Prairie Grass Pastures : Studies of Their Composition and Feeding Value for Milk Production

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

Valentini Kamugisha Rugambwa

(B.Sc., M.Sc., Dip. Agric.)

1993

Dedication

To my wife ***Margaret Kironde*** who took care of the children
and provided the final inspiration towards the completion of this work.

PRAIRIE GRASS PASTURES : STUDIES OF THEIR COMPOSITION AND FEEDING VALUE FOR MILK PRODUCTION

(Ph.D. Thesis, Massey University, 1993)

Author : V.K. Rugambwa
Supervisors: Professors C.W. Holmes and A.C.P. Chu

ABSTRACT

Two experiments were carried out to examine the effects of differences in pre-grazing herbage mass of prairie grass (***Bromus willdenowii*** Kunth) cv. Grasslands Matua pastures on herbage composition in summer, autumn, winter and spring (Experiment 1); and herbage composition and milk production by grazing cows during eight short-term (2-3 weeks) grazing trials in early spring, late spring, summer and autumn over two years (Experiment 2).

Swards with low (LM), intermediate (IM) and high (HM) (Experiment 1), and with LM and HM (Experiment 2) pre-grazing herbage mass were created and maintained by differential grazing. Simultaneous comparisons were made with conventional perennial ryegrass/white clover (RG) swards (Experiment 2). Prairie grass swards were grown with red clover (Experiment 1) or white clover (Experiment 2). Cows were given a common nominal herbage allowance of 50 kg DM/cow daily (Experiment 2). The LM swards were topped mechanically when required (Experiment 2). Mean pre-grazing and residual herbage masses (t DM/ha) were, respectively;

Experiment 1: LM, 4.4 and 1.9; IM, 6.5 and 2.6; HM, 6.7 and 3.5 ;
Experiment 2: RG, 3.2 and 2.1; LM, 4.2 and 2.2; HM, 5.7 and 3.6.

In Experiment 1, the low mass swards contained lower concentrations of stem and dead matter, but higher concentrations of leaf than the intermediate or high mass swards; the concentrations of clover in the three sward types were similar. Herbage from the low mass sward type was also more digestible, and contained greater concentrations of nitrogen.

In Experiment 2, the ryegrass swards contained greater mean proportions of leaf and smaller proportions of stem and senescent material than the two prairie grass sward types, which contained similar proportions of stem; low mass prairie grass swards contained greater and smaller proportions of leaf and senescent matter, respectively, than high mass swards. The proportion of clover was smaller in high mass prairie grass swards than ryegrass or low mass prairie grass swards, which contained similar proportions; that of unsown species was generally highest in low mass prairie grass swards. The proportion of prairie grass, tiller density and weight per tiller decreased over time in both prairie grass swards, but the decrease was faster in the low mass swards.

Herbage from the ryegrass swards was more digestible and had a greater concentration of nitrogen than the high mass prairie grass swards, while the low mass prairie grass swards showed intermediate values. There were only small actual differences between treatments in the digestibility and nitrogen concentrations of whole plants, leaf or stem, but values were generally lower in the high mass prairie grass swards; the digestibility of dead matter was very low (OMD < 48%) and was much lower in prairie grass swards. It appears that the high proportion of dead matter was largely responsible for the decrease in the quality of herbage from prairie grass swards, while the high proportion of stem was not important in this respect.

Apparent herbage intakes by cows from the three sward types were relatively high, but yields of milk and milk solids were smallest from cows grazing the high mass prairie grass swards. Yields of milk and milk solids from ryegrass and low mass prairie grass swards were similar in all periods, except in summer when yields were smaller from low mass prairie grass swards.

There were season x sward type interactions for herbage component concentrations, herbage digestibility, and milk production. However, the data were consistent in showing that high mass swards always contained lower proportions of green leaf and greater proportions of senescent matter; the digestibility and feeding value of the herbage, and milk production from the high mass swards were lower when compared with low mass swards, most probably due to smaller intakes of digestible nutrients from the former swards.

It was concluded that the feeding value for milk production of prairie grass swards maintained at low herbage masses was similar to that of conventional ryegrass swards, except during the summer period when that of low mass prairie grass was lower; but low mass prairie grass swards were less persistent, despite long grazing intervals of 5-6 weeks.

Suggestions were made for further research.

ACKNOWLEDGEMENTS

The studies being reported and the preparation of the present thesis depended on the support of many individuals and organisations. Academic supervision, guidance and encouragement on many occasions when the completion of this work seemed unattainable were patiently provided by Profs. Colin Holmes and Alex Chu. Prof. John Hodgson showed continued interest in this work and posed searching questions that stimulated lateral thinking.

Excellent technical help was received from Catriona Jenkinson, Dean Burnham, Annabel Whitton, Martin Chesterfield and Barry Parlane; and from fellow students Coby Hoogendoorn, Margaret Njaritta, Noel Sembuli, Mwamini Tulli, June Fussih and Phillimon Mapfumo. Support with chemical laboratory analyses was provided by Rosemary Watson, Dave Hamilton, Margaret Scott and Yvonne Moore.

Drs. Dorian Garrick and Ian Gordon gave many helpful suggestions regarding trial designs and statistical analyses. Prof. Stuart McCutcheon, Head of Department, promptly looked for solutions to administrative problems. Dr. Hugo Varela-Alvarez provided tuition on the statistical and graphics applications of the SAS computing package. The manuscript was humorously and skillfully typed by Jillian Jonasen, and Kathryn Hamilton expertly typed most of the tables and the bibliography. Margaret Scott and Rosemary Watson proof-read most of the thesis and gave valuable editorial advice, but any errors that may be contained in this work remain entirely my responsibility.

Financial support for this research programme was received from the Ministry of External Relations and Trade (NZ), McGowan Scholarship, Miss E.L. Hellaby Grasslands Research Trust, and the C. Almer Baker Trust. Profs. Colin Holmes and Tom Barry supported my efforts to obtain extra funding, without which my family's welfare would have been jeopardised. My employer, the Principal Secretary, Ministry of Agriculture and Livestock Development (Tanzania), granted me a leave of absence for the duration of the study.

The support and resilience of my dear wife Margaret; our children Lucia, Kamugisha, Gonzaga, Sanyu and Tibera; and our parents Petro Kamugisha and Felista Tibanywana, and Joseph Mukasa and Paulina Nnakalema made it all possible.

To these individuals and organisations; and to many friends in Palmerston North and elsewhere who provided me and my family moral and material support, and made our stay in New Zealand a memorable and enjoyable experience, I am deeply indebted. I sincerely say *asante sana, karibu Tanzania* (thank you very much, you are all welcome to Tanzania).

ABBREVIATIONS

ADF	:	Acid detergent fiber
d	:	day
DM	:	dry matter
DMD	:	digestibility of dry matter
DMI	:	dry matter intake
DOMA	:	digestible organic matter allowance
DOM(D)	:	digestible organic matter (in the dry matter)
GHA	:	green herbage accumulation
GMA	:	green matter allowance
GT	:	grazing time
HA	:	herbage allowance
HM	:	high herbage mass
hr	:	hour
IB	:	intake per bite
IM	:	intermediate herbage mass
LAI	:	leaf area index
LM	:	low herbage mass
ME	:	metabolisable energy
N	:	nitrogen
n	:	number
NA	:	not analysed statistically; not applicable
NHA	:	net herbage accumulation
NHP	:	net herbage production
NS	:	not statistically significant
OM	:	organic matter
OMA	:	organic matter allowance
OMD	:	digestibility of organic matter
pers. com	:	personal communication
PHM	:	pre-grazing herbage mass
PSH	:	pre-grazing sward surface height
RB	:	rate of bite
RG	:	perennial ryegrass
RHM	:	residual (post-grazing) herbage mass
RSH	:	residual (post-grazing) sward surface height
SD	:	standard deviation
t	:	tonne
Sign.	:	significance level
VFI	:	voluntary feed intake
Yr	:	year

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF PLATES

CHAPTER 1

BACKGROUND TO THE THESIS

1.1 THESIS OUTLINE

The present investigation involved nine grazing trials (in two experiments) with dairy cows during which a series of pasture and animal measurements were made over a range of seasons for three years. Several types of predominantly Matua prairie grass/clover swards were created and maintained by differential grazing management prior to the start of measurements (Plate 1.1). In Experiment 2, simultaneous comparisons were made with "conventional" (moderate mass) perennial ryegrass swards (Plate 1.1). Experiment 2 was comprised of eight grazing trials, but the data from these trials were analysed and presented as one experiment. The experimental procedures, results and discussions are presented in five chapters following two introductory chapters.

Chapter 1 introduces the thesis by presenting highlights of the dairy industry and pasture scene in New Zealand. It also presents the general aim of the entire study with an overview of the background literature. The chapter concludes with an outline of the specific objectives of the present study.

Chapter 2 contains a detailed review of literature pertaining to the effects of defoliation regime and season on herbage growth and composition, feed intake and lactational performance of dairy cows, herbage production and herbage quality of Matua prairie grass swards, and animal production from Matua dominant pastures in comparison to perennial ryegrass pastures.

Chapter 3 outlines materials and methods common to all the experiments. Specific experimental procedures are presented under the relevant chapters.

Chapter 4 details a one year grazing trial (Experiment 1) that measured pasture growth, sward morphology and herbage composition of three Matua-red clover sward types. The swards were grazed at low, medium or high pre-grazing herbage masses. No animal measurements were made.

Chapters 5 and 6 describe eight grazing trials with lactating dairy cows (Experiment 2) that were conducted during early spring, late spring, summer and autumn over two years to compare Matua-white clover swards (maintained at either low or high pre-grazing herbage masses) and "conventional" ryegrass-white clover swards. Sward characteristics and herbage quality are presented in Chapter 5, and feed intake and dairy cow performance in Chapter 6.

A general discussion and synthesis of the experimental results, a summary of the main observations, conclusions reached, and suggestions for further investigations are presented in Chapter 7, the final chapter.

1.2 NEW ZEALAND'S DAIRY INDUSTRY: AN OVERVIEW

Natural and sown temperate grasslands constitute about 25-30% of the total world area in permanent range and pasture (Reid and Jung, 1982, Hodgson, 1990b). These grasslands support about 35% of the world's ruminant livestock units (Leaver, 1985). In New Zealand, permanent pastures make up 97% of the total land area (14.1 million hectares) used for agriculture and horticulture, 9% of which is under dairy farms (Department of Statistics (NZ), 1990a). In 1989, dairy products accounted for approximately 20% of the country's total export earnings, while the entire pastoral subsector accounted for 52% of export income (Department of Statistics (NZ), 1990b). The importance of pastoral farming in New Zealand's economy is quite evident.

Approximately 10% of all milk produced in New Zealand is consumed directly as fresh liquid milk, with the remainder being processed into a variety of products mainly for the export market (Bryant and Sheath, 1987). Grazed pasture is the main component in the diet of cows (Bryant and Trigg, 1982; Holmes and Wilson, 1984). This low-cost and low-return (per cow) production system enables New Zealand to sell dairy produce on the world market at competitive prices in comparison to its trading partners (Bryant and Sheath, 1987; Bichan, 1990; Holmes, 1990a).

Strict reliance on grazed pastures, however, leads to low digestible energy intakes and low productivity per cow (<4,000 litres/lactation) in relation to genetic potential, and milk processing capacity is under-utilized during periods of low pasture growth in winter and early spring, and during dry summers (Leaver, 1987; Baldwin and Holmes, 1990; Bryant, 1990a, b).

Milk production and utilized metabolizable energy (UME) per hectare can be increased with cows of high genetic merit (Bryant and Trigg, 1981; Grainger et al., 1985; Holmes et al., 1987; Holmes, 1988); high stocking rates (McMeekan, 1956); choice of calving, drying-off and culling dates (Bryant and Holmes, 1985); and by feeding high quality conserved forage supplements, with or without concentrates, during periods of pasture shortage (Jennings and Holmes, 1985; Leaver, 1987, 1988; Thomas and Rae, 1988; Leaver and Fraser, 1989; Phillips, 1989). In New Zealand and Australia, however, supplementary feeding of lactating cows on seasonal-supply farms is uneconomic (Bryant and Trigg, 1982; Stockdale and King, 1982; Bryant, 1989, 1990a; Thomson et al., 1989; Holmes, 1987a, 1990b). Consequently, the feeding of conserved forage with no concentrates is restricted to periods of acute pasture shortages, e.g. winter and dry summers. This is to minimise losses of liveweight and body condition, and the adverse effects these have on the subsequent lactation (Grainger and McGowan, 1982; Wilson and Davey, 1982; Bryant, 1990a); and on the amount of feed on the farm during the early- to mid-spring period of high animal nutritional demand and responsiveness (Bryant, 1990a, b).

Most dairy production in New Zealand is seasonal in nature and is generally classified into two groups: seasonal-supply and town-supply dairy farms. Seasonal-supply farms (cows dried-off in autumn) that produce milk for processing mainly for the export market, made up 92% of dairy herds in the 1988/89 season (N.Z Dairy Board, 1989). These farms had an average herd size and effective land area of 157 cows and 65 ha, respectively, and less than 2 labour units (N.Z. Dairy Board, 1989). Corresponding figures for town-supply farms, 8% of total herds, producing liquid milk throughout the year for domestic consumption were 143 cows on 84 ha. Average milk[1] and milkfat production on factory- or seasonal-supply farms were 3400 litres and 154 kg/cow per lactation and 8,400 litres and 391 kg/ha, respectively, at mean stocking rates of 2.5 cows/ha (ibid). Most of this production is obtained under rain fed conditions, and irrigation is generally confined to the drier areas in the Bay of Plenty (North Island) and Canterbury (South Island).

There are, however, wide variations in stocking rates and production levels between regions and between farms within a region reflecting, at least partly, differences in soils, climate and management. New Zealand milked 2.3 million cows in the 1989-1990 season and the national herd was 3.3 million dairy cattle, 90% of which are in the North Island (about 70% in the South Auckland, Bay of Plenty and Taranaki regions) (N.Z. Dairy Board, 1990).

[1] Not fat corrected.

Several dairy companies have recently encouraged "out of season" milk production by seasonal-supply dairy farms through production contracts and price incentives (Bryant, Paul and Scott, 1988; Johnson, 1990; Macmillan, 1990). This is an attempt to utilize fully the massive investment in milk processing facilities and to stabilize the supply of liquid milk and short shelf-life dairy products for the domestic and export markets (Macmillan, 1990). Also, the milkfat-based payment system for the producer is being replaced by one that considers both milkfat and milk protein production with a slight penalty for the liquid component (Bryant et al., 1988). How these changes will influence the feeding and selection of dairy herds is not yet clear (Ahlborn and Bryant, 1992). However, New Zealand farmers may have limited options, in the long-term, other than breeding and selection to improve yields of milkfat and protein (Holmes, 1988; Kolver and Bryant, 1992). Since, for cows feeding on pasture, the proportions of fat and protein in the milk over a whole lactation are generally influenced neither by the level nor quality of nutrition over a wide range of stocking rates (2.7-4.5 cows/ha) (McFeely et al., 1975; L'Huillier, 1987c, 1988; Thomas and Martin, 1988; Thomson, 1988; Sutton and Morant, 1989; Bryant, 1990a; Stakelum and Dillon, 1991). Similarly, milk composition is generally not influenced by wide variations in grazing management (L'Huillier, 1987c, 1988; Thomson, 1988; Bryant, 1990a; Stakelum and Dillon, 1991; Kolver and Bryant, 1992).

1.3 NEW ZEALAND PASTURES AND GRAZING MANAGEMENT

Approximately 90% of cows calve in mid-winter to early-spring (July-September). This calving strategy coupled with strict rationing of pasture for dry cows during autumn and winter, and altering rotation lengths in early lactation, with or without early drying-off and culling in autumn, aim at transferring pasture *in situ* to early and mid-spring (Bryant and Cook, 1980; Bryant and Trigg, 1982; Sheath and Harris, 1985). The strategy also attempts to match increasing pasture availability and growth rates in spring with increasing feed requirements of the herd during early to mid lactation (Holmes and Wilson, 1984; Bryant and Sheath, 1987).

Ninety-eight percent of New Zealand pastures are dominated by perennial ryegrass and white clover yielding about 13-15t DM/ha annually with nil or limited N fertilization (Holmes, 1982; Bryant et al., 1982; Sheath and Harris, 1985, Korte, et al., 1987), but on better than average farms other grass species contribute about 20% of the grass cover (Harris and Chu, 1985; Lancashire, 1985a, b). Perennial ryegrass has a reputation for easy establishment, prolific tillering, aggressiveness and ability to compete, high nutritive value (digestibility), and for tolerance to mismanagement, to some extent, in comparison to other temperate perennial grass species (Raymond, 1969; Williams, 1980, Langer, 1990).

Perennial ryegrass has its limitations. It is susceptible to pest damage, mainly grass grub and Argentine stem weevil, particularly when low endophyte (*Acremonium lolii*) cultivars are grown with white clover (Goold, Thom and Prestidge, 1989; McCallum, Thomson and Roberts, 1990). It also shows poor growth during periods of low soil temperatures during late autumn to early spring, and during summer moisture deficits; and it requires high soil fertility. Depending on stocking rate, lactating cows may often not obtain sufficient pasture to enable maximum voluntary intake in early to mid lactation - a period of high nutritional demand. The cows' total lactational performance and fertility may be adversely affected, depending on the length and severity of under-feeding (Grainger and Wilhelms, 1979; Broster and Thomas, 1981; Bryant, 1990b). However, infertility is not perceived as a major problem in spring calving New Zealand herds (Macmillan, 1979; Bryant and Trigg, 1982), and cows are able to recover from 35% under-feeding in early lactation (first five weeks) (Grainger and Wilhelms, 1979; Bryant and Trigg, 1979, 1982; Trigg et al., 1980; Bryant, 1990b).

New Zealand plant breeders have persistently striven to develop cool-season and summer-active herbage cultivars, with complementary production and grazing management packages, to overcome feed shortages during periods of high animal nutritional demand. Many cultivars and ecotypes have been released during the past 20 years, by the Grasslands Division, Department of Scientific and Industrial Research (DSIR), e.g., Roa and Au-Triumph tall fescue; Kara and Wana cocksfoot; Matua prairie grass; Maru phalaris; Nui ryegrass; Pitau and Kopu white clover; Pawera red clover; Puna chicory; and Maku lotus (Lancashire, 1985b; Thom and Prestidge, 1988; Belgrave et al., 1990). Prairie grass cv. Grasslands Matua (*Bromus willdenowii* Kunth), to be referred to frequently in this thesis as Matua, is the focus of the present study.

1.4 ATTRIBUTES OF MATUA PRAIRIE GRASS

Prairie grass has long been recognized in New Zealand as a true perennial and a valuable pasture species (Rumball, 1967). The first commercial cultivar, Grasslands Matua was released in 1975. The cultivar was bred and selected for higher tiller production, and higher dry matter yields (by 15-35%) than other prairie grass lines and the common perennial ryegrass cultivars, respectively. Much of Matua's production superiority was realized during the cool periods and during summer when traditional perennial ryegrass pasture mixtures were low yielding (Rumball, 1974; Hill and Kirby, 1985). Matua prairie grass is reputed to be highly palatable, and with high digestibility despite large numbers of inflorescences from mid-spring to autumn (Crush et al., 1989; Hume, 1990a, b).

Although it was originally suggested that prairie grass was particularly suited to high fertility dairy farms under an infrequent and lax grazing regime (Rumball, 1974; Lancashire and Brock, 1983), there is no evidence to date of increased cow or farm productivity as a result of the incorporation of Matua into dairy pastures (McCallum, 1987; Penny, 1987; Thom and Prestidge, 1988; Sellars, 1988; A.M. Bryant, pers. com.). Ten to fifteen percent higher gross margins have, however, been reported where prairie grass was used in sheep farming systems in a dry region in the South Island, New Zealand (Fraser, 1985; Greer and Chamberlain, 1986). The defoliation regime used in these trials was intensive and of short-duration with long resting periods to allow for tiller recovery. High losses of dry matter and herbage quality through senescence and low leaf:stem ratios associated with lax and infrequent grazing regimes may account for depressed productivity of cows on Matua pastures. Experimental evidence, however, is lacking.

Matua's major limitations, in contrast to perennial ryegrass, have been its low tillering capacity and poor persistence under frequent or intense defoliation, and when grown under poor soil drainage conditions (Rumball, 1974; Hill and Pearson, 1985; Mwebaze, 1986). It is also susceptible to fungal (head smut and anthracnose) and insect attack (Argentine stem weevil and hessian fly) (Falloon, 1976; Falloon and Hume, 1988; Falloon and Rolston, 1990; Thom and Prestidge, 1988; Thom et al., 1989, 1990; Boom and Sheath, 1990). Head smut has been successfully controlled by seed dressing with benomyl or thiram (Falloon and Rolston, 1990), while Argentine stem weevil and hessian flies have been controlled by oxamyl and fensufothion insecticides, respectively (Thom et al., 1989). However, the economics of insecticide use is questionable.

Matua's poor persistence might also be related to damage to growing points (Alexander, 1985), although A.C.P. Chu (unpublished data) has found no evidence of crown damage under normal dairy grazing of Matua swards. Poor oxygen uptake due to soil compaction arising from frequent grazing and treading could affect Matua's root performance (Mwebaze, 1986; Eccles, Matthew and Chu, 1990). Black and Chu (1989) and Hume (1990a) have suggested a physiological constraint to Matua's persistence especially if it is grazed before replacement tillers appear at the base of the sward. It has also been postulated that the slow rate of recovery of tillers following defoliation may be more important to Matua's persistence than tillering ability (A.C.P. Chu, pers. com.; C.K. Black, unpublished data).

1.5 AIM AND OBJECTIVES OF THE PRESENT STUDY

It has been suggested that, in comparison to 'conventional' perennial ryegrass swards, the utilization of extra dry matter grown from Matua prairie grass-clover pastures could be improved through intense grazing, followed by a long recovery period of five to six weeks, without a significant loss in sward yield and persistence, herbage quality, and production per animal (Wilson, 1977; Alexander, 1985; Fraser, 1985; Matthews, 1986). The purpose of the studies reported in the present thesis was to test this hypothesis, with particular emphasis on the composition of the pasture and its feeding value for lactating dairy cows.

1.5.1 Primary objectives of the study

Prairie grass cv. Grasslands Matua is reputed to be a highly productive and nutritious pasture cultivar, but it suffers from poor persistence as a result of mismanagement and/or disease and pest damage. There is, however, no evidence to date of improved productivity per cow or per hectare as a result of incorporating prairie grass in a dairy production system. Similarly, there is very limited information on the effects of season and defoliation regime by dairy cows on the composition and feeding value of Matua prairie grass in comparison with perennial ryegrass dominant pastures.

The general objective of the present investigation was to provide some basic information on the composition and feeding value of prairie grass, to assist in the assessment of its role in in dairy production systems.

The specific objectives were:

1. To measure, over a range of seasons, the effects of differences in pregrazing herbage mass, created and maintained by variations in grazing intensity and/or frequency, of prairie grass cv. Grasslands Matua/clover pastures on sward characteristics (growth and structure) and pasture composition.

2. To measure the effects of differences in pasture structure and composition, consequent to variations in grazing regime, of Matua prairie grass swards on the feeding value of the herbage, and on subsequent pasture and dairy cow performance; with 'conventional' perennial ryegrass / white clover pasture used as a control treatment.

Plate 1.1 A 'conventional' perennial ryegrass/white clover sward (top foreground) and a low mass Matua prairie grass/white clover sward (bottom) under experimental grazing in late spring.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION TO LITERATURE REVIEW

The productivity of dairy cows feeding on pasture is largely dependent on the product of the quantity and quality of pasture consumed (Bryant, 1981a). This in turn is influenced by a wide range of soil and associated fauna, plant, animal, climatic and managerial factors (e.g., farm inputs and stock policies) that form a complex ecosystem (Snaydon, 1981). The components of the ecosystem interact to influence the biomass productivity upon which the animal production is achieved.

