

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.

# PASTURE DYNAMICS UNDER CATTLE TREADING

A thesis presented in partial fulfilment  
of the requirements for the degree of

*Doctor of Philosophy (PhD)*

in  
Plant Science



Institute of Natural Resources  
**Massey University**  
Palmerston North, New Zealand

Tara Nath Pande

2002

## ABSTRACT

Treading damage by cattle in wet winters is an important limitation for all-grass wintering systems in New Zealand. This study evaluated the impact of cattle treading in winter on pasture plants in both hill country and flat dairy pasture over three trials.

On hill country pasture, one severe treading treatment in winter resulted in losses in herbage accumulation rate of 9 kg (or 25%) DM ha<sup>-1</sup> day<sup>-1</sup> on tracks and 6 kg (or 26%) DM ha<sup>-1</sup> day<sup>-1</sup> on slopes compared to relatively untrodden treatments over a 9 month (Aug 98 to April 99) period. In repeatedly trodden treatments at heavy stocking rates, the loss in herbage accumulation rate averaged 19 kg (or 54%) DM ha<sup>-1</sup> day<sup>-1</sup> in tracks but found no loss on slopes compared to lightly grazed treatments over the same period. Treading seriously reduced pasture cover and changed species that contributed cover.

In flat dairy pastures, the loss of herbage accumulation rate was 29 kg (or 36%) DM ha<sup>-1</sup> day<sup>-1</sup> in highly damaged areas, and 5 kg (or 7%) DM ha<sup>-1</sup> day<sup>-1</sup> in low- to medium-damaged areas compared to untrodden areas during the 7 weeks regrowth after treading. This loss in herbage accumulation rate was associated with an initial 66% reduction in grass tiller density in high-damaged areas. Treading also reduced leaf area index. Post-treading pasture cover was only 43% in high-damaged areas compared to 80% in untrodden areas. Compared to other grass species, perennial ryegrass was least affected by treading. Losses in herbage mass and tiller density as a result of treading recovered, or tended to recover, by the end of the 7-week regrowth period.

In a second experiment on dairy pasture, treading in winter, again, greatly reduced residual herbage mass and tiller population density. Losses in both residual herbage mass and tiller density recovered by the end of the 7-week regrowth period. Differences in pasture height before treading did not effect pasture growth but, relative to the tall canopy height, the short canopy height enhanced tillering of ryegrass during the recovery period. The effect of treading on the weight of ryegrass tillers was small. An important aspect of treading was its role in increasing tiller appearance rate of ryegrass and encouraging faster growth of these newly developed tillers. Ryegrass-dominant pastures recovering from treading damage are reliant on the emergence and growth of new tillers.

**Keywords:** Treading, herbage accumulation rates, tiller density, tiller weight, leaf area index, grazing management, tiller appearance rate, cattle, sheep.

*This thesis is dedicated to my parents,  
Kushmakhar and Tilak Maya Pandey  
for all their love and support over the years.*

## ACKNOWLEDGEMENTS

I am particularly grateful to Professor John Hodgson, Institute of Natural Resources (Pasture and Crops), Massey University, for providing me with the opportunity to undertake a PhD study. Without his support, I would simply not have been able to accomplish it. I thank Professor John Hodgson for his enthusiasm, encouragement, guidance and generous support from the very initial correspondence, while I was doing M. Sc. Study in Wageningen Agricultural University, The Netherlands, to the completion of this degree.

I would like to express my deepest gratitude to my supervisors Dr Ian Valentine (chief) and Dr David Horne, Institute of Natural Resources, Massey University, and Keith Betteridge and Dr. Alec D. MacKay, AgResearch Grasslands, for their patience, enthusiastic encouragement, guidance and close supervision throughout the course of this study. Their invaluable advice, constructive criticism, understanding and continuous support have made this study fruitful. Above all, they have set numerous examples and a very high professional standard for me to follow and I have most joyfully benefited.

