Copyright is owned by the Author of the thesis. Permission is given for a copy to be downloaded by an individual for the purpose of research and private study only. The thesis may not be reproduced elsewhere without the permission of the Author.
The Effect of Feeding Willow
Upon the Death of Established Parasites
and Upon Parasite Fecundity

A Thesis presented in partial fulfilment of the requirements for the degree of
Master in Animal Science
at
Massey University, Palmerston North, New Zealand

Bornwell Mupeyo
2010
Declaration

The studies presented in this thesis were completed by the author whilst a Postgraduate student in the Institute of Veterinary and Biomedical Science, Massey University, Palmerston North, New Zealand. I hereby affirm that the content of this thesis is original research conducted by the author. All views and conclusions are the sole responsibility of the author. All references to previous work are included in the references section of each chapter. Any assistance received during the preparation of this thesis has been acknowledged.

I certify that the content of this thesis has not already been submitted for any degree and is not being currently submitted for any other degree. I certify that to the best of my knowledge any help received in preparing this thesis, and all sources of material used, have been acknowledged in the thesis.

Candidate: Bornwell Mupeyo
Signature:

Chief Supervisor: Professor Tom N. Barry
Signature:

Co-supervisor: Professor Bill Pomroy
Signature:
Abstract

Two indoor feeding experiments were conducted at the Animal Physiology Unit (APU) of Massey University, involving young sheep, to investigate the effect of feeding forage willow upon the death of established parasites and upon parasite fecundity, using chaffed lucerne as the control diet.

**Experiment 1**: Twenty-four (24) parasite-free weaned hoggets weighing 29.9 ±1.2 kg (SD) were individually penned and fed chaffed lucerne *ad libitum* during a pre-experimental adaption period of 5 weeks. They were then fed either lucerne chaff or chopped willow for a further 5 weeks (n = 12/group) and intakes were adjusted such that the DMI of the two groups was similar during weeks 9 & 10. All lambs were infected with L₃ larvae parasites comprising 20,650 *Teladorsagia*, 1,320 *Trichostrongylus* and 330 *Cooperia* through oral drenching 12 days before willow feeding started. This was done after confirmation that the sheep were free of nematodes through FEC analysis. Total faeces were collected for 3 day periods towards the end of weeks 9 & 10, to measure diet digestibility and total faecal egg excretion. The sheep were slaughtered at the end of week 10. Voluntary feed intake (VFI), FEC and liveweight were measured weekly, whilst burdens of individual parasites and carcass characteristics were measured after slaughter. Duplicate samples of each feed offered and individual animal refusals were taken daily and pooled weekly per animal for chemical analysis. Female worm fecundity was calculated by two methods. Blood samples for immunological analysis were collected on days 20, 34, 51 and 70, and analysed for components of white blood cells (WBC) and for lymphocyte subsets.

**Experiment 2**: A 2 x 2 changeover experiment was conducted, involving two time periods (Period 1 and Period 2 each of 14 days) with the same diets as used in Experiment 1, fed to 9 individually penned parasite-free young sheep randomly allocated to experimental diets. The parameters investigated were FEC and larvae hatching. Initially, a period of 7 days was allowed for acclimatisation in which both groups were fed on half willow and half lucerne chaff. This was followed by Period 1 with 4 lambs fed lucerne and 5 fed willow, after which the diets were changed over
for Period 2. Total faeces produced were collected from all animals on the last day of each period using bagged sheep. A known number of Teladorsagia eggs (500 epg) was then added to faecal samples from these sheep and faeces-egg mixtures were made from which FEC was determined, to see if egg recovery was affected by these diets. Faecal samples for Period 2 with added eggs were also incubated for 10 days to measure hatchability.

The recovery of added Teladorsagia eggs in Experiment 2 was 85% in lucerne-fed lambs and 53% willow-fed lambs (P<0.001); these were used as correction factors for Experiment 1 data. Larvae that hatched per gram of wet faeces in Experiment 2 tended to be lower for sheep fed willow than lucerne chaff (71% vs 83% of eggs added; P=0.08).