This review will concentrate on the animal and plant components of the grazing system (plant/animal interface). It will focus mainly on the effects of defoliation regime and season on the growth, accumulation and composition of temperate, specifically New Zealand pastures; and the effects of these on herbage intake and subsequent dairy cow performance. The roles of the remaining components of the pasture ecosystem have been reviewed elsewhere (Snaydon, 1981, 1987; Vickery, 1981; Hodgson, 1985, 1990b; Korte et al., 1987; Radcliffe and Baars, 1987). Finally, the limited evidence about the management for milk production and composition of prairie grass cv. Grasslands Matua pastures will be reviewed.

In this review, pasture composition will be used to mean the botanical, morphological and chemical composition of the herbage and the spatial distribution of these components in the sward (Waghorn and Barry, 1987); whereas defoliation regime will be used to mean the frequency and/or intensity with which a sward is cut or grazed.

An appreciation of the principles governing herbage growth is a prerequisite to understanding the effects of grazing on herbage accumulation and pasture composition, and the effects of these on milk production (plant/animal interface). For this reason, and because of the scarcity of recent scientific literature in the author's home country, herbage growth will be reviewed in considerable detail, and will be included as Appendix 2.1 of the present thesis.

2.2 EFFECTS OF DEFOLIATION REGIME AND SEASON ON HERBAGE GROWTH AND ACCUMULATION

A detailed review of this topic is presented as Appendix 2.1 of the present thesis, and only a summary of the main points will be presented here.

Total herbage accumulation is a result of the accumulation of the different pasture species and component parts (i.e., leaf, stem, seedhead and dead matter) of those species. Because of the different accumulation rates of these components, within and between seasons, the effect of management on herbage accumulation or availability to the grazing animal when expressed as total herbage, green herbage, or leaf lamina may be different (Butler et al., 1985, 1987; Hoogendoorn, 1986). Therefore, analysis of grazing management effects in terms of total dry matter production may be of limited value because no account is taken of the effects of management on the feeding value of the dry matter produced, mainly as a result of inclusion of dead herbage in the net herbage accumulation (NHA) equation. As a result, use of lamina mass as a measure of sward productivity has been suggested (Bircham, 1981; Holmes and Macmillan, 1982; Butler et al., 1987).

In the review (Appendix 2.1), the influence of changes in plant morphology, sward structure and pasture production following defoliation have been considered. Some indication has been given of how regrowth depends on the initial resources of leaf area and carbon compounds present in the stubble. An account has been given of how and when the accumulation of dry matter in new leaves is offset by losses of older leaves present in the stubble or accumulating during regrowth. Evidence has been presented showing how tiller populations are related to the level of herbage mass that is allowed to accumulate. However, the changing morphology of the plant strongly influences its response to defoliation in both the shorter and longer term. The structure of the grass sward varies considerably in response to defoliation, and the sward is capable of a high degree of adaptation to wide variations in management, such that net pasture production remains relatively constant (Bircham and Hodgson, 1983a; Figure 2.1).

In view of the complexity and plasticity of the response of the grass crop to defoliation, no single recipe for production can hold true under any but the most limited circumstance. In practice the need to sustain fluctuating grazing intensities and/or frequencies against a background of seasonal variation in both pasture and animal production requires a more flexible approach. An understanding through research of the physiological principles of the short term effects of defoliation on the accumulation and loss of matter in swards of varying botanical compositions, and of new cultivars in various environments is still necessary. This needs to be supported by an appreciation of the importance of avoiding marked deterioration in sward structure and growth in the long-term and during critical periods of the year. Consequently, farmers should be able to make management decisions that best suit their objectives and the changing conditions they experience. Such an understanding should increase the reliability and efficiency of production of the grass crop, and so increase confidence in the use of grass as an inexpensive feedstuff for ruminant animal production.

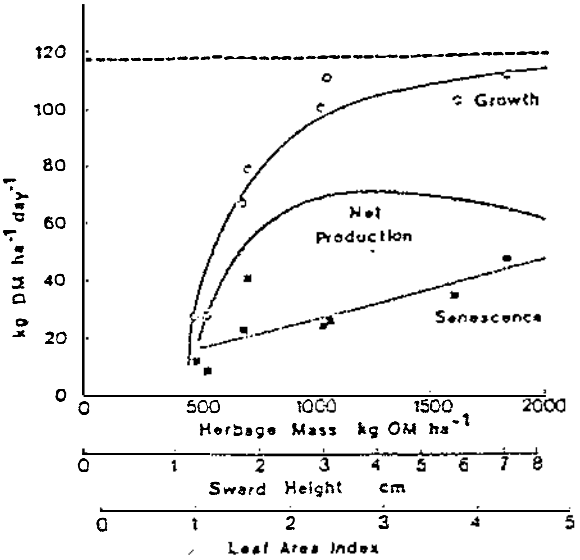


Figure 2.1 Combined species growth, senescence and net production rates (kg DM/ha per day) *vs* herbage mass, sward surface height, and leaf area index (Adapted from Bircham and Hodgson, 1983a).

2.3 EFFECTS OF DEFOLIATION REGIME AND SEASON ON PASTURE COMPOSITION

2.3.1 Composition of temperate pastures

A brief review of the composition of temperate pastures is presented as Appendix 2.2 of the present thesis.

The evidence presented in Appendix 2.2 indicates that temperate pastures are composed of a mosaic of grass and legume species, with perennial ryegrass and white clover being the most dominant. Similarly, evidence is presented that shows that legumes are superior to grasses in nutritive value (see also Figure 2.2).

The nutritive value of pasture herbage is generally influenced by stage of maturity, season, and grazing management via its effects on botanical composition, and proportions of leaf, stem and dead matter. It is also influenced by the rate of herbage accumulation and the degree to which herbage grown is harvested for consumption.

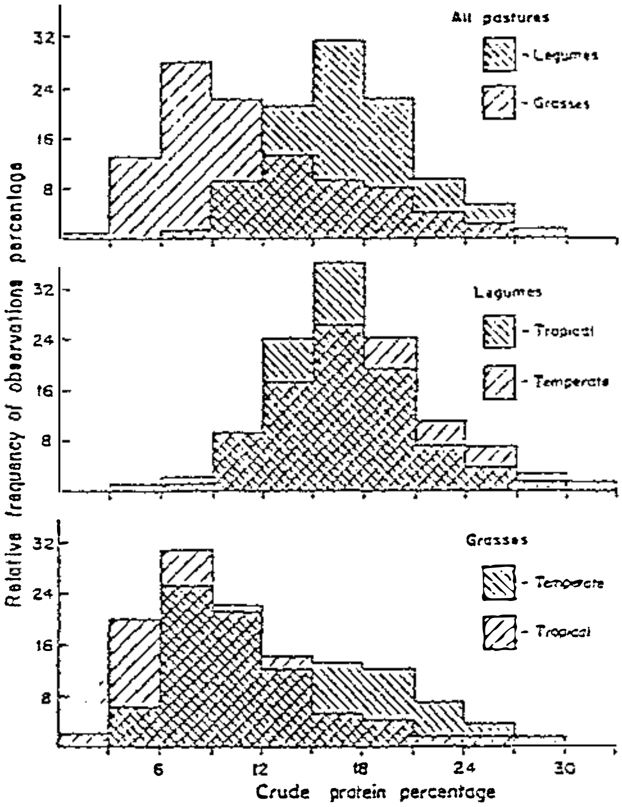


Figure 2.2 Frequency distributions of crude protein concentrations in tropical and temperate grasses and legumes. (After Minson, 1976).

2.3.2 Effects of defoliation regime on pasture composition

Whereas the proportions of pasture species sown and those of individual herbage components, and their spatial distribution in a sward may vary with sward age (Snaydon, 1987), defoliation practices and season are the dominant factors that influence the composition and structure of sown pastures (Harris, 1978; Brougham and Chu, 1987; Korte and Harris, 1987). Pasture defoliation practices and season influence sward composition mostly through their effects on rates of herbage accumulation, maturation and senescence (Bircham, 1981). The effects of season and plant maturity on pasture composition are difficult to separate, and often interact with the defoliation regime imposed (L'Huillier, 1987b).

2.3.2.1 Botanical composition

The effects of grazing management on the composition and utilization of pasture on dairy farms has been reviewed on many occasions (Bryant and Trigg, 1982; Holmes and Macmillan, 1982; Bryant and Holmes, 1985; Leaver, 1985; Bryant and Sheath, 1987; Christian, 1987; Holmes, 1987a; Bryant, 1990a). Increasing the frequency and intensity of grazing, e.g., short rotation lengths or set stocking at high stocking rates, generally leads to perennial ryegrass and clover dominance (Hay and Baxter, 1984; Sheath and Boom, 1985; L'Huillier and Bryant, 1987; L'Huillier, 1987b, 1988). Clovers are also favoured by control of competition during the spring and periodic spelling (infrequent grazing) in summer (Sheath and Boom, 1985; Cosgrove and Brougham, 1985; Hoogendoorn, 1986; L'Huillier, 1987c, 1988). Continuous lax grazing favours the taller species like cocksfoot, prairie grass and Yorkshire Fog (Hodgson, 1990b; Langer, 1990) whereas close continuous defoliation leads to a species-rich association with high concentrations of prostrate, creeping plants, such as brown top and Poa spp. (Harris, 1978; Michell and Fulkerson, 1985; L'Huillier, 1988).

The botanical composition of pasture is also modified by type of stock. For example, cattle- rather than sheep-dominated pasture systems result in reduced plant density and increased proportion of clover particularly at high stocking rates (Suckling, 1975; Stockdale and King, 1980; Curll, 1982; Lambert et al., 1986).

There are some conflicting reports, however, on the effects of defoliation regime on the relative productive and competitive abilities of pasture species (Baines et al., 1983, Michell and Fulkerson, 1987). Differences in response to defoliation may arise from differences in the timing and the extent of removal of photosynthetic area and meristematic tissue (Korte and Harris, 1987). They may also arise from differences in bud regeneration, flowering and seed production, soil seed reserves, and seedling regeneration, which depends on the degree of shading and the soil environment (Sheath and Boom, 1985; Korte and Harris, 1987; L'Huillier, 1987a, c). For example, extremes of winter management 128 *vs* 48d rotations) had no effect on either tiller density or the proportion of ryegrass, clover and dead material in the pasture in winter and early spring (L'Huillier, 1987c). On the other hand, 8 compared with 32d rotations in early spring resulted in more white clover, less ryegrass and dead material, and an increase in tiller density through the spring/summer period (ibid).

Changes in botanical composition of pasture can influence the total and seasonal distribution of herbage production or forage quality. However, several long term New Zealand studies indicate that general grazing methods differ little in their effects on botanical composition when operated at similar grazing intensities and with similar animals (Suckling, 1975; Cosgrove and Brougham, 1985; Lambert et al., 1986). This view is also supported by the work of Stockdale and King (1980), who observed a reduction in the concentration of subterranean clover and an increase in the proportion of grass due to hard grazing only during spring; otherwise grazing management had no effect on the botanical composition of pasture. Extremes of over- or under-grazing, however, will result in longer lasting changes in the botanical composition of swards (Suckling, 1975).

2.3.2.2 Morphological composition

Animals generally prefer the leaf fraction of pastures and avoid dead matter, preferring green herbage (Poppi et al., 1980; 1981a). It is therefore important to distinguish the effects of defoliation on these components. More frequent defoliation generally increases the proportion of leaf material in comparison to 'stem', and the proportion of green in comparison to dead herbage in the upper, more accessible sward horizons (Wilman et al., 1976a, b; Hoogendoorn, 1986; Hoogendoorn et al., 1987; L'Huillier, 1988). The interval between defoliations that maximises leaf yield is usually considerably less than one that maximises total DM yield (Wilman et al., 1976b), and is dependent on such factors as time of year, soil nitrogen status and plant species or cultivar. Frequent defoliation also increases the proportion of dead leaf to green leaf material (Wilman et al., 1977b), but decreases the concentration of dead material in the total sward (Hoogendoorn, 1986; L'Huillier, 1988).

Conversely, longer periods of uninterrupted growth increase the concentration of dead material accumulating mainly in the less accessible base of the sward (Korte and Sheath, 1979; Francis and Smetham, 1985; Hoogendoorn, 1986; Butler, 1986). Infrequent grazing permits stem development thus narrowing the leaf:stem ratio, and this is most marked during reproductive growth (Korte et al., 1984; Holmes and Hoogendoorn, 1985). Vegetative growth consists almost entirely of leaf and sheath whereas with reproductive growth, once stem elongation begins, most of the increase in DM mass is from stem rather than leaf growth (Wilman et al., 1976b; Korte et al., 1984; L'Huillier, 1988). The proportion of green leaf in the sward has been reported to decline from 80% to 5% of the total tiller mass during stem elongation (Wilman et al., 1976d).

The intensity with which pasture is grazed has important effects on pasture productivity, and on the composition of the herbage and its feeding value for dairy cows, both in the short and long term (McMeekan, 1960; Stockdale and King, 1980; Hoogendoorn et al., 1987;

L'Huillier, 1987b, c; Stakelum and Dillon, 1991). In general, intense grazing, as with frequent grazing, results in pastures with greater concentrations of clover, total green matter and green leaf, and smaller concentrations of stem and dead material than laxly grazed pastures (Korte et al., 1984; Hoogendoorn et al., 1985, 1987; L'Huillier, 1987b, 1988; Stakelum and Dillon, 1991).

The absolute differences in pasture composition arising from differences in grazing intensity (ibid, Santamaria and McGowan, 1982; Michell and Fulkerson, 1987) or frequency (Hoogendoorn et al., 1987; L'Huillier, 1987c, 1988) are greater in the mid spring to early summer period than the late summer to early spring period. This is probably because of the high rates of accumulation of stem and dead material during the former period.

During late spring-early summer, mechanical topping of previously laxly grazed swards (Holmes and McClenaghan, 1980; Bryant, 1982; Hoogendoorn, et al., 1985; MacDonald, 1986; Stakelum and Dillon, 1991), or intense grazing of part of the farm with late (November/December) conservation (Bryant, 1982; Thomson et al., 1984), or conservation in situ (L'Huillier, 1988; Thomson et al., 1989), or spraying growth retardants such as mefluidide (Goold et al., 1982; Brookes and Holmes, 1984; Hoogendoorn et al., 1985; McGrath, 1986) have been shown to improve slightly the quality of summer pasture. Subsequent reductions in the concentrations of stem and dead material of the herbage may explain the improvements in herbage quality observed during summer. However, for both topping and mefluidide spraying, the alternatives need to be evaluated, finally, in terms of financial returns.

2.3.2.3 Herbage quality

Grazing intensity and/or frequency influence the digestibility of herbage through their effects on herbage maturity and on the proportions in the sward of green leaf of high digestibility, and of stem and senescent matter of lower digestibility as was discussed previously. Managements that increase the concentrations of desirable grass species (e.g., ryegrass) and clover also tend to improve the digestibility and N concentration of the herbage on offer.

Intense and/or frequent grazing improves herbage digestibility and reduces herbage wastage through senescence (Bircham and Hodgson, 1983a, b; Holmes et al., 1992; L'Huillier, 1987b; Stakelum and Dillon, 1991). On the other hand, such managements often conflict with the need to maximise intake, which is best achieved at low grazing intensities in the short term. The factors that affect herbage intake at pasture are discussed in Section 2.4.3.

Changes in the proportion of nitrogen in the total herbage are closely correlated with DMD (Raymond, 1969). But, unlike digestibility that peaks in winter, % N of pasture herbage is highest in autumn, intermediate in winter/early spring and lowest in late spring/early summer (Hutton, 1961; Bryant and Trigg, 1982; Reid, 1986; Crush et al., 1989). The % N of a plant does, however, tend to decrease sooner than the DMD as the plant matures (Minson, 1981a). High values for % N are reported for herbage that is composed of predominantly young and growing tissue, and where leaf and legume proportions are high (Wilman et al., 1976d; Hoogendoom et al., 1987).

In general, a frequent and/or intensely grazed swards will have a greater proportion of young and actively growing plant tissue than swards that are less frequently and more leniently grazed. Thus, compared to infrequently grazed swards the DMD and % N of frequently and/or intensely grazed swards would be expected to be higher. Besides, any grazing regime that results in an increased proportion of dead material in the sward will result in a concomitant decrease in DMD and % N, since the DMD of senescent matter is low (<47%; Michell and Fulkerson, 1987).

2.3.3 Effects of season on pasture composition

Seasonal changes in pasture composition and plant maturity cannot be easily separated. Also, the amount of pasture left after grazing and the frequency of grazing may interact with season to influence the composition of pasture in the subsequent grazing period (Hoogendoorn, 1986; L'Huillier, 1987b, 1988). In general the proportion of clover in mixed pastures is smallest in the winter/early spring period but increases sharply in the late spring/summer period, declining slightly in autumn (Harris, 1978). However, intense or frequent grazing during spring will increase the proportion of clover in the sward because of decreased shading (Sheath and Boom, 1985; L'Huillier and Bryant, 1987). It will also reduce the proportion of erect grass species as was discussed previously (ibid).

The proportions of herbage components in intensively grazed swards are generally not affected by grazing interval during winter (Hoogendoorn, et al., 1987; L'Huillier, 1987c, 1988). However, during the spring period of high pasture growth rates, intense/frequent grazing or set stocking reduced the number of flower stems and dead material that develop during this period; and increased the concentration of green leaf and clover during late spring/early summer (Hoogendoorn et al., 1985,1988; Bryant and L'Huillier, 1987; L'Huillier, 1987c). Herbage digestibility during the same period (late spring/early summer) was not consistently affected by previous grazing management (ibid). Pastures generally contain a lower percentage of leaf, and a higher percentage of stem and dead material in the late spring/summer period than in winter or early spring (Hoogendoorn, 1986).

The nutritive and feeding value of pasture herbage for sheep, beef cattle and probably lactating dairy cows is lower for autumn pastures than spring pastures of similar digestibility or herbage allowance (Marsh, 1975; Clark and Brougham, 1979). This phenomenon, also called autumn ill thrift, has been reviewed by Scott et al. (1976) for New Zealand pastures, while reviews by Reed (1978) and Leaver (1985) provide a wider coverage of the subject. Seasonal changes in the digestibility and concentrations of nitrogen and metabolisable energy (M/D) of pasture herbage are highlighted in Appendix 2.2 and will not be repeated here (see also Hutton, 1961, 1962; Bryant and Trigg, 1982; L'Huillier, 1987c; Crush et al., 1989).

Intake of autumn herbage is typically between 10% (Corbett et al., 1963) and 19% (Steer and Kirchgessner, 1976) less than spring herbage of similar digestibility. Reid (1986) found that growing steers required less herbage allowance for maintenance in spring than in autumn/winter, and that potential growth rates in spring were double those of winter. The differences in growth rates in Reid's two year experiment were not associated with differences in herbage digestibility (70-78% in all trials) or N concentrations. Reid et al. (1988) also observed lower lamb growth rates between birth and weaning in autumn born than in spring born lambs. Many factors have been suggested for this disorder (ill thrift), which include high dead matter concentrations in the lower horizons of autumn swards, and the effect these have of reducing the depth of the grazed horizon (Le Du et al., 1981). A reduction in the area available for grazing because of faecal contamination may also contribute to autumn ill thrift (Phillips and Leaver, 1985a, b).

Autumn ill thrift may also be attributable to more structural and less water soluble carbohydrates, greater N concentrations, and longer rumen retention times of autumn than spring pasture (Rattray and Joyce, 1974; Reid, 1986; Waghorn and Barry, 1987). It was also suggested by Corbett et al., (1966) and Ulyatt et al. (1980) and confirmed by MacRae et al. (1985) that the efficiency of utilization by sheep of ME for production from autumn herbage is lower than that of spring herbage. MacRae and associates (ibid) also found differences in the absorption of non-amino N and total amino acids in the small intestines between autumn and spring herbage, which was greater on spring herbage. This would suggest that most of the extra N in autumn herbage is degraded and lost from the rumen in comparison to N in spring herbage of higher outflow rates (ibid).

Reductions in milk yields of dairy cows fed on cut autumn herbage have been less than 5% (Gordon, 1974). This is probably because of the higher acetate:propionate ratio from autumn herbage (greater and lower concentrations of structural and soluble carbohydrates, respectively) than spring herbage. A high acetate:propionate ratio stimulates a diversion of nutrients to milk and milkfat synthesis. Similar data with grazing dairy cows is limited. But it may be possible that the efficiency with which ME from spring herbage is utilized for production may be less important for dairy cows (Leaver, 1985).

Plant alkaloids and fungal toxins have also been implicated in the autumn ill thrift disorder (Brewer et al., 1971; Ulyatt, 1981; Lauren et al., 1988; Reid, 1989), but the available evidence is inconclusive and further work is still needed to confirm this suggestion.

2.3.4 Summary

Intense or frequent grazing increases the proportions of clover, prostrate species, and green leaf, and reduces the proportion of dead matter in the sward. The digestibility of herbage is also increased.

In the long term, the effects of defoliation regime on pasture composition may not be consistent. Nevertheless, grazing methods differ little in their effects on pasture composition when operated at similar grazing intensities and with similar animals. This is particularly so during the summer/autumn period (L'Huillier, 1987b; Bryant, 1990b). However, one hard grazing during autumn (autumn clean up) will reduce considerably the amount of dead matter carried over from summer, thus improving further the quality and density of the pasture (Holmes and Wilson, 1984).

In the short term, deterioration in the quality of dairy pastures and a decline in dairy cow performance (see Section 2.4.4.) can be reduced by avoiding high herbage masses in the late spring to early summer period. This may be achieved by high stocking rates, or conservation of surplus herbage as hay, silage or *in situ*. Topping following lax grazing, set stocking or fast rotations of 10-20 days, and previous hard rather than lax grazing will also improve the feeding value of late spring/summer pasture herbage. Besides, such practices will improve ryegrass tillering and sward density, and help to maintain high ratios of green to dead matter and clover to grass. On the other hand, there is a paucity of similar information for the non-traditional, more erect grass species, e.g., prairie grass and tall fescue under dairy farming conditions. It appears that perennation of prairie grass is favoured by lax grazing during late spring, then hard grazing after seedhead emergence (Matthew et al, in press).

The feeding value of autumn pasture is lower than that of spring pasture of similar digestibility at constant herbage allowance. The reasons for the difference in feeding value between autumn and spring pasture are not yet clearly established and require further research, particularly with lactating dairy cows. Also, there is considerable uncertainty of the ability of temperate pastures to meet the undegradable nitrogen requirements of high producing cows, especially in early lactation. Thus further investigations on the nitrogen nutrition of grazing dairy cattle are warranted.

2.4 EFFECTS OF SWARD STRUCTURE AND COMPOSITION ON DAIRY COW PERFORMANCE

2.4.1 Introduction

Animal productivity from grazed pasture, as was stated in the introduction to this review, is largely dependent on the product of the quantity and quality of pasture consumed. This in turn is influenced by a wide range of sward, animal and environmental factors, which were also highlighted at the beginning of this review (Section 2.1). One of the major limitations to improving animal production at pasture is the inability to optimise feed intake relative to the animal's requirements and/or production potential. This is because of our inability to predict the quantity and quality of herbage consumed by the grazing animal with some degree of certainty (Meijs, 1981; Forbes, 1988a). Defoliating the sward over a short period makes this task even more difficult as sward canopy structure and nutritive value of the remaining pasture undergo rapid simultaneous change. In such circumstances of correlated change, it is difficult to ascribe intake to sward variables (Hodgson, 1982a).

Current grazing management systems in New Zealand regularly constrain animals to graze to low post-grazing pasture masses so as to optimise output per hectare or to ration pasture (Bryant and Trigg, 1982). This has led to a description of good grazing management of a single sward as the methods of grazing required to alter or control the rate of feed use, severity and frequency of grazing (Bryant and Sheath, 1987). It is the control or manipulation of grazing required to accumulate, transfer and allocate pasture from periods of surplus to those of deficit or from times of low to those of high animal responsiveness; in attempting to optimise the extent to which the requirements of both stock and pasture are satisfied throughout the year (Wallace, 1959; Holmes and Macmillan, 1982; Bryant and Sheath, 1987). Grazing management has also been described in more general terms as the manipulation of existing plant and animal populations to make the most effective use of a given set of farm resources and variable costs - particularly fertilizer (Hodgson and Maxwell, 1981).

