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.
PHYSIOLOGICAL AND MORPHOLOGICAL RESPONSES OF TALL FESCUE (*Festuca arundinacea* SCHREB.) AND PERENNIAL RYEGRASS (*Lolium perenne* L.) TO DEFOLIATION

A thesis presented in partial fulfilment of the requirements for the degree of Doctor of Philosophy (Ph. D.) in *Pasture Ecology and Physiology*

Department of Plant Science
Massey University

*$HOSSEIN TAVAKOLI*$

1993
Massey University Library
Thesis Copyright Form

Title of thesis: Physiological and Morphological responses of fall fescue and perennial ryegrass to defoliation

(1) (a) I give permission for my thesis to be made available to readers in Massey University Library under conditions determined by the Librarian.

(b) I do not wish my thesis to be made available to readers without my written consent for 6 months.

(2) (a) I agree that my thesis, or a copy, may be sent to another institution under conditions determined by the Librarian.

(b) I do not wish my thesis, or a copy, to be sent to another institution without my written consent for 6 months.

(3) (a) I agree that my thesis may be copied for Library use.

(b) I do not wish my thesis to be copied for Library use for 6 months.

Signed

Date 3/12/03

The copyright of this thesis belongs to the author. Readers must sign their name in the space below to show that they recognise this. They are asked to add their permanent address.

NAME AND ADDRESS

DATE
ABSTRACT

Tall fescue (*Festuca arundinacea* Schreb.) has been suggested as an alternative to perennial ryegrass, particularly in conditions of moisture limitation, but there is little comparative information on the plant characteristics influencing regrowth in the two species, particularly under continuous stocking. The objectives of this study were to: i) examine the response of tall fescue to continuous stocking in terms of tillering activity, leaf growth and competition, and ii) determine which physiological or morphological factors are important in influencing regrowth after defoliation, using perennial ryegrass as a reference standard. Experiments were undertaken in field, glasshouse and controlled environment conditions.

In the field sown swards of tall fescue (*Festuca arundinacea* Schreb. cv. 'Grassland Roa') and white clover (*Trifolium repens* L. cv. 'Grassland Tahora'), with volunteer grasses mainly consisting of perennial ryegrass (*Lolium perenne* L. cv. 'Grassland Nui') were continuously stocked with varying numbers of sheep to maintain sward surface heights 90-100 mm (Lax, L), 50-60 mm (Medium, M) and 30-40 mm (Hard, H). Measurements were made on areas with and without clover by removal of white clover with clopyralid. Tiller population density, tiller weight, and leaf growth and productivity of tall fescue were all reduced under hard grazing. Tall fescue was susceptible to competition from companion species, particularly perennial ryegrass, and tended to be replaced by other species under hard grazing.

Under glasshouse conditions individual plants of tall fescue and perennial ryegrass were defoliated to stubble heights of 100 mm (Lax, L), 60 mm (Medium, M), 30 mm (Hard1, H1) and 30 mm (Hard2, H2) 9 times with 5 day intervals over a period of 45 days. Treatments L, M, and H1 were initiated at an average of 11 tillers per plant for each species; treatment H2 commenced at 6 tillers per plant. Both species showed sensitivity to severe cutting treatments by reduction in tiller number, tiller weight, leaf growth and less shoot and root growth. Tall fescue showed lower leaf growth, tillering activity and herbage harvested per plant than perennial regress, but it produced larger tillers.
The comparative response of tall fescue and perennial ryegrass to leaf defoliation was studied under controlled environment conditions at both the vegetative and reproductive stages of growth. The oldest leaf lamina was defoliated regularly to maintain four, three, two or only one live leaf per tiller for six or seven leaf appearance intervals. In both species repeated removal of older leaves had little effect on tiller production, tiller weight, leaf growth rate and consequently total accumulated shoot and root weight, and mean shoot and root relative growth rates. Removal of all fully expanded leaves resulted in significant reduction in the above components, though leaf elongation rate was little affected. Leaves were shorter, narrower and lighter under hard defoliation, but leaf appearance rate was not affected. Hard defoliation affected tall fescue tiller weight more than perennial ryegrass. Water soluble carbohydrate concentrations in stem bases of plants decreased with increasing severity of defoliation especially for tall fescue. Leaf photosynthetic capacity per unit area was not influenced by defoliation intensity, but photosynthetic capacity per unit leaf weight increased under hard defoliation. Hard defoliation decreased the proportion of root mass to shoot mass, and increased the proportion of leaf mass to shoot mass. Plants showed relatively similar sensitivity to defoliation at vegetative and reproductive phases of growth. At both phases tall fescue again produced larger tillers with longer leaves and had a longer leaf life-span than perennial ryegrass, but it had lower leaf growth and appearance, and produced fewer tillers per plant. Photosynthetic activity per unit leaf area was similar for the two species, but tall fescue often had lower photosynthetic rate per unit leaf weight than perennial ryegrass.