Willow feed offered had lower DM (P<0.001) and CP (P<0.05) content, but had a significantly higher OM content (P<0.01) than lucerne chaff. Condensed tannin content of chopped willow was 27 g/kg DM, with only traces for lucerne. Apparent digestibility for DM (62.4% vs 59.5%; P≤0.05), OM (64.8% vs 59.9%; P≤0.001), DOMD (58.1% vs 55.0%; P≤0.01) and calculated ME (9.48 MJ/kg vs 8.96 MJ/kg; P≤0.01) were higher for the willow diet. VFI was similar for both groups during the adaption period (P>0.05) but declined with the introduction of willow in week 6 (P<0.001) and then progressively increased until it was similar to lucerne-fed sheep in weeks 9 & 10 (P>0.05). Calculated DM intake per head/day during the last two weeks of Experiment 1 was similar for the two groups (P>0.05); while the willow group had higher ME (P<0.01) and CP (P<0.001) intake per animal/day. Liveweight increased for the two groups during the adaption period (P>0.05), then declined for willow-fed lambs in week 6 (P<0.001) but later increased and by week 10 was similar to that of lucerne-fed lambs. The willow-fed lambs had lower carcass GR than the lucerne-fed lambs (P<0.01) when carcass weight was used as a covariate. Adjusted total daily egg production in Experiment 1 was lower in willow-fed sheep than lucerne-fed sheep, due to reductions for Haemonchus spp. (P<0.05) and Teladorsagia spp. (P<0.05). The per capita fecundity for Haemonchus worm spp. (P<0.05) and the in utero fecundity in both abomasal Teladorsagia spp. and small intestinal Trichostrongylus spp. (P<0.001) were lower for willow-fed sheep. There was reduced production of larvae for both Haemonchus spp. and Teladorsagia spp. (P<0.05) in willow-fed sheep.
Feeding willow reduced the burden of *Haemonchus* adult worms in the abomasum (P<0.01) but reduced female worm burden only in *Teladorsagia* spp. (P<0.05) and reduced *Cooperia* spp. in the small intestines (P<0.01). Total WBC, total lymphocytes, subsets of lymphocytes and other white-cell groups were not affected by willow feeding (P>0.1).

It was concluded that feeding chopped willow to young sheep reduced nematode worm burdens in the abomasum, especially both male and female *Haemonchus* spp., and reduced female worm burdens of *Teladorsagia* spp. Female worm fecundity of both species was also reduced by willow feeding. These reductions have been associated with CT content in the willow feed and the reduced worm burdens have been attributed to the death of the established worms by CT, since there was no evidence of immune priming in willow-fed sheep. Compounds present in the faeces of willow-fed sheep have been found to mask some of the nematode eggs, making them invisible by microscopic examination while keeping their viability. It is postulated that this could be due to binding of nematode eggs to insoluble CT associated with indigestible fibre in the faeces of willow-fed sheep. Conventional methods of measuring FEC therefore underestimated nematode eggs present in the faeces of willow-fed sheep and this needs to be checked for other CT-containing forages.
Acknowledgements

Acknowledgement is due to my supervisors: Professor T.N. Barry and Co-supervisors; Professor W.E. Pomroy and Dr. N. Lopez-Villalobos. They all gave unstintingly of their time, were constantly available and extremely supportive. In addition, I would like to thank all of the staff and support people in the Institute of Veterinary and Biomedical Sciences who have assisted in the process of study and the completion of my research report. Particular mention goes to Kevin Stafford – Head of IVABS for his supportive stance throughout the writing process. Thanks are also due to the following: Geoff Purchas, Dr. C. Ramirez-Restrepo, A. Pernthaner, Barbara Addlington and Anne Tunnicriffe; without their assistance the research would not have been possible. Special thanks go to The Taupo Animal Welfare & Veterinary Society and Massey University for sponsoring this research. Thanks also go to staff at Greater Wellington Regional Council for providing willow fodder used in the experiments. Many thanks to staff at New Zealand Veterinary Pathology Ltd and Massey University Nutrition laboratory for analysing my samples.

