	
L3	Albendazole 1.9% m/v	Orally	Valbazen (Pfizer)	1/29 3%		1/24 4%		2/28 7%	
L4	Albendazole 1.9% m/v	Orally	Valbazen (Pfizer)	5/29 17%		2/24 8%		2/28 7%	
S1	Levamisole HCl 2.5% m/v	Orally	Tramisol (Intervet)	5/29 17%	0/23 0%	5/24 21%	0/22 0%	7/28 25%	0/19 0%
S2	Rafoxanide 3% m/v	Orally	Ranox (rafoxanide)	9/29 31%	0/21 0%	6/24 25%	0/19 0%	6/27 22%	0/19 0%
S3	Doramectin 1 %	Injectable	Dectomax (Pfizer)	12/29 41%	1/21 5%	9/23 39%	0/19 0%	13/26 50%	0/18 0%
S4	Moxidectin 1 % m/v	Injectable	Cydectin (Ford Dodge)	6/29 21%	2/20 10%	6/23 26%	0/19 0%	4/26 15%	0/18 0%
S5	Albendazole 1.9% m/v	Orally	Valbazen (Pfizer)	2/29 7%	1/19 5%	2/23 9%	1/19 5%	3/26 12%	0/18 0%
S6	Rafoxanide 3% m/v	Orally	Ranox (Pfizer)	4/29 14%	2/18 11%	0/23 0%	1/19 5%	1/26 4%	2/18 11%
S7	Moxidectin 1 % m/v	Injectable	Cydectin (Ford Dodge)	5/29 17%	5/18 28%	3/23 13%	1/19 5%	1/26 4%	3/18 17%
S8	Moxidectin 1 % m/v	Injectable	Cydectin (Ford Dodge)	2/29 7%	2/16 13%	4/23 17%	1/18 6%	2/25 8%	1/18 6%
G1	Levamisole HCl 2.5% m/v	Orally	Tramisol (Intervet)	2/29 7%	1/16 6%	1/22 5%	1/17 6%	3/25 12%	4/16 25%
G2	Levamisole HCl 2.5% m/v	Orally	Tramisol (Intervet)	3/29 10%	0/14 0%	0/22 0%	3/17 18%	2/25 8%	0/15 0%
G3	Levamisole HCl 2.5% m/v	Orally	Tramisol (Intervet)	0/29 0%	0/14 0%	0/22 0%	2/16 13%	1/25 4%	0/15 0%
G4	Levamisole HCl 2.5% m/v	Orally	Tramisol (Intervet)	3/29 10%	2/14 0%	1/22 5%	4/16 25%	5/25 20%	1/15 7%

3.11 Calculation of gross margins

The gross margin of each group was calculated at two points, at S8, at the end of the second period of supplementary feeding (Gross margin 1) and at G4, the end of the experiment (Gross margin 2). In both cases the calculations were made in the same way. First income from wool was calculated: the weight of the fleece x the clean yield percentage x the actual sale price, which was R31.52 for the medium micron wool and R31.80 for the fine micron wool. The potential meat income from the lambs was then calculated as the live weight of lambs in kg x R8 (the current live weight market price). The two totals were added together for each ewe and the costs of the licks were subtracted. [Thus this is not a true gross margin as other costs were not taken into account. However for the purpose of this trial, other costs are regarded as equal for the three groups as they were treated equally.]

3.12 Statistical procedures

Statistical analysis was done by the Department of Statistics, University of Pretoria, using SAS and BMPD Statistical Software (SAS, 1987). Data were analysed with the following procedures: Analysis of Variance with Repeated Measures using Scheffe's Test, Duncan's Multiple Range Test and the Chi-square test (Steyn *et al*. 1989). All faecal egg counts were log transformed before analysis, while the individual faecal egg count analysis at the beginning of the trial was done with Non-parametric measures using Wilcox's test (Steyn *et al*. 1989).

CHAPTER 4

RESULTS

4.1 Protein intake of ewes

4.1.1 Protein requirements of ewes

To evaluate the following results, the protein requirements of ewes are briefly summarised as follows for convenience.

Maintenance: crude protein = 89 g per day for a 50 kg ewe; first 15 weeks of gestation = 90 g per day for a 50 kg ewe; last four weeks of gestation = 145 g per day for a 50 kg ewe carrying a single lamb; first four to eight weeks of lactation = 276 g per day for a 50 kg ewe nursing a single lamb (NRC, 1985).

4.1.2 Protein from grazing

The average CP value of camp D was 8.7%, camp E 7.2% and camp F 10.6 %. Thus the average CP of the three camps was 8.8%. The average body mass of the ewes during the experiment was: Mineral group = 46.2 kg, RUP group = 45.9 kg and RDP group = 45.7 kg. Assuming an average daily dry matter intake of ewes of about 2% of body mass, the calculated average daily dry matter intake was: Mineral group = 920 g, RUP group = 918 g and RDP group = 914 g. The average daily crude protein intake from grazing in camps D, E and F was: Mineral group = 81 g, RUP group = 81 g and RDP group = 80 g. An analysis of the grazing is summarised in Table 4.1. As can be seen from the data, the three camps had similar quality grazing. Sheep are very selective grazers and these values should be seen as minima; the average true daily protein intake from the grazing was in all probability considerably higher than these estimates (Arnold *et al*. 1981; Forbes & Beattie, 1987; L'Huillier *et al*. 1984.)

Table 4.1 Analysis of grazing in camps D, E and F

	Camp D	Camp E	Camp F
Dry matter %	94.6	94.7	95.7
Moisture %	5.4	5.3	4.3
Crude protein %	8.3	6.8	10.1
Crude fibre %	35	32.6	35.1
ADF %	38.4	38.7	39.2
NDF %	75.5	77.9	73.9

4.1.3 Protein intake from supplements

An analysis of the protein supplements is summarised in Table 4.2. The two protein supplements had almost equal amounts of crude protein. The supplement of the RUP group had a CP value of 28% protein. Thus at an intake of 250 g per day the average CP intake was 70 g, at 350 g per day, the average CP intake was 98 g per day and at an intake of 550 g per day, CP intake was 154 g per day. The supplement of the RDP group had a CP value of 29%. Thus at an intake of 250 g per day the average CP intake was 72 g, at an intake of 350 g per day, the average CP intake from this supplement was 101 g per day and at an intake of 550 g per day, CP intake was 160 g per day.

This means that ewes in the RUP group had an average CP intake of 179 g per day during late pregnancy and early lactation and 235 g per day during lactation. Ewes in the RDP group had an average CP intake of 181 g per day during late pregnancy and early lactation and 240 g per day during lactation.

This shows that ewes in the Mineral group had a CP deficiency of 64 g per day (44%) during late pregnancy and a shortage of 195 g per day (71%) during lactation. Ewes in the RUP and RDP groups had an average of 35 g CP excess per day (23%) during late pregnancy and a CP shortage of 39 g per day (14 %) during lactation. This data are summarised in Table 4.3. However, keeping in mind that sheep are very selective grazers, these are estimated values.

Table 4.2 Analysis of protein supplements

	RUP	RDP
Crude protein %	28	29
RUP %	30-35%	<5%
MJ ME	9.3	8.5
Crude fibre %	13	11

Table 4.3 Protein intake of ewes

		Mineral	RUP	RDP
Protein requirements	Early gestation Late gestation Lactation	90 g 145 g 276 g	90 g 145 g 276 g	90 g 145 g 276 g
Protein intake	Grazing	81 g	81 g	80 g
	Supplements Late gestation Lactation		 179 g 235 g	 181 g 240 g
Total protein intake per day	Late gestation Lactation	81 g	260 g 316 g	261 g 320 g
Protein deficiency or excess (in brackets)	Late gestation Lactation	64 g [44%] 195 g [71%]	(35 g) [23%] 39 g [14%]	(35 g) [23%] 39 g [14%]

4.2 Ewe Data

4.2.1 Body weights of ewes

The data recorded was summarised in Figure 4.1. Significant differences ($P < 0.05$) were recorded as follows and are indicated with an asterisk (*) on all the graphs:

F2-R1: the RDP group differed from both the RUP and Mineral groups. The RDP group lost body weight while the other two groups had a slight increase in body weight. During the first period of supplementation, there was no adaptation period to the supplements. This happened because of a veld fire. During the time that the ewes should have been adapting, they could not be moved to the three camps. It was decided not to continue the adaptation period and to start flushing at once.

P3-P4: the Mineral group differed from the RDP group. Two ewes in the Mineral group carried twins. Also nearly 60% of the Mineral group lambed in the first two weeks (see Table 4.3) while only 36% of the RDP group lambed in the first two weeks. Thus this difference was most likely due to the difference in pregnancy status.

P7-PL1: the RDP group differed from both the Mineral and RUP groups. This difference was also probably due to the difference in pregnancy status. See P3-P4.

PL1-PL2 and PL2-L1: the RUP group differed from both the RDP and Mineral groups. This difference was most likely due to the effect of the supplements. As can be seen from Fig. 4.1, the RUP group had a significant weight increase from PL1 to PL2 and the RDP group had a similar increase from PL2 to L1.

L3-L4: the RUP group differed from the Mineral group. This difference was probably due to a combination of supplemental effect and lambing. By this time, more than half of the Mineral group was more than three weeks into lactation, while the RUP group had only just finishing lambing and had the advantage of more than six weeks of supplemental feeding.

S2-S3: the RUP group differed from the Mineral group.

S3-S4: the RUP group differed from both the Mineral and RDP groups. The RUP group gained weight during S2-S3 and lost weight during S3-S4, while the other two groups maintained weight. [No available explanation could be found for the S2-S3 and S3-S4 differences. One possibility is a data recording error. During the S3 recording the RUP group's data was recorded approximately 3 h after the other two groups. This happened because of an accident on the farm. During all other recording all the groups were done within 30 minutes of each other.]

S4-S5 and S5-S6: RDP group differed from both the Mineral and RUP groups.

S6-S7: all three groups differed from each other. The ewes were shorn during this period, which probably led to the loss in BW. The difference was probably caused by the different individual reaction within the groups.

S7-S8, S8-G1 and G1-G2: the RUP group differed from both the Mineral and RDP groups. Although the trend of the RUP group was similar to the RDP and Mineral groups, the levels were slightly higher. This probably happened because all the ewes, except one, had a lamb suckling, which would mean that they were under the most stress.