Therefore, the objective of grazing management may not necessarily be an increase in output per unit area of land or per animal, though it often is. Greater predictability or uniformity of production (at the top end of the production curve), or greater management convenience may be more important objectives on many farms, with financial viability of the farm as the ultimate practical test (Hodgson, 1990b).

For most of the year, therefore, those properties of the pasture that influence the ease of harvesting by the grazing animal (non-nutritional), and are mainly a function of grazing management and the environment, are the most important factors limiting intake. How grazing management may alter sward characteristics over time, and the mechanisms through which these changes may influence the future productivity of the pasture, were examined in Section 2.2 and Appendix 2.1. The following part of the review will discuss the factors that control voluntary feed intake (VFI) in general, and more specifically the influence of grazing management and the resultant sward characteristics (quantity, structure and composition) on herbage intake and subsequent animal output.

2.4.2 The control of herbage intake

Control of intake in grazing ruminants may be viewed as a balance between the drives for nutrients (feeding drive stimuli) and their sensitivity to metabolic, physical and behavioural inhibitory stimuli (McClymont, 1967). Until the interaction between sward structure and behaviour was shown to be a major determinant of grazing intake (Allden and Whittaker, 1970) it was incorrectly presumed that metabolic and physical models of intake control developed with pen fed animals were also adequate for the grazing animal.

Plant and animal factors, and their influence on the mechanisms (metabolic, physical and behavioural) determining grazing intake have been extensively reviewed (Wiepkema, 1971; Forbes, 1980, 1986, 1988b; Meijs, 1981; Minson, 1981b, 1987; Hodgson, 1982, 1985a, 1986; Poppi et al., 1987; Weston and Poppi, 1987; Black, 1990). Holmes and Jones (1964) observed that for dairy cows the most important animal factors reflecting herbage intake are milk yield, liveweight and liveweight change, and these were recently reviewed by Mayne and Wright (1988). In general, lactating cows at pasture eat 43-76% more herbage than dry cows of similar liveweight (Hutton, 1963; Hodgson and Wilkinson, 1967); and herbage organic matter intake and animal liveweight or liveweight gain are closely correlated (Hodgson and Wilkinson, 1967). With dairy cows however, post partum appetite lags behind milk yield, reaching a maximum four months after peak milk production (Figure 2.3). High yielding cows have to mobilise body fat and protein to support production in early lactation. Reasons for this lag in voluntary intake are unclear (Forbes, 1986).

A conceptual illustration of the plant/animal interface and its influence on herbage intake is presented in Figure 2.4. This figure illustrates the interactions between sward characteristics (quantity and character), the grazing process, and the physical and metabolic processes within the animal. When the quantity of available herbage is high enough for *ad-libitum* intake, nutritional factors (animal factors and the character of the forage e.g., digestibility or quality, proportion of leaf in the herbage) are the most important determinants of intake through the distention mechanism, or the metabolic mechanism in the case of very high quality forages (Figures 2.4A & 2.5 (ascending section)).

When the quantity of forage and/or pasture allowance is low, forage character may have little effect on intake, which in this case is limited by behavioural (non-nutritional) factors or mechanisms e.g., number and size of bites, grazing time and herbage accessibility (Figures 2.4B & 2.5 (asymptotic section)). At higher quantities of herbage, even ad-libitum levels, the 'availability of desired forage' or forage 'accessibility' may affect intake through limits on the number and/or size of bites. Figure 2.4C combines the many possible intake-limiting factors, although this still is an over-simplification of a complex system. In addition, Figure 2.4C illustrates a 'feedback' regarding the effect of intake (the act of consumption) on the quantity and character of forage available in the following period.

All factors affecting herbage intake can operate simultaneously. However, in any particular situation, one or two factors may be most limiting. For example, when herbage mass and/or pasture allowance is limiting, behavioural (non-nutritional) mechanisms would be expected to predominate (Figure 2.5, ascending section). In such conditions, Chacon and Stobbs (1976) demonstrated that cattle were unable to compensate completely for the removal of rumen digesta by increasing grazing activity. This response may also be dependent on the amount and packing density of the digesta removed (Black, 1990). As swards are progressively defoliated, the digestibility of the diet may not change, yet intake may decrease by 30% (Collins, 1989). In such pasture conditions the animals were prepared to maintain diet quality at the expense of intake. Intake was presumably restricted by the scarcity, accessibility and ease of harvesting of the preferred sward components.

The lower digestibility of stem and dead material present in the lower sward horizons is often used to explain the reduced intake by animals forced to graze to a low post-grazing pasture mass or offered low pasture allowance. The correct explanation is that the increased difficulty of harvesting pasture depresses intake (Poppi et al., 1987). In practice, however, digestibility must remain as the major measure of pasture 'quality'. This is because of its influence on the M/D value of forage. However, digestibility may not be quite as important in the control of intake of both silage (Wilkins et al., 1971; Gill et al., 1988) and pasture herbage (Forbes, 1986; Poppi et al., 1987) as previously thought. Rather, digestibility is a function of the same components that influence intake, i.e., rate of digestion or degradation and rate of passage of ingested herbage out of the reticulo-rumen (Poppi et al., 1981a, 1987; Thomas and Chamberlain, 1990).

Physical distention mechanisms of intake control are usually considered in terms of level of rumen fill and the rate of disappearance of digesta. In the early stages of defoliation of a tropical sward cattle were able to compensate fully for the removal of rumen contents (Chacon and Stobbs, 1976), which suggests that rumen fill was limiting herbage intake. On high herbage mass temperate swards, rumen fill limited the intake of grass but not legume by lambs, which stopped grazing at a level of fill approximately 25% lower than their grass fed contemporaries (Thornton and Minson, 1973; Thomson et al., 1985; Cruickshank, 1986). Rumen digesta load is positively related to the difference between the capacity of the animal to use energy and the energy supplied from the diet, or the energy deficit of the animal (Weston, 1985; Gherardi and Black, 1989). Although this may explain the difference in digesta load and intake between the legume and grass fed lambs cited above, considering that legumes have a higher M/D value than grass, it questions the view that animals stop grazing when the rumen is full. It also questions the basis of the physical regulation concept for controlling pasture intake. Besides, the inability of the legume fed lambs to increase intake to the stage when rumen fill became limiting, and their reported failure to grow to their genetic potential suggest a shortage of chemical nutrients or imbalance of metabolites supplied to and utilized by the tissues (metabolic control).

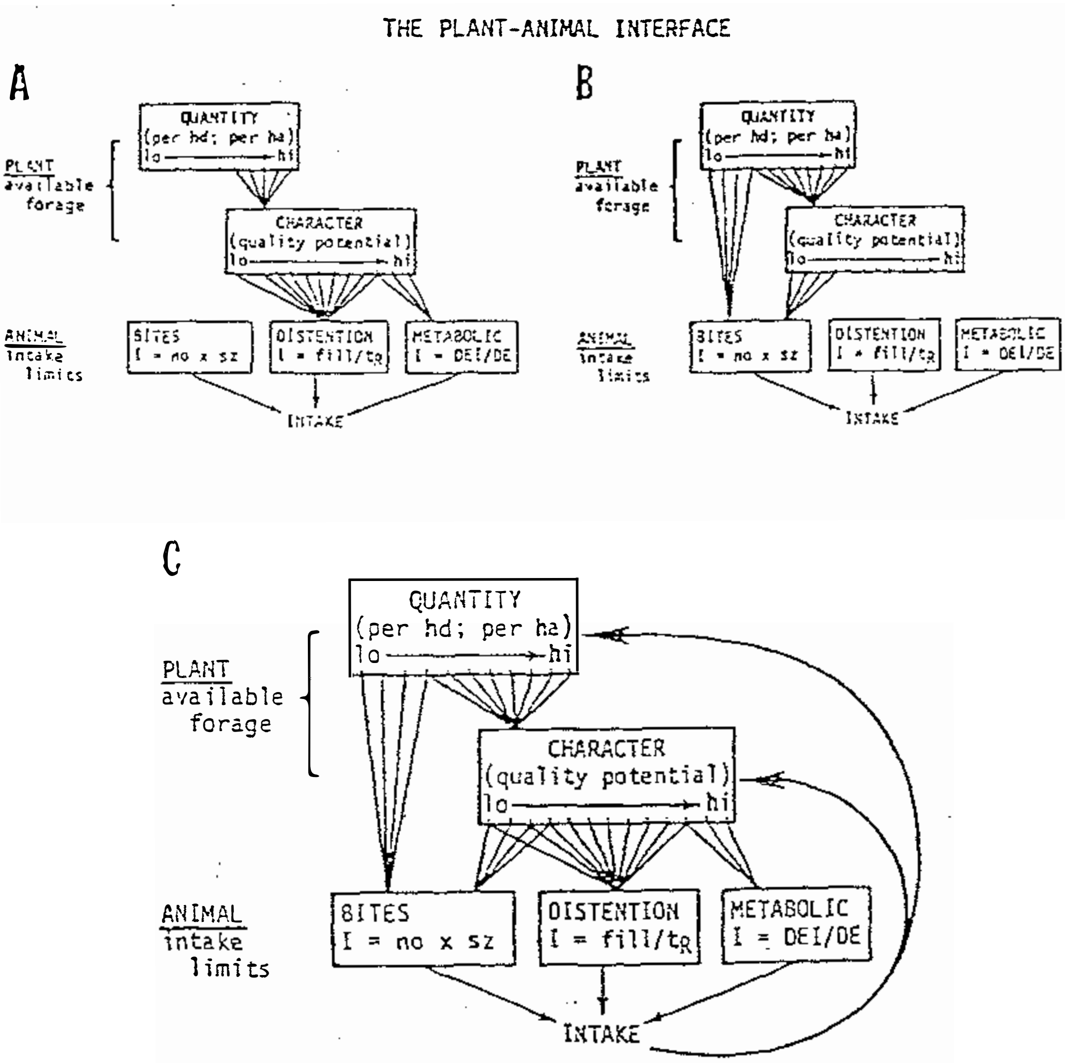


Figure 2.4 Conceptual illustration of the plant-animal interface in grazed pasture: (A) intake limited by distention or metabolic mechanisms; (B) intake limited by bite number and/or bite size (sz); and (C) combined limits, plus the effect of intake on quantity and character of available forage (t_R = retention time; DEI = digestible energy intake; DE = digestible energy content of forage) (After Minson, 1981b).

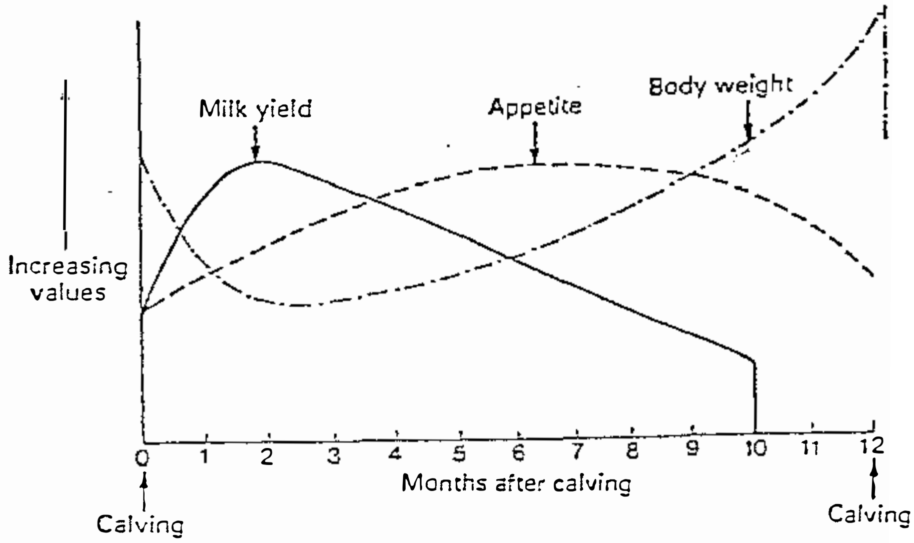


Figure 2.3 Changes in milk yield, body weight and appetite of dairy cows during lactation (Adapted from Mepham, 1987). The exact timing of events depends on the type of feed and feeding level.

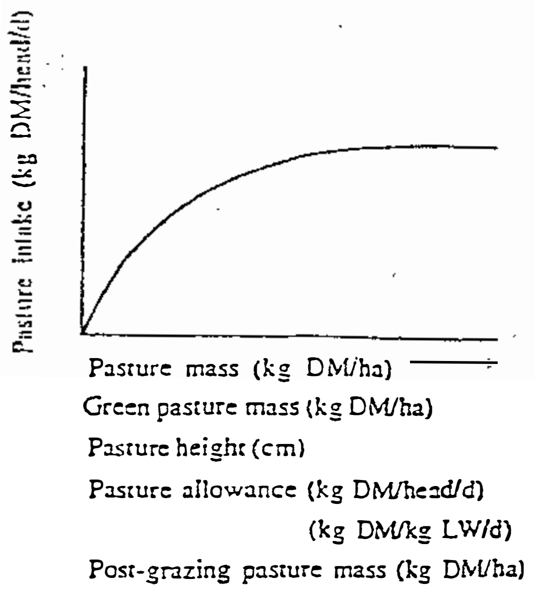


Figure 2.5 The relationship of pasture intake to various pasture characteristics and methods of pasture allocation (After Poppi et al., 1987)

Metabolic and physiological aspects of intake regulation have been the subject of extensive reviews (Bell, 1971; Bines, 1971; Forbes, 1971, 1986, 1988b; De Jong, 1986; Hogan et al., 1987; Weston and Poppi, 1987; Baile et al., 1988; Thomas and Chamberlain, 1990), and will not be reviewed here. However, it appears likely that protein quality (amino acid balance and degradability) and/or quantity is limiting both intake and production of lambs fed fresh forage, even pure legume (Barry, 1976; Poppi, 1990), of beef cattle (Vadiveloo and Holmes, 1979), and of dairy cows (Clark, 1975; Oldham, 1984; Chamberlain, et al., 1989; Thomas and Chamberlain, 1990). The most probable explanation is the amount of undegraded dietary nitrogen reaching the duodenum. The response in ME intake by dairy cows for each increment of 10g CP/kg DM dietary protein concentration was estimated to be 4-5 MJ ME for rations based on grass silage, and 7-8 MJ ME for rations based on maize silage (Oldham, 1984). The range of dietary protein concentrations was from about 100 to 160g CP/kg DM (ibid). Deficiencies in dietary protein for dairy cows grazing temperate pastures especially in early lactation, have also been demonstrated (Rogers et al., 1979, 1980; Minson, 1981c; Thomson, et al., 1984).

There is very limited data from New Zealand and elsewhere on the effects of source, form and quantity of dietary N on the voluntary feed intake and productivity of dairy cattle grazing temperate pastures as a sole source of dietary energy. This is particularly so for cows producing 20 kg of milk or more daily (Brookes, 1982; Bryant and Trigg, 1982; Holmes and Wilson, 1984; Leaver, 1985). A similar observation can be made with beef cattle with a high growth rate potential on pasture (Mayne, 1991). With silage based rations, big increases of milk production have also been observed in the absence of increases of silage intake following protein supplementation of between 120 to 240g CP/kg concentrate DM (Girdler et al., 1988; Beever et al., 1991). But in most reports much of the increased milk production can be explained by the extra ME supply from the increased digestibility and voluntary intake of silage (Oldham, 1984; Chamberlain et al., 1989).

On the other hand, protein supplementation of dairy cows on temperate pastures has not consistently increased milk and/or milk solids production (Castle et al., 1979; Jennings and Holmes, 1983,1984). Where increases in production were observed, they were associated with increases in efficiency of utilization of nutrients, e.g., more amino acids reaching the intestines, or with differences in the extent tissue was used for milk production, but not to increased pasture intake (Le Du and Newberry, 1980; Rogers et al., 1980; Minson, 1981c; T.E. Trigg, cited by Bryant and Trigg, 1982). In other studies where casein was infused abomasally in lactating dairy cows, resultant increases in milk and protein yields were not associated with increases in the efficiency of nutrient utilization or partitioning for milk production (Clark, 1975). Protein supplementation of dairy cows on temperate pasture that provides ample rumen degradable nitrogen, the source of N, and timing of supplementation in relation to the physiological state of cows and pasture variables, need more research.

Mycotoxins, secondary compounds such as tannins, which at high concentrations precipitate microbial CHO-degrading enzymes and cellulases (Barry and Blaney, 1987), and intestinal parasites ingested by grazing animals (Sykes, 1987) are also likely to inhibit intake via metabolic pathways. However, the extent of such inhibition is unknown. On the other hand, condensed tannins (CT) in *Lotus pedunculatus* (a legume) when fed to sheep in low concentrations (20 to 30g CT/kg DM) have been shown to improve feed intake, liveweight gain and wool growth. Such improvements in production are due to the ability of CT to bind plant proteins during mastication thus protecting them (within pH range 3.5 - 7.0) from degradation in the rumen (Barry and Blaney, 1987; Waghorn et al., 1987). Beneficial effects for dairy cows at pasture, in terms of feed intake and milkfat production, of feeding condensed tannins have yet to be demonstrated.

It has become increasingly obvious that there is no simple single factor which controls herbage intake, even where sward conditions are considered non-limiting. In these circumstances control of intake is probably a combination of physical, metabolic and physiological factors (Forbes, 1988b). It is well accepted that the central nervous system coordinates behavioural responses and physiological functions such that energy balance is maintained, but little is known about the specific sites or neurotransmitters involved in these functions in the dairy cow. A dual brain control mechanism has been proposed where the first centre would integrate signals related to eating, ruminating and resting; and the second, visceral information related to products of digestion, satiety, body temperature and health status (Forbes, 1980; Della-Fera and Baile, 1985). Each centre would summate positive and negative signals until critical or threshold levels were reached when appropriate action would be taken. This dual centre concept of control where centre one has precedence over two has not been critically assessed because of insufficient data.

In summary, at low herbage masses sward-induced modification of grazing behaviour appears to control intake. However, when sward characteristics are presumably not limiting intake, metabolic and/or physical mechanisms predominate.

2.4.3 Influence of sward characteristics and herbage allowance on intake

Herbage intake in a grazing situation can be partitioned into its behavioural components, which represent the final compromise between the animal's grazing strategy, nutrient demand and changing pasture characteristics (Hancock, 1952; Spedding et al., 1966; Allden and Whittaker, 1970; Figure 2.4). The components of ingestive behaviour that determine intake (Hancock, 1952) are the weight of herbage harvested per bite (IB), the rate of biting or bites per unit time (RB) and total grazing time (GT). Thus intake (I) over a 24 hr period is a product of the time spent grazing and the rate of herbage intake during grazing, and is expressed as follows:

$$I = IB \times RB \times GT$$

Some values of the components of ingestive behaviour for cattle feeding on pasture are presented in Table 2.1, while recent reviews by Hodgson (1985a, 1986), and Mayne and Wright (1988) cover most aspects of ingestive behaviour. The rate of intake can refer either to I/GT or IB x RB, depending on the method of measurement.

Intake per bite (bite size), biting rate and grazing activity are usually interrelated although herbage intake can be influenced by variations in any of these parameters, which in turn are influenced by variations in sward conditions - particularly sward height (Penning, 1985; Hughes et al., 1991; Mitchell et al., 1991). IB is the most critical factor influenced by sward structure that determines intake (Hodgson, 1981; Leaver, 1986). The present review will now consider the influence of sward characteristics on the components of ingestive behaviour and herbage intake.

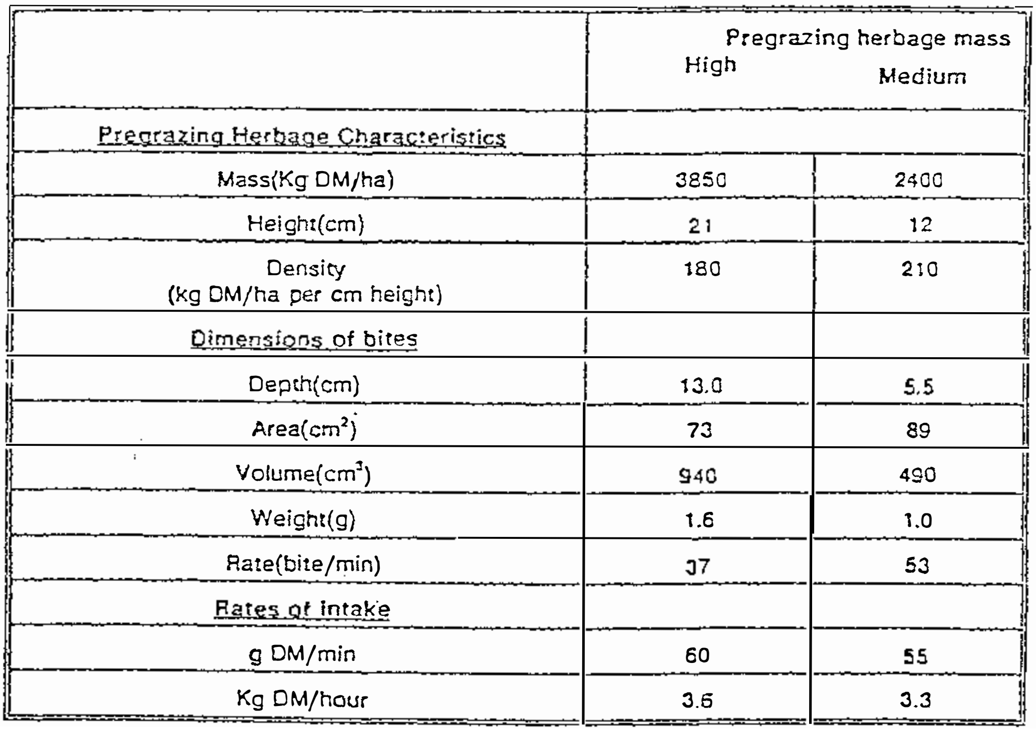
2.4.3.1 Herbage mass

Pre-gazing mass

Dry matter intake by lactating cows grazing temperate pasture is not affected consistently by pre-grazing herbage mass (PHM) in the range of 2 to 4t DM/ha when pasture allowance is constant (Holmes, 1987b; Mayne and Wright, 1988). In some studies intakes of lactating cows were not influenced by PHM in the range 1400 to 4800 kg DM/ha (Bryant, 1980, 1983; Bryant and Cook, 1980; Meijs, 1983); and neither were those of young cattle (Hodgson, 1977) and dry cows (Holmes et al., 1979) grazing a range of temperate pastures. In other studies intake of cattle increased with increasing PHM under both set stocking and intermittent grazing (Jamieson and Hodgson, 1979b; Bryant and Trigg, 1982; Stockdale and King, 1983; Forbes and Hodgson, 1985; Stockdale, 1985a; Stakelum, 1986). Conversely, decreases in herbage intake with increasing herbage mass have been observed by

Combellas and Hodgson (1979) with lactating cows (PHM of 1.8-5.8t OM/ha), by Hodgson et al. (1977) with calves, and by Reardon (1977) and Bartholomew et al. (1981) with beef cattle, both at set stocking and intermittent grazing.

Table 2.1 Some values for important components of ingestive behaviour for non-lactating dairy cows grazing on pasture with high or medium herbage mass (A.W. Dine and C.W. Holmes, unpublished data).