I am also very grateful to Sylvia Hooker, Olive Pimentel, Natalia Benquet and Dianne Reilly. These four persons make up the Massey face of NZAID and they are the most wonderful, caring and supportive people I have ever meet. I am deeply indebted to NZAID through the Ministry of Foreign Affairs and Trade, NZ; their assistance and caring approach should not be underestimated. I am sure that the generous support my family and I have received from the New Zealand government will enable me to make a contribution to Zambia – a gift that will forever be a small part of New Zealand. Mention is due also to the Zambian Government through the Ministry of Agriculture and Cooperatives for allowing me to undertake my studies.

Furthermore, I would like to extend my thanks to my colleagues Eugene Ndeke & family, Ben Bauer, Belen Lazzarini, Juriah Kamaludeen and Ishmael Mumba who have sat alongside me for nearly two years now; I will miss them. To all of the local Zambian community who have become my family – thank you. The many foreign nationals who have entered my life and I theirs – thanks. To all the New Zealanders who made this a memorable moment in my life – Kia Ora.
Finally, a special mention is due to my loving wife Florence and our four wonderful children, Kerry, Bornwell (Jr), Nchimunya and Lushomo. Each of them has made a sacrifice in order for me to reach my potential and I thank them. All of us will miss New Zealand, it is with great sadness that we leave however, it is with great joy, new knowledge and improved understanding of the world that we take our leave – *mucaale cibotu!*
Dedication

I dedicate this work to my Chief Supervisor Prof. T.N. Barry (Tom) who, even in his time of illness, was able to encourage me to keep working. To you I say: Bravo!!

NDALUMBA KAPATI
<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AA</td>
<td>Amino Acids</td>
</tr>
<tr>
<td>AAD</td>
<td>Amino-acetonitrile derivatives</td>
</tr>
<tr>
<td>ADF</td>
<td>Acid Detergent Fibre</td>
</tr>
<tr>
<td>AFRC</td>
<td>Agriculture and Food Research Council</td>
</tr>
<tr>
<td>AOAC</td>
<td>Association of Official Analytical Chemists</td>
</tr>
<tr>
<td>ARDOM</td>
<td>Apparently Rumen Digested Organic Matter</td>
</tr>
<tr>
<td>ATP</td>
<td>Adenosine Triphosphate</td>
</tr>
<tr>
<td>Ca</td>
<td>Calcium</td>
</tr>
<tr>
<td>CCK</td>
<td>Cholecystokinin</td>
</tr>
<tr>
<td>CH₄</td>
<td>Methane</td>
</tr>
<tr>
<td>CHO</td>
<td>Carbohydrate</td>
</tr>
<tr>
<td>CO₂</td>
<td>Carbon dioxide</td>
</tr>
<tr>
<td>CP</td>
<td>Crude Protein</td>
</tr>
<tr>
<td>CSIRO</td>
<td>Commonwealth Scientific and Industrial Research Organization</td>
</tr>
<tr>
<td>CT</td>
<td>Condensed Tannins</td>
</tr>
<tr>
<td>CV</td>
<td>Coefficient of variation</td>
</tr>
<tr>
<td>CW</td>
<td>Carcass weight</td>
</tr>
<tr>
<td>DM</td>
<td>Dry Matter</td>
</tr>
<tr>
<td>DMI</td>
<td>Dry Matter Intake</td>
</tr>
<tr>
<td>DOMD</td>
<td>Digestible Organic Matter in the Dry Matter</td>
</tr>
<tr>
<td>DP</td>
<td>Digestible Protein</td>
</tr>
<tr>
<td>EAA</td>
<td>Essential Amino Acids</td>
</tr>
<tr>
<td>epg</td>
<td>Eggs per gram</td>
</tr>
<tr>
<td>FEC</td>
<td>Faecal Egg Count</td>
</tr>
<tr>
<td>FV</td>
<td>Feeding value</td>
</tr>
<tr>
<td>GDP</td>
<td>Gross Domestic Product</td>
</tr>
<tr>
<td>GI</td>
<td>Gastrointestinal</td>
</tr>
<tr>
<td>GIN</td>
<td>Gastrointestinal nematodes</td>
</tr>
<tr>
<td>GIT</td>
<td>Gastro-intestinal tract</td>
</tr>
<tr>
<td>GR</td>
<td>Girth Rib (measurement of carcass fat thickness)</td>
</tr>
<tr>
<td>HCL</td>
<td>Hydrochloric Acid</td>
</tr>
</tbody>
</table>
HT  Hydrolysable Tannins
K   Potassium
Kcal Kilocalories
LDA Larval Development Assay
LMI Larval Migration Inhibition
LW  Liveweight
LWG Live weight Gain
M   Million
MAF Ministry of Agriculture and Forestry
MAFF Ministry of Agriculture, Fisheries and Food
ME  Metabolisable Energy
Mg  Magnesium
MJ  Mega Joules
MP  Metabolisable Protein
MW  Molecular Weight
N   Nitrogen
NAN Non-Ammonia Nitrogen
NDF Neutral Detergent Fibre
NEAA Non-Essential Amino Acids
NH₃ Ammonia
NV  Nutritive Value
OM  Organic Matter
OMD Organic Matter Digestibility
OR  Ovulation Rate
P   Phosphorus
PA  Proanthocyanidins
PEG Polyethylene glycol
SAS Statistical Analysis System
SEM Standard error of the means
SI  Small intestine
SolCHO Soluble carbohydrates
SSH Sward surface height
Spp. Species
UDP Un-degradable Protein
<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>UoB</td>
<td>University of Aberdeen</td>
</tr>
<tr>
<td>VFA</td>
<td>Volatile Fatty Acids</td>
</tr>
<tr>
<td>VFI</td>
<td>Voluntary Feed Intake</td>
</tr>
<tr>
<td>WBC</td>
<td>White Blood Cells</td>
</tr>
</tbody>
</table>
# Table of Contents