In conclusion, hard defoliation intensity reduced both tiller population density and tiller weight and consequently decreased pasture regrowth through a reduction in LAI, life-span of leaf area, photosynthetic efficiency, and shortage of carbohydrate reserves. The factors that resulted in the regrowth of tall fescue being less responsive to hard defoliation than perennial ryegrass were slower leaf turnover, slower leaf appearance rate, lower tillering capacity and longer leaf life-span. These resulted in lack of plasticity in tiller population density of tall fescue in response to hard defoliation.
ACKNOWLEDGEMENTS

First of all praise to almighty God for giving me the ability to learn.

I would like to express my deepest gratitude to my chief supervisor Dr Peter David Kemp and co-supervisor Professor John Hodgson for their patience, enthusiastic encouragement, guidance and close supervision throughout the course of this study. I was provided with friendly answers at any time that I needed their help.

I am deeply indebted to Dr Cory Matthew for his generosity in time and useful advice made available to me through his "open door".

Thanks are extended to Drs I.L. Gordon and S. Ghaneshanandam for statistical advice, Drs A.C.P. Chu, I. Valentine and K. Harrington (from Department of Plant Science), Mr J. Brock and Drs D. Hume, and D.F. Chapman (from AgResearch CRI), Drs D.W. Fountain, C.A. Cornford and Professor R.G. Thomas (from Department of Plant Biology) for their helpful comments; Messrs B. Butler, for his tissue turnover programme, T. Lynch and M.A. Osborne for their technical field assistance, R. Johnstone, C. Forbes, G. Russell, for assisting in the preparation of the Growth Cabinets and Glasshouse facilities, the staff of Horticulture CRI for organising the Climate room, Mrs S. Cleland for her technical assistance; and Mrs J. Cave, and especially, Ms C. McKenzie and Ms Frith Brown for their technical and organisational assistance made available to me at any time.

The friendly environment provided by my fellow graduate students in Plant Science Department is much appreciated, especially the friendship of Mr Manzoor-ul-Haque Awan which will never be forgotten.

The presence of all Iranian postgraduate students and their families in Palmerston North made my family and I feel at home. It is my pleasure to thank and wish them a happy and prosperous future.
I would like to express my sincere thanks to the Ministry of Jahad-e-Sazandegi and Ministry of Culture and Higher Education of IRAN, for awarding me the scholarship to undertake this study.