	Pregrazing herbage mass	
	High	Medium
Pregrazing Herbage Characteristics		
Mass(Kg DM/ha)	3850	2400
Height(cm)	21	12
Density (kg DM/ha per cm height)	180	210
Dimensions of bites		
Depth(cm)	13.0	5.5
Area(cm^2)	73	89
Volume(cm^3)	940	490
Weight(g)	1.6	1.0
Rate(bite/min)	37	53
Rates of intake		
g DM/min	60	55
Kg DM/hour	3.6	3.3

In view of the many interacting sward and animal factors that influence the herbage intake of the grazing cow, several attempts have been made to derive intake prediction equations based on multiple regression analysis (Curran and Holmes, 1970; Stockdale, 1985a, b; Caird and Holmes, 1986; Forbes, 1988a). The prediction equation derived by Caird and Holmes (1986) indicated that for rotationally grazed cows, total organic matter intake was positively correlated with milk yield, mean liveweight, concentrate intake and herbage allowance; and negatively correlated with herbage mass. But the equation proposed by Stockdale (1985b) showed that pasture intake was positively influenced by pasture allowance, amount of pasture on offer (intake rose by 1.1 kg DM/cow for each 1t DM/ha increase in PHM) and its digestibility, and was not consistently related to botanical composition (r=-0.01 to 0.04). Even then, intakes tended to be greater on ryegrass than paspalum dominant pastures. The contradiction in the effect of PHM on intake in the intake prediction equations cited above may be partly explained by the confounded effects of substitution of concentrates for herbage intake, and manifested by a reduction in grazing time (Leaver, 1986; Mayne, 1991); and the decrease in the digestibility of herbage with increasing mass.

Dry matter intake by sheep generally shows a positive relationship with increasing PHM both for rotationally and set stocked swards (Jagusch et al., 1979; Bircham, 1981; Rattray et al., 1982a; Rattray and Clark, 1984). However, in some studies dry matter intake of lambs (Jagusch et al., 1979) and ewes (Rattray et al., 1982b; Burlison et al., 1991) was not always influenced by PHM. This was attributed to small changes in herbage digestibility and proportion of green material with increasing mass, although intakes were depressed by declining masses of green leaf in the grazed horizon.

Daily herbage intake usually increases at a progressively decreasing rate as the available herbage mass per unit area increases, and declines at an increasing rate below a critical mass (Hodgson, 1977; Figure 2.5). However, the critical herbage mass below which intake declines has been reported to vary over a two-fold range for young cattle grazing temperate pastures (1100-2800 kg DM/ha) (ibid). Such a large variation may be a reflection of the inability of PHM to represent the diversity of either structural or compositional presentations of pasture commonly encountered. Besides, with set-stocking herbage mass remains 'constant' over 24 hours, and its effect on intake per day, probably via bite size, may not be as important as with rotational grazing. With rotational grazing herbage mass decreases rapidly during the grazing period, so does rate of intake. Thus, herbage mass averaged over the grazing period may probably be the important determinant of intake per day.

In general, as sward herbage mass decreases intake per bite decreases and biting rate increases, although this latter effect may not be a direct compensatory mechanism (Allden and Whittaker, 1970; Stobbs, 1973a; Chacon and Stobbs, 1976; Forbes and Hodgson, 1985). Nevertheless, on high mass swards a combination of these two effects tends to maintain intake, but as herbage mass declines any increase in biting rate will not compensate for the reduction in intake per bite (Chacon and Stobbs, 1976; Penning, 1986). With grazing dairy cows there is probably a limit on biting rate of 60-70 per minute (36,000 - 40,000 bites/day) (Phillips and Leaver, 1985b, 1986a). Biting rate tends to decrease as herbage mass declines below a critical level (Allden and Whittaker, 1970; Hodgson, 1981), and at high herbage masses (> 5t DM/ha; Combellas and Hodgson, 1979; Hodgson and Jamieson, 1981), because of increased 'chewing/swallowing' movements (A.W. Dine and C.W. Holmes, unpublished data, Table 2.1). Further, the ability of lactating cows to increase grazing time beyond 10 hrs/day to compensate for reduced intake rate appears to be limited (Stockdale and King, 1983; Hoogendoorn, 1986; Phillips and Leaver, 1986b).

Inconsistencies in the effects of PHM on feed intake by grazing dairy cows may reflect, partly, the failure to distinguish between set-stocking and rotational grazing, and differences in the rate of change in sward structure during grazing. The inconsistencies may also be a result of the confounding effects of concomitant changes in the structure and composition of the grazed sward horizon and/or the whole sward, and changes in the nutritive value of the herbage consumed. Nutritive value here refers to digestibility, which may decrease with increasing PHM (Stockdale and King, 1980; Hoogendoorn, 1986). For example, Stockdale and King (1980) reported a 2.7 % units decrease of OMD per 1t DM/ha increase in PHM. In temperate swards in a vegetative state the upper horizons consist mainly of live leaf of high digestibility (L'Huillier et al., 1986). The lower horizons contain progressively less leaf and more pseudostem and dead material, the proportions of which vary with season - such that the percentage of leaf is lower and that of stem and dead material is higher in summer than in winter and spring (Hoogendoorn, 1986; Ryan, 1986). At similar PHM digestibility is also lower in summer than spring (ibid). Thus PHM or standing DM fails to reflect the heterogeneity of pasture especially in the grazed horizon, and the effects of this heterogeneity on the bite size and the composition of the diet ingestion.

It is likely, therefore, that in some of the extreme examples of an asymptotic relationship between herbage mass and intake there is a progressive decline in herbage digestibility with increased mass. This would tend to limit artificially the response to variations in mass alone. Furthermore, with rotational grazing herbage allowance is often confounded with herbage mass present, and it has been suggested that the effect of herbage mass on intake is dependent on herbage allowance (Jamieson and Hodgson, 1979a). The effects of herbage allowance on intake, which are directly relevant to rotational grazing but indirectly relevant to set-stocking, seem to be greater than those of herbage mass (Combellas and Hodgson, 1979; Stockdale, 1985b; Hoogendoorn, 1986; also see Section 2.4.3.4).

Post-grazing mass

The association between post-grazing or residual herbage mass (RHM) and pasture intake by dairy cows, which is only directly applicable to rotational grazing, has recently been summarized by Holmes (1987b). In the short term there is a positive relationship between RHM and feed intake (Stockdale, 1985a; Figure 2.5), but there is considerable variation within and between seasons. Stockdale (ibid) observed intake increases of 3.2 to 5.1 kg DM/cow daily for every ton DM increase in RHM; however RHM explained only 61% of the variations in intake compared with 80% explained by herbage allowance. Higher intakes in spring than summer have been reported at similar RHM (King and Stockdale, 1984; Hoogendoorn, 1986). Although reasons for this difference are not clear, the high concentrations of dead matter at the base of the sward common in summer/autumn pasture may be a contributory factor (King and Stockdale, 1980; Thomson et al., 1984; Michell and Fulkerson, 1987).

Post-grazing herbage mass is dependent on pre-grazing herbage mass and herbage allowance (King and Stockdale, 1980; Stockdale and King, 1980; Stockdale, 1985a). Therefore, the relationship between RHM and intake may be modified by pre-grazing pasture mass at a common herbage allowance. For example, with very short (low mass) swards a high herbage allowance and high RHM may not result in increased intake because of difficulties in prehending herbage, and a reduction in intake per bite. In a study by Hoogendoorn (1986) the intake of cows given a common herbage allowance of 'short' and 'long' swards was similar despite a large difference (1t DM/ha) in post-grazing pasture mass. This was probably because of reduced IB arising from reduced accessibility of the preferred herbage components of the 'tall' swards.

In the long-term, high RHM may lead to lower intakes. This may be a result of declining pasture quality because of high concentrations of dead matter of low digestibility. Lower intakes may also be caused by decreases in the proportions of the prefered green herbage and in intake per bite, and by declining pasture growth rates and herbage availability.

2.4.3.2 Sward height and bulk density

Sward height

Sward height (pre / post grazing) is positively correlated with herbage mass but tends to influence intake more consistently than the latter. Intake, under rotational or continuous grazing management, usually increases with increasing pre/post grazing sward surface height in temperate swards (Allden and Whittaker, 1970; Hodgson, 1981, 1982; Burlison and Hodgson, 1985), although a decreased intake may be observed with particularly long herbage (more than 40-45 cm extended sward height for ryegrass pasture) (Hodgson et al., 1977; Hodgson, 1982; Figure 2.5).

If the extended height of the sward is measured, then the relationship between intake and sward height may be quadratic, with intake declining on either side of an optimum extended height (Hughes, 1983). This is presumed to be due to increased difficulty in prehending and severing both excessively long and short swards.

Post grazing sward surface height below which intake decreases, irrespective of allowance or stocking rate, has been reported to vary between 6 and 8 cm (Le Du et al., 1979; Baker et al., 1981a; Mayne et al., 1988; Stakelum and Dillon, 1991) or 8 to 12 cm (Mayne et al., 1987; Mayne and Wright, 1988; Stakelum and Dillon, 1991) for lactating cows on rotational grazing in early to mid season. For continuously grazed swards the critical post grazing sward surface height below which intake declines is estimated to be 6 to 8 cm (Le Du et al., 1979; Baker et al., 1981b) for lactating cows and 7 to 10 cm for beef cows (Nicol et al., 1976; Wright and Whyte, 1989).

The large variation in the critical residual sward height (below which intake starts to decline) may be attributable to differences in pre-grazing pasture mass (or height) between or within experiments and the inverse relationships between the two and organic matter digestibility of the grazing horizon (Stakelum and Dillon, 1991). The variation may be caused also by environmental conditions (Mayne et al., 1987, 1988), and technique of measuring sward height, e.g., extended tiller height or sward surface height by the first contact technique (Bircham, 1981), or sward height using a rising plate meter (Holmes, 1974). It may also be attributable to the genetic merit of the cows. Dairy cows of high genetic merit were shown to have a higher critical residual sward height below which intake and milk production start to decline than cows of lower production potential, (Mayne et al., 1987; Mayne and Wright, 1988). This is because high yielding cows may be more reluctant than low yielders to compensate for reduced IB on short swards by increasing grazing time (Mayne and Wright, 1988). At low sward heights high and low producing animals appear to have similar pasture intakes (ibid).

There is a clear need for a standard technique and terminology for measurement of sward height if it is to be widely adopted as a practical on-farm assessment of grazing severity and level of feeding for dairy cows (see Gibb and Ridout, 1986). Furthermore, the usefulness of sward height in defining behavioural responses in rotationally grazed swards is not clear. Different relationships exist between height and intake in continuous and rotationally grazed swards, arising from differences in tiller population and sward densities (Section 2.2.2), and the influence of these on intake per bite (Mayne and Wright, 1988).

The increase in intake with increasing sward surface height in temperate swards is due mainly to increased IB (Hodgson, 1982). Burlison and Hodgson (1985) noted a positive relationship between sward surface height and bite volume, bite depth and bite weight. Milne et al., (1982) found a positive linear relationship between the depth of the grazed horizon and sward surface height. Higher intakes have been measured on spring swards compared to summer and autumn regrowth of similar digestibility and herbage mass, which may be due to the more erect spring swards with a deeper leaf layer encouraging greater depth and size of bite (Hodgson, 1982).

The RB and GT are also affected by sward surface height. The RB tends to decrease as sward surface height increases due, in part, to the greater ratio of manipulative to ingestive jaw movements (Chambers et al., 1981). Since the rate of total jaw movements remains relatively constant (Black and Kenny, 1984; Penning, 1988), the change in RB is probably a direct effect of sward conditions and not an adaptive behavioural response by the animal (Hodgson, 1985a). The decline in RB with increasing sward height is more than offset by the simultaneous increase in IB (Hodgson, 1981). The grazing time of cattle on a rotational grazing system tends to increase with short versus long swards (Hancock, 1954; Hoogendoorn, 1986; Stakelum and Dillon, 1991) presumably in an attempt to compensate for decreased IB. Since the ability of the animal to make compensatory changes in GT to offset changes in IB and/or RB is limited, intake usually declines with decreases in height (Phillips and Leaver, 1986b). Reductions in intake of 15-20% were observed when cows were forced to graze down to a residual sward height of 5 cm under a rotational or continuous grazing management system (Le Du et al., 1979; Ernst et al., 1980).

Sward bulk density

Where sward bulk density and sward surface height have not been varied independently in an experimental situation herbage intake appears to be insensitive to change in bulk density (Hodgson, 1982). Since sward surface height and bulk density are often negatively correlated, the apparent lack of response to changes in bulk density may simply reflect the inability to separate the dominant effect of sward surface height. However, most research on tropical pastures has found bulk density rather than height to be the major determinant of intake per bite, and hence total intake (Stobbs, 1973a & b, 1975b; Chacon and Stobbs, 1976; Hendricksen and Minson, 1980; Ludlow et al., 1982). Generally, tropical pastures have a lower bulk density and higher stem:leaf ratio than temperate pastures (Mott, 1983), and the nutritional differentiation between plant components in tropical pasture is larger

(Minson, 1976, 1981a; Hacker and Minson, 1981). This may explain the positive relationship between bite size (IB) and rate of biting (RB) on mature tropical swards as the animals sought to separate leaf from stem (Chacon and Stobbs, 1976).

Where sward surface height and bulk density of temperate pasture have varied independently, each was positively correlated with intake (Black and Kenny, 1984; Hughes et al., 1991; Mitchell et al., 1991). Black and Kenny (ibid) found that the short-term rate of intake was best described by bulk density if herbage mass was greater than 1000 kg DM/ha, while the rate of intake was best predicted by the mass per unit area covered by one bite. This study (ibid) was conducted with sheep housed in individual cages grazing artifical swards for very short (10 min) periods, and thus the relationships reported may not apply to grazing dairy cows over 24 hour days.

In trials with caged sheep (Burlison and Hodgson, 1985; Hughes et al., 1991; Mitchell et al., 1991), deer (Mitchell et al., 1991), and with steers and bulls grazing real swards (Mursan et al., 1989) where a reasonable dissociation of sward surface height and density was achieved, sward surface height was found to have a greater influence than herbage density on short term bite weight, depth and volume. Height had little or no effect on bite area, while bulk density had a moderate negative effect. Mitchell et al. (1991) found that, on the average, 100% increase in sward height or bulk density resulted in a 64 or 21% increase, respectively, in bite weight; reflecting that bite volume increased in relation to height but decreased in relation to bulk density. Thus, with temperate ryegrass swards with 'average' densities, residual sward height, rather than sward density, remains the major determinant of bite volume, bite weight, and total intake through its influence on bite depth (Stobbs, 1973a & b, 1975b; Mitchell et al., 1991).

2.4.3.3 Spatial distribution and digestibility of pasture herbage

Spatial distribution of sward components

The degree to which grazing ruminants can consume herbage with a digestibility higher than the average of that on offer also influences daily herbage intake, and this will depend on the amount of herbage on offer and the botanical composition of the pasture (Stobbs, 1977; Rattray and Clark, 1984; Leaver, 1985). Sheep and cattle often ingest a diet that differs considerably from the total composition of the diet on offer (Dudzinski and Arnold, 1973; Hodgson, 1977; L'Huillier et al., 1986). The diet selected may be 3-10% higher in digestibility than the average of that on offer depending on herbage allowance (Hodgson and Jamieson, 1981; Le Du et al., 1981). Many reviews of diet selection by grazing ruminants have been published (Rattray and Clark, 1984; Black, Kenny and Colebrook, 1987; Malechek and Balph, 1987; Poppi et al., 1987; Black, 1990; Milne, 1991). However, there is considerable uncertainty whether grazing animals do select herbage to optimise metabolisable energy intake per unit time spent grazing. Optimal foraging and reinforcement theories, and their role in diet selection were reviewed by Malechek and Balph (1987) and Milne (1991). The present review will restrict itself to the relationships between the spatial distribution of sward components, the diet consumed and feed intake.

The extent to which the selection for or against certain components in the sward is a deliberate process is confounded by their relative proportions and accessibility in the sward. Differences in shear strength of the different components, and peak bite force required to sever the herbage (Hendricksen and Minson, 1980; Hughes, 1983; Hughes et al., 1991); and the species of animals grazing the sward and their internal and external environment (e.g., feeding drive, cold/heat stress, herbage contamination) (Wade and Le Du, 1981; Milne et al., 1982; Malechek and Balph, 1987; Young, 1987) also have an effect on the diet consumed.

Since the digestibility of plant tissue declines progressively with age, intake would be expected to decline progressively with increasing herbage maturity in space and time. Under grazing conditions, parallel changes in the structure of the sward canopy (set-stocking) or of the grazed horizon (rotational grazing) can influence the DM intake/digestibility relationship. Therefore, the ability of the grazing ruminant to prehend material for ingestion that is of different composition from the average of the herbage mass may not always be a positive selection. It may merely be a reflection of the differences in the distribution of leaf and stem and of dead material through a vertical section of the sward (Hodgson, 1985a; Kenny and Black, 1986; Black et al., 1989). Consequently, the digestibility of the diet ingested may differ from that of the herbage on offer, but this may not influence intake. Digestibility of pasture declines as the content of dead material and stem increases. The spatial distribution of these components and their proportions in the sward may mediate the diet digestibility/intake relationship through their effects on rate of bite, bite depth and intake per bite (Mursan et al., 1989; Hughes, et al., 1991; Mitchell et al., 1991).

In vegetative temperate swards the upper horizons consist mainly of live leaf of high digestibility, while the lower horizons contain progressively more pseudostem and dead material of lower digestibility (Hodgson, 1985a; Hoogendoorn, 1986; L'Huillier et al., 1986). The proportions and digestibility of these components in the sward horizons are significantly influenced by both grazing intensity and/or frequency and season (Hoogendoorn, 1986); and the differences become progressively smaller as the sward is grazed more intensely particularly under conditions of low herbage allowance (Hodgson, 1982; Stakelum and Dillon, 1991).

Cattle generally graze in the upper more accessible layers of a pasture such that the diet eaten, i.e., greater proportions of leaf and clover and lesser proportions of stem and dead material than the herbage on offer, is similar in composition to the upper horizons of the sward canopy (Forbes, 1982; Hodgson, 1982). This may partly explain the greater short term intakes achieved by animals offered a generous rather than a restricted herbage allowance (Kenny and Black, 1986).

Although animals are reported to graze indiscriminantly in the leafy upper horizons of temperate swards, probably because they contain very little dead matter (Milne, et al., 1982), sheep appear to graze where leaf is predominant irrespective of the horizon's position in the sward and herbage allowance (L'Huillier et al., 1986; Black et al., 1989). Conversely, the lower horizons of pasture containing pseudostem and dead matter are quite readily grazed by lactating dairy cattle, especially under restricted feeding (Forbes and Hodgson, 1985; Stakelum and Dillon, 1991). Nonetheless, an appreciation of the spatial distribution of the various components in the sward canopy is important if the interpretation of any differences between the composition of the sward, the diet of the grazing animal, and amount ingested is to be attempted (Hodgson, 1985b).

Much of the research attempting to relate behavioural components of grazing to intake has been done under rather artificial conditions using sheep or young ruminants. The behavioural components of intake are usually monitored over very short periods of time, and these results tend to be extrapolated to a longer term basis. The applicability of results obtained in this manner to the likely effects of sward chacteristics and composition on the ingestive behaviour of high producing dairy cows is uncertain. This problem is even more acute where non-traditional or newer, less dense pasture species or cultivars, e.g., tall fescue and prairie grass, are incorporated in a dairy farming system. Undoubtedly, it would be very difficult to study the relationships between pasture intake and sward variables under conditions whereby gross sward characteristics, nutrient concentrations, digestibility, plant defense mechanisms, and pasture allowance are varied independently. Nevertheless, the need for such research does remain. Such knowledge would help in the breeding and management of pasture plants so as to maximize dry matter intakes in relation to specific animal requirements and production levels, and to improve the accuracy of feed budgets.

Digestibility of herbage

There are several factors influencing the digestibility of the herbage on offer, none of which has a clearly defined effect on intake (Sections 2.3.1.3, 2.4.1 and 2.4.2), but collectively they have a major effect on the amount of pasture that a cow will eat. Digestibility *per se* does not consistently influence the dry matter intake of dairy cows at pasture when herbage allowance is constant and restricted (Stockdale, 1985a; Poppi et al., 1987), but it may influence intake if herbage allowance is very generous and unlimiting. There is very little experimental evidence for this however, and such observations contradict earlier reports, which indicated that herbage intake by cattle in both indoor (Hutton, 1962; Hodgson, 1977) and grazing situations (Stehr and Kirchgessner, 1976; Hodgson et al. 1977; Combellas and Hodgson, 1979) was linearly related to its organic matter digestibility of up to 82%.

Conrad et al. (1964) analysed a large volume of data from digestion trials with mixed roughage/concentrate diets (not pasture herbage) and observed that the relationship between voluntary intake of dry matter and digestibility was linear up to 67% DMD for low producing cows or 70% DMD for high producers, but declined after that. However, with high digestibility feeds digestible energy intake tended to remain constant despite the decrease in DMI, since the decrease in DMI was offset by higher concentrations of digestible energy of the diet. Conrad et al. (1964) concluded that feed intake is controlled mainly by physical means up to 67-70% DMD beyond which metabolic controls (energy deficits) become important. Earlier and subsequent studies showed that with cattle (milking cows and calves) at pasture the relationship between voluntary organic matter intake (OMI) and digestibility was linear up to 80-82% OMD (Stehr and Kirchgessner, 1976; Hodgson et al., 1977; Figure 2.6). Differences in digestibility of pasture in the studies cited (ibid, Figure 2.6) may have been confounded by differences in time and stage of lactation. Nonetheless, results from these digestibility/intake studies (Conrad et al., 1964; Stehr and Kirchgessner, 1976; Hodgson et al., 1977) showed that non-physical factors limiting intake come into operation at lower digestibility values with grain-based diets and at higher values with pasture alone; and that the higher the energy requirements the higher the digestibility above which intake was controlled metabolically. However, the point at which metabolic and physical factors diverge in controlling intake, i.e., the point of inflection of the intake/digestibility curve, is lower the faster the rate of disappearance of food from the digestive tract (Forbes, 1986). For dairy cows at pasture no data could be found to illustrate the intake/digestibility relationship after linearity ceases.

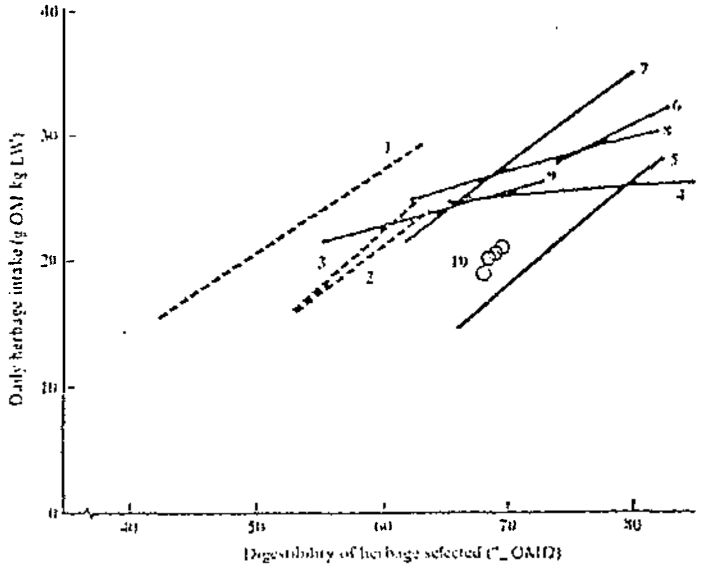


Figure 2.6 The relationship between herbage intake and the digestibility of the herbage selected; a comparison of published evidence (tropical swards ----; temperate swards ——). References as follows: 1, Elliott et al. (1961); 2, Topps (1969); 3, 8 (primary growth), 9 (secondary growth), & 10 (late secondary growth) , Hodgson et al. (1977); 4, Corbett et al. (1963); 5, Hodgson (1968); 6, Holmes et al. (1972); 7, Stehr & Kirchgessner (1976).

The herbage digestibility/intake relationships reported by Stehr and Kirchgessner (1976) and Hodgson et al. (1977) were for herbage cut to 2 cm above ground level, or the extrusa OMD. The digestibility/intake relationship for pasture sampled at ground level may be different. Furthermore, herbage allowance in the two reports (ibid), although generous (>twice intake), was held constant only in the studies of Hodgson et al. (1977). In the same experiments (ibid), pregrazing herbage mass, % green matter, and extended sward height, which are intercorrelated, were not controlled. These variables and % OMD explained 93% of the variation in OM intake, and their confounding effects on the OMD/intake relationship can not be discounted.