Abstract ........................................................................................................................................... i
Acknowledgements ......................................................................................................................... iv
Dedication ........................................................................................................................................ vi
List of Abbreviations ....................................................................................................................... vii
Table of Contents ............................................................................................................................ x
List of Figures ................................................................................................................................... xiv
List of Tables ..................................................................................................................................... xvi
List of Plates ..................................................................................................................................... xviii

CHAPTER 1 REVIEW OF THE LITERATURE ............................................................................. 1

1.1 INTRODUCTION ....................................................................................................................... 1

1.2 SHEEP PRODUCTION UNDER GRAZING IN NEW ZEALAND
(GRAZING SYSTEMS, NUTRITIONAL AND PARASITIC LIMITATIONS) ..................... 3

1.2.1 Sheep grazing systems .......................................................................................................... 3
   Set or Continuous stocking system ............................................................................................ 4
   Rotational paddock grazing system .......................................................................................... 5
   Strip grazing ............................................................................................................................... 5
   Choice of system ......................................................................................................................... 6

1.2.2 Nutritional limitation (excess/deficits - energy/protein) with fresh forage diets ................. 6

1.2.3 Limitations caused by parasite infections ............................................................................ 8

1.3 PLANT CHEMICAL COMPOSITION AND NUTRITIVE VALUE ...................... 10

1.3.1 Primary compounds in the plant ......................................................................................... 11
   1.3.1.1 Concentration in plants ............................................................................................... 11
   1.3.1.2 Digestion in animals .................................................................................................... 12

1.3.2 Secondary compounds in the plant ...................................................................................... 14
   1.3.2.1 Condensed tannins (CT) ............................................................................................ 15
   1.3.2.2 Role of CT .................................................................................................................. 17
   1.3.2.2.1 Protein digestion ..................................................................................................... 17
   1.3.2.2.2 Carbohydrate digestion .......................................................................................... 20
   1.3.2.2.3 Voluntary feed intake ............................................................................................. 20
   1.3.2.2.4 Animal production ................................................................................................. 21
   1.3.2.2.5 Mechanisms by which condensed tannins might affect parasites ......................... 22

1.4 FORAGE FEEDING VALUE .............................................................................................. 23

1.4.1 Grasses ................................................................................................................................. 23
1.4.2 Legumes .......................................................... 24
1.4.4 Tree forage ......................................................... 26
1.4.4.1 Willow as a tree forage ....................................... 26