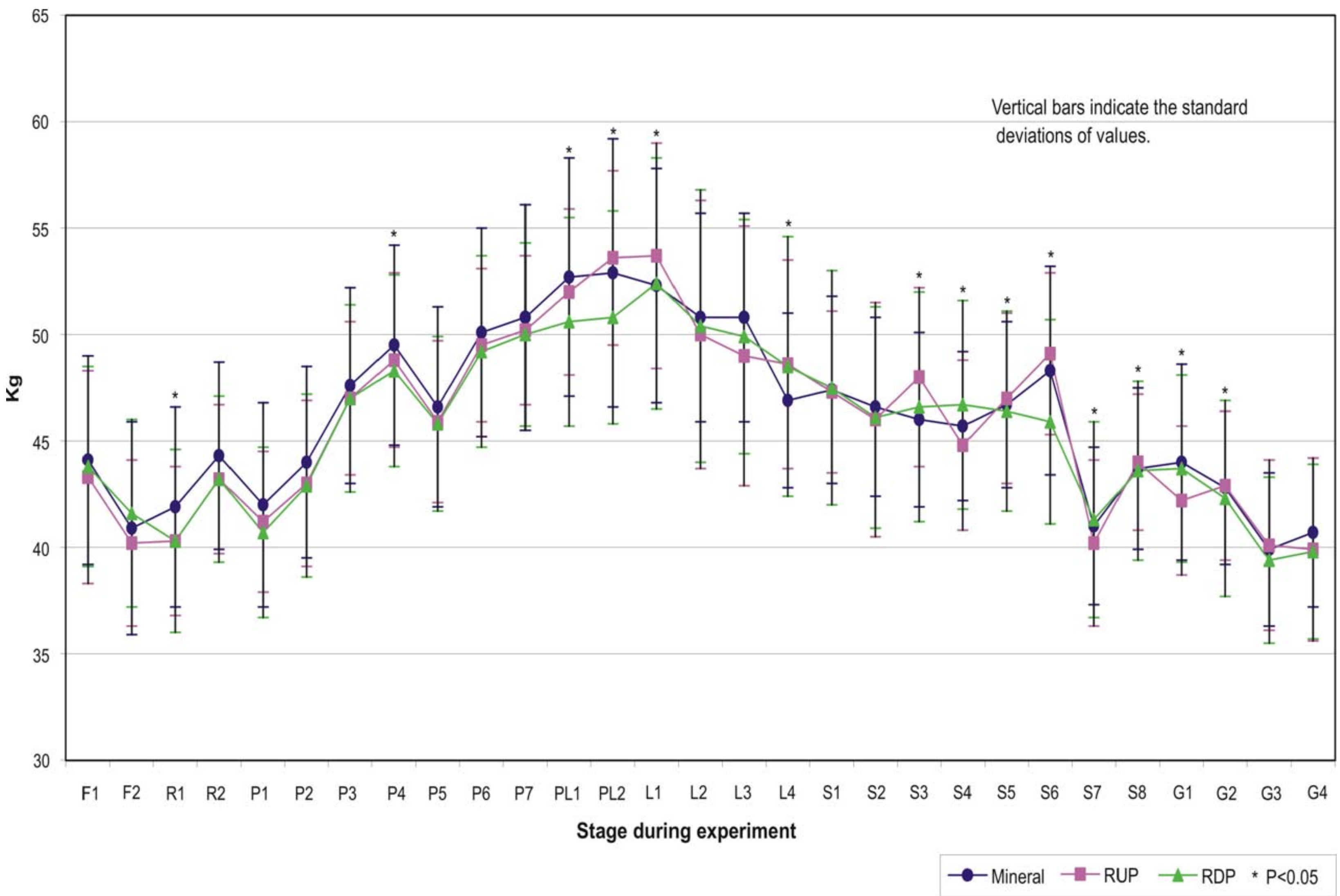


Figure 4.1 Body weight changes of ewes during the trial

As can also be seen from Figure 4.1, there were some general trends:
F1-F2: the weight loss in all the groups was probably due to the quality of the grazing. The three camps had all been used in the previous season. Weather conditions were also very inclement with extreme winds and cold environmental temperatures.
R1-R2: the body weight gain in the groups was probably ascribable to the grazing, since camp B had been rested the previous season.
R2-P1: the general weight loss probably relates to a period during which the weather suddenly turned very cold.
P1-P4: the general weight gain in all the groups occurred simultaneously with the start of the rainy season, which caused an improvement in the quality of the grazing. At P4 ewes were approximately 10 weeks pregnant, and therefore the weight of the foetuses started to play a role in BW of the ewes.
P4-P5: this weight loss was probably due to lower DM intakes during the heavy rains which occurred at this time. The experimental site on the farm had more than 100 mm of rain in these two weeks.
S6-S7: the ewes were shorn during this period. Apart from the wool weight loss, BW was probably affected because they had to be herded over 6 km to a shearing shed and back again the same day.
G2-G3: a general decrease in BW was recorded during the last stages of the trial when the quality of the grazing was deteriorating. Environmental temperatures had dropped and severe frost had been experienced. Also their rumen microbial populations need time to adjust to a change in diet and DM intake, which in turn will lead to a decrease in microbial protein synthesis.
When only the pregnant ewes were considered, the trends in changes in body weight changes were similar.

4.2.2 Body condition scores of ewes

The data are summarised in Figures 4.2 and 4.3. Significant differences ($P < 0.05$) were recorded as follows:

L1-L2: the Mineral group differed from RUP group. Most of the Mineral group lambed during the early stages of the lambing period (see Table 4.3) while most of the RDP group lambed later.

G1-G2: the Mineral group differed from the RDP group. The RDP group lost condition while the Mineral group had a slight increase in BCS. The RDP group had to adapt to a different DM intake.

G2-G3: the RDP group differed from the RUP group. Both the groups lost BCS after the supplemental period was finished. The most likely explanation is that the rumen microbial organisms probably took a bit of time to adjust to a roughage diet only. There was no carry-over effect of the supplements on body condition score after the supplemental period. The general trend of BCS (Figure 4.3) was very similar for the three groups.

4.2.3 FAMACHA scores of ewes

The FAMACHA scores of the ewes are summarised in Figures 4.4 and 4.5. As can be seen from Figure 4.4, there were no significant differences between the groups. Also the general trend was similar for all three groups (Fig. 4.5)

4.2.4 Gastrointestinal parasites of ewes

The data are summarised in Figures 4.6, 4.7 and 4.8. No significant differences were noted when the mean faecal egg counts (FEC) were compared (Fig. 4.6). The actual mean FEC of each group for the duration of the trial was 465 for the Mineral group, 685 for the RUP group and 371 for the RDP group. Also no significant differences were found when the mean percentages of ewes which needed dosing during each period were compared (Fig. 4.7). Generally the Mineral group needed the most anthelmintic treatments but this was not statistically significant. However, this indicates that the protein supplements might have increased the ewe’s resilience against nematodes because nearly all the ewes in the RUP and RDP groups lambed (96% and 89% respectively) while only 76% of the Mineral group lambed. (If fewer ewes lambed then the effect due to the peri-partal relaxation of resistance as well as the stress due to lactation should have been less.) All three groups had similar trends regarding treatments needed (Fig. 4.8).

4.3 Performance Data

4.3.1 Time of Lambing

The data are summarised in Table 4.4. As can be seen from Table 4.3, most of the ewes lambed during the first three weeks. An interesting observation was that although the Mineral group was not flushed, 57% of the ewes conceived within the first two weeks while only 48% of the RUP group and 36% of the RDP group conceived during the first two weeks of mating.

Table 4.4 Percentage of lambs born during each time period

	L1	L2	L3	L4
Mineral	28 %	29 %	33 %	10 %
RUP	26 %	22 %	43 %	9 %
RDP	12 %	24 %	48 %	16 %
Total	22 %	25 %	42 %	11 %

4.3.2 Ewe Performance

The data are summarised in Table 4.5. The RUP group had a significantly higher ($P < 0.05$) lambing percentage, percentage lambs born and weaning percentage than the Mineral group. The RDP group did better than the Mineral group but worse than the RUP group and was not significantly different from either of the other two groups. Two sets of twins were born in the Mineral group, although neither survived. The most likely cause of this was genetic potential. Both ewes had delivered twins before. However, one ewe in each of the RDP and RUP groups had also delivered twins before, but not during this trial.

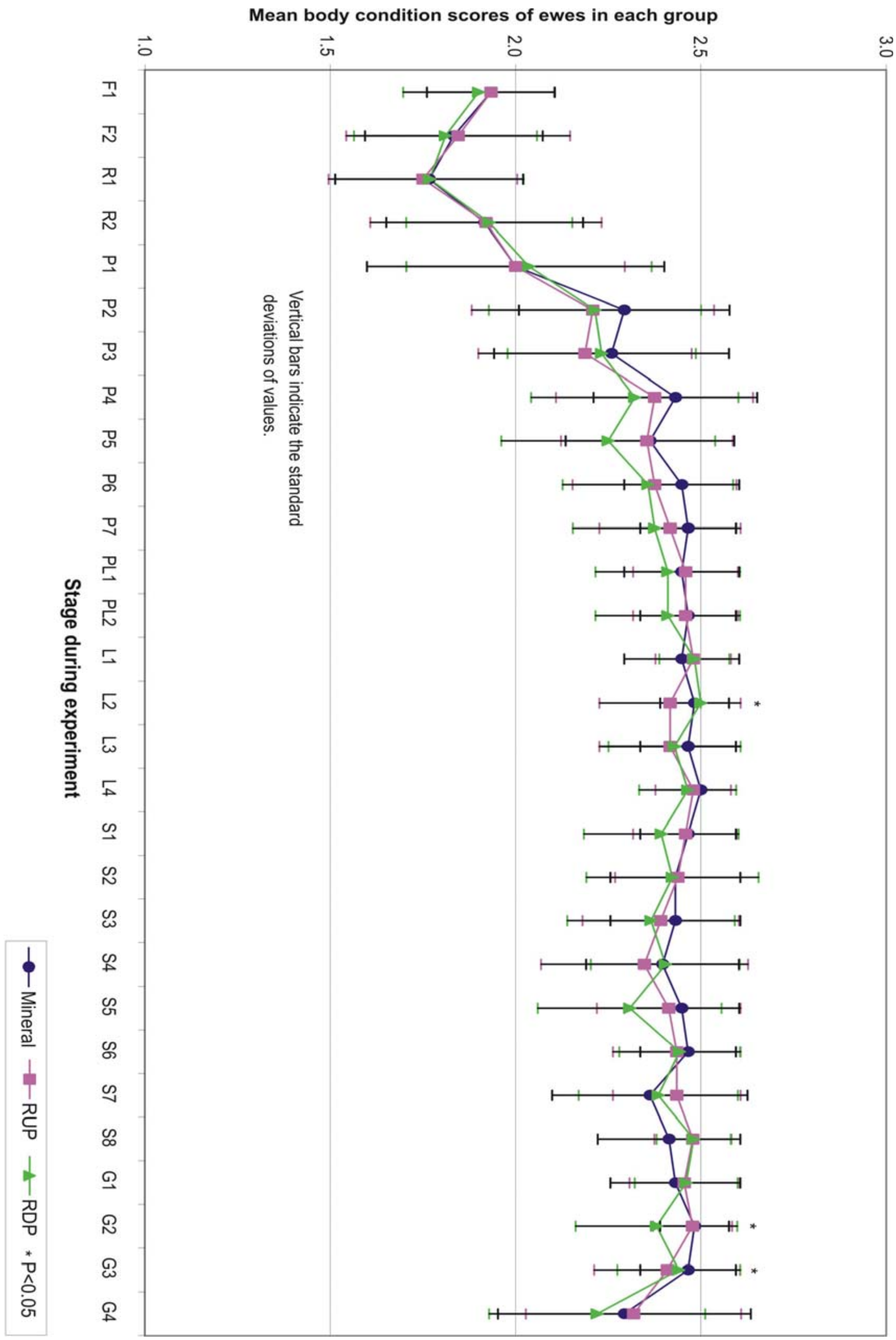
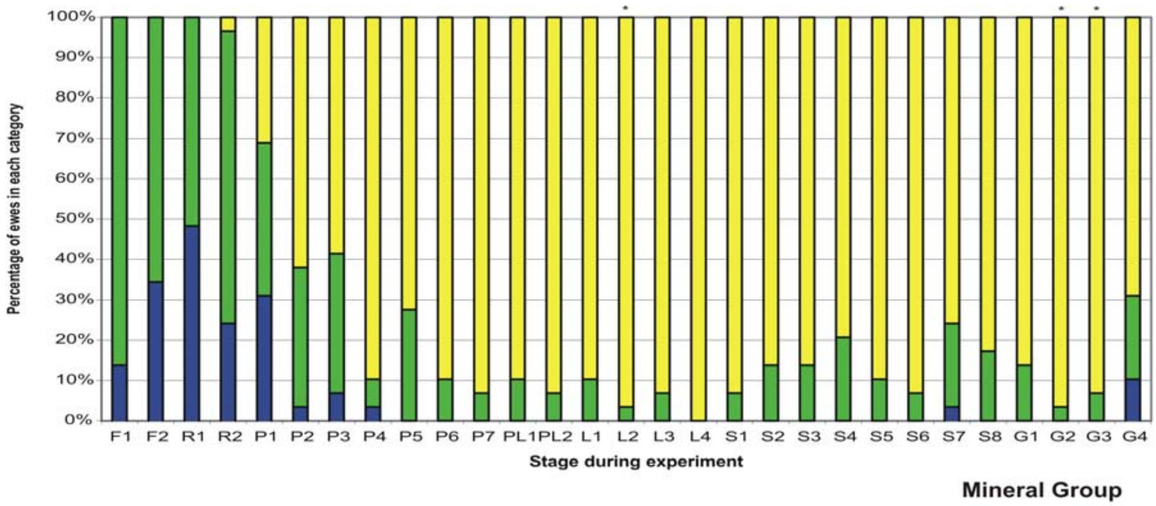
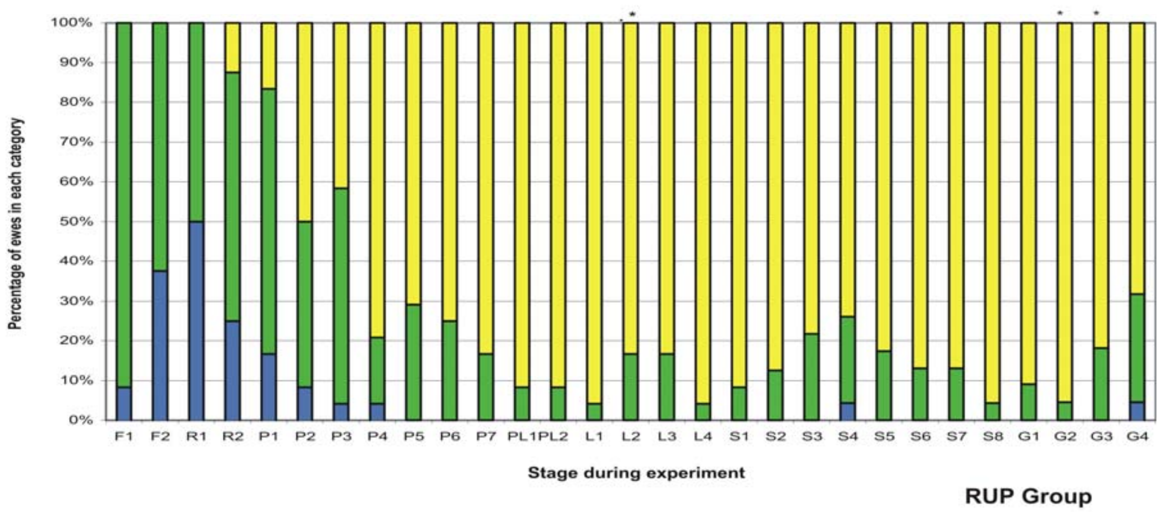