My special thanks to Dr. Cory Matthew, Dr. Peter Kemp and Dr. Kerry Harrington for their valuable help in different ways. I am grateful to Prof. Jacqueline S. Rowarth for her encouragement and support. Thanks to Dr. Greg Lambert and Dr. Peter Singleton, AgResearch, for giving me helpful advice and lending me invaluable reference material. Thanks are also extended to Duncan Hederly and Dr. Bruce Mackay, Massey University for statistical advice and Dr. Chris Anderson for valuable help and support.

I am grateful to the staff at AgResearch Grasslands, who helped me immensely to carry out both field and laboratory work. My thanks goes to Des Costall for his help and friendship from very beginning of the project to the end. His highly skilled sampling, measurement and data management techniques (together with his endless patience) is much appreciated. Thanks are extended to Yvonne Gray, Shona Brock, Christine van Meer and Margaret Greig (Herbage Dissection Laboratory), and to Ross Gray, Philip Budding and Julie McIntosh for their appreciable help and friendly manner in different ways.

In the field work I was helped by John Napier, Mark A. Osborne, Roger S. Levy, Gareth Evans and Martin Chesterfield, who made sure I had everything I needed, from the fencing set up, and sampling collection to invaluable help with cattle handling, I thank you all. I have also had the kind support of Kathy Hamilton, Hera Kennedy, Irene Manley, Pamela Howell, Lois Mather, Denise Stewart and Judith Kidd, to whom I am very grateful.

Many thanks to my fellow graduate students Nava Raj Devkota, Mohamed Ugool, Rudy, Binod Maharjan, Bijay and Bijaya Adhikari, Entin Daningsih, Andrew Wall, José Luis Rossi, Dora Duarte de Carvalho, Wagner Bescow, Christian Hepp, Patricia Salles, Melissa Ercolin, Sumanasena, Tri Priantoro and Daowei Zhou from whom I shared the enjoyable times, friendship and help in many ways. Thanks to all my Nepalese friends and families in Palmerston North and elsewhere in New Zealand. Their friendship and help cannot be forgotten.

My heartfelt thanks to George and Lesley Paton, Tony and Janine Rasmussen, Akira and Kikuko Doi, Terry and Jenny McGrath, Anthony and Helen Goldie, Kevin and Anne Bellringer, Bruce and Rosemary Teulon for their friendship and help; and to our

many other Kiwi, English, Asian and Latin American friends and families who made life in New Zealand so enjoyable for me and my family.

I am most grateful, and cannot describe the never ending support, encouragement and patience of my parents, Kushmakhar and Tilak Maya Pandey over the years of study to reach this goal. I thank them, and my brothers and sisters, nephews and nieces, all my relatives, friends and families in Nepal and elsewhere for their love, encouragement and eternal support.

Furthermore, I thank all other people who helped me during my study and are not mentioned here.

Finally, my profound gratitude to my wife, Narayani Tiwari, who has made my work possible and for bringing our family cheer and happiness; Narayani left everything and sacrificed her own career to accompany me to New Zealand and without her continuous infusions of love, support, encouragement and above all PATIENCE!... I just couldn't have made it. She always managed to pull all the difficult times into perspective and convince me that there is an end to everything.

My beloved son, Shreejan Pandey (18), taught me more than anything during these recent years and helped me wonderfully in both the home and field, and specially for caring for me while writing this thesis.