Similarly, in the study of Stehr and Kirchgessner (1976) herbage allowance and OMD jointly explained 66% of the variation in OMI. In this experiment some concentrates were fed. The associative and substitution effects of these on herbage digestibility and intake, besides other sward variables that were not held constant, may have confounded the herbage intake/digestibility relationship. In the experiments of Stehr and Kirchgessner (ibid) and Hodgson et al. (1977) neither the concentration of protein in the herbage nor its digestibility were correlated to herbage intake. However, in most experiments with grazing dairy cows, the relationship between herbage digestibility and intake has not been consistent (Curran and Holmes, 1970; Bryant, 1980b, 1983; Bryant and Trigg, 1982; Stockdale, 1985a, b; Hoogendoorn, 1986; Hoogendoorn et al., 1987; L'Huillier, 1987c). In the studies summarised by Stockdale (ibid) a significant increase in dry matter intake (DMI) of lactating cows on irrigated temperate pasture, which was associated with an increase in the DMD of the herbage, was demonstrated in only one out of the eight experiments. In this one experiment the DMD range of the herbage on offer was 62-72%, and the daily herbage allowance (21 kg DM/cow) was moderate.

In New Zealand, Bryant and Cook (1980), Bryant (1983) and Bryant and L'Huillier (1986) reported that herbage intake by lactating cows grazing spring pasture was not appreciably influenced by its digestibility between DMD values of 74-78%. Similarly, DMI by milking cows on summer pastures increased with increasing herbage allowance but not with increasing DMD over the range 64 to 74% (Bryant, 1980; Bryant and Trigg, 1982; Hoogendoorn et al., 1985; L'Huillier, 1987c). However, milkfat production (kg/cow daily) increased with increasing DMD of summer pasture, probably because of increased intake of digestible nutrients (Hoogendoorn et al., 1985; L'Huillier, 1987c). Munro and Walters (1986) concluded in a recent review that for dairy cows at pasture the relationship between intake and digestibility may not exist above DOMD (digestible organic matter in the dry matter) values of 0.70. Also in a recent study with sheep fed fresh forage indoors with a DMD range of 0.67 to 0.77, voluntary intake showed low and non-significant correlations with chemical composition and digestibility (John and Ulyatt, 1987).

Thus the relationship between diet digestibility and intake is not a simple one, because different plant species or components can differ in their rate of digestion, hence intake, at similar levels of digestibility. However, the digestibility of herbage does certainly influence the intake of digestible nutrients (Ulyatt, 1981a). With dried forages voluntary intake is usually well correlated with digestibility and chemical composition (Minson, 1982). Digestibility, as stated earlier, exerts its influence on herbage intake mainly through the rate of disappearance of digesta from the reticulo-rumen (Thornton and Minson, 1973).

For example, at similar levels of digestibility the legumes have lower ratios of structural carbohydrates to cell contents and of hemicellulose to cellulose than the grasses (Osbourn, 1980). So both the rate of digestion and the amount eaten are usually higher in legumes than grasses, which normally have longer rumen retention times (Laredo and Minson, 1973; Ulyatt, 1981a, b). Legumes were also found to have a higher packing density in the rumen than grasses, which enables higher intakes of legumes than grasses before rumen fill becomes limiting (Thornton and Minson, 1973).

Similarly within grasses, particularly of tropical origin, there are differences in intake between species, and between varieties within species at similar digestibility (Minson, 1971, 1972; Ulyatt, 1973; Munro and Walters, 1986). Also in an experimental situation, diets consisting largely of separated plant stems were eaten in much smaller quantities than diets of leaves of similar digestibility, because the structure of the stems means that they are digested more slowly resulting in a longer rumen retention time (Minson, 1972, 1983; Laredo and Minson, 1973; Poppi et al., 1980; Cruickshank, Poppi and Sykes, 1985). For tropical grasses, differences in intake between species of similar digestibility are not explained by differences in the proportion of leaf, and the difference in intake between leaf and stem is much larger than for temperate grasses (Minson, 1981a, 1987).

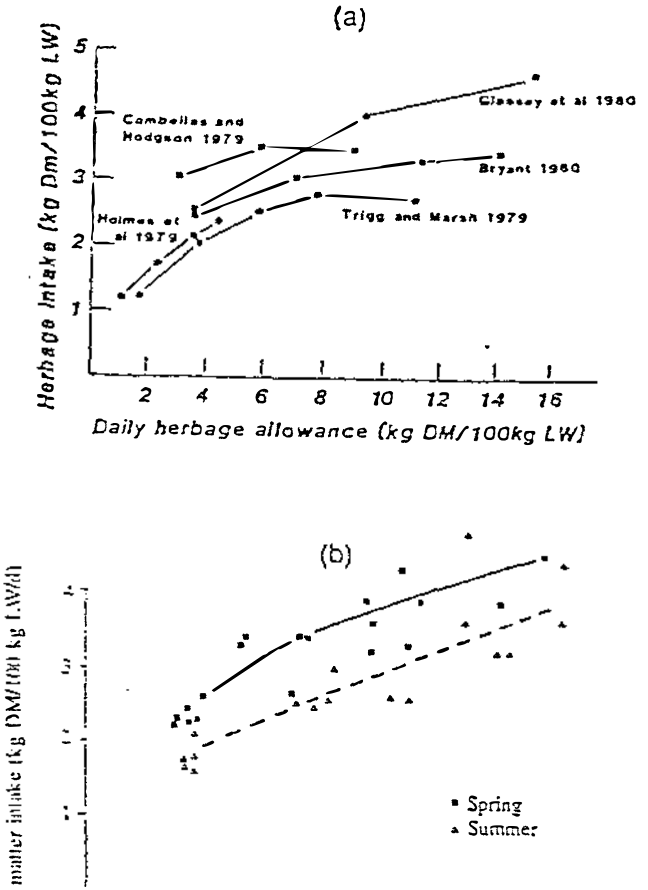
The shorter retention time of leaf was associated with a larger surface area, lower grinding energy, lower density, an apparent higher rate of digestion (degradation) of neutral detergent fiber (NDF) in vivo, and a higher rate of passage of NDF from the rumen (Poppi et al., 1981a). The shorter retention time was not caused by differences in the level of cell contents measured as the concentration of pepsin-soluble dry matter (Minson, 1981a). The retention time of large particles in the rumen was found to have no effect on the rate of passage of digesta from the rumen, whereas the retention time of small particles (< 1.18 mm), also dependent on water flow from the rumen, was the most important factor influencing dry matter intake (Poppi et al., 1981b).

2.4.3.4 Herbage allowance and water content

Herbage allowance

Herbage or pasture allowance is the weight of herbage made available (kg DM) per animal per day (or more precisely the weight of DM or OM measured to ground level per unit of animal liveweight (g/kg) per day) (Hodgson, 1975). Pasture allowance and its estimation are most relevant under rotational grazing management, but are also important under set-stocking or continuous grazing systems. In New Zealand, pasture allowance is probably the most important single factor influencing differences in production per animal between farms, between years, and between stocking rates (Rattray and Jagusch, 1978; Holmes, 1987b).

The amount of herbage on offer daily to the grazing animal is generally accepted as a major factor influencing herbage intake (Leaver, 1976), although green leaf allowance may be a better predictor of intake because it includes some effects of differences in pasture composition (Holmes and Macmillan, 1982; Rattray and Clark, 1984; Hoogendoorn, 1986; Butler et al., 1987). The importance of pasture allowance in influencing herbage intake has been demonstrated on many occasions both for lactating dairy cows (Bryant and Trigg, 1979; Bryant, 1980; Glassey et al., 1980, Meijs, 1983; Mitchell, 1985; Stockdale, 1985a) and for dry cows (Bryant, 1978; Holmes et al., 1979).



Note: Each point represents one treatment group. Pre-grazing pasture mass 2.0-2.5 and 2.1-5.4 kg DM/ha and digestibility of DM 74-78 and 64-74% in spring and summer respectively.

Figure 2.7 Relation between (a) pasture allowance, (b) season, and herbage intake by grazing dairy cows. (Adapted from Holmes & Wilson, 1984 (Figure 2.7a); and Holmes, 1987b (Figure 2.7b)).

The relationship between herbage allowance and herbage intake is curvilinear (Combellas and Hodgson, 1979; Le Du et al., 1979; Figures 2.4 & 2.7). When less herbage is offered than the animal is expected to consume, increasing increments in herbage allowance are likely to result in increments of almost equal magnitude in herbage consumed. As allowance is increased, further response is likely to become progressively smaller and a point is reached beyond which further increments have no effect on gross intake or milk production. For example, Stockdale (1985b) reported increases in daily DMI of 0.35 kg declining to 0.15 kg for every additional kg DM of pasture herbage offered to a cow; the greater partial regression coefficient being associated with the smaller herbage allowance. When herbage allowance increases, and provided the swards are not too short, then the quantity of available herbage becomes unlimiting, but other factors, e.g., digestibility or animal factors, become limiting to intake (Section 2.4.2, Figures 2.4 & 2.6). In the lactating cow, the increased DMI may cause increased milk yield, increased gain in liveweight or both. The extent to which ingested nutrients are used for milk and/or body tissue synthesis depends on the stage of lactation, previous nutritional regime and genetic merit for milk production.

When available herbage is measured to ground level, herbage intake and milk yield are often about maximal when the pasture allowance is twice the herbage intake (Combellas and Hodgson, 1979; Meijs, 1983; Stakelum 1986). However, other studies have shown maximal herbage intake and milk production responses at much higher allowances of herbage of up to three to four times intake (Hodgson, 1975; Bryant, 1980; Bryant and Cook, 1980; Glassey et al., 1980; Grainger et al., 1982; Stockdale, 1985b; Figure 2.7a). Some of the variations in results between experiments are probably due to different techniques of measuring herbage intake (e.g., chromic oxide dilution *vs* sward sampling technique) and pasture allowance. Differences in sward structure, e.g., leaf to stem ratio, ratio of green leaf to dead material, DMD, or physical structure (height, mass and plant density) are also likely to be implicated as was discussed previously; and so is the substitution effect of concentrates for pasture intake where the two are fed together (e.g., Meijs, 1983; Stakelum, 1986). Combellas and Hodgson (1979) varied herbage mass and allowance independently and observed no interaction between the effects of mass and allowance on intake. However, both of the herbage masses were relatively high (3700 or 5770 kg DM/ha).

Stockdale (1985a) observed that with dairy cows on temperate and sub-tropical pastures, when other sward characteristics were considered, herbage allowance was the most important factor influencing animal intake. However, Hodgson (1984) stated that herbage allowance should be seen to influence intake indirectly through its influence on the rate of change in sward conditions and the effects of these on average bite size as the sward is progressively grazed down. While this may be true when herbage allowance is generous, at more restrictive allowances, herbage allowance, but not herbage character, is probably the most important factor determining intake (still indirectly) under both set stocking and rotational grazing systems.

Working with calves, Jamieson and Hodgson (1979a) noted that intake per bite, rate of biting, and grazing time were greater for animals on the low compared to high herbage allowance on entry to a fresh break. However, near the end of the day the situation was reversed. Reduced daily intake on the low allowance could be explained by reductions of approximately equal magnitude in mean daily IB, RB and GT. This was attributed to increased difficulty in prehending and ingesting shorter pasture (1430 kg DM/ha RHM) for animals on the lower allowance.

Although herbage allowance *per* se does affect herbage intake, at a given allowance there will be a difference in absolute intake due to the effect of sward canopy structure, herbage digestibility, and chemical and botanical composition of herbage. Therefore DM is an inadequate description of a feed, and herbage allowance expressed as digestible DM, green DM or green leaf DM may reduce the effects of these variables. However, the effects of these will probably be smaller at low allowances when the animal is very hungry and has a strong drive to eat. At a similar herbage allowance, a sward canopy with a high leaf to stem ratio and a high bulk density or sward height will encourage a greater intake per bite compared to a sparse sward with a low leaf to stem ratio (Stobbs, 1973a, b; Hoogendoorn, 1986). This may explain the 20% lower intake of lactating cows observed on summer pasture compared to that on spring pasture reported by Stockdale and King (1980) and Hoogendoorn (1986), despite a similar generous herbage allowance across seasons (Figure 2.7b).

Water content of herbage

The water content of herbage includes both the internal and external moisture (Phillips, 1989). Although some authors have concluded that there is no effect of water (external moisture) *per* se on the DM intake of herbage (Holmes and Lang, 1963; Wilson, 1978), nevertheless DM intakes of herbage are reduced at very low DM contents (Vérité and Journet, 1970; Kenny et al., 1984; Black et al., 1987; Butris and Phillips, 1987). For dairy cows at pasture the critical DM % below which intake of herbage declines considerably appears to be about 18% (Vérité and Journet, 1970), and between 12.5 - 14.5% for grazing sheep; which in farming practice would only occur in immature grass during the winter/early spring period (Wilson, 1978).

When water in balloons was added to the rumen *per fistulam* there were no detrimental effects on the intake of fresh forages (Campling and Balch, 1961; John and Ulyatt, 1987) suggesting that the effect of water content on herbage intake may be a preference effect and not the bulk effect on rumen fill. This hypothesis was recently tested by Black et al. (1987) and John and Ulyatt (ibid) by offering sheep grass containing 11, 36 or 95% DM (Black et al., ibid) or 12 to 25% DM (John and Ulyatt, 1987). In these studies, sheep selected strongly for and consumed more of the grass with the higher DM content, but the degree of preference for the drier forage decreased sharply as the DM content of the grass increased above 36% DM (Black et al., 1987). In the study of John and Ulyatt (ibid) feed intake was positively correlated (r=0.89) with forage DM content at all stages of forage maturity, with no interaction between the effects of DM % and maturity.

Although the IB (DM basis) and RB have been reported to decline under low herbage DM conditions (Combellas et al., 1979) such effects may be transitory if the wet feed is offered continuously, as the mechanisms for extracting surplus water from the digestive tract are efficient (Hodgson, 1990b). Rates of intake (g DM/min) of cattle fed dry or soaked herbage have been reported not to differ significantly, but the animals fed soaked herbage ate less DM because of a reduction in feeding time of about 1 hour (Butris and Phillips, 1987). Driving rain or wind will cause a decrease in grazing time of cattle (Hinch et al., 1982). Lower rates of passage through the reticulo-rumen of wet herbage, because of reduced production of saliva, rather than physical limitation to prehension, have been suggested as the reason for lower intakes of high moisture herbage (Butris and Phillips, 1987). However, in warm environments natural rain may enhance body cooling and reduce the heat load of grazing cows, which may result in increased pasture intake. Conversely, natural rain may increase the thermal drain and cold stress of cows in cold environments leading to increased energy demand and intake, mainly to meet increased maintenance needs (Holmes and Wilson, 1984; Young, 1987).

Studies of the effects of moisture on the intake of grazed herbage by dairy cows are scarce. Studies of similar effects conducted with silage (see Gill et al., 1988; Thomas and Chamberlain, 1990) cannot be extrapolated to grazing situations, mainly because of the confounding effects of the products of fermentation on silage intake. This area requires further research.

2.4.4 Effects of feeding level, herbage allowance and pasture composition on dairy cow performance

The daily amounts of milk and milk solids produced per cow from grazed pasture depend on the potential yield of the cow and its intake of nutrients (Figure 2.8). The potential yield is a function of genotype, stage of lactation and previous nutritional regime. The degree to which the cow achieves its potential intake is determined by sward and environmental factors, and supplementary feeding (see Sections 2.4.1-3). The interactions of these and many other animal and managerial factors and their effects on milk production from temperate pastures have been reviewed on many occasions (Bryant and Trigg, 1982; Holmes and Macmillan, 1982; Bryant and Holmes, 1985; Leaver, 1985; Bryant and Sheath, 1987; Holmes 1987a & b, 1988; Stakelum and Dillon, 1991). Recent reports by Bryant (1990b) and Holmes (1990b, Figure 2.8) contain succinct summaries of the influence of managerial, plant and animal factors on milk production on New Zealand dairy farms. This part of the present review will examine the effects of feeding level, herbage allowance, and pasture composition, because of variations in grazing management, on the production of milk and milk solids.

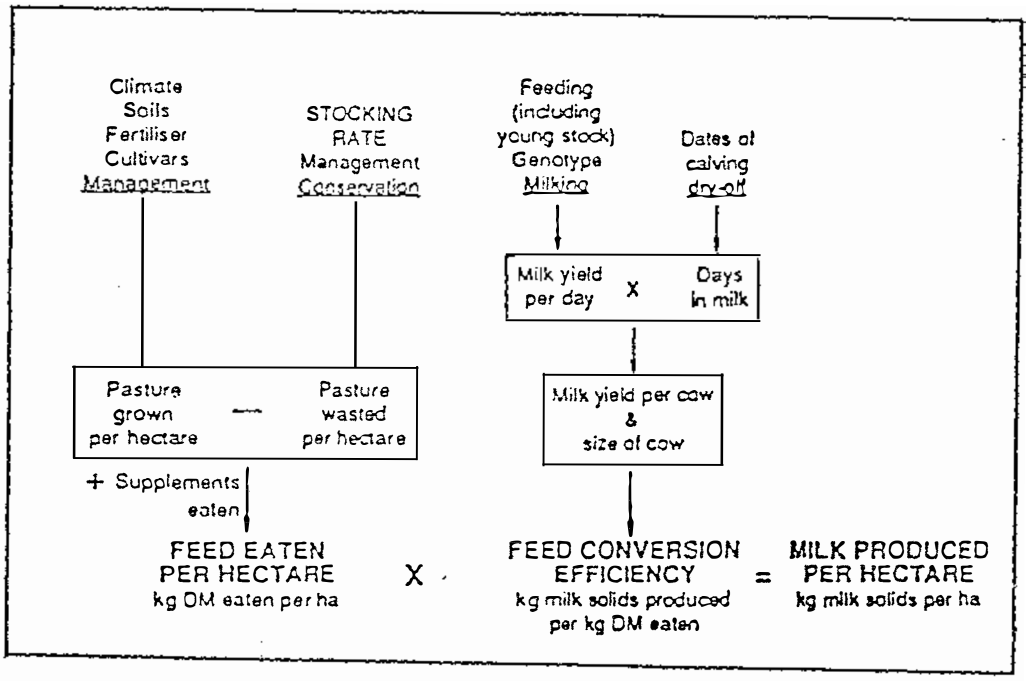


Figure 2.8 A simplified illustration of the key elements of milk production per hectare, and of the factors that affect the key elements (After Holmes, 1990b).

2.4.4.1 Effects of level of feeding on milk yield

Immediate effects

The dairy cow is a complex farm animal as she can be growing, lactating and pregnant simultaneously. Thus the fate of the dietary nutrients is an interaction among these various physiological demands, plus that of maintenance, which are themselves changing almost continuously (Johnson, 1986). The system is a dynamic one in which body reserves are mobilized or deposited at various stages of lactation as well.

Variations in feeding level may elicit immediate and/or subsequent responses in milk production, milk composition and liveweight of dairy cows. An increase in milk output can be clearly expected as an increasing amount of nutrients, particularly digestible energy, is made available to the cow in excess of her maintenance requirements. However, it is important to remember that the response in output to increased feed inputs in dairy cows is only a partial response, since the energy that is not recovered in milk is largely retained in body tissue as fat (or in the conceptus). This means that in the short term there may be no simple relation between nutrient intake and milk production (Holmes, et al., 1981).

Milk yield response to an increased level of feeding and thus energy intake, is negatively curvilinear (Broster, 1976; Figure 2.9), but positively curvilinear for liveweight change (ibid). The declining response in milk yield with successive increments in energy intake (Figure 2.9) can be explained by the 'saturation' of the mammary gland's ability to synthesize milk, with a consequent increase in the rate of nutrient diversion to tissue deposition (Broster, 1972). The joint response of both output pathways to changing intake is linear in energy terms (Broster, 1976).

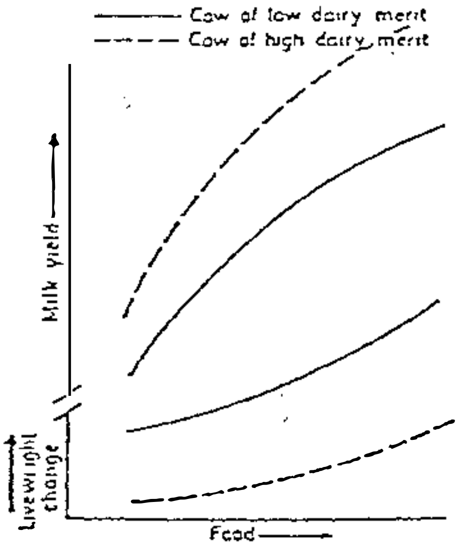


Figure 2.9 Simplified models of milk and liveweight responses of dairy cows to increasing levels of feed intake (After Broster, 1976).

The production response by cows to different levels of energy intake was extensively reviewed by Broster (1976), but the majority of the data reviewed were from experiments where concentrates and conserved forages made up the bulk of the diet. The type of the diet can affect partitioning of energy by the cow, and the curvilinearity of response in milk yield with feeding level (Grainger and McGowan, 1982; Johnson, 1986). Increasing the proportion of concentrates in the diet will alter the roughage:concentrate ratio towards the latter. This may depress the digestibility of the forage component and increase the production of propionate, with a consequent reduction in the efficiency of utilisation of dietary energy for milk and milkfat synthesis and a greater diversion of the ME towards body energy stores (Smith, 1988).

In contrast to the curvilinear response obtained with cows fed on concentrate/roughage diets, most available data for pasture fed cows indicate a linear response in milk yield to increases in feeding level (Bryant, 1980; Glassey et al., 1980; King and Stockdale, 1981; Grainger et al., 1982). The linearity of response is because even at the higher yields, the animal's capacity for milk synthesis has not been reached (i.e., at the steep part of Broster's curve in Figure 2.9). However, negative curvilinearity may develop as lactation advances (Bryant, 1980b), presumably because dairy cows partition less intake energy to milk yield than to body weight gain in late lactation (Hutton, 1963). Early New Zealand work conducted at Ruakura showed that underfeeding in early lactation resulted in a decline in milkfat production during the experimental period (Gerring and Young, 1961). Summarizing work conducted in Australasia during the seventies, Bryant and Trigg (1982) concluded that in early lactation a 38% restriction in DM intake resulted in a 24% decrease in milkfat yield in comparison with well-fed cows. For each 1 kg DM increase in intake, milkfat yield increased by 0.039 kg and liveweight by 0.174 kg per day. During late lactation Bryant (1978) observed that restricting pasture intake by 47% (7.5 vs 14.1 kg DM/cow daily) resulted in a 21% decrease in milkfat yield and a decrease in liveweight. In a stall feeding experiment King and Stockdale (1981) observed a linear decline in milk yield during two 28-day periods of underfeeding in the eighth and ninth months of lactation, when intakes were reduced from 14.7 to 7.3 and 15.2 to 8.2 kg DM/cow daily, respectively. Liveweight decreased in a curvilinear manner.

Subsequent effects

The subsequent (residual) effect of feeding level on dairy cows' performance is regarded as the prolongation of the effects of differential feeding after this itself has ceased (Broster and Broster, 1984), and is expressed relative to the immediate effect measured during the differential feeding period. Residual effects on the performance of dairy cows due to variations in feeding level, and following their return to a common level of feeding, were reviewed for 46 experiments worldwide (Broster and Thomas, 1981). When low and medium planes of nutrition were evident in early lactation, subsequent effects on milk yield were 55% of the immediate effects, provided these exceeded 1.5 kg milk/cow daily. There were no residual effects on milk production when cows were fed a high plane of nutrition in early lactation.

A review of Australasian research indicates that similar trends to those just described above exist for cows on pasture (Bryant and Trigg, 1982). However, significant effects of underfeeding during early lactation on subsequent milk production have not been confirmed by New Zealand studies (Bryant and Trigg, 1979; Trigg et al., 1980). For example, Bryant (1990b) restricted intake of three groups of cows at pasture by 50, 38 and 23% of ad libitum feeding for 56 days during early lactation (from calving in late July to mid September). Feed intake was 6.2, 7.8 and 9.6 kg DM/cow daily for the restricted groups, and 12.5 kg DM/day for the unrestricted cows. The cows were fully fed from mid September to March. Yields of milk solids per cow up to March were highest for cows whose intake was restricted by 38 and 23%, indicating that cows were able to recover from at least 35% underfeeding in early lactation. Per cow performance was lowest for cows on a 50% intake restriction.