Figure 4.2 Body condition score changes of ewes during the trial





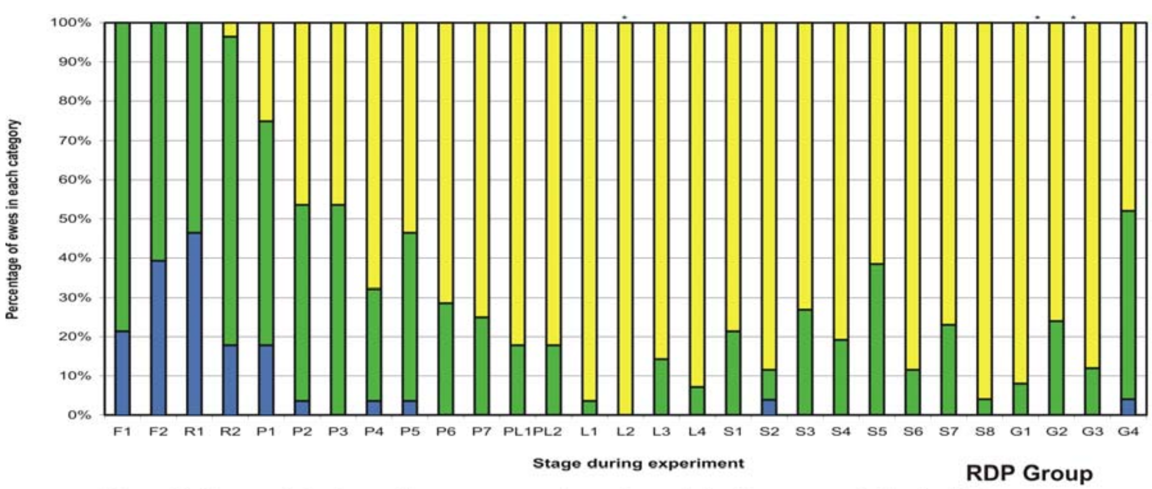


Figure 4.3 Changes in body condition score proportions of ewes in the three groups during the trial

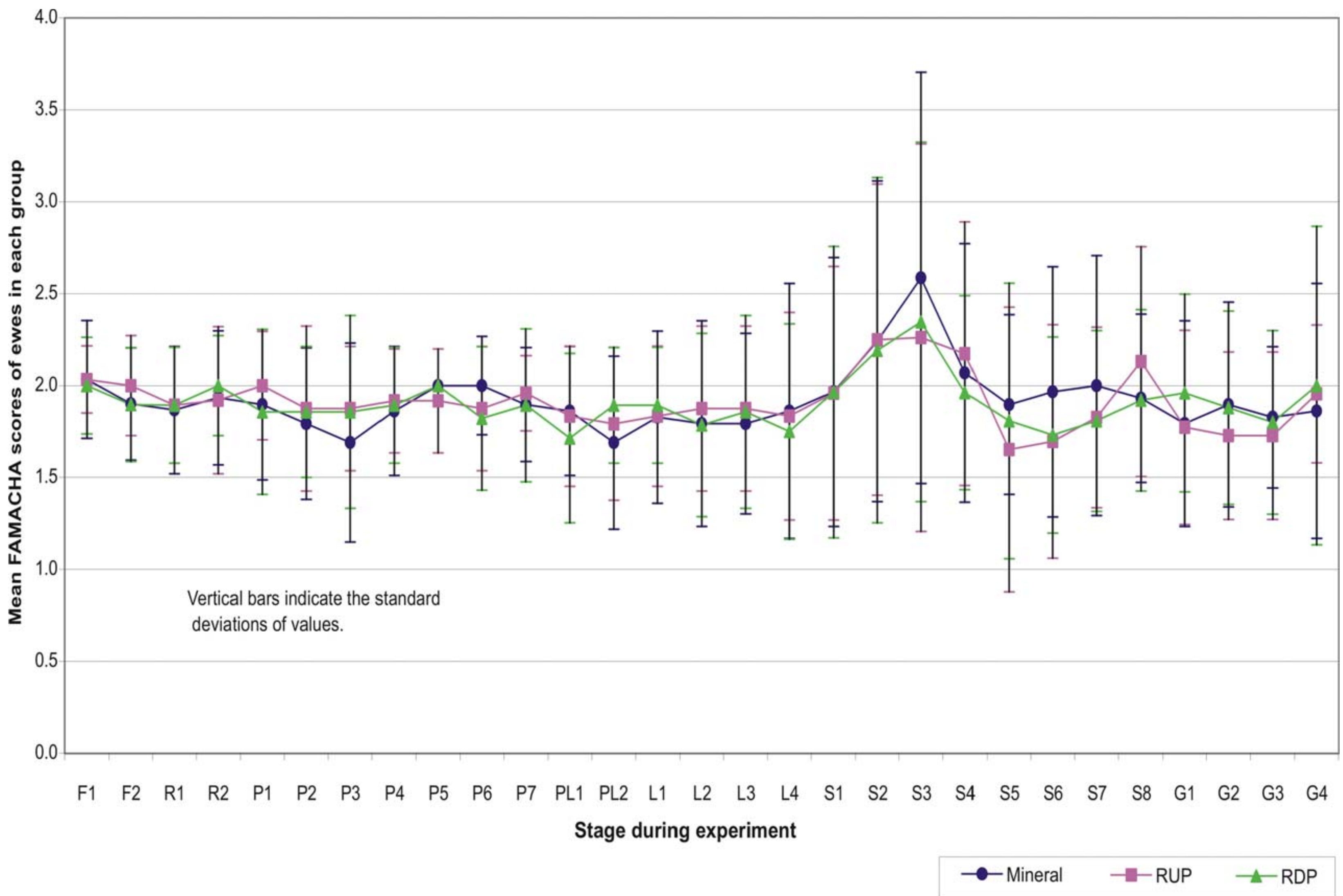
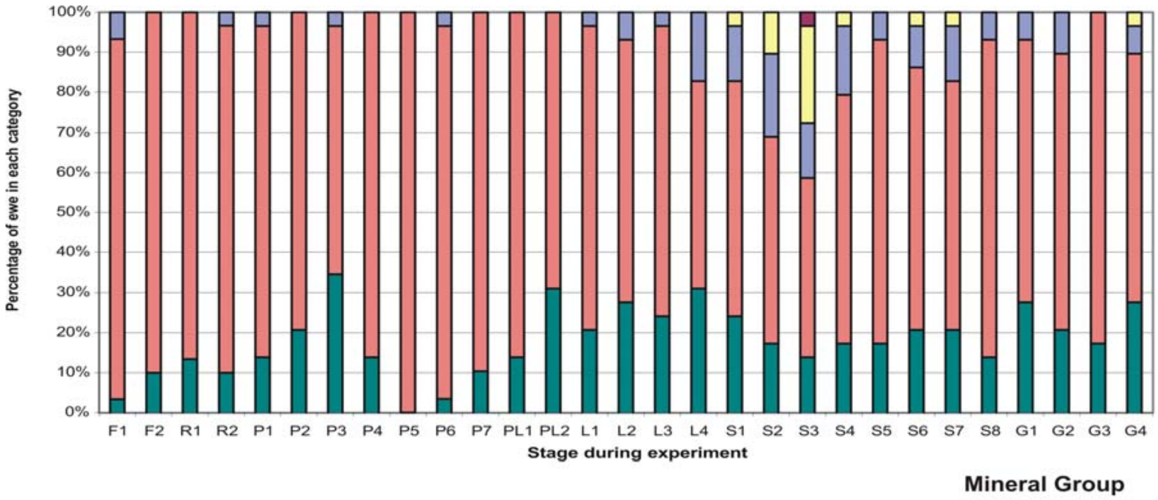
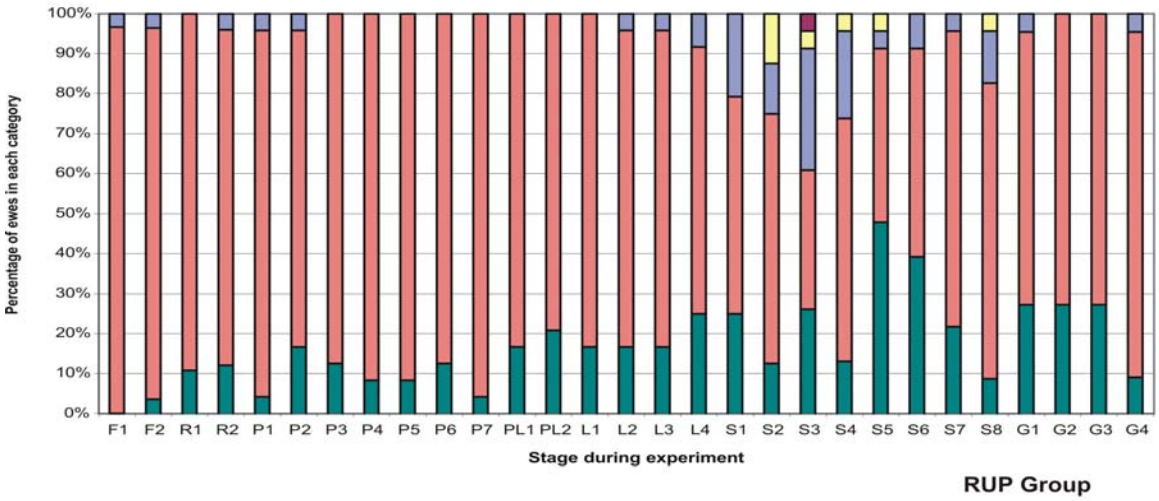


Figure 4.4 FAMACHA scores of ewes during the trial





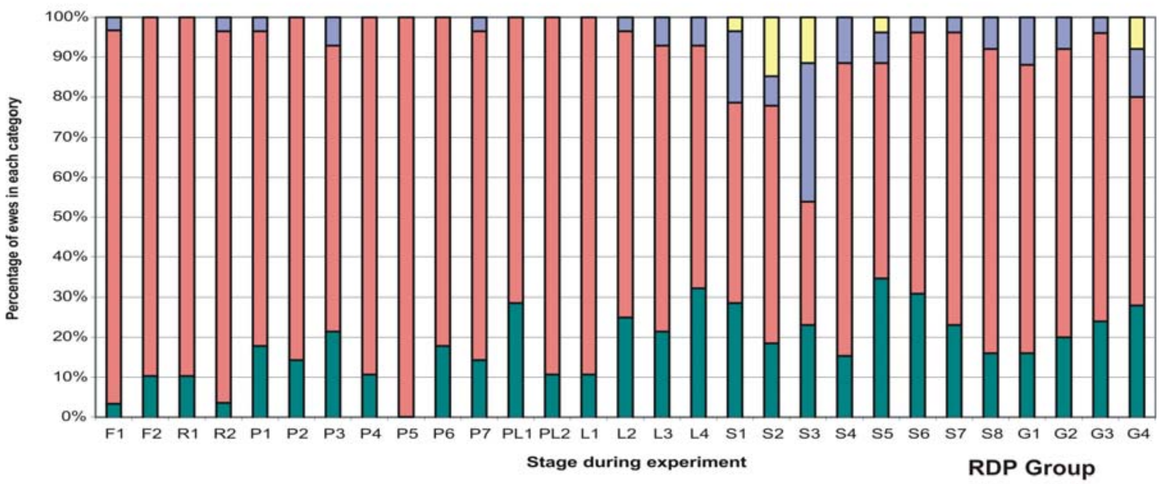


Figure 4.5 Changes in FAMACHA score proportions of ewes in the three groups during the trial