1.5 INTERNAL PARASITES AND THEIR ROLE IN SHEEP PRODUCTION IN NZ .................................................. 28
1.5.1 Gastrointestinal nematode classification ......................... 28
1.5.2 Life cycle ............................................................ 29
1.5.3 Role of nematodes on farm production and profit ............... 31
1.5.4 Anthelmintic control and drench resistance .................... 31
1.5.5 Alternative nematode control strategies ......................... 35

1.6 MECHANISMS OF ALTERNATIVE NEMATODE CONTROL .......... 38

1.7 METHODOLOGY FOR MEASURING EFFECTS OF INTERNAL PARASITES ......................................................... 38
1.7.1 Effects of bioactive forages ....................................... 40
1.7.1.1 Nematode establishment ...................................... 40
1.7.1.2 Nematode fecundity ............................................ 41
1.7.1.3 Egg hatching .................................................... 42
1.7.1.4 Larval development ............................................ 44
1.7.1.5 Larval migration on plants .................................... 44
1.7.1.6 Immunological aspects ........................................ 44
1.7.1.7 Grazing systems studies ....................................... 46

1.8 CONCLUSION AND NEED FOR FUTURE RESEARCH ............. 48

1.9 REFERENCES FOR LITERATURE REVIEW ............................ 52

CHAPTER 2 ..................................................................... 69
THE EFFECT OF FEEDING WILLOW UPON THE DEATH OF ESTABLISHED PARASITES AND UPON PARASITE FECUNDITY ....... 69

2.1 INTRODUCTION ................................................................ 70

2.2 MATERIALS AND METHODS ........................................... 72
2.2.1 EXPERIMENT 1 .......................................................... 72
2.2.1.1 Animals and housing ............................................. 73
2.2.1.2 Feeds ................................................................. 73
2.2.1.3 Voluntary feed intake and apparent digestibility .......... 74
2.2.1.4 Parasitology ........................................................ 75
2.2.1.5 Haematology and Immunology ............................... 76
2.2.1.6 Slaughter sampling and measurements ..................... 77
# Appendices for Raw Data

## References

2.2.2.1 Animals and feeds ........................................ 80
2.2.2.2 Parasitology .............................................. 80
2.2.3 Statistical analyses ........................................ 81

## Results

2.3 RESULTS ........................................................................ 83

2.3.1 Diet composition .................................................. 83
2.3.2 Voluntary feed intake ............................................ 84
2.3.3 Liveweight and carcass weight ................................ 85
2.3.4 Nematode counts at slaughter from GI sections ......... 86
2.3.5 Faecal egg and L3 larval count .................................. 89
2.3.5.1 Faecal Egg Counts ............................................. 89
2.3.4.3 Worm Fecundity .............................................. 93
2.3.4.2 Total Egg Output for the Nematodes ................. 93
2.3.4.4 Larvae hatching from incubated faeces .................... 92
2.3.6 Immunological results ........................................... 95

## Discussion

2.4 DISCUSSION .................................................................. 97

2.4.1 Worm burdens ..................................................... 97
2.4.2 Fecundity ............................................................ 100
2.4.3 Action of condensed tannins on nematodes in the gut 100
2.4.4 Immunology ........................................................ 101
2.4.5 Determining FEC in animals fed CT-containing forages 102
2.4.6 Effects of CT on the life cycle of gastrointestinal nematodes 105

## Conclusion

2.5 CONCLUSION ................................................................ 106

## Appendices

APPENDICES .................................................................... 115

### Appendices for Materials and Methods

Appendix 1: Artificially infecting lambs with Ostertagia, Trichostrongylus and Cooperia ............................................. 116
Appendix 2: Modified McMaster Method for counting of eggs ......................................................... 117
Appendix 3: Larvae culture .................................................. 118
Appendix 4: Baermann’s Technique for larvae recovery ............................................. 119
Appendix 5: Counting third stage larvae ...................................... 120
Appendix 7: Worm count ..................................................... 122
Appendix 8: Recovery of nematode eggs from faeces samples ..................................... 125
Appendix 9: Procedure for Faecal Pie Making - SOP ................................................. 127