It was concluded in the review by Bryant and Trigg (1982) that the subsequent effects of underfeeding in early lactation were one half or less of the immediate effects. Massey University studies indicated that subsequent effects of underfeeding in early lactation ranged from 0.1 to 1.3 times the immediate effects (Grainger, 1982; Ngarmsak, 1984). Conflicting results amongst the studies reported here are probably due to variations in both the level and duration of underfeeding during the treatment period, and to the level of feeding during the post treatment period (Grainger and Wilhelms, 1979; Broster and Thomas, 1981).

The subsequent effects of underfeeding in late lactation on milk yield are less well documented, because cows are usually dried off shortly after the period of underfeeding. However, the extra liveweight gain by those animals receiving the higher plane of nutrition could have subsequent effects on milk yield in the following lactation (Grainger et al., 1982; Grainger and McGowan, 1982; Wilson and Davey, 1982;). Increases in milkfat yields in early lactation of 0.1 to 0.3 kg MF/kg liveweight gain between drying off and calving have been observed under experimental conditions (Grainger et al., 1982).

These subsequent effects are due mainly to the fact that underfeeding causes loss of liveweight. Subsequently, the cows regain the lost weight, thereby diverting nutrients away from milk production until liveweight is restored (ibid).

The rate of liveweight gain following underfeeding in early lactation is generally higher than that of well fed cows (Bryant and Trigg, 1982). Trigg et al. (1980) observed that in the partioning of ME in the energy balance trials the originally underfed group showed less production, less milk energy and more tissue energy retention; although such response and the ability of cows to recover from underfeeding, regarding milk yield and liveweight, may vary between animals.

Cows of high genetic merit produce more milk and milk solids (up to 20-30%), have greater voluntary intake (5-15%), use more of their body reserves in early lactation and have a higher gross and marginal efficiency of milk production at a given level of nutrient intake than cows of low genetic merit (Bryant and Trigg, 1981; Grainger, Davey and Holmes, 1985; Grainger et al., 1985; Holmes, 1988; McCutcheon et al., 1989). Consequently, cows of high breeding index are generally lighter at drying off than their low breeding index contemporaries (Holmes et al., 1987). The ability of dairy cows to recover in body condition at a given level of feeding depends on the body condition score at calving (Grainger et al., 1982; Holmes, 1988). Condition score at calving was shown to affect milk yield in early lactation (Grainger et al., 1982), but provided body condition score at calving was not lower than 4.5, then restricting intake in winter and early lactation (first 5-8 weeks), to ensure optimum feeding in September to November, had no detrimental effect on milkfat yield per cow up to March (Grainger et al., 1982; Bryant and L'Huillier, 1986; Bryant, 1990b). In New Zealand the amount of feed on the farm in mid September (early/mid spring) has been shown to have a greater effect on milk production up to December than body condition score at calving in July/August (Bryant and MacDonald, 1983; Bryant and L'Huillier, 1986; Bryant, 1990b).

2.4.4.2 Effects of herbage allowance on milk yield

Increases in herbage allowance are generally associated with increases in the production of milk and milk constituents because of increases in short term intake of dry matter (Combellas and Hodgson, 1979; Le Du et al., 1979; Bryant, 1980a; Glassey et al., 1980; Thomson et al., 1984; Hoogendoorn, 1986; Stakelum and Dillon, 1991). The absolute level of daily per animal production with increasing herbage allowance depends on many other factors such as stage of lactation; age, breed and genetic merit of the cows; sward characteristics (mass, proportions of leaf and dead matter); and season (Thomson et al., 1984, 1991; Hoogendoorn, 1986; Holmes, 1987b, Michell and Fulkerson, 1987). However, increases in pasture allowance above relatively high levels (e.g., 2.5-3.5 times intake) may cause only small increases in milk production, but large increases in liveweight gain (Bryant, 1980a; Glassey et al., 1980), or in liveweight and condition score of dry cows (Holmes et al., 1979; Ngarmsak, 1984). This is because each cow has some upper potential for milk production, which can not be exceeded despite very high DM intake (Holmes, 1987b). For example, cows offered pasture allowances of 53, 33 and 13.5 kg DM/cow daily for 5 weeks in early lactation ate 15.8, 14.3 and 9.6 kg DM/cow daily, respectively (Glassey et al., 1980). Yields of milk and milk solids for cows offered 53 and 33 kg DM/cow were similar, but the cows on the higher allowance had greater liveweight gains; cows on the smallest allowance produced less milk and milk solids and lost weight and condition (ibid).

2.4.4.3 Effects of pasture composition on milk yield

Herbage from grazed pasture contains many different components that can differ widely between and within components, in composition and digestibility (Terry and Tilley, 1964; Hacker and Minson, 1981; Hacker, 1982; Minson, 1982). Grazing management can influence the component composition of herbage (Section 2.3.2; Stockdale and King, 1980; Hoogendoorn, 1986; L'Huillier, 1987b, c; Stakelum and Dillon, 1991), and it would be expected therefore also to influence the feeding value of the herbage (Ulyatt, 1981).

The effects of differences in herbage composition on the performance of dairy cows grazing temperate pastures have been assessed in several experiments in which herbage composition was controlled by differences in intensity or frequency of grazing to create low mass or high mass swards; both under set stocking (Le Du et al., 1981; Baker and Leaver, 1986) and rotational grazing systems (Santamaria and McGowan, 1982; Thomson et al., 1984, 1989; Hoogendoorn et al., 1985, 1987, 1988; L'Huillier and Bryant, 1987; Michell and Fulkerson, 1987; Stakelum and Dillon, 1991).

Winter/early spring period

In the experiments that measured the effects of pasture composition in early spring on milk production during the same period, grazing intervals and intensity during winter varied from 48 to 128 days, and 800 to 1500 kg DM/ha post grazing herbage mass, respectively (Santamaria and McGowan 1982; Hoogendoorn et al., 1987; Holmes et al., 1992). During spring, the low mass swards were created and maintained by defoliation intervals of 8 to 20 days, or by set stocking, and by defoliation intervals of 21 to 32 days for the high mass swards; at fixed or variable stocking rates (herbage allowances). Grazing intervals in early spring and summer were 18-24d and 30-32d, respectively. Grazing management during summer was generally common across swards that were grazed intensely or frequently but laxly (low mass), and those laxly or infrequently grazed (high mass) during the preceding spring. In some experiments, the composition of pasture, consequent to spring grazing management, was examined in association with the conservation of herbage as silage, hay or *in situ* (Thomson et al., 1984, 1989; Michell and Fulkerson, 1985; L'Huillier, 1988), or with topping (Bryant, 1982; Hoogendoorn et al., 1985; Stakelum and Dillon, 1991) in late spring/early summer.

Santamaria and McGowan (1982) and Hoogendoorn et al., (1987) observed a negative relationship between digestibility of the herbage on offer and pasture mass in early spring following wide variations in winter grazing intensities or frequencies (900-1500 kg DM/ha RHM or 55-110d rotations, respectively). In the study of Hoogendoorn et al., (ibid), given a daily common pasture allowance (24 kg DM/cow) in early spring, the cows grazing on the low mass swards produced 10% and 8% more milk and milk solids, respectively, than cows on the high mass swards, despite dry matter intake (DMI) being similar. In this study (ibid) the low mass pastures (3 *vs* 5t DM/ha) contained, in early spring, lower concentrations of stem (17 *vs* 22%) and dead matter (8 *vs* 18%), and greater concentrations of clover (21 *vs* 8%); and the digestibility of total herbage, hence digestible nutrient intake, was higher (75 vs 69% DMD) than for the high mass swards.

Mid spring/early summer period

The effects of pasture composition in spring on milk production per cow and per hectare during the same and subsequent periods have been consistent. Low mass swards have been shown to contain, in spring and early summer, greater concentrations of clover and green leaf, and lower concentrations of stem and dead matter, and are usually more digestible than high mass swards (Stockdale and King, 1980; Hoogendoorn, et al., 1985, 1988; Bryant and L'Huillier, 1986; L'Huillier, 1987c; L'Huillier and Bryant, 1987; Michell and Fulkerson, 1987; Stakelum and Dillon, 1991). When given a common daily pasture allowance during early/mid spring, the daily intake of organic matter and production of milk and milk solids per cow were greater on low than high mass swards (Thomson et al., 1984; Hoogendoorn, et al., 1985; 1988; Stakelum and Dillon, 1991). At a common daily green leaf allowance, (16 kg/cow) milkfat production and DMI were similar for low and high mass swards (Hoogendoorn et al., 1988) but residual herbage mass from the high mass swards was very high. Conversely, when herbage allowance was not common across swards (e.g., at similar stocking rates), cows grazing the low mass or short swards (5-6 cm) produced less milk and milk solids and had smaller rates of liveweight gain than cows grazing the high mass swards, because of the lower herbage allowance and organic matter intake (Le Du et al., 1981; Bryant and L'Huillier, 1986; L'Huillier, 1987c, 1988; L'Huillier and Bryant, 1987; Michell and Fulkerson, 1987; Hoogendoom et al., 1988).

Summer/autumn period

In late spring/early summer, cows receiving a generous herbage allowance (48 kg DM/cow daily) produced more milk and milk solids (by 12 and 19% respectively) when grazed on low mass than when grazed on high mass swards (Hoogendoom et al., 1992). The low mass swards had a higher digestibility (DMD 74.1 vs 67.2%), greater proportions of leaf and clover, and smaller proportions of stem and dead matter than the high mass swards. The difference in herbage mass (2 *vs* 5 t DM/ha) between low and high mass swards was large, and may have influenced the magnitude of the difference in milk production between the sward types.

On the other hand, topping of the high mass swards in late spring or early summer (Bryant, 1982; Hoogendoorn et al., 1985; Stakelum and Dillon, 1991), or early conservation (October to November) from low stocked swards (Thomson et al., 1984, 1989, L'Huillier, 1988) resulted in yields of milk solids during summer similar to those for swards intensely grazed in spring. Topping or early conservation of previously laxly grazed swards reduced the proportion of dead matter and improved that of green matter and the digestibility of the herbage on offer in summer and autumn.

2.4.4.4 Practical implications of variations in pasture allowance and composition on dairy farm productivity

An increase in pasture allowance is likely to require an increase in the area of the farm to be grazed each day. This in turn may result in waste of pasture and a decrease in milk production per hectare, despite a possible increase in milk production per cow (Bryant and Cook, 1980). An increase in pasture allowance, therefore, may affect the quality as well as the quantity of the herbage consumed, since, as allowance increases, there is less need for the animal to graze into the less digestible base of the sward.

For cows at pasture high herbage allowances, at a given level of pregrazing herbage mass, are associated with high post grazing herbage masses (Holmes, et al., 1979; Bryant, 1980; Glassey et al., 1980; Stockdale and King, 1980; Hoogendoom, 1986). In the long term high residual pasture masses lead to a shortage of pasture on the farm. This is because large proportions of the farm are grazed daily in a rotational grazing system. Consequently, the proportion of trampled and contaminated herbage is increased, and pasture growth rates are reduced; because of the adverse effects of shading and increased rates of senescence on tiller development and rates of photosynthesis (Hodgson and Maxwell, 1981; Sections 2.2 & 2.3). Furthermore, the proportion of pasture grown that is grazed, and milk production per hectare, usually decline (Thomson et al., 1984; Stockdale, 1985b; Bryant and L'Huillier 1986; Hoogendoorn, 1986; Stakelum and Dillon, 1991). Therefore, it may be necessary to restrict pasture allowance and intake, in early spring, to promote pasture growth rates, reduce waste of DM, minimise deterioration in pasture quality, and maintain high milk yield per hectare or per cow, at a given stocking rate, during late spring and early summer (Thomson et al., 1984; Hoogendoorn 1986; L'Huillier, 1988; Bryant, 1990b).

Stocking rate, which is the number of animals carried per hectare over a specified period, is the most important determinant of annual farm production (McMeekan, 1956, 1960, Holmes and Macmillan, 1982). Over a whole lactation, increasing stocking rate results in a reduction in herbage allowance and intake, a linear decline in milk yield per cow, and a linear increase in milk yield per hectare, mainly because of an increase in the proportion of pasture grown that is consumed (King and Stockdale, 1980; Stockdale and King, 1980; Holmes and Macmillan 1982). Reviews of Australasian experiments showed that milkfat production per cow decreases by 18 to 35 kg, and per hectare production increases by 70 kg, on the average, for every one cow/ha increase in stocking rate (Holmes and Macmillan, 1982; Holmes and Parker, 1992). It has been suggested that production of milk and milk solids per unit area can be maximised when production per cow declines by 20-30%, with some restriction on the daily pasture allowance offered (Le Du et al., 1979; Holmes and Macmillan, 1982). In New Zealand and parts of Australia this may mean stocking rates greater than five cows/ha (4.5 cows/ha with replacements) (Wright and Pringle, 1983), which are usually not carried on commercial or research farms. This is because stocking rates of such magnitude cause large decreases in pasture allowance and growth rates, per cow milk production, liveweight, and body condition, particularly if little or no supplements are fed during periods of pasture scarcity (Stockdale and King, 1980; King and Stockdale, 1980; Holmes and Bryant, 1985; Holmes, 1987a, b).

In New Zealand, it is possible that on highly stocked farms, the availability of pasture in early spring may be a more important determinant of milk production per cow during that period than pasture composition and quality, consequent to variations in grazing management in the preceding winter (Bryant and Trigg, 1980; Bryant and L'Huillier, 1986; Bryant, 1990b). Differences in per animal and per hectare productivity over the whole lactation may be small or difficult to predict, because of the positive correlation between the amount of pasture on the farm in early spring and subsequent pasture growth rates (Santamaria and McGowan, 1982; L'Huillier, 1987b; Bryant, 1990b); and the negative effects of high residual herbage masses during the same period on both pasture quality and growth in late spring/early summer (Korte et al., 1984; L'Huillier, 1987b).

Whereas high herbage masses, as consequences of lax or infrequent grazing in the early/mid spring period, may promote higher per cow performance, pasture quality tends to decline during the late spring and early summer periods of high pasture (stem) accumulation rates (Korte et al., 1984; Hoogendoorn et al., 1988). Avoiding high herbage masses during this period is, therefore, considered important in order to avoid a decline in pasture density and quality, and milk production in late spring/summer period (Bryant and Sheath, 1987; Hoogendoorn et al., 1988; Section 2.3.2).

In a Tasmanian study, intense grazing (3.4 *vs* 1.9 cows/ha) in mid to late spring resulted in a non-significant decline in milkfat production per cow during that period, but subsequently at a common stocking rate (1.7 cows/ha) in summer, the production of both milkfat and protein was higher (by 6%) on the previously intensely than laxly grazed swards (Michell and Fulkerson, 1987). In summer, the digestibility of the herbage on offer was lower for swards laxly grazed than intensely grazed swards during spring (57 *vs* 61% DMD), whilst that of the ingested herbage was similar between swards (ibid). This was true despite the greater and lower proportions of dead matter and green leaf, respectively, of the originally high mass swards, as cows rejected the dead component. Pregrazing and residual herbage masses in late spring were, respectively, 2.6 and 1.7 t DM/ha for the intensely grazed swards, and 3.2 and 2.6 t DM/ha for the laxly grazed swards. In summer, PHM for the intensely and laxly grazed swards were 2.2 and 3.0 t DM/ha, respectively. Apparent daily DMIs, estimated by the 'difference' technique, were similar between the treatment groups during late spring and summer (11.8 and 8.3 kg DM/cow, respectively).

It was concluded from the Tasmanian study (ibid) that the presence of dead herbage in swards laxly grazed in spring reduced animal production by reducing the availability and intake of green herbage (including stem) or digestible nutrients in summer, rather than reducing the digestibility of the diet ingested by the cows. Results from a similar New Zealand study (Thomson et al., 1984), seem to support this conclusion, with the added observation that, unlike the dead matter component, the proportion of stem in the pasture was not significantly correlated to per cow milkfat production. On the other hand, Hoogendoorn et al., (1985) observed that higher levels of milk production by cows on summer pastures that were intensely grazed in late spring were mainly a result of the greater digestibility (72.5 *vs* 67.6% DMD) of previously intensely than laxly grazed swards, as feed intake at common pasture allowances varied considerably between years and between treatments. Nevertheless, the conclusions reached in the studies just cited must be taken with caution because it is difficult to separate the effects of intake from the effects of digestibility of the diet on animal performance, since it is not easy to measure each individually in a grazing situation.

Similar trends to those reported from Tasmania (ibid) have also been observed in several New Zealand studies involving higher stocking rates. For example, at a common grazing intensity (stocking rates of 4 to 6 cows/ha) Bryant and L'Huillier (1986) and L'Huillier and Bryant (1987) observed greater yields of milk solids per cow during the summer/autumn period from swards either frequently grazed (8-12d) or set stocked during mid to late spring than from infrequently grazed swards (30-32d). However during the mid to late spring period daily yields of milk solids were greater on infrequently than frequently grazed or set stocked swards, despite the greater proportions of clover and lower proportions of dead matter of the low mass (frequently grazed or set stocked) swards. Herbage mass values in mid spring for PHM and RHM were, respectively, 3.74 and 1.54 t DM/ha for the long rotation (32d) swards, and 2.07 and 1.31 t DM/ha for the short rotation (8d) swards (Bryant and L'Huillier, 1986). Total herbage masses for the experiment involving the set stocking treatment were not reported, but pasture growth rates during spring were smaller with set stocking than with 30 or 12d rotations (ibid). This may have led to a lower level of feeding of the set stocked cows. The DMD % of the herbage on offer in December was similar across swards (L'Huillier and Bryant, 1987).

It can be concluded that on farms with high stocking rates, in relation to annual pasture production, variation in pasture composition because of grazing management in mid spring through summer seems to exert little effect on animal performance over the whole lactation (<10 kg milkfat) (Bryant, 1990b). This conclusion applies as long as pasture allowance during spring does not decline below a critical minimum of around 32-35 kg DM/cow daily (1400-1700 kg DM/ha RHM or 4-5 cm sward height) (Thomson et al., 1984; Baker and Leaver, 1986; Bryant and L'Huillier, 1986; Michell and Fulkerson, 1987; L'Huillier and Bryant, 1987; L'Huillier, 1987c, 1988; Hoogendoorn, et al., 1988). High stocking rates with late conservation, set stocking or fast rotations during mid spring to early summer may reduce per cow production up to late spring because of a reduction in herbage allowance and NHA rates (mainly stem), but this may not influence total performance (L'Huillier and Bryant, 1987; Michell and Fulkerson, 1987). Subsequently, improvements in the quality of summer/autumn pasture (less dead matter and greater proportions of clover and green matter of high digestibility) tend to compensate for the lower feeding level during late spring arising from attempts to control stem and dead matter accumulation. These benefits are generally carried through the summer/autumn period irrespective of the type of management imposed during that time (L'Huillier, 1988; Bryant, 1990b).

In addition, intense or more frequent mid/late spring grazing promotes ryegrass tillering in late spring to early summer, and herbage accumulation during dry summers when soil moisture is limiting (Korte et al., 1984; L'Huillier, 1987a, c, 1988). Maintaining low herbage masses in mid spring to early summer results in an increase in animal production per hectare with only a small loss in per cow production. This arises from an improvement in the proportion of herbage grown that is consumed and/or conserved, an increase in the proportion of desirable pasture components and their feeding value, and improvements in pasture density and resilience (Thomson et al., 1984; L'Huillier, 1987a, b & c; Michell and Fulkerson, 1987; Bryant, 1990b). However, the overall stocking rate, through its effects on pasture allowance and intake, and on production per cow and per hectare (Section 2.4.4.1); and stock policies which are beyond the scope of this review (see Section 1.1; Bryant and Trigg, 1982; Holmes and Macmillan, 1982; Bryant and Sheath, 1987; Bryant, 1990b), are the major determinants of long term farm productivity. These are much more important than grazing management and its effects on pasture composition.

2.4.5 Effects of the composition of prairie grass pastures on the performance of dairy cows

2.4.5.1 Features of prairie grass

Prairie grass is an erect (up to 60 cm; Plate 1.1), tufted and short lived perennial with a C3 metabolic pathway, which originated from the Pampas of South America, and now has a wide geographical distribution (Rumball, 1967; Anon., 1982; Hill and Pearson, 1985; Hopkins et al., 1989; Hume, 1990b). The species has no vernalization requirements, with a long photoperiod being the only requirement for reproductive development extending from mid-spring to mid-autumn (Evans, 1964; Wilson, 1977; Langer and Hill, 1982; Hume, 1991a). Prairie grass (*Bromus willdenowii* Kunth; synonyms *B. catharticus* Vahl, *B. schraderi* Kunth, *B. unioloides* H.B.K.) is also known in the USA, UK and France as rescue grass, brome grass, Schraders brome grass, and as 'paardegras' in Holland (Langer and Hill, 1982; Hume (1990a). In the highlands of East Africa, prairie grass is known as Nakuru grass (Bogdan, 1977). The better known commercial cultivars of prairie grass are 'Grasslands Matua' (Australasia, Europe, USA), 'Primabel', 'Cabro' and 'Bellegarde'

(Europe) (Anon., 1982; Hume, 1990b).

In New Zealand and elsewhere, many of the agronomic aspects of prairie grass cv. Grasslands Matua have been extensively studied over the last two decades, and management and pest damage are two of the main factors determining its persistence and production (Section 1.3; Black and Chu, 1989; Thom et al., 1989, 1990; Boom and Sheath, 1990; Hume, 1990b, 1991a-d). Most reports showed that prairie grass yielded more dry matter per annum (up to 22 t DM/ha) than other perennial grass species, with most of the production being realized during the mid spring to late winter period (Rumball, 1974; Baars and Cranston, 1977, Rys et al., 1978; Clark, 1985). Defoliating prairie grass swards at 30 to 50 day intervals (shorter in spring and longer in summer-winter), and leaving a stubble height of 5 to 8 cm (>2000 kg DM/ha RHM) increased tiller numbers and sward persistence (Hill and Pearson, 1985; Bell and Ritchie, 1989; Black and Chu, 1989; Hume, 1990b, 1991a-d). Intense grazing, frequent defoliation or set-stocking resulted in the disappearance of prairie grass from the swards within two years (Lancashire and Brock, 1983; Anon., 1982; Webby et al., 1990). In some reports prairie grass had no advantage in seasonal or annual dry matter production over perennial ryegrass, regardless of the defoliation regime imposed, or the perceived DM yield advantage had disappeared by the third year post-establishment (Savage et al., 1985; Hopkins et al., 1989; Stevens and Hickey, 1989; Boom and Sheath, 1990; Webby et al., 1990). The proportion of clover in prairie grass swards has been shown to decline under lax and/or infrequent defoliation regimes (Rys et al., 1978; Anon., 1982; Alexander, 1985; Cosgrove, 1986).

Similarly, the limited available information on the component composition and feeding value of Matua prairie grass dominant pastures is from studies where defoliation was achieved by either cutting (Rys et al., 1978; Savage et al., 1985; Hopkins et al., 1989; Hume 1990a & b, 1991d), or by grazing with sheep or bulls (Rys et al., 1978; L'Huillier et al., 1986; Cruickshank et al., 1985; Fraser, 1985; Cosgrove and Brougham, 1988; Crush et al., 1989; Boom and Sheath, 1990). In most of these studies, the swards were defoliated at low pregrazing herbage masses (< 2.5t DM/ha), which would not represent prairie grass pastures commonly found on New Zealand dairy farms (Ridler, 1985; Ridler et al; 1988; Thom et al., 1990).