FAMACHA = 1 FAMACHA = 2 FAMACHA = 3 FAMACHA = 4 FAMACHA = 5

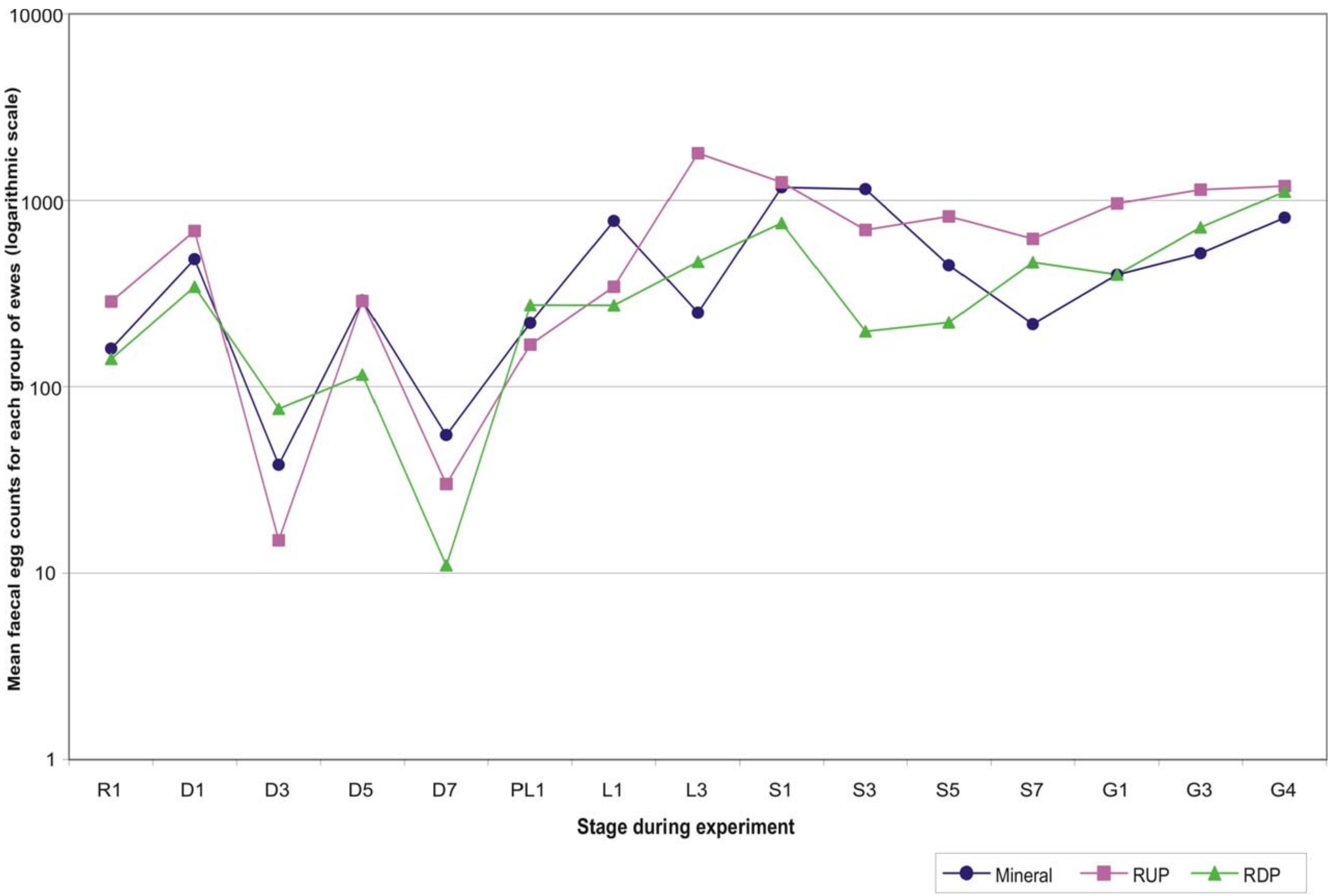


Figure 4.6 Mean faecal egg counts of ewes during the trial

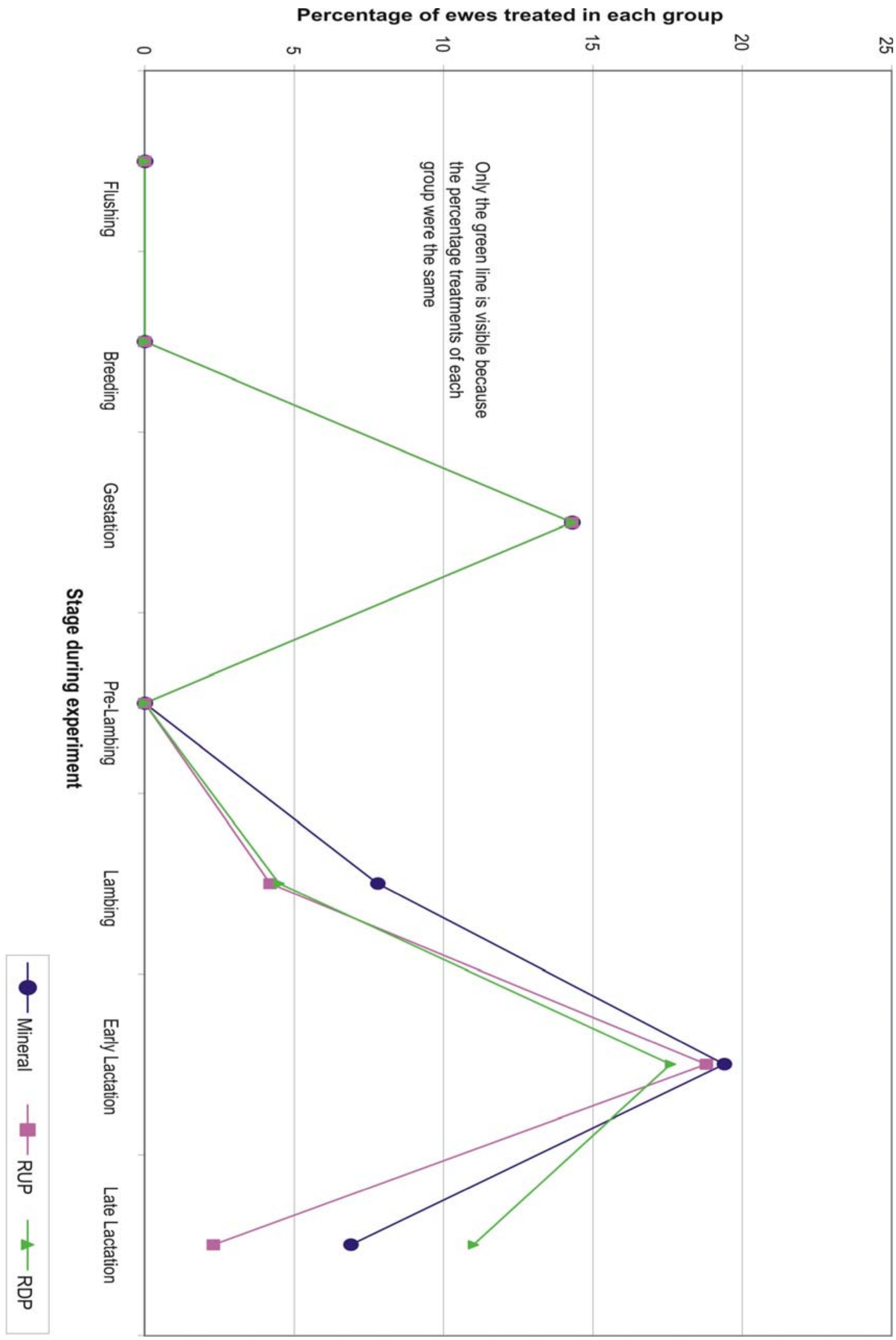


Figure 4.7 Percentage of ewes treated in each group during each stage of the trial

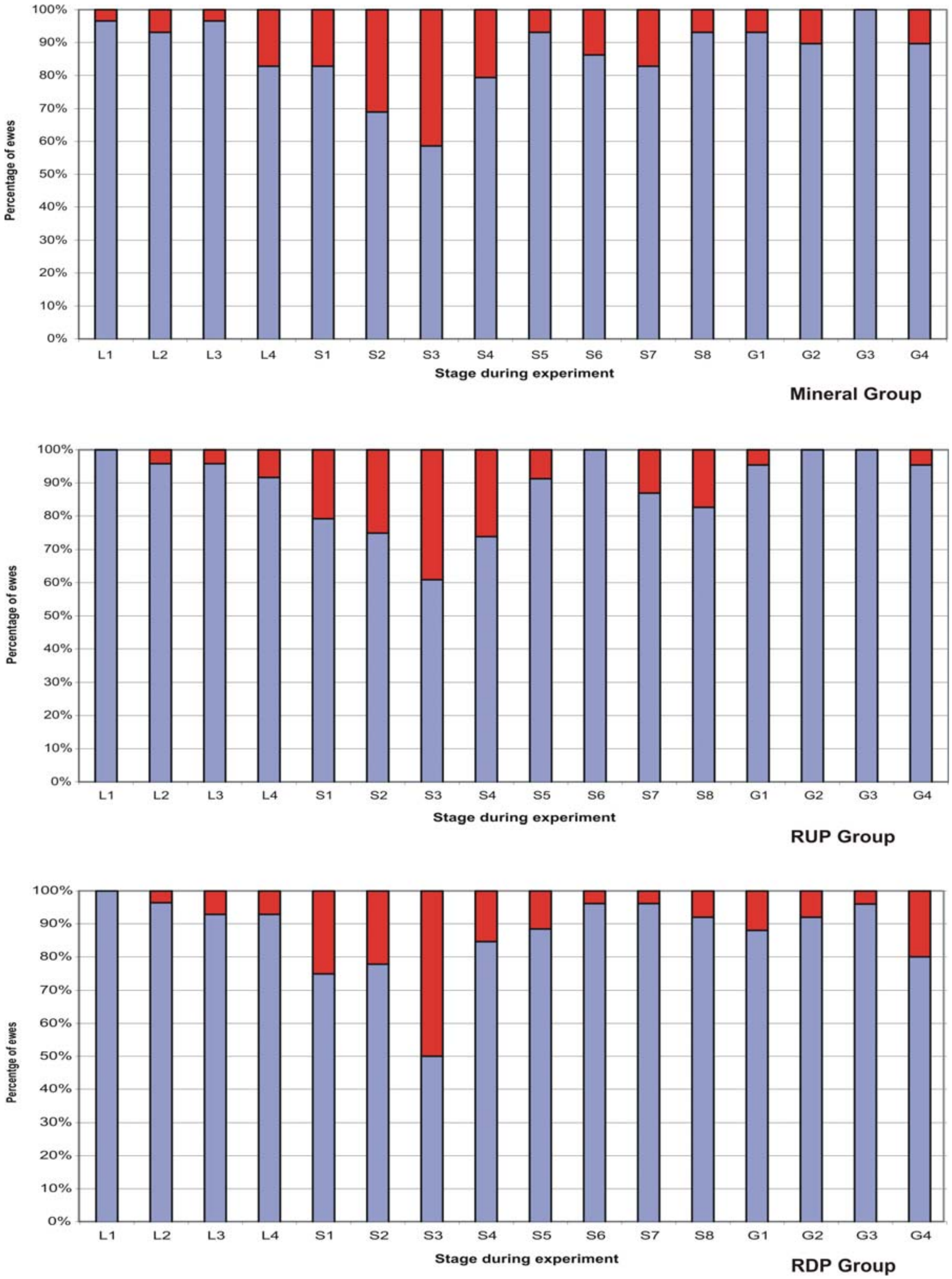


Figure 4.8 Percentage of ewes treated in each group during the trial

Table 4.5 Performance data of ewes

	Mineral*	RUP*	RDP
Lambing percentage	76	96	89
Percentage lambs	83	96	89
Survival percentage at end of supplements	55	75	64
Survival percentage at end of experiment	48	63	57

* = $P < 0.05$

4.3.3 Lamb mortalities

The data are summarised in Tables 4.6, 4.7 and 4.8. As can be seen from these results there were no significant differences in the type and time period of lamb mortalities in each group. When the groups were compared to each other with regard to number of lamb mortalities (percentage lamb mortality), only lambs which actually died, were included in this calculation. The category "Ewe dead/Stolen" was not included. When the percentage lamb mortality in each group was compared, the Mineral group (42%) differed significantly from the RDP group (24%) ($P < 0.05$). The RUP group was in between with 30 %. The high lamb mortality rate in the Mineral group was probably because both sets of twins died.

Table 4.6 Categories of lamb mortalities

	Mineral	RUP	RDP
Stillbirths	0	0	2
Maternal agalactia/ Mismothering	4	4	2
Nematodes	5	3	1
Disease	1	0	1
Ewe dead/Stolen	0	1	3
Total	**10**	**8**	**9**

Table 4.7 Total number of lamb mortalities during each time period

	Mineral	RUP	RDP
S1	1	4	3
S2	2		1
S3			
S4	1		
S5	1		
S6	1		
S7			
S8	2		1
G1		1	
G2	2	1	
G3		1	1
G4			
Total	**10**	**7**	**6**

Table 4.8 Percentage of lamb mortality in each group

Group	Lambs born	Lamb mortalities	Percentage lamb mortality
Mineral *	24	10	42%
RUP	23	7	30%
RDP *	25	6	24%

* = $P < 0.05$

4.4 Environmental observations

The monthly means of the rainfall and temperatures recorded by the farmer are summarised in Table 4.9.

Table 4.9 Summary of monthly rainfall and mean daily temperatures

	Aug	Sept	Oct	Nov	Dec	Jan	Feb	March	April	May
Monthly rainfall (mm)	0	0	105	150	130	109	123	72	32	18
Mean maximum (minimum) daily temperature (°C)	13 (0)	14 (0)	20 (1)	22 (3)	23 (6)	25 (8)	26 (7)	20 (3)	18 (0)	16 (-2)

The following weather observations were made either by the farmer or data recorder:

August 2001: Very windy. Days becoming mild but nights still cold. Dry environment. Veld fires.

September 2001: Very windy during early September. Environmental temperatures very erratic with some days being quite hot while others are still very cold. Dusty.

October 2001: Generally better weather but a cold spell of about one week during the early part of the month. Still dry environment, dusty.

November 2001: The rainy season had started. Warmer day temperatures were experienced and less variation between days.

December 2001: Generally good weather but some heavy rainfall during the latter part of the month.