Special thanks to my wife Tayebeh for her patience, considerable encouragement and assistance in a number of ways, but especially undertaking my own duty to educate our children. The patience of my son Mosslem and my daughter Maryam and their positive responses to education provided for them made me happy and encouraged me to cope with difficulties. Finally the forbearance and encouragement of my other family members and friends is deeply appreciated.
TABLE OF CONTENTS

ABSTRACT ................................................................. ii
Acknowledgments ......................................................... iv
Contents ................................................................. vi
List of Tables ............................................................. xi
List of Figures .............................................................. xvii
List of Plates .............................................................. xviii

CHAPTER 1: General introduction and objectives ................. 1

CHAPTER 2: Literature review ........................................... 3

2.1 Introduction ............................................................ 3
2.2 The morphology and growth characteristics of perennial ryegrass and tall fescue. ....................................................... 3
2.3 Performance of tall fescue .......................................... 6
2.4 The effect of defoliation on pasture production ................. 7
2.5 Effect of defoliation on persistence of plants .................... 9
2.6 Cutting vs. grazing managements .................................. 11
2.7 Factors influencing regrowth after defoliation ................. 13
   2.7.1 Residual leaf area .............................................. 13
   2.7.2 Leaf growth .................................................... 14
   2.7.3 Leaf carbon budget .......................................... 15
   2.7.4 Tillering activity ............................................ 18
   2.7.5 Meristem damage ............................................ 19
   2.7.6 Carbohydrate reserves ..................................... 21
   2.7.7 Stage of growth ............................................ 22
   2.7.8 Root growth ................................................ 23
   2.7.9 Plant competition .......................................... 24
2.8 Effects of defoliation on plant size and structure ............ 26
2.9 Summary and conclusion ........................................... 28
CHAPTER 3: Regrowth and competitiveness of tall fescue under grazing management

3.1 Introduction .............................................. 29
3.2 Materials and methods .................................. 29
   3.2.1 Experimental conditions ........................ 29
   3.2.2 Measurements .................................. 30
   3.2.3 Statistical analysis .............................. 33
3.3 Results .................................................. 35
   3.3.1 Herbage mass ................................... 35
   3.3.2 Botanical composition ............................. 35
   3.3.3 Tiller population density and tiller weight .... 39
   3.3.4 Leaf area index and leaf area per tiller ....... 41
   3.3.5 Leaf growth ..................................... 42
   3.3.6 Leaf defoliation .................................. 45
3.4 Discussion .............................................. 48
   3.4.1 Regrowth of tall fescue in response to defoliation .. 48
   3.4.2 Botanical composition ............................. 50
3.5 Summary ............................................... 52

CHAPTER 4: Effect of cutting on regrowth of tall fescue and perennial ryegrass

4.1 Introduction .............................................. 53
4.2 Material and methods .................................. 53
   4.2.1 Experimental conditions ........................ 53
   4.2.2 Measurements .................................. 54
   4.2.3 Statistical analysis .............................. 56
4.3 Results .................................................. 57
   4.3.1 Herbage harvested ............................... 57
   4.3.2 Tiller number and tiller weight ................. 60
   4.3.3 Leaf growth ..................................... 64
4.3.4 Total herbage harvested and plant shoot and root mass ........................................ 64
4.4 Discussion .................................................. 67
4.5 Summary .................................................... 70

CHAPTER 5: Response of tall fescue and perennial ryegrass to leaf defoliation ......................... 71

5.1 Introduction .................................................. 71

5.2 Vegetative stage ............................................. 72

5.2.1 Material and methods- experiment 1 .............. 72
   5.2.1.1 Experimental conditions ...................... 72
   5.2.1.2 Measurements .................................... 73
   5.2.1.3 Statistical analysis ............................ 79
5.2.2 Results- experiment 1 .................................. 80
   5.2.2.1 Plant herbage mass components and relative growth rate ........................ 80
   5.2.2.2 Tiller number and tiller weight ................ 85
   5.2.2.3 Leaf appearance and site filling ................. 89
   5.2.2.4 Leaf growth ...................................... 90
   5.2.2.5 Leaf characteristics ............................. 92
   5.2.2.6 Leaf photosynthesis and respiration ............. 94
   5.2.2.7 Water soluble carbohydrate .................... 94
5.2.3 Material and methods- experiment 2 .............. 97
   5.2.3.1 Experimental conditions ...................... 97
   5.2.3.2 Measurements .................................... 98
   5.2.3.3 Statistical analysis ............................ 99
5.2.4 Results- experiment 2 .................................. 100
   5.2.4.1 Plant herbage mass components and relative growth rate ........................ 100
5.2.4.2 Leaf area per plant and leaf area ratio . . . 105
5.2.4.3 Tiller number and tiller weight ............ 105
5.2.4.4 Leaf appearance and site filling ............ 108
5.2.4.5 Leaf growth .................................. 109
5.2.4.6 Leaf characteristics ......................... 112
5.2.4.7 Leaf photosynthesis and respiration ......... 114
5.2.4.8 Water soluble carbohydrate .................. 120