Tara

# TABLE OF CONTENTS

Abstract .....	i
Acknowledgements.....	iii
Table of contents .....	vi
Appendices .....	x
List of Tables.....	xi
Lists of Figures .....	xiv
List of Plates.....	xvi
<b>CHAPTER 1 GENERAL INTRODUCTION .....</b>	<b>1</b>
<b>CHAPTER 2 LITERATURE REVIEW .....</b>	<b>4</b>
2.1. INTRODUCTION AND OVERVIEW .....	4
2.2. DEFINITION.....	6
2.3. GRAZING MANAGEMENT.....	8
2.3.1. Loss of pasture production.....	9
2.3.2. Animals.....	11
2.3.2.1. Treading pressure .....	12
2.3.2.2. Stocking rate.....	13
2.4. EFFECT OF TREADING ON PASTURE.....	13
2.4.1. Plant damage .....	13
2.4.2. Recovery .....	15
2.4.2.1. Species specific effects .....	17
2.4.2.2. Bare ground.....	19
2.4.2.3. Recruitment .....	19
2.5. EFFECTS OF TREADING ON SOIL.....	21
2.5.1. Mechanisms of soil failure under treading .....	25
2.5.1.1. Compaction (near field capacity) .....	25
2.5.1.2. Plastic deformation (near saturation).....	27
2.5.2. Effects of treading on soil physical properties.....	29
2.5.3. Effect of treading on chemical processes .....	32
2.5.4. Effect of treading on biological processes.....	32
2.6. BENEFICIAL EFFECTS .....	32
2.7. ENVIRONMENTAL EFFECTS .....	33
2.8. MANAGEMENT PRACTICES TO LIMIT TREADING DAMAGE .....	35
2.9. SUMMARY AND CONCLUSIONS .....	37



**CHAPTER 3 THE IMPACT OF CATTLE TREADING ON HILL PASTURE..... 39**

3.1. INTRODUCTION.....	39
3.2. MATERIALS AND METHODS .....	41
3.2.1. Site and pasture.....	41
3.2.2. Trial history .....	42
3.2.3. Design and treatments.....	43
3.2.4. Measurement dates .....	46
3.2.5. Measurements.....	46
3.2.5.1. Soil moisture.....	46
3.2.5.2. Soil bulk density, infiltration rate, air-filled porosity and total porosity .....	46
3.2.5.3. Canopy cover .....	47
3.2.5.4. Herbage accumulation.....	49
3.2.5.5. Botanical composition.....	50
3.2.5.6. Tiller density.....	50
3.2.6. Statistical analysis.....	50
3.3. RESULTS .....	51
3.3.1. Soil water content (vSWC) .....	51
3.3.2. Soil dry bulk density and infiltration rate .....	52
3.3.4. Air-filled porosity and total porosity .....	54
3.3.5. Herbage accumulation rates on tracks and slopes .....	55
3.3.6. Botanical composition .....	58
3.3.7. Bare ground and pasture species cover.....	61
3.3.8. Tiller population density .....	64
3.4 DISCUSSION .....	66
3.4.1. Soil conditions.....	66
3.4.2. Treatment effects on herbage accumulation .....	68
3.4.3. Pasture cover, botanical composition and tiller density .....	72
3.4.4. Relationship between pasture accumulation rate and pasture cover .....	80
3.5. CONCLUSIONS.....	81

**CHAPTER 4 TREADING DAMAGE AND REGROWTH OF A DAIRY PASTURE..... 84**

4.1. INTRODUCTION.....	84
4.2. MATERIALS AND METHODS .....	85
4.2.1. Soil and Pasture .....	85
4.2.2. Trial Design and grazing/treading damage .....	86
4.2.3. Measurements.....	90
4.2.3.1. Soil moisture.....	90
4.2.3.2. Rainfall and soil temperature.....	90
4.2.3.3. Soil surface roughness .....	90
4.2.3.4. Soil dry bulk density, macroporosity and infiltration rate .....	91

4.2.3.5. Cover and basal cover .....	91
4.2.3.6. Pasture height .....	92
4.2.3.7. Herbage mass, species composition and leaf area estimation .....	92
4.2.3.8. Tiller density and unattached plant material .....	93
4.3. STATISTICAL ANALYSIS .....	93
4.4. RESULTS .....	93
4.4.1. Pasture conditions before grazing/treading .....	93
4.4.2. Rainfall, soil temperature and soil moisture .....	94
4.4.3. Soil surface roughness .....	96
4.4.4. Soil bulk density, porosity and infiltration rate .....	98
4.4.5. N fertiliser effects on pasture recovery .....	99
4.4.6. Cover .....	99
4.4.7. Basal cover .....	101
4.4.8. Pasture height .....	102
4.4.9. Herbage mass .....	103
4.4.10. Botanical composition .....	104
4.4.11. Detached plant material .....	107
4.4.12. Herbage accumulation rates .....	107
4.4.13. Tiller density .....	108
4.4.14. Tiller weight .....	109
4.4.14. Leaf area index (LAI) .....	110
4.5. DISCUSSION .....	111
4.5.3. Soil conditions .....	113
4.5.4. Pasture conditions .....	115
4.6. CONCLUSION .....	121