### Appendices for Raw Data

xii
Appendix 10: Dry matter intake per day.................................................................129
Appendix 11: Weekly Liveweight (kg) .................................................................130
Appendix 12: GR Measurements........................................................................131
Appendix 13: Weekly FEC (eggs/g faeces).........................................................132
Appendix 14: Egg output during the first 3 days of the last week of willow feeding
...........................................................................................................................133
Appendix 15: Egg output per Nematode species (uncorrected) .......................134
Appendix 16: Egg output per Nematode species (corrected) .........................135
Appendix 17: Production of L3 larvae through egg incubation ....................136
Appendix 18: Adult worm counts – Abomasum ..............................................137
Appendix 19: Adult worm counts – Small intestines .......................................138
Appendix 20: Female worm fecundity (per capita & in utero) ..........................139
Appendix 21: Experiment 2 egg recovery data..................................................140
List of Figures

Figure 1. 1: Showing protein metabolism in sheep infected with gastrointestinal nematode (Sykes & Greer, 2003) ........................................................................................................... 9

Figure 1. 2: Showing chemical composition of pastures (McWilliam, 2004; PhD thesis) .................................................................................................................................................. 10

Figure 1. 3a & b: Chemical structures of (a) hydrolysable (HT: Mueller-Harvey, 2001) and (b) condensed (CT: Saito et al., 2002) tannins. ...................................................... 15

Figure 1. 4: Duodenal non-ammonia nitrogen (NAN) flow per unit total nitrogen intake as a function of herbage condensed tannin concentration in sheep fed on Lotus species. (O), High- and (●) low-tannin Lotus pedunculatus; (Δ), high- and (▲) low-tannin Lotus corniculatus. Results are compared with the non-tannin-containing herbage; (=□), short rotation ryegrass; (□), perennial ryegrass; (■), white clover. All results are for a nitrogen intake of 28 g/d and refer to fresh forages. From Barry & Manley (1984) ........................................................................................................ 19

Figure 1. 5: (a) General life cycle of nematodes (b) Life cycle of Nematodirus. (From University of Aberdeen; UoA, 2006) ..................................................................................... 30

Figure 1. 6: Showing regression analysis of percentage of eggs hatched in various concentrations of oxfendazole and condensed tannins in vitro (Iqbal et al., 2007). ........................................................................................................................................ 43

Figure 1. 7: Showing the relative distribution of infective nematode larvae on pasture (Vlassoff, 1982) .................................................................................................................... 47

Figure 2. 1: Dry matter intake for the whole experimental period in penned sheep offered either lucerne chaff (■) or chopped willow (Δ) diets. Solid line (▬) is the period of adaption on lucerne chaff. (*** ) DMI during these weeks differ significantly (P≤0.001). (І) Standard error of the means. larval infection given. ................................................................................................................................. 84

Figure 2. 2: Liveweight for the whole experimental period in penned sheep offered either lucerne chaff (■) or chopped willow (Δ) diets. Solid line (▬) is the period of adaption on lucerne chaff. (*** ) and (*) Liveweight during these weeks differ significantly (P≤0.01 and P≤0.05, respectively). (І) Standard error of the means. larval infection given. ................................................................................................................................. 85

Figure 2. 3(a), (b), (c) and (d): FEC for penned sheep offered either lucerne chaff (■) or chopped willow (Δ) diets. Solid line (▬) is the period of adaption on lucerne chaff. (*), * and *** FEC during these weeks differ significantly (P<0.10; P≤0.05 and P≤0.001 respectively). (І) Standard error of the means. larval infection given, with willow feeding started 12 days later. ........................................ 90
Figure 2. 4a & b: Relationship between corrected faecal egg count (Δ) and dry matter intake (■) in young sheep fed either chaffed lucerne or chopped willow diets in Experiment 1.
List of Tables

Table 1.1: Productivity and the New Zealand Sheep Population, 1982-2008. ............2

Table 1.2a: Dry matter (DM), crude protein (CP) and neutral detergent fibre (NDF) composition of fresh leaf forages.................................................................11

Table 1.2b: Seasonal variation in the mean digestible organic matter in the dry matter (DOMD), acid detergent fibre (ADF), neutral detergent fibre (NDF), crude protein (CP), soluble carbohydrates (SolCHO), pectin, phosphorus (P), calcium (Ca), and magnesium (Mg) concentration (g/100g DM) of pastures (adapted from (Penno, 2002)) .................................................................11