5.3 Reproductive stage .................................. 121

5.3.1 Material and methods- experiment 3 ............ 121
  5.3.1.1 Experimental conditions ..................... 121
  5.3.1.2 Measurements ................................ 122
  5.3.1.3 Statistical analysis .......................... 123

5.3.2 Results- experiment 3 ............................ 124
  5.3.2.1 Plant herbage mass components and
        relative growth rate ............................. 124
  5.3.2.2 Tiller number and tiller weight ............. 128
  5.3.2.3 Leaf growth .................................. 133
  5.3.2.4 Leaf characteristics ......................... 133
  5.3.2.5 Leaf photosynthesis .......................... 136
  5.3.2.6 Water soluble carbohydrate .................. 139

5.3.3 Material and methods- experiment 4 ............ 140
  5.3.3.1 Experimental conditions ..................... 140
  5.3.3.2 Measurements ................................ 140
  5.3.3.3 Statistical analysis ......................... 140

5.3.4 Results- experiment 4 ............................ 141
  5.3.4.1 Plant herbage mass ........................... 141
  5.3.4.2 Tiller number and tiller weight ............. 141
  5.3.4.3 Water soluble carbohydrate .................. 144

5.4 Discussion .......................................... 147

5.5 Summary ............................................. 156
CHAPTER 6: General discussion and conclusion .................... 157

6.1: General discussion ........................................... 157
6.2 Comment and conclusion ..................................... 163

REFERENCES ......................................................... 165

APPENDICES ......................................................... 185

Appendix 3.1: Summary of rainfall, temperature and sunshine . . 185
Appendix 3.2: Number of sheep in each plot over trial period. . . 186
Appendix 3.3: Analysis of variance of tall fescue herbage mass ......................................................... 187
Appendix 4.1: Analysis of variance of herbage harvested for the two grass species and different treatments over time. . . . . 188
Appendix 4.2: Effect of cutting heights on herbage harvested per plant of perennial ryegrass and tall fescue. ................. 189
Appendix 4.3: Effect of cutting heights on tiller number per plant of perennial ryegrass and tall fescue. ..................... 190
Appendix 5.1: PAHBAH regent. ................................. 191
Appendix 5.2: Standard curve for determination of WSC ......... 192
LIST OF TABLES

CHAPTER 3:

Table 3.1: Effect of grazing management on leaf, pseudostem and total herbage mass of tall fescue. .......................... 36

Table 3.2: Effect of grazing management on leaf, pseudostem and total herbage mass of tall fescue grown with and without clover ........................................ 36

Table 3.3: Herbage mass of tall fescue, white clover, other grasses and total biomass under different grazing management: with clover. ........................................ 37

Table 3.4: Herbage mass of tall fescue, other grasses and total biomass under different grazing management: without clover. ........................................ 37

Table 3.5: Effect of grazing management on tall fescue tiller population density and tiller weight ........................................ 40

Table 3.6: Tiller population density and tiller weight of tall fescue grown with and without clover. ........................................ 40

Table 3.7: Effect of grazing management on tall fescue leaf area index and leaf area per tiller. ........................................ 41