January 2002: High rainfall during early part of the month with misty conditions, mild days. Latter part of month, hot temperatures.

February 2002: Fairly normal summer temperatures but higher than normal daily temperatures during the last week.

March 2002: Temperatures still high during early part of month but fairly normal autumn weather (cooler days) during second half of month.

April 2002: Normal autumn weather. Some cool days alternating with warmer days. Nights cold with some mild frost during the last week. Late season rain during second week.

May 2002: Cold spell during first ten days with severe frost at night. Second half of month, normal early winter weather with generally mild days and cold nights.

4.5 Animal health management procedures and ewe losses

Three ewes were attacked by a baboon on 7 January 2002. Two of these were in the Mineral group and one was in the RDP group. All three were treated as follows: their wounds were cleaned, debrided and sprayed with an aerosol spray containing 0.125 mg trypsin, 290 mg castor oil, 40 mg peru balsam, 200 iu vitamin A and 5 iu vitamin E per gram (Debrizyme, Kyron). Areas around the wounds were treated with diazinon 30% m/v (Dazzel NF, Milborrow) to prevent flystrike. Ewes were treated with 5 ml injectable antibiotics for five days, procaine benzylpenicillin 200 mg per ml and dihydrostreptomycin 200 mg per ml (Depomycin, Intervet) and 2 ml of phenylbutazone, 200 mg per ml (Fenylbutazone 20% Phenix, Phenix) for three days. All three ewes recovered without further incident and were retained in the trial.

Seven ewes – three in the Mineral group, two in the RDP and two in the RUP groups - were treated for fly strike with diazinon 30% m/v (Dazzel NF, Milborrow) during 8 February to 22 February 2002. Ewes were shorn by machines during the last week of supplementation on 11 April 2002.

Three ewes were stolen on 9 September 2001, one in the RDP group and two in the RUP group. Four ewes were stolen on 18 September 2001, three in the RUP group and one in the RDP group. An ewe in the RUP group died on 26 September 2001. On post mortem examination a bladder tumour was diagnosed (Dr P. Schoeman, Hendrina Animal Clinic). One ewe of the Mineral group was stolen on 4 October 2001. All the above-mentioned ewes were ignored during analysis of the data.

Later in the trial four ewes died of verminosis. Two in the RDP group on 11 March 2002 and two in the RUP group of which one on 10 March 2002 and one on 21 April 2002. One ewe of the RDP group was stolen on 16 April 2002.

4.6 Lamb data

4.6.1 Body weights of lambs

The data are summarized in Figure 4.9. Significant differences, indicated with an asterisk (*) on all graphs, were recorded as follows:
S4-S5: the Mineral group differed from both the RDP and RUP groups' probably due to age differences. The lambs of the Mineral group were older than the other two groups' lambs.

S5-S6: the RUP group differed from both the Mineral and RDP groups probably due the supplement. The RUP lambs were probably growing better because their mothers produced more milk.
S6-S7: the RDP group differed from both the RUP and Mineral groups. Lambs in the RDP group were gaining weight while the lambs of the other groups were losing weight. This difference may have been due to the supplement or the difference in ages.
S8-G1: the Mineral group differed from the RUP group. Lambs of the Mineral group were gaining slightly more weight than the lambs of the RUP group. The Mineral group's lambs were probably starting to graze at this time.

The Mineral group had lower body weights throughout the experiment even though they were marginally older. However, as soon as the supplements were withdrawn the differences in body weight between the lamb groups became much smaller. This indicates that there was no carry-over effect due to the supplements on milk production.

4.6.2 Body condition scores of lambs

The data are summarised in Figures 4.10 and 4.11. A significant difference was only recorded at G1-G2 when the Mineral group differed from the RDP group. Lambs in the Mineral group were losing BCS compared to the RDP lambs, which were maintaining their BCS. In general the BCS of the Mineral group was lower than the BCS of the RUP and RDP groups. This indicated that the ewes of the Mineral group probably had lower levels of milk production compared to the RDP and RUP groups.

4.6.3 FAMACHA scores of lambs

The data are summarised in Figures 4.12 and 4.13. Significant differences were recorded as follows:
S8-G1: the Mineral group differed from the RUP group. The lambs in the RUP group were probably under more stress because of the withdrawal of the ewes' supplements.
G1-G2: the RDP group differed from the RUP group. This may have been the same cause

as previously (S8-G1) but with a delayed effect.
G2-G3: the RUP group differed from the Mineral group. The lambs of the RUP group were probably still struggling because of the ewes. This data indicated that the stress of the ewes may have been transferred to their lambs in the form of poor milk supply.

4.6.4 Anthelmintic treatments of lambs

As can be seen from Figures 4.14 and 4.15, no significant differences were found between the percentages of lambs dosed in each group at each stage. However, when looking at Figure 4.14 it seemed that the peak nematode burden in each group occurred at different times. This was probably due in part to the age differences and also because the ewes of the RUP group were stressed the most towards the end of the experiment.

4.7 Wool analysis comparison

As can be seen from Figure 4.16, no significant differences were found when the three groups were compared. Their wool had similar lengths, strengths, fibre diameters, yields, weights and CVs. The point of break was also similar, although the RUP group tended to break slightly more towards the middle of the fibre.