## **CHAPTER 5 EFFECT OF CANOPY HEIGHT AND CATTLE TREADING ON HERBAGE**

### **GROWTH PARAMETERS..... 123**

5.1. INTRODUCTION .....	123
5.2. MATERIALS AND METHODS .....	125
5.2.1. Site .....	125
5.2.2. Design and treatments .....	126
5.2.3. Measurements .....	129
5.2.3.1. Soil moisture content .....	129
5.2.3.2. Surface roughness .....	129
5.2.3.3. Basal cover .....	129
5.2.3.4. Soil compaction, unsaturated hydraulic conductivity and compressibility .....	130
5.2.3.5. Plant population density .....	130
5.2.3.6. Herbage mass .....	131
5.2.3.7. Leaf extension .....	131

5.2.3.8. Appearance of new tillers.....	132
5.2.4. Statistical analysis.....	133
5.3. RESULTS.....	133
5.3.1. Pasture conditions before treading.....	133
5.3.2. Rainfall, soil temperature and soil moisture.....	133
5.3.3. Soil Surface Roughness.....	135
5.3.4. Basal cover.....	136
5.3.5. Soil compaction.....	137
5.3.6. Herbage mass and accumulation rates.....	139
5.3.7. Tiller density.....	140
5.3.8. Tiller weight and leaf area of ryegrass.....	144
5.3.9. Leaf and pseudo-stem extension rate of ryegrass.....	146
5.3.10. Weight of mother and daughter tillers of ryegrass.....	149
5.3.11. Leaf and pseudo-stem area of mother and daughter tillers of ryegrass.....	151
5.3.12. Leaf appearance rate (LAR), tiller appearance rate (TAR) and sites occupied by new tillers (TAR/LAR).....	152
5.3.13. Ryegrass tiller appearance and growth in glasshouse.....	153
5.3.13.1. Appearance of new tillers.....	153
5.3.13.2. Weight of established and new tillers in glasshouse.....	154
5.4. DISCUSSION.....	156
5.4.1. Soil conditions.....	156
5.4.2. Pasture dry matter yield and tiller dynamics.....	157
5.4.3. Growth of established and new tillers.....	166
5.5. CONCLUSIONS.....	167
<b>CHAPTER 6 GENERAL DISCUSSION AND CONCLUSIONS.....</b>	<b>169</b>
6.1. PASTURE PRODUCTION.....	169
6.2. PASTURE COVER.....	170
6.3. TILLER DYNAMICS AND REGROWTH.....	171
6.5. SOIL IMPACTS.....	176
6.6. SPECIES COMPOSITION.....	176
6.7. MANAGEMENT STRATEGIES.....	177
REFERENCES.....	180
APPENDICES.....	200

## APPENDICES

- Appendix 3.1 The guide to read the data in Appendices 3.2 and 3.3: (a) diagonal shaded data in the table represents the stability of the species or species group contributing cover, (b) unshaded data in rows represents the loss of species or species group from the previous measurement (left-hand column) (c) unshaded column data represents the cover gained from different species or species group relative to those present at the earlier date (rows). 200
- Appendix 3.2 Count of change in species classification between July (pre-treading) and September (post-treading) for treatments and contour classes. Rows represents the counts of species in July and columns represent the counts of species in September. 201
- Appendix 3.3 Count of change in species classification between September (post-treading) to October (regrowth period) between treatments and contour classes. Rows represents the count of September and columns represent the count of October. 202
- Appendix 3.4 Proportion of species classes (Stability Quotient) (a) bare ground, (b) ryegrass, (c) HFR grasses, (d) LFT grasses, (e) legumes and (f) other species (broadleaf weeds and dead material) at each of 400 first-hit-pin positions per treatment that did not change between measurement periods July-September and September-October. 203
- Appendix 3.5 Proportion of treatment all species or group of species at each of 400 first-hit-pin positions per treatment that did not change between measurement periods July-September and September-October. 204
- Appendix 3.6 SAS output of the GENMOD analysis of change in species, groups of species and bare ground at specific positions between (a) July and September and (b) September and October for treatment and contour classes. Data in the highest order interaction term in the shaded areas represent the finding of interest. All earlier factors define the base model. 205