Table 3.8: Leaf area index and leaf area per tiller of tall fescue grown with and without clover. ........................................ 41

Table 3.9: Total leaf elongation, senescence and net leaf elongation rates under different grazing managements ........................................ 43

Table 3.10: Tall fescue total leaf elongation, senescence and net leaf elongation rates grown with and without clover. ........................................ 43

Table 3.11: Estimation of net leaf elongation rates per unit area and net leaf weight production of tall fescue under different grazing managements ........................................ 44

Table 3.12: Estimation of net leaf elongation rates per unit area and net leaf weight production of tall fescue grown with and without clover. ........................................ 44
Table 3.13: Comparison of leaf defoliation (%) of marked tillers between different grazing treatments. .......................... 46

Table 3.14: Comparison of leaf defoliation (%) of marked tillers of tall fescue grown with and without clover. ...................... 47

CHAPTER 4:

Table 4.1: Comparison between herbage harvested per plant of perennial ryegrass and tall fescue. ................................. 58

Table 4.2: Effect of cutting treatments on herbage harvested per plant. ................................................................. 58

Table 4.3: Herbage harvested per tiller of the two grass species. .. 59

Table 4.4: Effect of cutting treatments on mean herbage harvested per tiller. .......................................................... 59

Table 4.5: Tillering rates of perennial ryegrass and tall fescue; mean of treatments L and M. ............................... 63

Table 4.6: The effect of cutting treatments on tillering rates. ....... 63

Table 4.7: Tiller weight of perennial ryegrass and tall fescue under different cutting treatments at final harvest. ................. 63

Table 4.8: Comparison of total herbage harvested, total plant shoot mass and root mass of perennial ryegrass and tall fescue. .. 66

Table 4.9: Effect of cutting treatments on total herbage harvested, total plant shoot mass and root mass. ......................... 66

CHAPTER 5 (Vegetative stage- experiment 1)

Table 5.1: Accumulated dry mass of leaf, pseudostem, total shoot, and mean shoot relative growth rates of perennial ryegrass and tall fescue. ................................................................. 81

Table 5.2: Effect of defoliation on accumulated dry mass of leaf, pseudostem, total shoot, and mean shoot relative growth rates. ........ 82

Table 5.3: Tiller number per plant of perennial ryegrass and tall fescue (unadjusted mean). ............................ 86
Table 5.4: Effect of defoliation on tiller number per plant of pooled perennial ryegrass and tall fescue (unadjusted mean) .... 86

Table 5.5: Tiller number per plant of perennial ryegrass and tall fescue (adjusted mean) ........................................... 87

Table 5.6: Effect of defoliation on tiller number per plant of pooled perennial ryegrass and tall fescue (adjusted mean) ........ 87

Table 5.7: Tillering rates of perennial ryegrass and tall fescue .... 88

Table 5.8: Effect of defoliation treatments on mean tillering rates of perennial ryegrass and tall fescue ......................... 88

Table 5.9: Effect of defoliation on tiller weight ..................... 88

Table 5.10: Leaf number, leaf appearance rates and site filling of perennial ryegrass and tall fescue ................................ 89

Table 5.11: Leaf number, leaf appearance rates and site filling of the two species under different defoliation treatments ... 89

Table 5.12: Leaf elongation rates of the two grass species ........ 90

Table 5.13: Effect of defoliation on leaf elongation rates .......... 91

Table 5.14: Leaf lamina growth rates of perennial ryegrass and tall fescue ................................................................. 91

Table 5.15: Effect of defoliation on leaf lamina growth rates .... 91

Table 5.16: Individual leaf characteristics of perennial ryegrass and tall fescue .......................................................... 93

Table 5.17: Individual leaf characteristics of the two grass species under different defoliation treatments .......................... 93

Table 5.18: Leaf photosynthetic and dark respiration rates of the uppermost fully expanded leaf of the two grass species .... 95