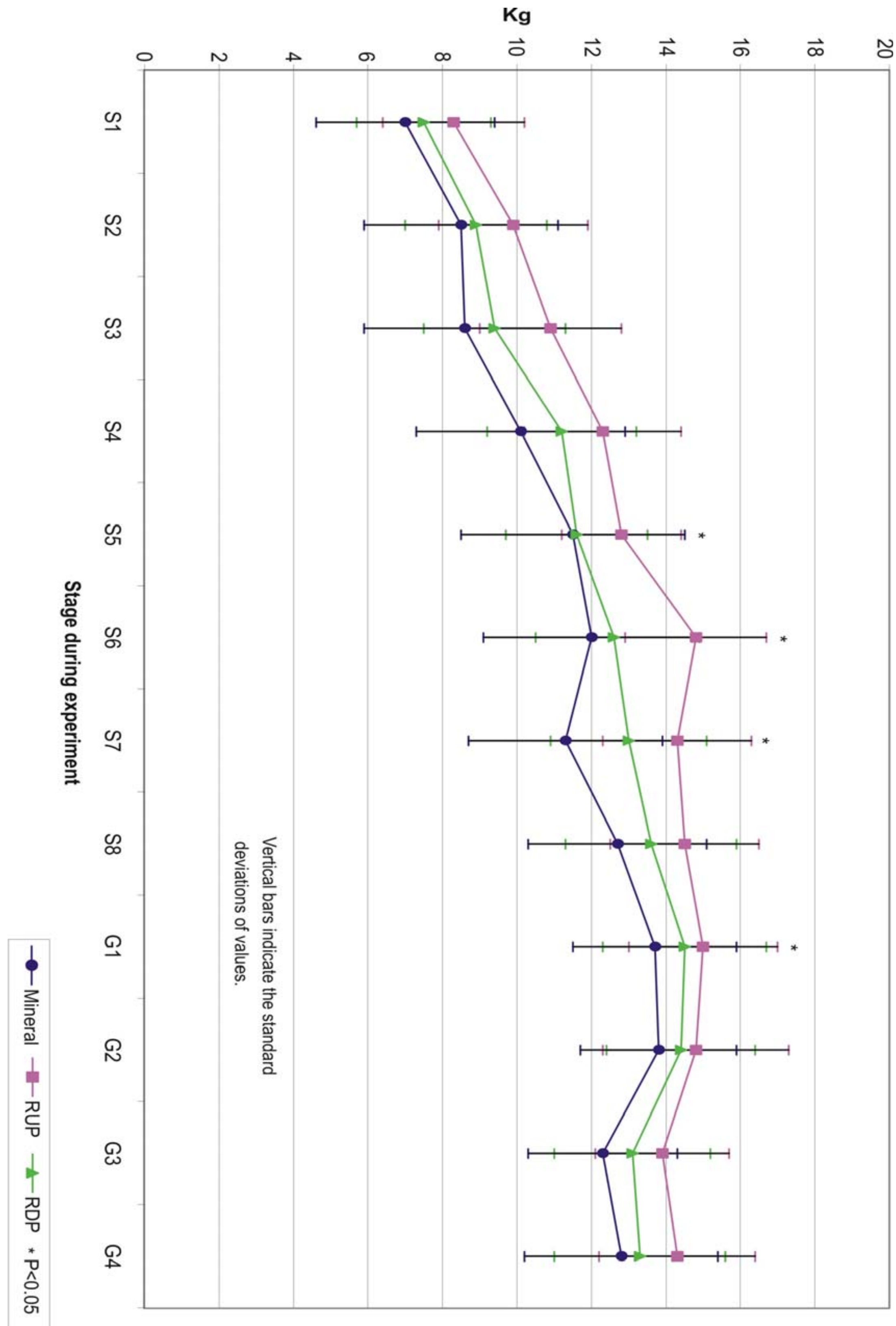


Figure 4.9 Body weight changes of lambs during the trial

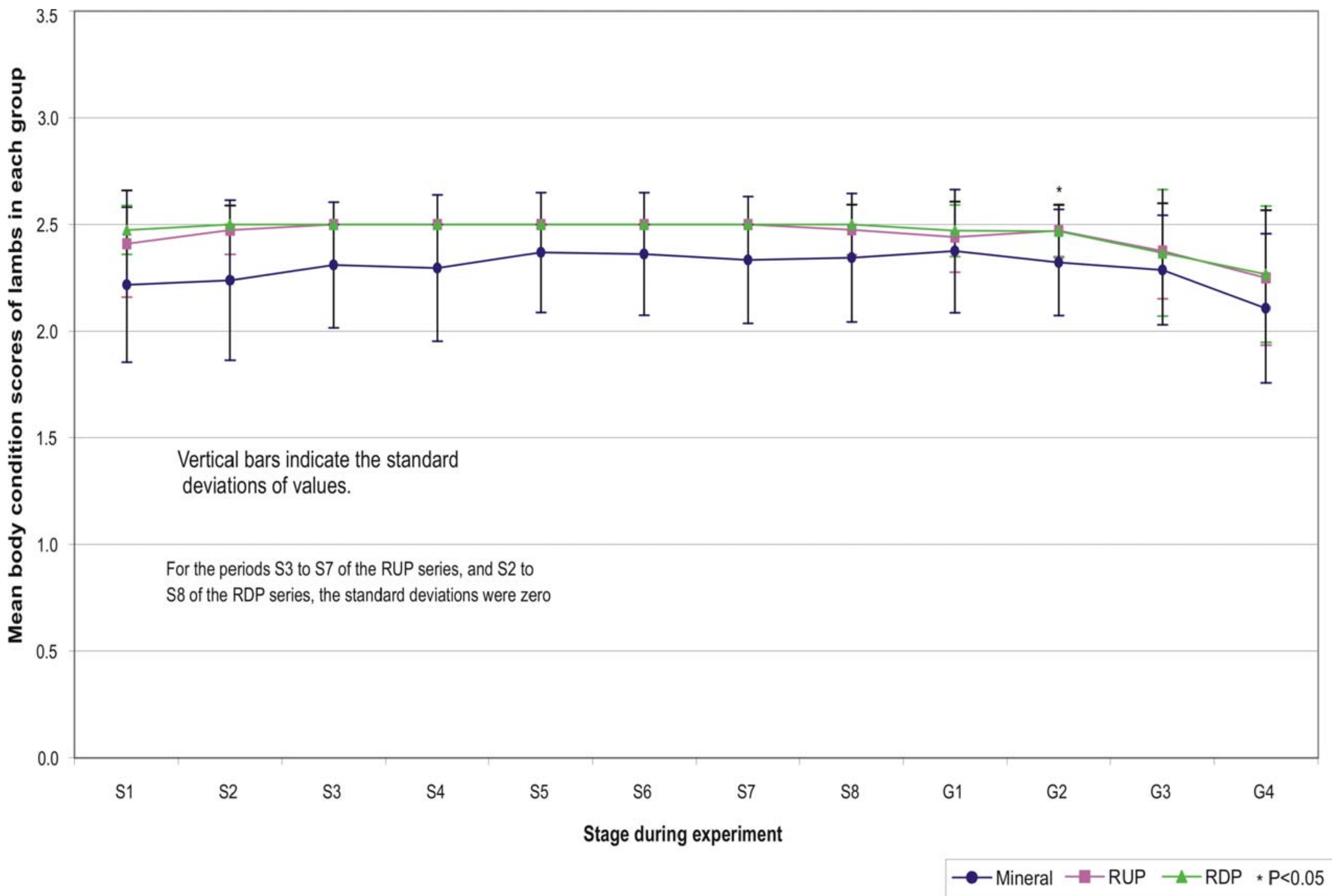


Figure 4.10 Body condition scores of lambs during the trial

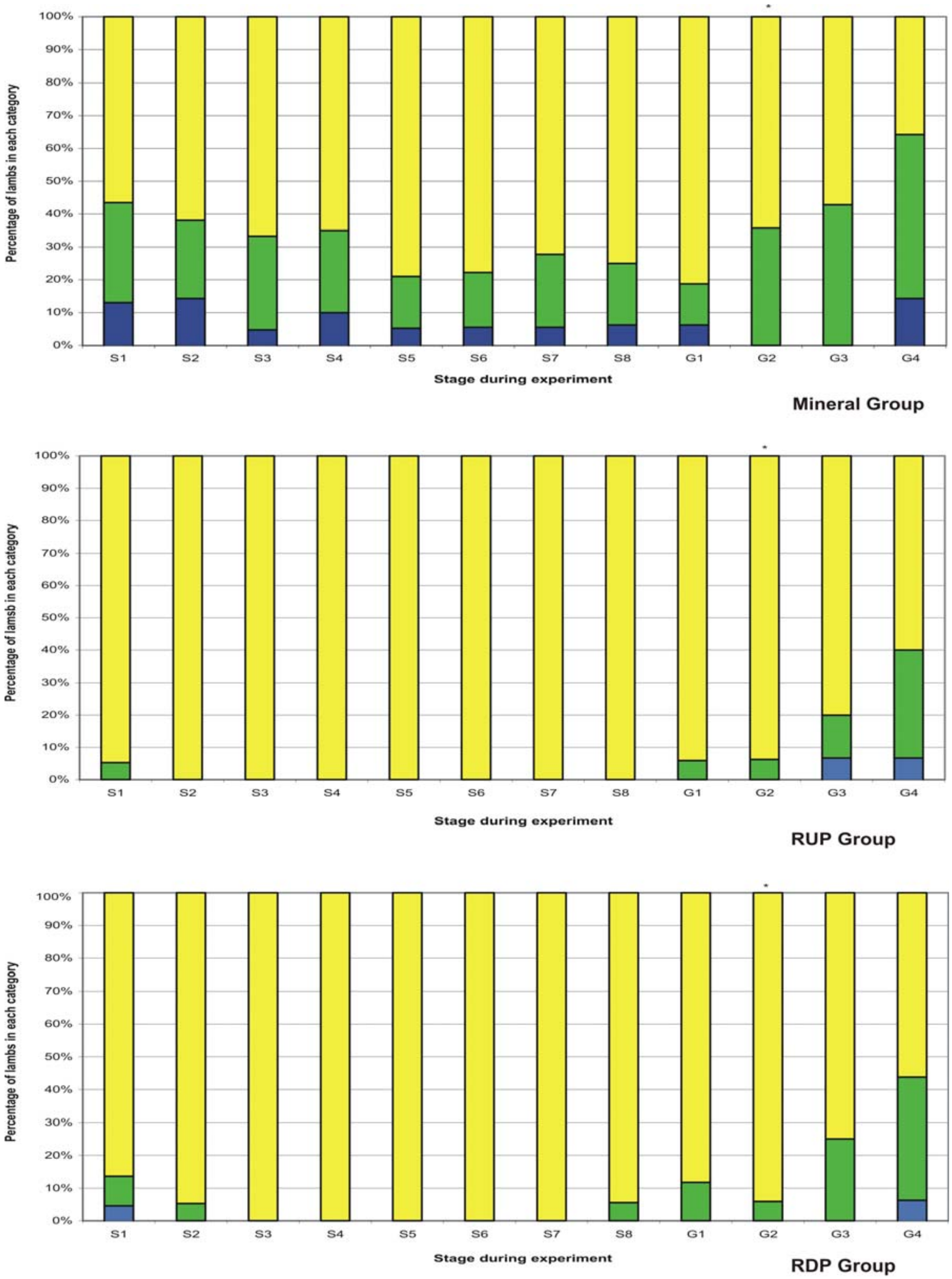


Figure 4.11 Changes in body condition score proportions of lambs in the three groups during the trial

1.5 2 2.5 * P < 0.05

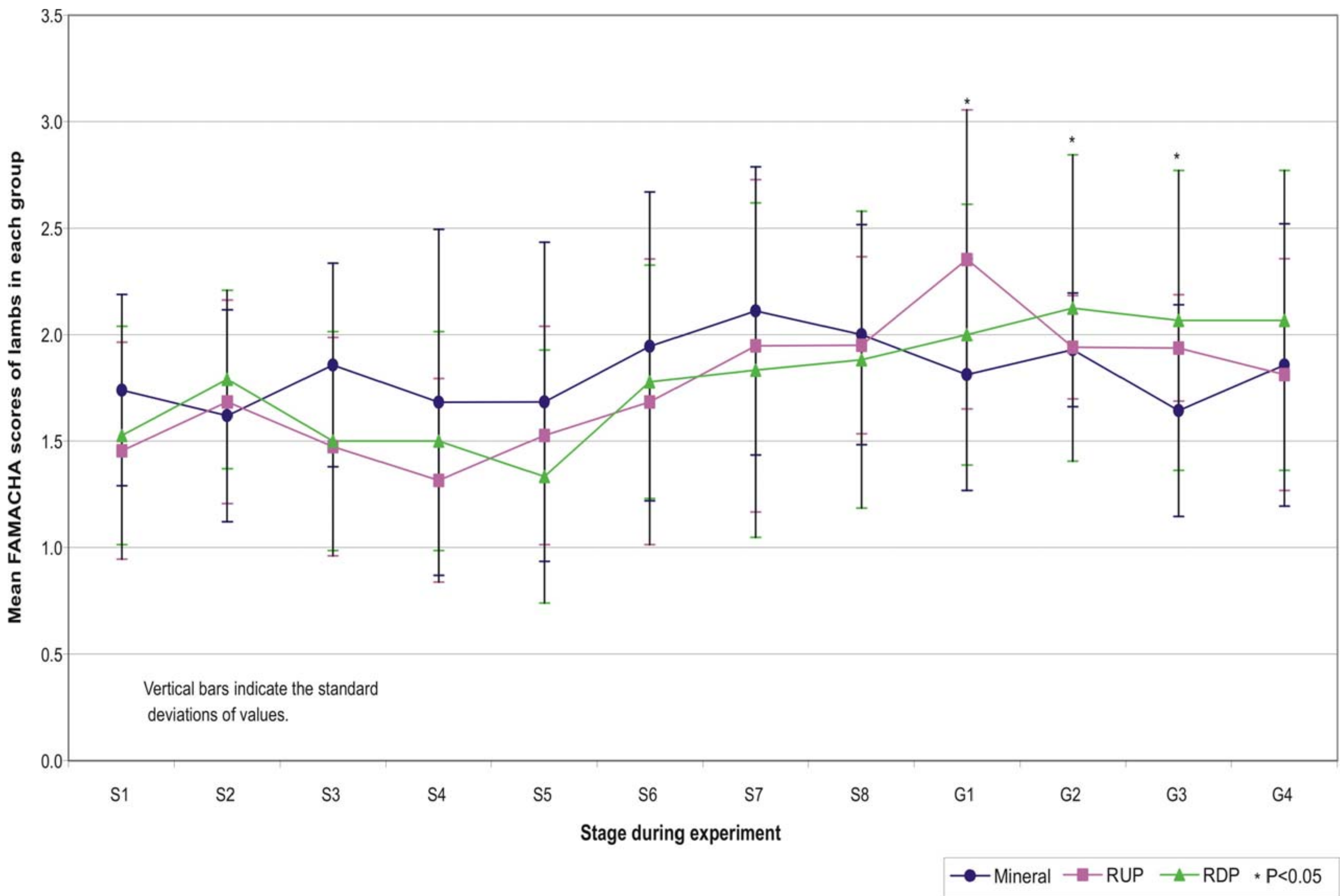


Figure 4.12 FAMACHA scores of lambs during the trial

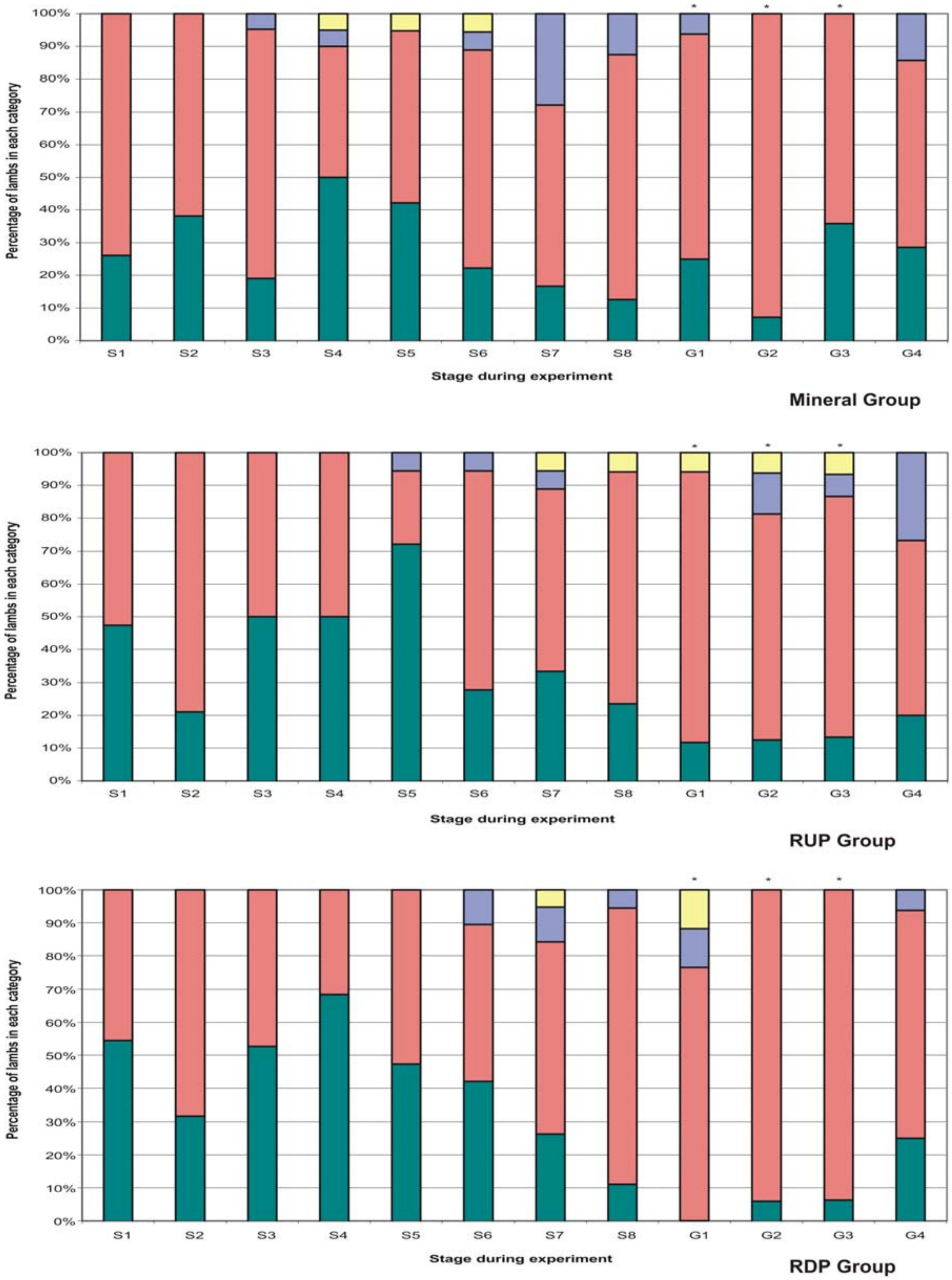


Figure 4.13 Changes in FAMACHA score proportions of lambs in the three groups during the trial