## LIST OF TABLES

Table 3.1	Mean stocking density of dry cows and soil water content (SWC) factor used to apply treatments from August 1998 to March 1999.	44
Table 3.2	Mean volumetric soil water content (vSWC) from five treatment regimes and contour classes within the treatments.	52
Table 3.3	Mean bulk density ( $\text{g cm}^{-3}$ ) from treatment A and D in September and November 1998, and February, March and May 1999.	53
Table 3.4	Mean infiltration rates ( $\text{mm h}^{-1}$ ) from treatments A and D in September and November 1998, and February, March and May 1999.	53
Table 3.5	Mean air-filled porosity (%) in treatments A and D in September and November 1998, and February, March and May 1999.	54
Table 3.6	Total porosity (%) from treatment A and D in September and November 1998, and February, March and May 1999.	55
Table 3.7	Mean herbage accumulation rate on tracks from five management regimes over seven regrowth periods.	57
Table 3.8	Mean herbage accumulation rate on slopes from five management regimes over seven regrowth periods.	57
Table 3.9	Total contour adjusted herbage accumulation (track and slope weighting 1:4) from five management regimes over seven regrowth periods.	58
Table 3.10	Tiller density of ryegrass, HFR and LFT grasses, legumes, other components and total plants ( $\text{No. m}^{-2}$ ) of tracks, medium-slope and high-slope areas in treatments A, B+C+D <sup>1</sup> and E, measured in May 1999, after the trial finished.	65
Table 4.1	Mean volumetric soil moisture (%) and soil temperature at 10 cm depth at Days 3, 20, 33 and 48 after treading from untrodden, and low-, medium- and high-damaged areas.	96
Table 4.2	Mean roughness (percent decrease in chain length) at Days 3, 18 and 33 after treading from untrodden, and low-, medium-, and high-damaged areas.	97
Table 4.3	Soil dry bulk density ( $\text{g cm}^{-3}$ ) and soil macroporosity (%) 15 days after treading	98

Table 4.4	Mean saturated infiltration rates ( $\text{mm h}^{-1}$ ) from untrodden, and low-, medium-, and high-damaged areas at Days 5 and 50 after treading.	99
Table 4.5	Mean cover (%) at Days 3, 18, 33 and 48 after treading from untrodden, and low-, medium-, and high-damaged areas.	100
Table 4.6	Mean basal cover (% of green tissue at the ground level) at Days 3, 18, 33 and 48 after treading from untrodden, and low-, medium- and high-damaged areas.	102
Table 4.7	Mean pasture height (cm) from untrodden, and low-, medium-, and high-damaged areas at Days 20, 35 and 50 after treading.	103
Table 4.8	Mean herbage mass <sup>1</sup> ( $\text{DM kg ha}^{-1}$ ) of ryegrass and ‘other grasses’ at Days 3, 18, 33 and 48 after treading from untrodden, and low-, medium-, and high-damaged areas.	104
Table 4.9	Mean mass ( $\text{DM kg ha}^{-1}$ ) of detached plant material on the pasture at Day 3 after grazing/treading.	107
Table 4.10	Mean herbage accumulation rate ( $\text{kg DM ha}^{-1} \text{ day}^{-1}$ ) of ryegrass and ‘other grasses’ during the regrowth periods Day 3 to 18 and Day 33 to 48 after grazing and/or treading from untrodden, low-, medium- and high-damaged areas.	108
Table 4.11	Mean tiller density of ryegrass and ‘other grasses’ ( $\text{No. m}^{-2}$ ) at Days 3, 18, 33 and 48 after treading from untrodden, and low-, medium-, and high-damaged areas.	109
Table 4.12	Mean tiller weight (mg) of ryegrass and ‘other grasses’ at Days 3, 18, 33 and 48 after treading from untrodden, and low-, medium-, and high-damaged areas.	110
Table 4.13	Mean leaf area index (LAI) of ryegrass, ‘other grasses’ and total grasses at Days 18, 33 and 48 after treading from untrodden, and low-, medium- and high-damaged areas.	111
Table 5.1	Treatment combinations used in trial 3.	127
Table 5.2	Mean volumetric soil moisture content (%) on two days before treading and four days after treading.	135
Table 5.3	Mean soil surface roughness (%) two days before treading and two days after treading.	136
Table 5.4	Basal cover (percent of green tissue at the ground level) at Days 2 and 86 after treading.	137
Table 5.5	Difference in pre- and post-soil penetration depth (mm) 2 days before treading and at Day 3 after treading.	138