Table 5.19: Effect of defoliation on leaf photosynthetic and dark respiration rates of the uppermost fully expanded leaf ......... 96

Table 5.20: Effect of defoliation on water soluble carbohydrate concentrations in the stem bases of the two grass species .... 96
CHAPTER 5 (Vegetative stage- experiment 2)

Table 5.21: The accumulated dry mass of leaf, pseudostem, shoot mass, root mass and total biomass, and mean shoot and root relative growth rates of perennial ryegrass and tall fescue. .................. 101

Table 5.22: Effect of defoliation on accumulated dry mass of leaf, pseudostem, shoot, root and total biomass, and mean shoot and root relative growth rates .................. 102

Table 5.23: Leaf area per plant, leaf area ratio per shoot mass and per biomass of the two grass species under different defoliation treatments. 105

Table 5.24: Tiller number per plant of the two grass species. .......... 106

Table 5.25: Effect of defoliation on tiller number per plant: mean of perennial ryegrass and tall fescue data. .................. 106

Table 5.26: Tillering rates of perennial ryegrass and tall fescue. ........ 107

Table 5.27: Effect of defoliation on tillering rates .................. 107

Table 5.28: Effect of defoliation on tiller weight. .................. 107

Table 5.29: The mean leaf number per tiller, leaf appearance rates and site filling of perennial ryegrass and tall fescue. .................. 109

Table 5.30: Leaf number, leaf appearance rates and site filling of the two species under different defoliation treatments. .................. 109

Table 5.31: Leaf elongation rates of the two grass species. .......... 110

Table 5.32: Effect of leaf defoliation on mean leaf elongation rates ...... 111

Table 5.33: Leaf lamina growth rates of the two grass species. .......... 111

Table 5.34: Effect of defoliation on leaf lamina growth rates. .......... 111

Table 5.35: Individual leaf characteristics of the two grass species. ... 113

Table 5.36: Individual leaf characteristics of perennial ryegrass and tall fescue plants under different defoliation treatments. .................. 113

Table 5.37: The leaf photosynthetic rates of control plants. ........... 115

Table 5.38: Photosynthetic rates of leaves in different position in a tiller of control plants. .................. 116
Table 5.39: Leaf photosynthetic rates of the two grass species. .......... 117

Table 5.40: Effect of defoliation on leaf photosynthetic rates. .......... 118

Table 5.41: Water soluble carbohydrate concentrations in stem bases of the two grass species under different defoliation treatments. ...... 120

CHAPTER 5 (Reproductive stage - experiment 3)

Table 5.42: Accumulated dry mass of leaf, pseudostem, seed head, total shoot, and mean shoot relative growth of the two grass species. ... 125

Table 5.43: Effect of defoliation on accumulated dry mass of leaf, pseudostem, seed head, total shoot, and mean shoot relative growth rates. ........................................................ 126

Table 5.44: Tiller number per plant of the two grass species (unadjusted mean). .................................................. 129

Table 5.45: Effect of defoliation on mean tiller number per plant of the two grass species (unadjusted mean). ....................... 129

Table 5.46: Tiller number per plant of perennial ryegrass and tall fescue (adjusted mean). .............................................. 130

Table 5.47: Effect of defoliation on mean tiller number per plant of perennial ryegrass and tall fescue (adjusted mean). ............... 130

Table 5.48: Tillering rates of perennial ryegrass and tall fescue. .... 130

Table 5.49: Effect of defoliation on tillering rates. ...................... 131

Table 5.50: Percentage of tillers with seed heads under different defoliation treatments. .................................................. 132

Table 5.51: Effect of defoliation on tiller weight. ...................... 132

Table 5.52: Leaf elongation rates of the two grass species. .......... 134

Table 5.53: Effect of defoliation on mean leaf elongation rates of perennial ryegrass and tall fescue. ............................. 134