Table 1.3: Condensed tannin concentration in temperate forage species which are of significant value to New Zealand farming systems. CT measured by butanol-HCL method° and is a sum of extractable, protein-bound and fibre-bound CT fractions..................................................................................................................16

Table 1.4: Effect of condensed tannins (CT) on the digestion of amino acids in the small intestine of sheep fed L. corniculatus (22 g CT/kg DM) or L. pedunculatus (55 g CT/kg DM) with (-CT) or without (+CT) a continuous intra-ruminal infusion of polyethylene glycol .................................................................20

Table 1.5: Chemical composition and nutritive value of perennial ryegrass with maturity as % of DM. .................................................................................................24

Table 1.6: A comparison of chemical composition in perennial ryegrass, red clover and chicory...........................................................................................................25

Table 1.7: Comparison of feed break down and outflow from the rumen in red deer fed perennial ryegrass and chicory under indoor conditions. .........................25

Table 1.8: Chemical composition of pasture diet selected by ewes grazing low quality drought pastures which have been supplemented with willow cuttings. ........27

Table 1.9: Chemical composition of control drought pasture and willow folder block selected diet grazed by sheep.................................................................28

Table 1.10: Important NZ nematode parasites of sheep ..............................................29

Table 1.11: Rank transformed total adult nematode intensity per gram organ weight of lambs naturally infected with parasites, after grazing chicory, lotus and ryegrass/white clover for 35 days. .........................................................40

Table 1.12: The effects of ryegrass and lotus on adult male and female O. circumcincta and T. colubriformis establishment, eggs per female and male to female ratios.........................................................................................................................41
Table 2. 1: Chemical composition of the forages offered to penned sheep fed either lucerne chaff or chopped willow.................................................................83

Table 2. 2: Apparent digestibility of dry matter, organic matter and calculated metabolisable energy concentration in penned sheep fed either lucerne chaff or chopped willow........................................................................83

Table 2. 3: Calculated intakes of dry matter, crude protein and condensed tannins during the last two weeks of experiment in penned sheep fed either lucerne chaff or chopped willow...............................................................................85

Table 2. 4: The effect of feeding either lucerne chaff or chopped willow on the final liveweight, carcass weight and carcass fatness of sheep.................................................................86

Table 2. 5a: The effect of feeding lucerne chaff or chopped willow upon the burdens of adult worms in the abomasum and small intestines of young sheep...............87

Table 2. 5b: Nematode speciation data showing proportion of worm species found in the abomasum and small intestines of lambs fed either lucerne chaff or chopped willow.................................................................88

Table 2. 6: Recovery of Teladorsagia eggs added to the faeces (500 eggs/g wet faeces) of parasite-free young sheep fed either chaffed lucerne or chopped willow (log_{10} transformed data with back transformed data in parenthesis). ....89

Table 2. 7: Calculated daily faecal egg production per female worm1 and eggs/female worm recovered at necropsy2 in young sheep fed chaffed lucerne or chopped willow. .................................................................................................94

Table 2. 8: Daily faeces egg production in young sheep fed chaffed lucerne or chopped willow. Adjusted data have been corrected for loss of egg recovery determined in Experiment 2.................................................................91

Table 2. 9: Daily larvae developing to ensheathed L3 from incubated faeces of young sheep fed chaffed lucerne or chopped willow. (Log_{10} transformed data with back transformed means for a range of nematode species). ..............................................92

Table 2. 10: Square root transformed white blood cell (WBC) data for young sheep fed lucerne and willow using the mean of pre-treatment Day 20 and Day 34 as a covariate. Values in parenthesis are back-transformed.................................95
List of Plates

Plate  1: Lamb eating chaffed lucerne.................................................................74
Plate  2: Lamb eating chopped willow ...............................................................74
Plate  3: Pushing the stomach tube into the stomach in readiness for worm infection75
Plate  4: Administering the infective larvae.....................................................75
Plate  5: Bag attached for faecal collection .......................................................76
Plate  6: Blood sampling....................................................................................76
Plate  7: Sorting out GIT sections.....................................................................77