Table 5.6	Effect of canopy height and treading treatments on mean unsaturated hydraulic conductivity under 5 mm, 20 mm, 40 mm and 100 mm supply potential tension and compressibility of soil at Day 3 after treading.	138
Table 5.7	Effect of canopy height and treading treatments on herbage mass (kg DM ha <sup>-1</sup> ) of ryegrass, 'other species' and total herbage. Date and days are given for pre-treading, and the start and end of two growth periods after treading.	141
Table 5.8	Effect of canopy height and treading treatments on tiller density (No. m <sup>-2</sup> ) of ryegrass, 'other species' and total herbage. Date and days are given for pre-treading and post-treading periods.	142
Table 5.9	Effect of canopy height and treading treatments on herbage accumulation rate (kg DM ha <sup>-1</sup> day <sup>-1</sup> ) of ryegrass, 'other species' and total herbage during the period Day 4 to 49 and Day 52 to 86 after treading.	143
Table 5.10	Mean dry weight of leaf, pseudo-stem and total weight of ryegrass tillers (mg) observed on two days before treading and at Days 4, 49 and 86 after treading.	145
Table 5.11	Mean leaf area (cm <sup>2</sup> ) tiller <sup>-1</sup> of ryegrass observed on 2 days before treading and at Days 4 and 49 after treading.	145
Table 5.12	Mean dry weight (mg) of leaf, pseudostem, dead tissue and total weight of mother tillers marked on 20 Aug and harvested on 18 Sept and mean dry weight of daughter tillers (mg) produced by marked mother tillers during regrowth period 1.	150
Table 5.13	Mean dry weight (mg) of leaf, stem, dead tissue and total weight of mother tillers marked on 15 Oct and harvested on 9 Nov and mean dry weight of daughter tiller (mg) produced by marked mother tillers during regrowth period 2.	150
Table 5.14	Mean leaf area, stem area and total area of mother tillers marked on 20 Aug and 15 Oct and mean leaf, stem and total area of their daughter tillers (cm <sup>2</sup> ) that appeared during regrowth periods, harvested on 18 Sep (Period 1) and 9 Nov (Period 2) respectively.	152
Table 5.15	Effect of treading and cutting height on leaf appearance rate (LAR), tiller appearance rate (TAR) per mother tiller and sites occupied by new tillers (TAR/LAR) during the period Days 5 to 35 after treading.	153