Table 5.54: Leaf lamina growth rates of the two grass species. .... 134

Table 5.55: Effect of defoliation on mean leaf lamina growth rates of perennial ryegrass and tall fescue. ............................. 134
Table 5.56: Individual leaf characteristics of the two grass species .... 135
Table 5.57: Individual leaf characteristics of perennial ryegrass and
tall fescue under different leaf defoliation treatments. .................. 135
Table 5.58: Photosynthetic rates of the uppermost fully expanded leaf of perennial ryegrass and tall fescue. ......................... 136
Table 5.59: Effect of defoliation on photosynthetic rates of the uppermost fully expanded leaf ........................................... 137
Table 5.60: Water soluble carbohydrate in stem bases of perennial
dying grass and tall fescue under different defoliation treatments. .......... 139

CHAPTER 5 (Reproductive stage- experiment 4)
Table 5.61: Total accumulated shoot mass of the two grass species . 142
Table 5.62: Total accumulated shoot mass of perennial ryegrass and
tall fescue under different defoliation treatments. ........................ 142
Table 5.63: Tiller number per plant of the two grass species (adjusted mean). ................................................................. 143
Table 5.64: Effect of defoliation treatments on mean tiller number per plant of perennial ryegrass and tall fescue (adjusted mean). ....... 143
Table 5.65: Tiller number per plant for perennial ryegrass and
tall fescue (unadjusted mean). .................................................. 143
Table 5.66: Effect of defoliation treatments on mean tiller number per plant of perennial ryegrass and tall fescue (unadjusted mean). ....... 144
Table 5.67: Tiller weight of perennial ryegrass and tall fescue. ........ 145
Table 5.68: Effect of defoliation on tiller weight of perennial
ryegrass and tall fescue. ............................................................ 145
Table 5.69: Water soluble carbohydrate in the stem bases of perennial
dying grass and tall fescue. ....................................................... 146
Table 5.70: Water soluble carbohydrate in stem bases of perennial
dying grass and tall fescue under different defoliation treatments. ........ 146
LIST OF FIGURES

CHAPTER 3:
Figure 3.1: Botanical composition of pastures grown with clover. .... 38
Figure 3.1: Botanical composition of pastures grown without clover. ... 38

CHAPTER 4:
Figure 4.1: Tiller number per plant of the two grass species ............ 61
Figure 4.2: Effects of cutting heights on tiller number .................. 62
Figure 4.3: Leaf elongation rates of the two grass species .............. 65
Figure 4.4: Effect of defoliation on leaf elongation rates .............. 65

CHAPTER 5: (Vegetative stage- experiment 1)
Figure 5.1: Leaf defoliation treatments .................................. 74
Figure 5.2: Effect of defoliation on proportion of leaf to shoot mass ... 84

CHAPTER 5: (Vegetative stage- experiment 2)
Figure 5.3: Effect of defoliation on proportion of leaf to shoot mass ... 104
Figure 5.4: Effect of defoliation on proportion of root to shoot mass ... 104
Figure 5.5: Effect of leaf age on photosynthetic efficiency ............ 119
Figure 5.6: Effect of leaf age on respiratory activity ................... 119

CHAPTER 5: (Reproductive stage- experiment 3)
Figure 5.7: Effect of defoliation on proportion of leaf to shoot mass ... 127
Figure 5.8: Effect of leaf age on photosynthetic efficiency ............ 138

CHAPTER 6:
Figure 6.1: Relationship between tiller weight and population density of tall fescue. ....................................................... 161
Figure 6.2: Relationship between tiller weight and population density of three grass species. ................................. 161
LIST OF PLATES

Plate 3.1: General views of the grazing experiment ............... 31
Plate 4.1: A general view of cutting experiment .................. 55
Plate 5.1: Measurement of Leaf carbon exchange by ............... 77
Plate 5.2: A general view of individual plants of .................. 83
Plate 5.3: Accumulation of root mass ............................... 103