On the other hand, when compared to other pasture grasses, the digestibility and/or feeding value (for meat and milk production) of prairie grass has been shown to equal that of perennial ryegrass; and is potentially comparable to the annual or short rotation ryegrasses at similar stages of maturity and herbage allowance (Wilson and Grace, 1978; Anon, 1982;

L'Huillier et al., 1984, 1986; Cruickshank et al., 1985; Fraser, 1985; Cosgrove and Brougham, 1988; Crush et al., 1989; Hopkins et al., 1989; Hume, 1990 a & b, 1991d; Webby et al., 1990). L'Huillier et al. (1984, 1986) observed 87% greater intakes of dry matter by sheep grazing on Matua prairie grass/clover than on perennial ryegrass/clover swards during the summer/autumn period, probably because a greater proportion of green leaf in Matua than ryegrass swards was distributed in the upper, more accessible sward horizons. On the other hand, spring intakes of OM by lambs given a generous herbage allowance were similar for Matua and 'pure' perennial ryegrass swards despite the smaller mean retention time of Matua dry matter in the reticulo-rumen (Cruickshank et al., 1985), suggesting that sward structure may limit the DM intake of sheep on Matua swards in spring, but may promote it in the summer/autumn period.

At a similar stage of maturity prairie grass cv. Grasslands Matua was reported to contain greater concentrations of both water-soluble carbohydrates and cell wall constituents than tetraploid Westerwolds ryegrass, but the digestibility of the cell wall fraction and the concentration of N in the two species were similar (Wilson and Grace, 1978; Hume, 1990a & b, 1991d). Crush et al. (1989) did not observe significant differences in the mean chemical composition and digestibility of Matua and perennial ryegrass from swards grazed by bulls over the whole year. The mineral composition of prairie grass cv. Grasslands Matua shows considerable intra-species variation, particularly in Ca, Mg and I levels. However, reports that the concentrations of these minerals tend to be lower in the cultivar than those of the ryegrasses, especially in early spring (Rumball et al., 1972; Wilson and Grace, 1978; Rys et al., 1978), have generally not been confirmed (Crush et al., 1989; Thom et al., 1990). Besides, no major health problems have been observed with lactating cattle grazing on Matua based pastures (Wilson and Grace, 1978; Thom and Prestidge, 1988).

2.4.5.2 Milk production from prairie grass

There are very limited experimental data from New Zealand and elsewhere on the relationships between grazing regime of prairie grass pastures by dairy cows, herbage composition and the productivity of animals grazing on such pastures (Thom and Prestidge, 1988; Sellars, 1988; Crush et al., 1989).

In one of the three reported New Zealand studies, there was no significant difference in milkfat yield during spring between identical twins grazed on 'pure' stands of either prairie grass cv. Grasslands Matua, or Westerwolds ryegrass cv. Grasslands Tama, or mixed perennial ryegrass/white clover pasture (Wilson and Grace, 1978). In a more recent study at Ruakura milkfat production per cow and per hectare during one lactation from a 50:50 Matua prairie grass and Nui perennial ryegrass/white clover pasture was slightly (3%) lower than yields from well established perennial ryegrass/white clover or one year old Nui perennial ryegrass/white clover swards (Thom and Prestidge, 1988; A.M. Bryant, pers. com.). In the latter experiment, insect and disease damage of Matua prairie grass swards was high, resulting in a reduction in herbage yield, a very low population of Matua plants, and termination of the experiment in its second year. Reports from France indicated that summer milk production by cows grazed on prairie grass cv. Bellegarde was 7% greater than production from tall fescue/cocksfoot swards, but prairie grass did not persist beyond four years (Anon., 1982; Parneix, 1982).

In none of the studies cited above was the management of the sward varied in order to control the composition of the herbage at different values. The effect of the composition of prairie grass pastures on milk production is unknown.

2.4.6 Summary

It is clear from the evidence discussed that herbage intake and consequently animal production can be influenced by many sward and animal characteristics. Many individual effects have been described, but at present the knowledge to predict with certainty their combined effects on herbage intake is lacking.

1. Three principal factors seem to influence the herbage intake of grazing animals, namely the feeding drive, the sensation of satiety, and behavioural constraints. Sward characteristics exert their effects on intake through limits imposed on the animal's ability to satisfy its 'requirements' or feeding drive; the ability to ingest herbage DM and nutrients through behavioural constraints, e.g., bite size and bite rate. The digestibility of the herbage will affect the nutritive value of the DM ingested. Sward characteristics also limit herbage consumption by affecting the animal's ability to process ingested herbage, and herbage of low digestibility may increase rumen fill and reduce the feeding drive.

   All factors influencing intake operate simultaneously, but in most cases one factor may be the most limiting. For example, when available feed is low, digestibility and feeding drive have no important effects on intake, but bite size and grazing time become important. With high feed availability, digestibility of DM and feeding drive are the key factors affecting intake , and intake is not limited by bite size or grazing time.

2. Increases in herbage allowance will increase milk yield per cow in the short term, through increases in intake per cow, up to some maximum yield depending on the cow's inherent capabilities. Also at high herbage allowance and intake there is an increase in rate of liveweight gain.

3. The composition of herbage can affect milk yield, either with no effect on intake of DM but through effects on intake of metabolisable energy, or with effects on DM intake, or with both DM and ME intake.

4. In a practical situation on a pastoral dairy farm, application of different grazing management has effects on herbage allowance, intake and milk yield in the short term, but also on herbage supply, composition and growth in the long term; with subsequent effects on milk production. The overall effect of short term variations in pasture allowance and composition on dairy farm productivity is difficult to predict.

5. Prairie grass is a short lived perennial reputed for high cool and warm season growth, and high nutritive value. There is no evidence to date of improved milk production per cow or per hectare from incorporating prairie grass in a pastoral dairy production system. The effects of variations in composition of Matua prairie grass pasture on milk production are not known.

CHAPTER 3

MATERIALS AND METHODS COMMON TO ALL EXPERIMENTS

3.1 EXPERIMENTAL SITE

The experiments reported in the present thesis were conducted between January 1987 and May 1989 at Massey University's No. 4 Dairy Farm (Experiment 1) and Dairy Cattle Research Unit (Experiment 2). The two properties are adjacent to each other and are operated as seasonal-supply dairy farms. No. 4 Dairy is a 137 ha farm supporting approximately 400 milking cows and their replacements. The Dairy Cattle Research Unit (DCRU) supports 120 cows with replacements on 48 ha. These farms are approximately 75m above sea level and are within the immediate vicinity of Massey University located at 40° 23' S and 175° 37' E.

The soil type is Tokomaru silt loam (Cowie et at., 1972) and is characterized by a 15-30 cm layer of heavy silt above a mottled clay loam, but the farms are extensively tile- and mole-drained.

The predominant pasture species at the beginning of these studies were perennial ryegrass with white clover (100% of DCRU and 85% of No. 4 Dairy Farm), and Matua prairie grass with red clover (15% of No. 4 Dairy Farm). These pastures are fenced into paddocks of approximately 0.8 ha at the DCRU, and 2.5 ha at No. 4 Dairy. Surplus herbage occurring during mid to late spring is conserved as silage, and any hay fed on these farms is purchased. Concentrates are not fed.

Approximately 375 kg/ha of 15% potassic superphosphate is applied in one dressing during autumn, and 50 kg/ha of urea nitrogen is applied in two dressings during autumn and early spring.

3.2 WEATHER

Monthly meteorological data for the period May 1986 to April 1989, with 30 year means, are presented in Appendix 5.1a,b. These data were recorded by the Grasslands Division, Department of Scientific and Industrial Research (DSIR, now Crown Research Institute (CRI), Palmerston North, situated 1 km North-East of the experimental site.

3.3 SEASONS

During the entire study, seasons were categorized as follows:

early spring	September/mid October
late spring	Late October/early December
summer	Mid December/early March
autumn	Mid March/May
winter	June/August

3.4 SWARD MEASUREMENTS

3.4.1 Sward surface height

Sward height (cm) was measured with a ruler (100 cm long), before and after grazing, at regular intervals along a diagonal transect using the first contact technique (Bircham and Hodgson, 1983b). The reading taken was the highest point, on the same side of the ruler, in contact with any live part of a plant (Matua swards) or live leaf (perennial ryegrass swards). The measurements were made on undisturbed sward canopy within 36 hours before and after grazing. Forty readings were taken per plot or replication on each measurement day.

3.4.2 Herbage mass (kg DM/ha)

Pre-grazing and post-grazing (residual) herbage masses (PHM and RHM, respectively) were estimated for each replication within 36 hours before and after grazing. Herbage within rectangular quadrats placed at regular intervals along a diagonal transect was cut to ground level, using a sheep-shearing hand-piece powered by a portable petrol motor (Frame, 1981). The size of the quadrats used and the number of quadrats cut are indicated under experimental procedures specific to each experiment.

Herbage cut for estimating herbage mass was bulked within each replication, mixed and subsampled for determination of pasture composition (Experiment 1), and washed to minimize soil and faecal contamination. The washed herbage was dried at 80°C for 36-48 hours in a forced-air draught oven and weighed. Herbage masses (kg DM/ha) were then calculated. Dry weights of subsamples taken from herbage cut for estimating herbage yield were included in herbage mass calculations.

3.4.3 Sward bulk density

Sward bulk density (kg DM/ha per cm sward surface height) of pre-grazing herbage was calculated by dividing herbage mass by the mean surface height of the swards.

3.4.4 Morphological components of herbage

Fresh or frozen (-20°C) pre- and post-grazing herbage subsamples (10-20 g dry weight) were dissected manually into ryegrass and/or prairie grass stem, leaf lamina and inflorescence; clover leaf and stem; other species leaf lamina and stem; and into senescent matter. The specific definitions of these herbage components are given in Section 3.7.

The dissected components were washed and either dried at 80°C for 24-36 hours in a forced-air draught oven (Experiment 1) or freeze-dried (Experiment 2) and weighed. Their relative proportions in the swards were calculated on percentage dry weight basis. Actual mass of each component in the swards was calculated using the percentage composition of the component in the herbage. Details of herbage subsampling and sample handling protocols are given under the specific experiments in Chapters 4 and 5.

3.4.5 Botanical composition

The botanical composition of the herbage on offer was determined by summing the dry weights of the morphological components of individual plant species, as described in Section 3.4.4 but excluding senescent matter, and calculating the proportion of each plant species in the pre-grazing herbage based on dry green biomass. The botanical components of the swards were categorized into Matua prairie grass, clover and other species for Matua swards; and ryegrass, clover and other species for perennial ryegrass swards. This approach saved time by eliminating duplication of the labour-intensive task of herbage dissections.

3.4.6 Net herbage production

Net herbage production (kg DM/ha) was calculated as the difference between pre-grazing herbage mass at the subsequent grazing and post-grazing mass of the previous grazing. Rates of net herbage production (kg DM/ha/day) were obtained by dividing net herbage production by the number of days between consecutive grazings. No attempt was made to quantify dry matter disappearing through death and decomposition or herbage accumulating between pre- and post-grazing herbage cuts and grazing.

3.4.7 Chemical composition and digestibility of herbage

Dried samples of total pre-grazing herbage, ryegrass and prairie grass whole plants, and the leaf and stem fractions of ryegrass and prairie grass plants were bulked per experimental plot or paddock within each season per year. Dried samples of inflorescence and dead matter were bulked within treatments (swards types) as mentioned above. Samples for the determination of gross energy, neutral detergent fibre (NDF), acid detergent fibre (ADF) and lignin were also bulked, after grinding, within sward types during each season within a year on equal weight basis. Results of chemical determinations of samples bulked within sward types or treatments are reported as simple means with their standard deviations. Dried herbage samples were ground using a 1mm sieve on a Thomas Wiley Laboratory mill (Model ED-5, Thomas Scientific, USA). All analyses were made in duplicate, and expressed on a DM basis.

3.4.7.1 Organic Matter

Organic matter (OM) was determined on 2 g samples as a loss in weight after incinerating the sample for 18 h at 500°C in a muffle furnace (McGregor and Sons (NZ) Limited) (Association of Official Agricultural Chemists, 1975). Ash content was the residue remaining following incineration of the sample.

3.4.7.2 Total Nitrogen

Total N was determined by the Kjeldahl procedure, using 0.3 - 0.35 g dry herbage samples. The samples were digested (Digestion System 20; Tecator Ltd., Sweden) in 10 ml of concentrated H_2SO_4 for 25-50 minutes at 420°C, using a selenium catalyst (Macrokjeltab; 15 mg Se; 3000 mg K_2SO_4). After digestion, the samples were cooled, diluted with 30 ml distilled water, and steam-distilled on the Kjeltec Auto Analyser 1030 (Tecator Ltd., Sweden). The acid digest was made strongly alkaline by automatic dispensing of 50 ml of NaOH (40% w/v). The ammonia released was distilled into 25 ml boric acid (1% w/v) containing the mixed indicator bromocresol green and methyl red, and automatically titrated with 0.1M HCl. The % ammonia recovery by the distillation process was determined by using ovendried (temperature 100°C) $(NH_4)_2\,SO_4$, and was 99-101%.

3.4.7.3 Gross energy

Heat of combustion was determined by using an adiabatic bomb calorimeter. The herbage samples were made into 0.6 - 0.8 g (DM basis) pellets, on a briquette press (12 mm diameter) prior to combustion.

3.4.7.4 Cell-wall constituents

Neutral detergent fibre, (NDF), acid detergent fibre (ADF) and lignin were determined according to Robertson and Van Soest (1981).

3.4.7.5 Digestibility determinations

Estimates of dry matter digestibility (DMD), organic matter digestibility (OMD) and the amount of digestible organic matter expressed on a dry matter basis (DOMD), were obtained using the *in vitro* cellulase incubation method (Roughan and Holland, 1977; Dowman and Collins, 1982). Six herbage standards, of known apparent *in vivo* DMD, OMD and DOMD, were included in each sample batch, and the relationships between the *in vivo* and *in vitro* values for these were determined by linear regression. The digestibility results reported in the text are apparent *in vivo* values predicted from the regression equations. The OMD range of the pasture herbage standards was 72.1 to 81.0 %. Standards of hay with OMD range of 56.3 to 61.9% were used in the *in vitro* runs to predict apparent *in vivo* digestibilities of senescent matter in the pasture herbage.

3.4.7.6 Metabolisable energy

The ME concentration of herbage samples was calculated from their predicted DOMD (D value) according to the following equation of MAFF (1975), modified slightly for New Zealand pasture herbage (Ulyatt *et al*., 1984):

$$\mathrm{ME}\ (\mathrm{MJ/kg\ DM}) = 0.163\ (\%\ \mathrm{DOMD})$$

Estimates of ME using the above equation agreed closely with estimates derived from the relationship (ME MJ/kg DM = 0.181 ± 0.01 OMD% - 2.68 ± 0.66 (Bryant and Trigg, 1982)). The former equation was chosen for simplicity.

3.4.8 Masses of herbage components

Masses of the morphological components of herbage (kg DM), total N and digestible organic matter (DOMD) (g/m^2) were calculated from the % composition of the component in the herbage.

3.5 OTHER MEASUREMENTS

3.5.1 Sward measurements

The procedures employed in measuring tiller density, vertical distribution of sward components, daily herbage allowance, and diet composition, by the sward sampling technique, are explained in the experimental procedures sections of Chapters 4 and 5.

3.6 EXPERIMENTAL DESIGN AND STATISTICAL PROCEDURES

3.6.1 Experimental designs

The design used in the two experiments, to test the effects of sward types created by differential defoliation regimes, on the measured or derived sward and herbage variables, was a split-plot in time (Steel and Torrie, 1980). Sward types constituted the main plots and seasons the sub-plots. Details of the specific treatments are presented in Chapters 4 and 5. The analysis of data from a split-plot design results in two different estimates of natural variation (error mean square). The larger of the estimates is associated with the whole plots, and the smaller with the sub-plots. This enables a more precise examination of the factor allocated to the sub-plot (Steel and Torrie, 1980; Stokoe, 1983).

In Experiment 1, the three Matua prairie grass sward types were laid out in a randomized complete block arrangement with three blocks but with unequal observations. These arose from differences in grazing and cutting (sampling) frequencies of the different sward types, over the one year period. In Experiment 2, in which one ryegrass and two Matua sward types were being compared, the basic experimental layout was similar to that of Experiment 1 but with four replications (blocks). Additional details of the design are presented in Chapter 5.

3.6.2 Statistical analyses

Data for sward characteristics (herbage yields, tiller density, sward height, botanical and morphological components) and chemical composition of herbage were subject to analysis of variance, to examine the significance of between sward type and between season differences, using a Generalized Linear Models procedure (SAS, 1985). The linear model used to describe the data for a balanced split-plot in time design with unequal observations was:

$$Y_{ijk} = \mu + B_i + T_j + (BT)_{ij} + S_k + (BS)_{ik} + (TS)_{jk} + e_{ijk}$$

where Y_{ijk} = observation in the i^{th} block from the j^{th} sward type during the k^{th} season

μ = overall mean

B_i = effect of the i^{th} block; i = 1,2,3 (Experiment 1) or i = 1,...,4 (Experiment 2)

T_j = effect of the j^{th} sward type; j=1,2,3

$(BT)_{ij}$ = error term associated with the i^{th} block and the j^{th} sward type

S_k = effect of the k^{th} season; k = 1,...,4 (Experiment 1) or k = 1,...,8 (Experiment 2)

$(BS)_{ik}$ = error term associated with the i^{th} block and the k^{th} season

$(TS)_{jk}$ = interaction between the j^{th} sward type and the k^{th} season

e_{ijk} = random residual error associated with the i^{th} block, the j^{th} sward type and the k^{th} season;

and $(BT)_{ij}$, $(BS)_{ik}$ and e_{ijk} are assumed to be normally and independently distributed with mean 0 and variance σ^2.

The significance of the effects of sward type and season were tested using block x sward type interactions ($(BT)_{ij}$) and block x season interactions ($(BS)_{ik}$), respectively, as error terms; and sward type x season interactions were tested using the random residual error. Analyses of data expressed as percentages were performed on untransformed data as they did not violate the assumptions of normality for analysis of variance (Sokal and Rohlf, 1981). Year effects (Experiment 2) were not isolated in the general linear models used as it was deemed unnecessary, and because of the complexity of interpreting higher order interactions.

3.6.3 Presentation of data

The symbols +, *, **, *** and NS (not significant) are used throughout the text to indicate significance levels of $P<0.10$, $P< 0.05$, $P<0.01$, $P<0.001$ and $P>0.05$, respectively. Unless indicated otherwise, all means presented are least squares means (lsm) and their associated standard errors (S.E.$_{lsm}$). The abbreviation "Sign." stands for significance level. Other abbreviations in the text are defined in the list of abbreviations, following the acknowledgements page.

3.7 DEFINITIONS OF TERMINOLOGY

The terminology and definitions used in this thesis are according to the recommendations of Hodgson (1979) for grazing studies, Thomas (1980) for studies of grassland plants and Bryant and Holmes (1985) for pasture utilization criteria. Otherwise, the definitions of terminology that are specific to this thesis are given below:

green/live : refer to plants or morphological components of plants that were less than 50% chlorotic.

senescent/dead matter : any plants or parts of a plant that were more than 50% chlorotic.

whole plant : refers to a live ryegrass or prairie grass plant cut to ground level, with senescent parts, if any, still attached.

grass leaf : ryegrass or prairie grass leaf lamina including the ligule but not the leaf sheath.

grass stem	:	ryegrass or prairie grass pseudostem and true stem in reproductive tillers.
clover leaf	:	leaf lamina and petiole.
clover stem	:	any above ground stolon protruding above the cutting height including the flower-head.
inflorescence/ seed-head	:	ryegrass or prairie grass flower-head beyond the flag leaf.
other species	:	grasses other than ryegrass in perennial ryegrass swards or other than prairie grass in Matua swards, and broad-leaved weeds.
sward leaf	:	green/live leaf laminae of all plants in the sward.
sward stem	:	green/live stem of all plants in the sward.

3.8 SCIENTIFIC NAMES

The scientific names of grass and weed plants, pests and disease-causing fungi mentioned in the present thesis are listed below.

3.8.1 Pasture plants and weeds

Grasses

Brown top	:	*Agrostis capillaris* L.
Cocksfoot	:	*Dactylis glomerata* L.
Phalaris	:	*Phalaris aquatica* L.
Poa	:	*Poa* spp.
Ryegrass		

(perennial) : *Lolium perenne* L.

Ryegrass (Westerwolds) : *Lolium multiflorum* Lam.

Tall fescue : *Festuca arundinacea* Schreb.

Yorkshire Fog : *Holcus lanatus*

Legumes

Clover (white) : *Trifolium repens* L.

Clover (red) : *Trifolium pratense* L.

Lotus : *Lotus pedunculatus*

Sainfoins : *Onobrychis* spp.

3.8.2 Insect pests

Argentine stem weevil : *Listronotus bonariensis* Kuschel.

Grass grub : *Costelytra zealandica* White

Hessian fly : *Mayetiola destructor* Say.

3.8.3 Pathogenic fungi

Anthracnose : *Colletotricum graminicola* Wilson.

Endophyte (Lolium) : *Acremonium lolii.*

Head smut : *Ustilago bullata* Berk.

CHAPTER 4

INFLUENCE OF GRAZING REGIME AND SEASON ON THE GROWTH AND COMPOSITION OF PRAIRIE GRASS-RED CLOVER SWARDS

(EXPERIMENT 1)

4.1 INTRODUCTION

New Zealand's dairy production relies heavily on grazed pastures based on perennial ryegrass (*Lolium perenne* L.) and white clover. Periods of drought in summer/autumn, and of low temperatures in autumn/winter, often reduce feed supply, shortening the lactation period (Bryant and Holmes, 1985; Thom et al., 1989; Bryant 1990b). A number of grass species with supposedly better summer/autumn/winter production potential and insect tolerance than perennial ryegrass have become available over the last twenty years (Rumball, 1974; Lancashire, 1985a, b; Belgrave et al., 1990). Consequently, dairy farmer interest in using these grasses increased in the 1980s; prairie grass (*Bromus willdenowii* Kunth) is especially favoured as a potential alternative or complement to ryegrass (Thom and Prestidge, 1988; McCallum, 1987; Penny, 1987; Belgrave et al., 1990). However, very few studies have been conducted to evaluate the effects of different defoliation regimes on the growth, composition and nutritive value of prairie grass cv. Grasslands Matua in an applied dairy cattle production system (Brookes and Holmes, 1986; Thom and Prestidge, 1988). There are some data on the composition of prairie grass pastures grazed by young bulls (Crush et al., 1989; Boom and Sheath, 1990). These and similar data obtained from small plot evaluations of new pasture species, either by cutting or "on-off" grazing by classes of stock other than dairy cows, may not be applicable to dairy farming situations (Korte and Harris, 1987; Thom and Prestidge, 1988).

The objective of the present experiment was to assess the effects of grazing regime (low, medium or high pre-grazing herbage mass) by dairy cows, over a range of seasons (summer, autumn, winter and spring), on the growth and composition (including digestibility) of Matua prairie grass grown in association with red clover (*Trifolium pratense*).

4.2 EXPERIMENTAL PROCEDURE

The experiment was conducted for 10 months (mid January, 1987 to mid November, 1988) on four year old predominantly Matua prairie grass-red clover swards. Dairy cows (lactating from early spring to autumn but non-lactating during winter) were used to defoliate the swards. No animal measurements were made.

4.2.1 Pasture establishment

Two paddocks (2.5 ha each) on Massey University's No. 4 Dairy Farm, (described in Section 3.1) were sown in 1982 under prairie grass cv. Grasslands Matua and red clover cv. Grasslands Pawera. Seed rates were 40 kg Matua and 5 kg red clover per hectare. Grazing management during the first two years of sward establishment was lax (2200-3000 kg DM/ha post-grazing herbage mass) and infrequent (5-6 week rest periods). Such a grazing regime was thought to favour the persistence of Matua prairie grass (Rumball, 1974; Ridler, 1986). During the following two years, the swards were grazed more intensely (approximately 1500 kg DM/ha post-grazing mass) but still maintaining 5-6 week defoliation intervals. The change in grazing strategy was intended to improve the harvesting efficiency of the dry matter grown while maintaining sward persistence (Matthews, 1986). Fertilizer was applied as described in Section 3.1. Herbage mass was estimated using an Ellinbank rising plate pasture meter (Holmes, 1974; Earle and McGowan, 1979).