## LISTS OF FIGURES

Figure 2.1	Framework for Literature review of the effect of animal treading on pastures and soils.	7
Figure 2.2	Good and poor soil structure profiles. Redrawn from McLaren and Cameron (1996).	24
Figure 2.3	Effect of treading on compaction of the soil. Redrawn from Batey (1988).	28
Figure 3.1	Mean botanical composition (% by weight) of the swards from tracks and slopes in (a) spring, (b) summer and (c) autumn from different management regimes. Data have not been adjusted for the 1:4 ratio of tracks: slopes when calculating the mean values.	59
Figure 3.2	Botanical composition of cut swards in (a) spring, (b) summer and (c) autumn from tracks and slopes of different management regimes.	60
Figure 3.3	Percentage (a) Bare ground, (b) Ryegrass, (c) HFR grasses, (d) LFT grasses, (e) Legume and (f) Other components based on 200 first-hit scores across two replications under five treading treatment regimes.	62
Figure 3.4	Relationships between pasture accumulation rate ( $\text{kg DM ha}^{-1} \text{ day}^{-1}$ ) and pasture cover (%) from treatment E, treatments B+C+D (data were pooled) and treatment A.	81
Figure 4.1	Plot selection and an example of subdivision of the plot for sampling, all carried out at Day 3 after treading, H, M, L, and U are the sample plots which denote high-damaged, medium-damaged, low-damaged and untrampled respectively.	89
Figure 4.2	(a) Rainfall and (b) Soil temperature (10-cm depth) data recorded daily during trial period at the AgResearch Meteorological Station, Palmerston North, approximately 700 m from the experimental site.	95
Figure 4.3	Relationship between soil surface roughness (%) at Day 3 and volumetric soil moisture content (%) in the 0-10 cm depth at Day 33 after treading.	97
Figure 4.4	Effect of grazing/treading on the botanical composition of the swards at Days 3, 18, 33 and 48 after treading.	106
Figure 5.1	Layout model of experimental area.	128



Figure 5.2	Time-line of cutting, treading, regrowth Period 1 and regrowth Period 2.	132
Figure 5.3	(a) Rainfall data and (b) soil temperature (10-cm depth) data, both recorded daily during trial period (1 Aug. to 10 Nov., 2000) at the AgResearch Meteorological Station, Palmerston North, approximately 700 m from the experimental site.	134
Figure 5.4	Effect of canopy height and treading intensity on ryegrass leaf extension rate ( $\text{mm day}^{-1}$ ) marked over regrowth period 1 (20 Aug to 18 Sep) and regrowth period 2 (15 Oct to 9 Nov), respectively.	147
Figure 5.5	Effect of canopy height and treading intensity on ryegrass pseudostem and stem extension rate ( $\text{mm day}^{-1}$ ) marked over regrowth period 1 (20 Aug to 18 Sep) and period 2 (15 Oct to 9 Nov), respectively.	148
Figure 5.6	Mean tiller appearance rate ( $\text{No. m}^{-2} \text{day}^{-1}$ ) of ryegrass from trodden and untrodden treatments observed at three different periods (Days 3 to 18, Days 19 to 33 and Days 34 to 65) after treading.	154
Figure 5.7	Mean tiller weight (mg) at harvest on Day 65 of successive cohorts of ryegrass tillers from trodden and untrodden treatments, marked at Day 3 (established tillers), and at Days 18, 33 and 65 (new tillers) after treading.	155
Figure 5.8	Relationships between mean weight per tiller and tiller density of ryegrass from trodden and untrodden treatments observed two days before treading (-2) and at Days 4, 49 and 86 after treading.	162
Figure 6.1	Relationship between effects of grazing cattle on soil physical properties and sward structural characteristics of ryegrass.	174
Figure 6.2	Recovery trend of ryegrass pastures after grazing.	175

## LIST OF PLATES

Plate 3.1	A view of a plot at the <i>Ballantrae</i> study site.	42
Plate 3.2	Soil and pasture damage resulting from cattle treading on wet soil.	45
Plate 3.3	Contometer used to measure pasture cover (First-hit). In this study, instead of 40 pins, only one pin was used. It was manually placed through each of 40 pin-holes, and lowered first-pin-hit touched a plant or bare ground.	48
Plate 4.1	Cows grazing/treading in the upper left corner at No. 4 Dairy pasture and sites selected for the (a) untrodden (b) low-damaged, (c) medium-damaged, and (d) high-damaged areas to study damage and recovery of soil and pasture (August, 1999). Photos taken immediately after grazing and/or treading.	88
Plate 4.2	Recovery of pasture in high damaged areas at Day 30 after treading showing large areas of bare ground.	101
Plate 5.1	A view of the study site.	126
Plate 5.2	Tiller cores after treatment shows loss in tillers as a result of treading (compare with untrodden tiller core on right).	143