■FAMACHA = 1 ■FAMACHA = 2 ■FAMACHA = 3 ■FAMACHA = 4 ■FAMACHA = 5 * P < 0.05

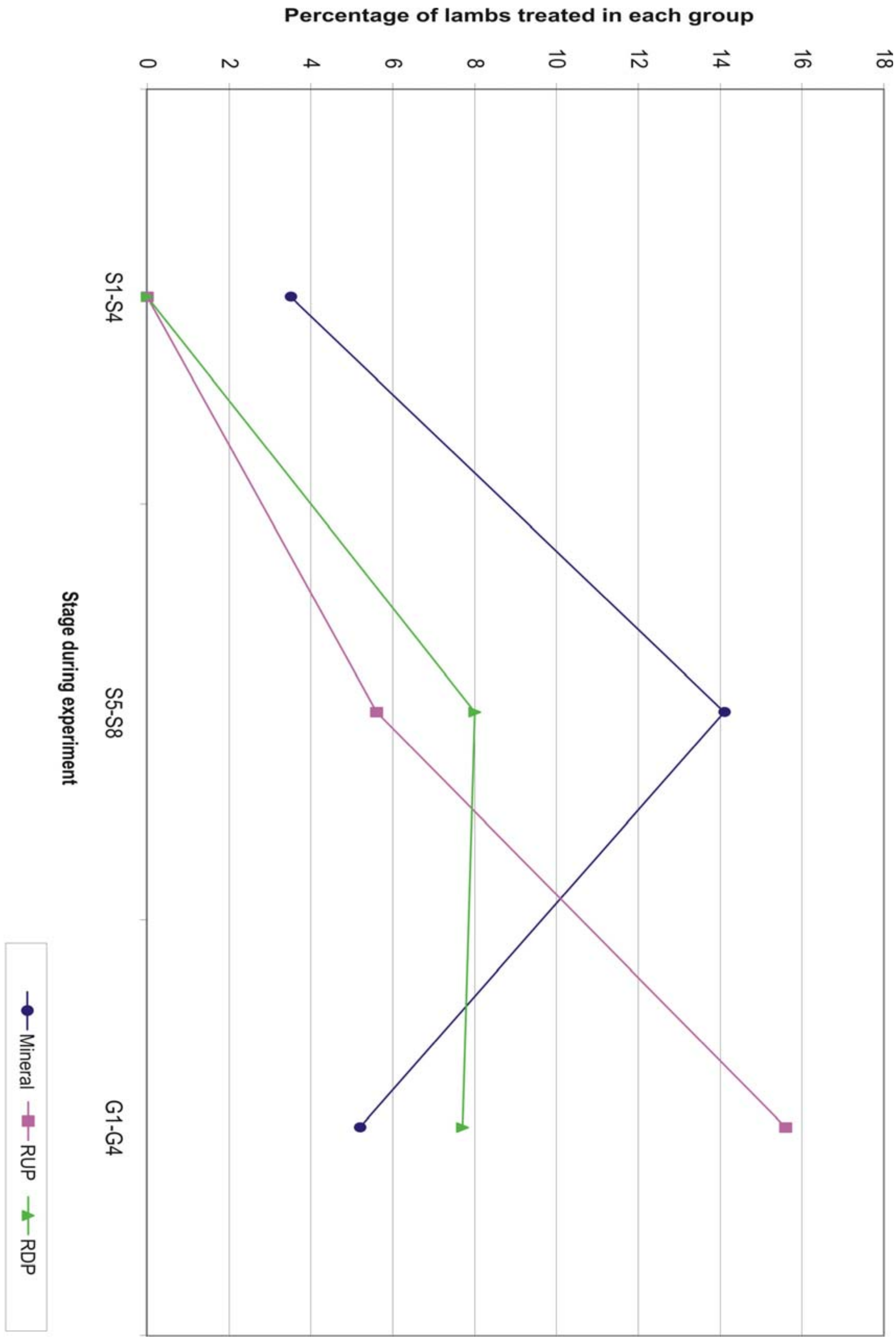


Figure 4.14 Mean percentage of lambs treated in each group during each stage of the trial

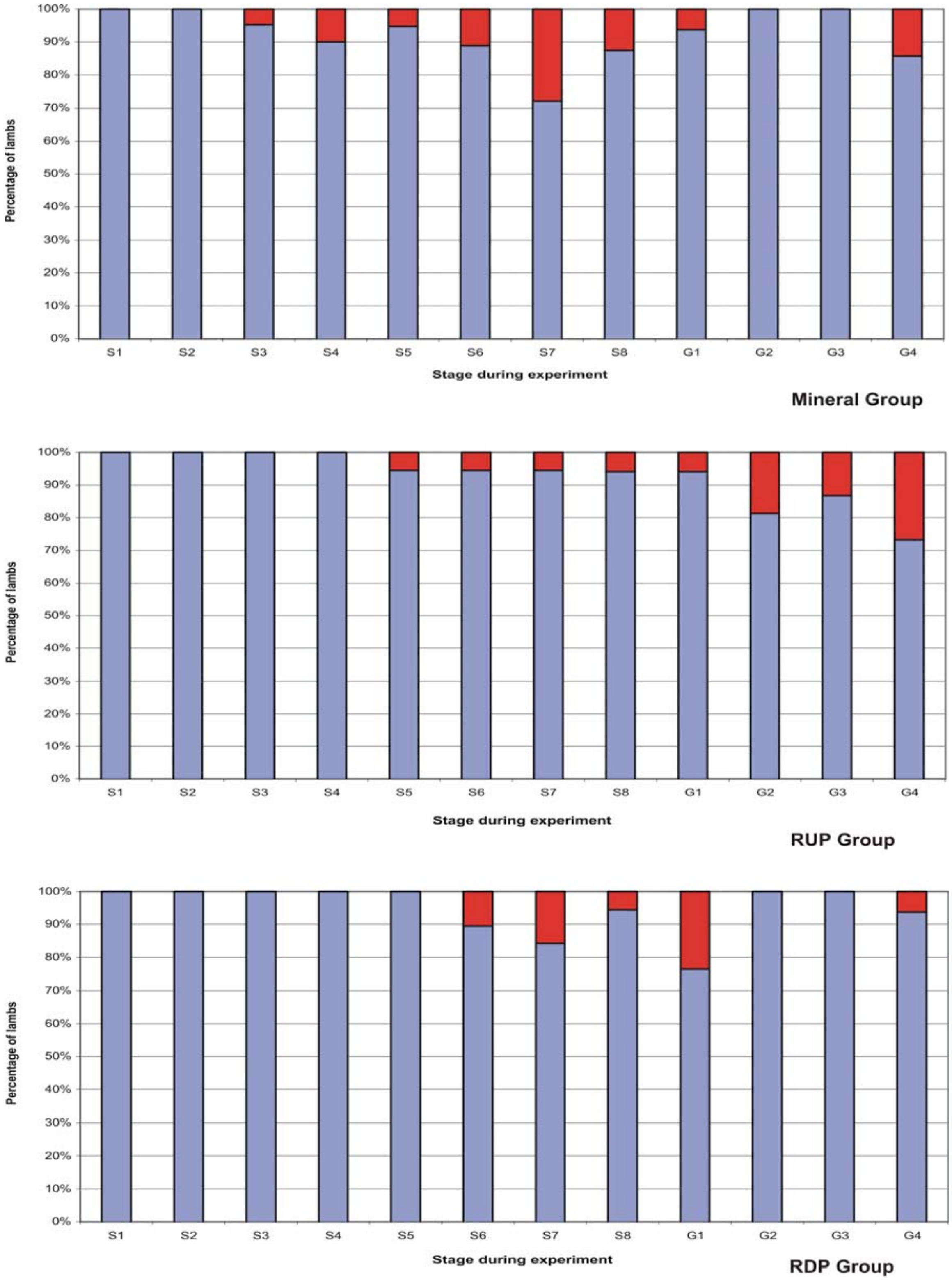


Figure 4.15 Percentage of lambs treated in each group during the trial

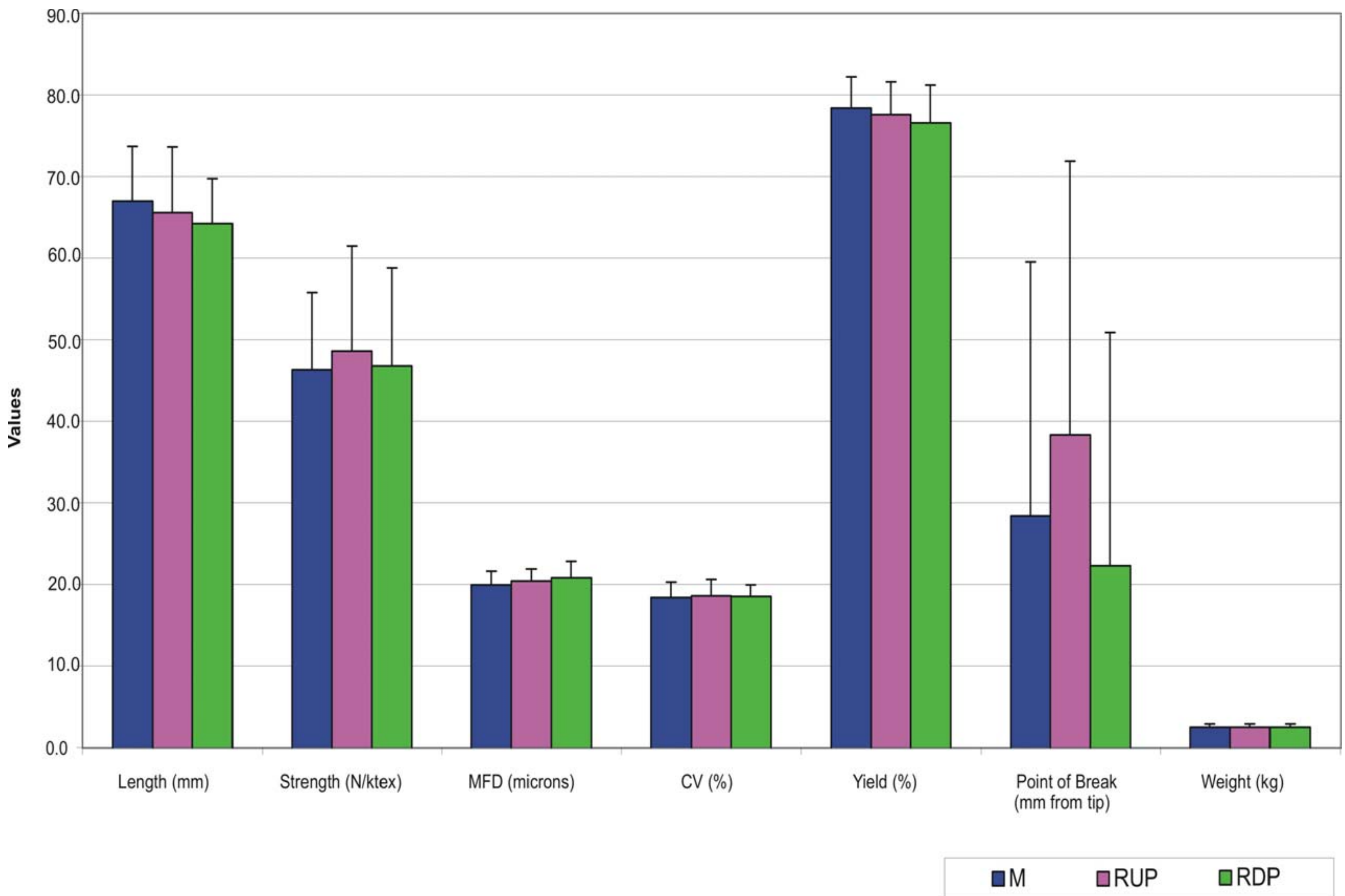


Figure 4.16 Comparison of wool test results in the three groups

4.8 Gross margin comparison

The gross margin comparison is illustrated in Figure 4.17 and Table 4.10. No significant differences were found when the wool income was compared but the three groups differed significantly (P< 0.03) when the gross margins were compared at the end of the second supplementary period as well as at the end of the experiment (P < 0.008). The Mineral group earned nearly twice as much as the RUP group, with the RDP group between them. The standard deviations were large because some ewes had only a wool income while others had both a lamb and wool income. As can be seen, the difference in gross margins was even more significant at the end of the experiment. This was because there was no carry-over effect from the feeding of the supplements.

Table 4.10 Gross margin comparison

	Mineral	**RUP**	**RDP**
Wool income	R61.98	R60.80	R60.73
Average lamb weight (kg) at the end of the second supplementary period	12.7	14.5	13.5
Average lamb weight (kg) at the end of the trial	12.8	14.3	13.3
Income 1 – at the end of the second supplementary period	R61.98 + (12.7 x R8 x 0.55) = R117.86	R60.80 + (14.5 x R8 x 0.75) = R147.80	R60.73 + (13.5 x R8 x 0.64) = R129.85
Income 2 – at the end of the trial	R61.98 + (12.8 x R8 x 0.48) = R111.13	R60.80 + (14.3 x R8 x 0.63) = R132.87	R60.73 + (13.3 x R8 x 0.57) = R121.38
Cost of supplements	R3.75	R75.11	R45.07
Gross margin 1 (* P < 0.03)	R114.35 *	R70.43 *	R82.69
Gross margin 2 (* P < 0.008)	R107.77 *	R54.93 *	R74.12

[The calculation of income 1 and income 2 in this table was done using averages and round off numbers, i.e. lamb weights and lamb survival. Wool income, cost of supplements, gross margin 1 and gross margin 2 were the actual amounts calculated during the analysis of the data.]

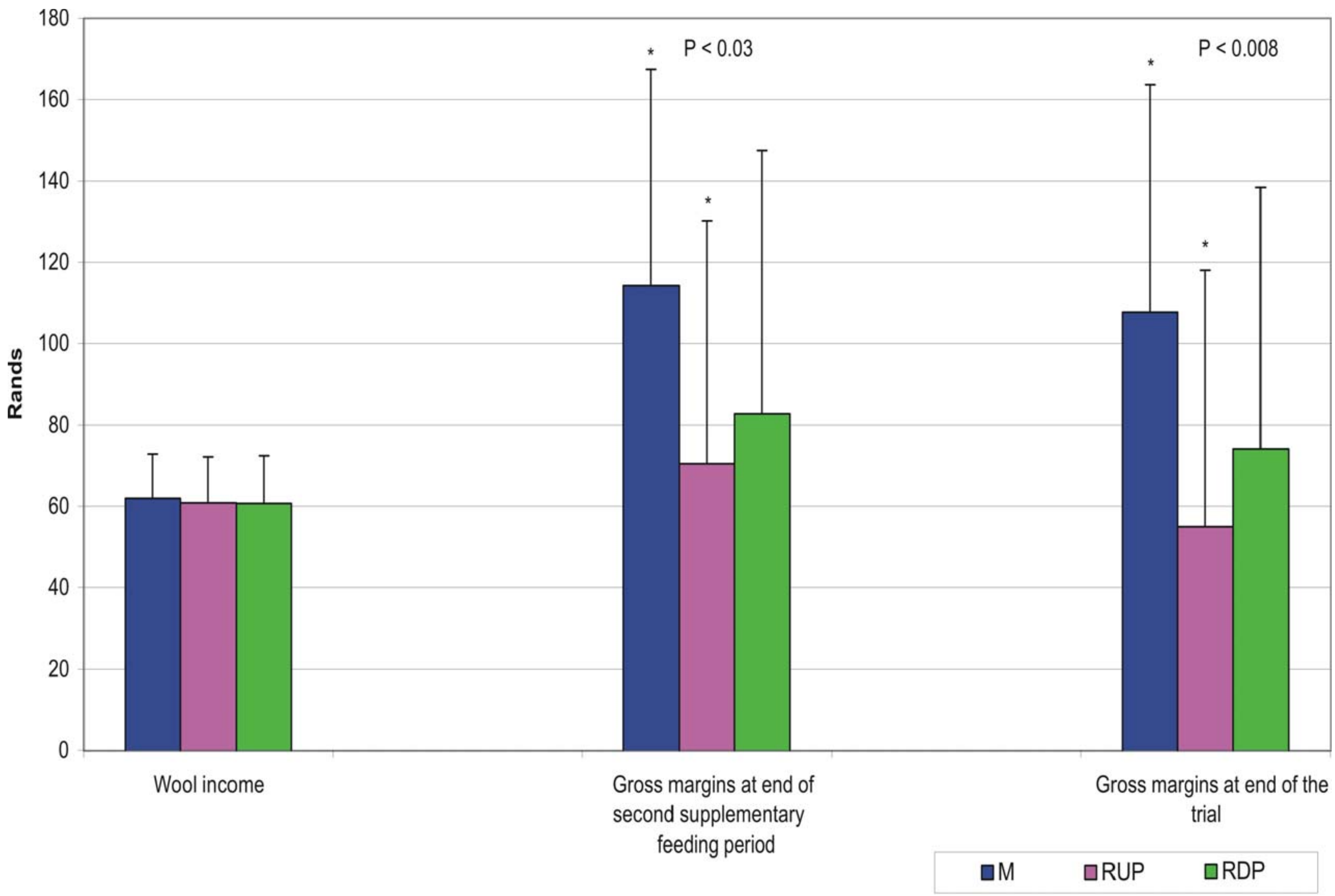


Figure 4.17 Comparison of gross margins of the three groups

CHAPTER 5

DISCUSSION

In this study there were several significant differences between the three groups regarding production of lambs but not wool. The RUP group had a significantly higher lambing percentage (96%) than the Mineral group (76%), with the RDP group in between (89%) ($P < 0.05$). This difference was also noted with regard to the percentage of lambs born per group (fecundity): RUP was 96%, Mineral 83% & and RDP 89% ($P < 0.05$ only between RUP and Mineral group). Since the Mineral group was the only group which had ewes with twins (2 ewes), the most likely explanation for this observation is an inherent difference in genetic potential. Both the ewes had delivered twins previously, however of the RDP and RUP groups there was one ewe in each, which had also delivered twins before, but neither had twins during this study.

Differences were also seen in the survival percentages. In the RUP group, 20 percentage points more lambs survived (75%) than in the Mineral group (55%) ($P < 0.05$) at the end of the second supplementation period. This finding was consistent with the data of earlier studies which have shown that protein supplementation and especially RUP increases lamb survival. The RDP group (64%) was not significantly different from either the RUP or Mineral groups. When survival percentages were recorded again six weeks after supplementation ended, the differences were no longer significant. The RUP group's lamb survival percentage was 12 percentage points lower, while the Mineral and RDP groups' were only 7 percentage points lower. Thus it seems there was no carry-over effect regarding lamb survival. The average weight of the RDP and RUP groups' lambs decreased by 0.2 kg during this period, while the weight of the Mineral group's lambs increased by 0.1 kg. There were no differences regarding lamb mortalities either by type or period, but the lamb mortality percentage differed significantly ($P < 0.05$) between the RDP group (24%) and the Mineral group (42%). The RUP group was in between with 30%. The high lamb mortality in the Mineral group may be ascribed to the death of both sets of twins. This indicates that nutrition may not have been adequate for twin-bearing ewes. A way to answer this question would be to do a similar study with twin-bearing ewes.

There were some differences between the ewes groups with regard to BW and BCS. These differences were especially noticeable towards the end of the second supplementation period. However during the period after the second supplementation and the end of the experiment, these differences were negated. At the end of the second supplementation period, the average BCS of the RUP and RDP groups' were 0.1 point higher than the Mineral group. At the end of the experiment, the BCS of the RUP and Mineral groups were the same with the RDP group's 0.1 point lower. A difference of just 0.1 in BCS between groups is in any case not noteworthy because of the inherent subjectivity of measurers.

At no time were there any significant differences with regard to FAMACHA scores or FEC's. However at lambing, there was a trend for the RUP and RDP groups FEC's to be lower compared to the Mineral group's FEC, and both the RUP and RDP groups tended to need less treatments during this period. This is consistent with literature cited earlier. A possible explanation for the lack of significant differences is the presence of resistant *H. contortus* strains. Anthelmintic resistance could possibly have masked the effects of the supplements. The opposite happened at the end of the experiment with the FEC of the Mineral group tending to be lower than the FEC's of the RUP and RDP groups. This is probably due to the withdrawal of these supplements towards the end of the experiment. Thus there was no carry-over effect of the protein supplementation with regard to resilience against nematodes.

A possible explanation for the absence of a carry-over effect on lamb survival or a response in resilience/resistance to gastrointestinal parasites, is that almost all the ewes had single lambs and were therefore not under severe nutritional stress. Merinos are also a relatively resistant breed to *H. contortus* (Preston & Allonby, 1978). This inherent resistance could have masked the effect of the protein supplementation. Another explanation for the lack of carry-over effect is the quality of the grazing, which was good during lambing and early lactation. The first severe frost took place two weeks after the end of the second supplementation period, leading to the quality of the grazing deteriorating quickly. Furthermore the ruminal micro-organisms of the RUP and RDP groups would have taken some time to adapt to a roughage only diet, which could explain the lower milk production and thus the decrease in lamb growth rates. Lambs of the RUP and RDP groups were also slightly younger than the lambs of the Mineral group, and they were therefore probably more dependent on the ewes for nutrition than the lambs of the Mineral group, which were likely to be grazing more at this time. It is also possible that lambs of the Mineral group had started grazing at an earlier time, because their dams probably had a lower milk production than the RDP and RUP groups. A way to answer this question is to do further studies using either twin-bearing ewes, lower quality grazing or using higher stocking rates.

No significant differences were found when the wool production parameters were compared. This could have been due the length of the wool which was shorn at 10 months instead of 12 months. Shorter wool tends to be stronger because there is less along-fibre variation, and this may help to explain why the wool of the Mineral group was not weaker than the wool of the RDP or RUP groups. Wool of the Mineral group was slightly finer than the RDP and RUP groups but the differences were not significant. Also the price the farmer received for the two fibre diameter groups were similar, R31.52 for the fine microns and R30.80 for the medium microns. Thus it made little difference when the income from the wool was calculated, with the RUP and RDP groups' incomes only 2% lower than that of the Mineral group.

If the wool income is recalculated using prices from about 1996, when the average wool price was much lower (about 50% less) and had a difference of about 10% between fine and medium wool, the economic differences become slightly more obvious with the RUP group 3% lower, and the RDP group 6% lower than the Mineral group. However, in contrast, if prices from 2000 are used, which were about 15% higher than the 2002 prices with a difference of about 25% between fine and medium micron wool, the difference becomes more substantial. The income from the RDP group is then 10% lower while the

RUP group's income is just 5% lower than the Mineral group's. This indicates that supplementation may have a negative effect on wool income if the price of fine micron wool is substantially higher than that of medium micron wool.

The cost of the supplements of the RUP and RDP groups were respectively about 20 times and 12 times more expensive than the Mineral group's supplement. Thus even though the lamb incomes obtained from the RDP and RUP groups were higher than that of the Mineral group, the cost of the licks made it unviable from a cost-benefit perspective. The profit made from the Mineral group was significantly higher than that of the RUP group for both calculations. It was however, more significant at gross margin 2 ($P < 0.008$) compared to gross margin 1 ($P < 0.03$).

In this trial, the ratio of the price of 1 kg wool compared to 1 kg meat was about 4:1. Therefore the loss of income due to a low weaning percentage was mostly eliminated because even though some ewes did not produce a lamb, they still produced wool. If the market changes and the ratio become smaller e.g. 2:1, not producing a lamb would have a more significant impact. Thus, for instance, if the meat price was R10 for 1 kg live weight and the wool price was R20 per kg medium micron wool and R25 for fine micron wool, then the wool income per group would be about R57 per ewe for the Mineral group and R55 and R52 for the RUP and RDP groups respectively. The meat income at the same average weights and weaning percentages as in the trial, would be R61, R90 and R76 for the Mineral, RUP and RDP groups respectively. Thus total income would be R118, R146 and R128 for the Mineral, RUP and RDP groups respectively. If the feed costs are then subtracted (using the same as in the trial) the respective gross margins (Mineral, RUP, RDP) would be R114, R71 and R83 which is similar to the results of the present study (Mineral = R107.77; RUP = R54.93 and RDP = R74.12). If feed costs are decreased by 25%, the respective gross margins of the Mineral, RUP and RDP groups would be R115, R90 and R94. Thus even with half the wool income and a 25% decrease in feed costs, the Mineral group would still be the most profitable. If the ratio is taken at 1:1 with meat at R10 per kg and all wool at R10 per kg (thus disregarding fibre diameter) then the respective gross margins are R82, R40 and R55 at full cost of supplements and

R83, R58 and R67 at 75% of feed costs. Thus even at an equal meat to wool price ratio, the Mineral group would probably still be more profitable.

Accelerated breeding e.g. lambing three times in two years, is a strategy used to increase farm profit. If such a system is used and the same survival percentages are used, the expected number of lambs weaned per ewe would be 0.72, 0.95 and 0.86 for the Mineral, RUP and RDP groups. The gross margins, using a 4:1 ratio would then be R186, R123 and R147 at full feed costs, or R188, R151, R163 at 75% of feed costs for the Mineral, RUP and RDP groups respectively. If a 2:1 ratio is used the respective gross margins would be R136, R73 and R97 at full feed costs or R137, R101 and R114 at 75% of feed cost for the Mineral, RUP and RDP group. Thus even in an accelerated breeding system where meat income forms a bigger part of the profit, the Mineral group would probably still be the most profitable.

Nearly all the ewes had single lambs. In a flock with more multiples, the results may look very different, especially if it is taken into account that both the sets of twins in the Mineral group died. Thus as said earlier, using multiple bearing ewes would put ewes under more stress, which in turn could alter the results. Another possibility for further research would be to do a similar trial in other grazing areas.

The aim of this study was to determine if protein supplementation affected ewe performance and nematode resilience and if the improved performance was enough to justify the extra costs. In this study, ewe performance and lamb survival were increased, but the additional cost of the supplements made it an unviable option. Thus the hypothesis that strategic protein supplementation improves production proved correct but incorrect in respect to increasing gastrointestinal nematode resilience and being economically beneficial to ewes on natural grazing.

In all of these scenarios, substantial price increases and differences did not make protein supplementation economically viable under the conditions studied. However, all of these calculations are based on results from this study, therefore it is important to remember that this trial was done in a specific grazing area, the sourveld, during a good grazing season and the sample size was relatively small. Another factor is the breed and type of sheep used. The ewes in this study have been selected for good quality wool production over an eight year period. If a more meat-type breed with lower quality wool were used, the results could have been different. This trial only covered a single breeding season. It would be difficult to speculate on the performance of the ewes in the next season, thus a trial covering several breeding seasons would be good for further research.

CONCLUSIONS AND RECOMMENDATIONS

Strategic protein supplementation as applied in this experiment, improved performance data significantly. It did not influence the resilience of the ewes to nematodes or the parameters of their wool production. However, the cost of the licks was not justified economically by the improvements in performance. Thus during good grazing seasons on the Highveld, protein supplementation is not necessarily cost-effective. Farmers and their advisors should therefore carefully consider the following before making decisions regarding the advisability of protein supplementation:

- do they expect a good grazing season?
- do they have enough good quality grazing?
- what is the main product, meat, wool or both?
- do they expect a high percentage of multiples?
- what is the ratio of the meat price income compared to the wool price?
- what is the cost of supplements?
- do they plan to breed the ewes once a year or with an accelerated system?

Only after considering all the factors carefully can an informed decision be made. This is very important because feed supplements can be very expensive and although they may be cost effective in certain circumstances, in other situations they will not be economically justifiable.

CHAPTER 6

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