Prior to the start of this study, however, the swards had thinned out considerably, with other plant species, mainly perennial ryegrass, having partially replaced Matua prairie grass.

4.2.2 Preparation of experimental plots

One of the two Matua paddocks at No. 4 Dairy Farm was selected for this experiment, and was grazed by lactating dairy cows to approximately 1500 kg DM/ha post-grazing herbage mass on 9 November 1986. Urea was applied at 32 kg N/ha the following day, and 0.43 ha of the paddock was fenced into 3 blocks with 3 subdivisions (experimental plots) per block, each measuring 12 m x 40 m (0.048 ha). The nine experimental plots were grazed again on 2 December 1986 to a common post-grazing herbage mass of approximately 1700 kg DM/ha. The experimental plots were irrigated for one month starting 4 December, 1987 following a very dry November. The three experimental grazing regimes and resultant sward types (treatments) were then randomly assigned to the plots within each block, and the resulting treatment combinations per block were assigned at random to the three blocks (replications). The periods of sward measurement are shown in Table 4.2.

4.2.3 Design and treatments

The experimental design was a split-plot in time with three replications in randomized complete block arrangement as described under Section 3.6.

The treatments (sward types), created and maintained by differential grazing management, and their respective target pre- and post- grazing herbage masses are shown in Table 4.1.

Table 4.1 Treatments and their nominal target pre- and post- grazing herbage masses.

Treatment (Sward type)	Target herbage mass (kg DM/ha) Pre-grazing (PHM)	Post-grazing (RHM)
Low mass (LM)	2000 - 3000	1,000 - 1,500
Intermediate mass (IM)	3000 - 4000	1,500 - 2,000
High mass (HM)	4000 - 6000	2,000 - 3,000

Target herbage masses and ranges shown represent herbage dry matter yields that would normally be encountered in New Zealand when Matua swards are subjected to intense-infrequent, intermediate, and lax-infrequent defoliation regimes for LM, IM and HM sward types, respectively (Rumball, 1974; Ridler, 1986; Brookes and Holmes, 1986). Corresponding defoliation intervals would be 4-5, 5-6 and 6+ weeks (Rumball, 1974; Cosgrove, 1986). Actual herbage masses achieved during this study are presented in Table 4.2 in Section 4.3.

The three sward types were defoliated and sampled at varying frequencies during each of the four seasons (defined in Section 3.3), i.e. summer, autumn, winter and spring.

Dates of defoliation (grazing) and sward sampling, and defoliation intervals (days) for each treatment during each measurement period (season) are outlined in Appendix 4.1.

4.2.4 Experimental grazing management

During each grazing period 20-30 cows were allowed access to the appropriate treatment plots at 0800 to 0900 hours. The three replications of each sward type were grazed simultaneously, and were sampled on the same day. The cows were removed from individual plots when target RHM (estimated by eye) had been reached, or when further grazing seemed unlikely.

Time spent by the cows on each plot varied from 2 to 5 hours depending on the pre-grazing herbage mass, season, the day's weather, state of satiety of the cows on entry into the plots, and on the need to minimize herbage trampling and sward damage.

Each treatment was grazed as soon as possible after average PHM, estimated using an Ellinbank rising plate pasture meter (after calibration), reached the target PHM.

4.2.5 Sward measurements

The following variables were either measured or derived, as discussed in Chapter 3, during each measurement (defoliation) period:

- pre- and post-grazing herbage mass (kg DM/ha)
- pre- and post-grazing sward surface height (cm)
- rate of net herbage production (kg DM/ha per day)
- botanical and morphological components of herbage before grazing (% of dry weight)
- concentrations of total nitrogen and ash in the herbage before grazing (% of dry weight)
- apparent digestibility of herbage on offer and prairie grass
- masses of nitrogen and digestible organic matter in the dry matter (g/m^2) at the time of sampling (measurement).

Herbage mass was estimated by cutting eight (pre-grazing) and six (post-grazing) quadrats ($0.1891m^2$) per experimental plot as outlined in Section 3.4.2. Three subsamples were taken from the bulked pre-grazing herbage from each plot for:

(i) dissection into herbage morphological components and determination of botanical composition.

(ii) chemical analysis and determination of apparent digestibility.

(iii) separation of prairie grass plants for chemical analysis and to determine apparent digestibility of prairie grass alone.

Masses of total N and digestible organic matter in the dry matter (DOMD) (g/m^2) were calculated as was explained in Section 3.4.8.

4.2.6 Statistical analysis

The data were subject to analyses of variance according to a split-plot in time design, with unequal observations, in a randomised complete block arrangement. Sward types constituted the main plots and seasons the sub plots (see also Section 3.6.2).

4.3 RESULTS

4.3.1 Grazing frequency

The dates during each of the four periods of measurement (summer, autumn, winter and spring) on which each of the three treatments (low mass, LM; intermediate mass, IM; high mass, HM) were grazed, and the intervals (in days) between grazing are presented in Appendix 4.1. During the ten months experimental period (January 1986 - November 1987), the LM treatment was grazed eight times, and six times for both the IM and HM treatments. Grazing intervals (mean ± standard deviation) were LM, 45 ± 11 days; IM, 60 ± 8 days; and HM 61 ± 13 days. These grazing intervals were generally longer during the mid autumn/winter period (range 47 - 81 days).

Average daily temperatures during the experimental period were similar to the 30 year averages (Appendix 5.1), although total rainfall was 22% lower than the 30 year average, particularly during the months of November and December, 1986, and May to August, 1987. Consequently, the experimental plots were irrigated for one month, following pre-experimental grazing on 2 December, 1986. Precipitation in November/December, 1986 was 28 *vs* 92 mm 30 year average.

4.3.2. Herbage mass, sward height and net herbage production (NHP)

Herbage mass

Pre-grazing (PHM) and post-grazing or residual (RHM) herbage masses for each sward type, averaged across periods, are presented in Table 4.2. The proposed grazing intensities for each sward type (Table 4.1) were generally not achieved. Actual average PHMs were higher than the proposed range by 1.4, 2.5 and 0.7 t DM/ha for LM, IM and HM sward types, respectively. Corresponding average values for RHMs were higher by 0.4, 0.6 and 0.5 t DM/ha. These differences between the proposed and actual herbage masses were evident only in the summer and spring periods (Appendix 4.2). Average PHMs were similar for the IM and HM treatments (mean 6.6 t DM/ha), but were smaller for the LM treatment (4.4 t DM/ha, $P < 0.01$). Average RHMs were slightly smaller for LM than IM (NS; $P > 0.05$; mean 2.3 t DM/ha), but were greater (mean 3.5 t DM/ha) for HM ($P < 0.01$) than those of the remaining sward types.

However, there were significant ($P < 0.01$) season x treatment effects for PHM and not for RHM, but for both variables the simple effects of season were highly significant ($P < 0.001$) (Appendix 4.2). Compared with the remaining sward types, PHMs from LM swards were smaller in the summer, autumn and spring, and were similar to those of IM in winter. Those of HM were greatest in summer, were slightly-greater ($P > 0.05$) than those of IM in autumn and winter but were smaller in spring. Generally, PHMs were highest in the spring; were slightly lower in summer, decreased substantially in autumn, and more steeply in winter. Post-grazing masses, averaged across sward types, differed significantly between periods (spring > summer > autumn > winter; means 4.1, 3.2, 2.2 and 1.3 t DM/ha respectively; Appendix 4.2).

Sward height

Pre-grazing (PSH) and post-grazing or residual (RSH) sward surface heights, averaged across periods, are also presented in Table 4.2. mean values for PSH were for HM, IM and LM, respectively, 32cm, 28cm and 24cm (HM > LM, $P < 0.05$; HM = IM; IM = LM), but treatment effects were not significant ($P = 0.07$). Corresponding values for RSH were 12cm, 9cm and 7cm (HM > IM > and LM, IM = LM; $P < 0.01$). Season x treatment interactions were significant for both variables ($P < 0.01$, Appendix 4.2). PSH was similar for the three sward types in summer and winter (average 34cm); that of HM was greater than that of LM in autumn but it was similar to that of IM during this period and during spring. LM and IM swards showed similar values for PSH in autumn, but LM swards were the shortest in spring. Post-grazing sward heights for the three treatments were similar during summer and winter. They tended to be greater for LM and HM swards than the IM swards in autumn; and were similar and greater in HM and IM swards than LM swards in spring. Averaged across treatments, PSHs were generally similar in autumn and winter, but increased steeply in spring, and remained high in summer (Appendix 4.2). RSHs were very high in spring, compared with other times when they were generally constant (Appendix 2).

Net herbage production

Rates of net herbage production (NHP), averaged across periods, are presented in Table

4.2. The rate of NHP was slightly smaller (NS) for HM swards compared wtih the remaining sward types, and the simple effect of sward type was not significant ($P > 0.05$) for this measurement (average 67 kg DM/day). Season had a significant effect ($P < 0.001$) on rate of NHP, but season x treatment interaction was not significant (Appendix 4.2). Rate of NHP was significantly ($P < 0.05$) greater in spring (average 112 kg DM/ha daily) than in summer (average 84 kg DM/ha daily), and these were significantly greater ($P < 0.001$) than those in autumn and winter (average 33 *vs* 22 kg DM/ha daily respectively; $P = 0.10$).

4.3.3 Pasture Composition

Botanical composition of herbage

Averaged across periods, there were no significant treatment differences ($P > 0.05$) in the percentages of prairie grass, red clover or other species (Table 4.2). However, the percentage of other species was slightly greater in HM swards compared with those of LM and IM swards ($P > 0.05$). Average concentrations of these components in the pre-grazing herbage were Matua prairie grass 38%, red clover 32% and other species 10%. The percentage of dead matter in the LM and IM swards was similar (average 19%), and was significantly smaller ($P < 0.05$) than that in HM swards (mean 22%).

Season x treatment interactions were not significant for % other species and % dead matter contained in the pre-grazing herbage, but were significant for % prairie grass ($P < 0.01$) and % red clover ($P < 0.05$) (Table 4.3). Percent Matua prairie grass was greater in IM swards during spring (63%) compared with the remaining treatments which contained similar percentages of Matua (average 43%). At other times, % Matua in the herbage did not differ significantly between the treatments ($P > 0.05$), although in summer it was slightly greater in LM and HM swards than in IM swards, and was slightly greater in LM and IM swards than in the HM swards in autumn. The IM swards contained approximately one fifth of the clover content measured in LM and HM swards in spring, whereas in winter the HM swards contained approximately half of the same component in LM and IM swards. These differences in % clover content in the herbage were significant ($P < 0.01$ in winter, $P < 0.05$ in spring). In summer and autumn % clover in the three sward types did not differ significantly.

The seasonal patterns of the botanical composition of the herbage before grazing are given in Table 4.5. The simple effects of season were highly significant ($P < 0.01$) for % prairie grass, % red clover and % other species, and were significant ($P < 0.05$) for % dead matter. However, only general seasonal trends will be presented for % prairie grass and % red clover in view of the interaction effects highlighted previously. Averaged across treatments, the percentage of Matua in the herbage was similar and was generally smaller in the summer and autumn (average 26 %), but showed a two fold increase in the winter and spring periods (average 51%). The opposite trend was observed for % red clover. Summer herbage generally contained more than 50% red clover, which decreased slightly in autumn, and to greater extent in winter and spring (range 8-56%) (see also Plate 4.1). Percent other species in summer did not differ significantly from that in autumn (average 3%), but it showed a four fold increase in winter (mean 11%) and a seven fold increase in spring (mean 21%). Percent dead matter in summer was similar to that in winter (average 16.7%); it increased to similar values in autumn and spring (average 23%).

Morphological composition of herbage

Morphological compositional details of the three sward types, averaged across the periods of measurement, are also presented in Table 4.2.

The low mass (LM) swards contained a larger proportion of green leaf than the intermediate mass (IM) or high mass (HM) swards ($P < 0.01$), while the IM and HM swards contained a similar but larger proportion of stem ($P < 0.01$). The proportions of seed head, clover leaf or clover stem contained in the herbage did not differ significantly between the three sward types ($P > 0.05$). The LM and IM swards contained a larger leaf:stem ratio than the HM swards although those of clover leaf and clover stem were slightly higher in LM and HM swards, respectively, than in the remaining sward types ($P < 0.05$). Mean values for grass leaf were LM 56%, IM and HM 45%; for green stem values were LM 26%, IM and HM 33%; and for seedhead, clover leaf and clover stem values were 4, 22 and 10%, respectively. Values for leaf:stem ratio were LM and HM 2.4, and 1.7 for HM swards.

Season x sward type interactions were significant for all the morphological components of herbage, except for clover leaf and leaf:stem ratio (Table 4.4).

The LM swards contained a greater proportion of green leaf than the IM or HM swards in spring and summer; values for LM, IM and HM swards did not differ significantly in autumn, but were slightly lower for HM swards. In winter the proportions of leaf in LM and IM swards were similar, and were greater than that of HM swards. The proportion of leaf in HM swards was slightly smaller (NS) than that of IM swards in summer, but it was greater in spring.

The proportions of green stem in the three sward types did not differ significantly in autumn or winter, although those in HM swards were generally the highest (NS). LM and IM swards contained similar proportions of green stem in summer, which were significantly smaller than that of HM swards ($P < 0.01$). During spring the proportion of stem was smallest in LM swards and greatest in IM swards, that of HM swards was intermediate; the differences between means were significant (Table 4.4).

Differences between the three sward types in the proportions of seedheads were apparent only in spring and summer; during other periods the proportion of seedheads in the swards was negligible. The HM swards contained a greater proportion of seedheads in summer than LM or IM swards, which contained similar values. In spring, the proportion of seedheads was significantly smaller in LM swards than IM or HM swards.

The LM and IM swards contained similar proportions of clover leaf in summer and winter, which were greater than those of HM swards. The proportions of clover leaf in the three sward types were similar in winter; LM and HM swards contained similar proportions of clover leaf in spring, which were greater than that of IM swards.

The effects of season on the morphological components of herbage are shown in Table 4.5 Of all the herbage components only clover stem and the leaf:stem ratio were affected by season independent of sward type (Table 4.4). Averaged across sward types, the proportion of clover stem was greater in summer compared with autumn; winter and spring values were similar, but it declined substantially during the later periods compared with the former periods. The leaf:stem ratio was greatest in autumn, it decreased significantly in winter, spring and summer. The smallest value for leaf:stem ratio was observed in spring, when it was less than half the values measured in the remaining periods.

In general, the proportion of total green leaf was highest in winter, intermediate in summer and autumn and lowest in spring; that of green stem was high in spring and summer, but the autumn and winter values were approximately one half those of the remaining periods. The proportion of clover leaf was high in summer and autumn, but decreased steeply in winter and spring.

4.3.4. Herbage quality

Effects of sward type on herbage quality

Mean values, averaged across periods, for the concentration of nitrogen and apparent digestibility (measured in vitro) of herbage before grazing, and of prairie grass whole plants are presented in Table 4.6. Nitrogen concentration (OM basis) in the total herbage was greatest in LM swards (2.8%), intermediate in IM swards (2.6%) and smallest in HM swards (2.3%) ($P < 0.001$). Percent N in prairie grass whole plants did not differ significantly between sward types (average 2.6%), but it was slightly higher in plants from the LM swards ($P > 0.05$). Actual differences in % N of the total herbage and of whole plants from the three sward types were small.

Apparent digestibility of organic matter (% OMD), averaged across periods, of the total herbage was highest in LM swards (69.3%), intermediate in IM swards (67.5%) and lowest in HM swards ($P < 0.01$). For whole prairie grass plants, % OMD was higher in LM (78%, $P < 0.01$) than IM or HM plants, which contained similar values for this measurement (average 72.4%). The LM and IM herbage contained greater concentrations ($P < 0.01$) of digestible organic matter in the dry matter (DOMD), and hence metabolisable energy (ME; calculated), than HM herbage (Table 4.6). Mean values in LM and HM herbage were DOMD 61% and ME 10 MJ/kg DM; values for HM herbage were 57% DOMD and 9.3 MJ ME/kg DM. Concentrations of DOMD and ME in prairie grass plants were greater ($P < 0.01$) in LM than IM or HM plants which contained similar values (Table 4.6). Mean values for the concentrations of DOMD and ME in prairie grass plants were, respectively, LM, 67% and 11 MJ/kg DM; IM and HM, 63% and 10.3 MJ/kg DM.

Interactions between season and sward type (Table 4.7) were not significant ($P > 0.05$) for % OMD and DOMD or ME in the total herbage, but they were significant for % N ($P < 0.001$). Percent nitrogen contained in the three sward types did not differ significantly in summer; LM and HM swards contained similar % N in autumn which was smaller than that in IM swards. During winter, % N was greater and in LM and similar in IM swards compared with HM swards, while LM swards contained a greater percentage of N in spring than IM and HM swards for which % N was similar.

For whole prairie grass plants, season x sward type effects were highly significant ($P < 0.01$) for all the components of herbage quality measured (Table 4.8). The LM and IM plants contained a similar concentration of N in summer, which was greater than that of the HM plants. Differences between the three sward types in the concentration of N in Matua plants were not significant during autumn and winter, while during spring % N in LM Matua plants was greater than that in IM and HM plants, which contained similar values. Percent OMD was slightly higher (NS) in LM than IM plants during summer and winter, but it was significantly higher than that of HM plants during the same periods. The LM and HM plants showed similar OMDs in autumn, but % OMD of IM plants was significantly lower; while in spring the OMD LM plants was higher than those of the remaining treatments, which were not significantly different. DOMD or ME concentrations were significantly greater in LM than

IM or HM plants during all periods of measurement, except during winter when values for these variables were not significantly different. The IM and HM plants contained similar concentrations of DOMD or ME in spring, but those of IM plants were smaller in autumn.

Effects of season on herbage quality

The season of measurement had a significant effect ($P < 0.01$) on the OMD and DOMD or ME of the herbage before grazing, irrespective of the grazing regime imposed (Tables 4.7 and 4.9). The OMD of the herbage was highest in autumn (73%); it showed a slight but significant decrease in summer (70%) and a sharp decrease in winter and spring (average 63%). The calculated ME of the pre-grazing herbage was higher in summer and in autumn (average 10.2 MJ/kg DM) than winter or spring (average 9.4 MJ/kg DM),

Percent N (OM basis) in the herbage and all components of herbage quality measured in Matua plants varied with season and sward type. In which case, only general seasonal trends for these will be outlined. In general, % N of the herbage increased substantially in autumn, and reached a peak in winter; N values were lower in spring and summer. Percent N in prairie grass plants showed a general trend similar to that of N in total herbage. The OMD of prairie grass plants was, in general, highest during the autumn and winter periods, intermediate during summer, and was lowest in spring. The concentrations of DOM and ME in Matua plants tended to remain constant during summer through winter, but decreased substantially in spring.

Mass of nutrients

The masses of N and DOM contained in the herbage at the time of grazing of each sward type are presented in Table 4.6. Averaged across the periods of measurement, the HM swards contained a greater N mass per square metre of dry herbage than that in LM swards; N mass in IM swards was not significantly different from that contained in either LM or HM swards. The overall effect of sward type on N mass was not significant ($P = 0.09$). DOM mass was smaller in LM than IM or HM swards, which contained similar DOM masses ($P < 0.01$).

Interaction effects of season and sward type on the masses of N and DOM in the herbage are shown in Appendix 4.3. Nitrogen mass did not differ between sward types in winter or spring, but it was slightly smaller in LM swards in winter, and slightly larger in spring compared with the remaining sward types. In the summer and autumn, N mass was smaller in LM swards than in IM swards (NS in summer; $P < 0.01$ in autumn), and was smaller than that in HM swards in both periods (P < 0.01).

4.4 DISCUSSION

4.4.1 Herbage mass and net herbage production

Actual pre-grazing and residual herbage masses (PHM and RHM) for each sward type, averaged across the periods of measurement, were higher (by 1-2.5t DM/ha) than was intended (Tables 4.1 and 4.2). However, the difference between the intended and actual herbage masses were evident only in the summer and spring (Appendix 4.2). The summer of 1986/87 was very dry, and attempts to reduce the moisture deficit by irrigating the swards in December 1986 encouraged the accumulation of red clover more than that of prairie grass (Table 4.3). Similarly, the autumn of 1987 was drier than average (Appendix 5.1) which also favoured the growth of red clover compared with that of prairie grass. Consequently, the proportion of red clover in the herbage from the three sward types (LM, IM and HM) was very high during these periods (mean 56% in summer, NS; and 47% in autumn, NS), even though it is usually highest during the summer/autumn period (Harris, 1978). Increasing the interval between successive defoliations in summer and autumn to allow for more prairie grass growth, also resulted in more clover accumulation.

Grazing intervals during spring were longer than planned, mainly because of resource (labour) constraints during this period. This, and the fact that the spring period was not split into early and late spring resulted in the large herbage masses reported for the three sward types during this period (Appendix 4.2). However, these shortcomings were rectified in the subsequent series of experiments.

Averaged over periods, there was no difference in actual PHM for IM and HM swards (mean 6.6t DM.ha); that of LM swards was significantly smaller (4.4t DM/ha). Average RHMs for LM and IM swards were similar (mean 2.3t DM/ha), and smaller than that of HM swards (3.5t DM/ha). The high PHMs measured may explain the similar rates of net herbage production among the three sward types. NHP is usually reduced by intense or frequent grazing (Brougham, 1959b; Pinneiro and Harris, 1978a). At high pregrazing herbage masses (within the range of practical interest) rates of net herbage production are generally insensitive to variations in grazing regime (Hodgson et al., 1981a; Bircham and Hodgson, 1983b). In the present study, the overall small proportion of prairie grass in the herbage may have made only a small contribution to the rates of NHP (Webby et al., 1990) such that sward type had no effect on this measurement. In swards with a higher proportion of prairie grass compared with that of the present experiment NHP tended to decrease in low mass swards relative to high mass swards (Xia, 1991, Appendix 5.16).

Rates of NHP for the three sward types were greater in summer and spring than in autumn and winter (Appendix 2.4). The high summer NHP rates were not surprising in view of the high proportion of red clover in the swards (Webby et al., 1990), and due to irrigation during December, which alleviated the soil moisture deficit normally experienced during this period. Over the year, growth rates of the herbage were greatest in the late spring; the stem component constituting the greatest proportion of the herbage particularly in the IM and HM sward types (Table 4.4). This is in accordance with previous reports which show high stem accumulation rates during the spring period (Korte et al., 1984; L'Huillier, 1987b Hoogendoorn et al., 1992).

4.4.2. Botanical and morphological composition of herbage

The proportions of prairie grass (average 38%), red clover (average 32%) and other species (average 10%) in the herbage were generally not affected by sward type, while season x sward type effects were evident only in spring and only for prairie grass and red clover (Tables 4.2 and 4.3). The lack of sward type effects on the botanical composition of the herbage were unexpected. Grazing regimes with cattle that result in low mass swards tend to increase the proportions of clover and perennial ryegrass in ryegrass/clover swards (L'Huillier and Bryant, 1987; L'Huillier, 1987b; Sheath and Boom, 1985) because of reduced shading and increases in tiller density. Similarly the proportion of clover has been reported to increase in Matua swards with increasing grazing pressure or frequency with sheep or cattle but Matua tiller densities and plant population decreased under such management (Pinneiro and Harris, 1978b, Alexander, 1985, Black and Chu, 1989, Thom et al., 1990). Conversely, lax infrequent grazing of Matua sward caused reductions in the clover component and increased tiller numbers -probably by reductions in tiller death and not by increased tillering (Alexander, 1985; Cosgrove, 1986, Black and Chu, 1989).

In the present study, the proportion of clover in LM or IM swards was greater than that in HM swards only during winter. The proportion of clover and Matua in IM swards were smaller than those in the other two sward types in spring (Table 4.3). At other times the swards contained similar proportions of clover and Matua prairie grass. The swards used in the present study were four years old, and already contained a low proportion of prairie grass and a high proportion of red clover (Table 4.3), which may have influenced the effects of the three grazing regimes. The clover content in New Zealand pastures ranges between 15-40% depending on grazing management, season and topography (Smetham, 1977; Hoglund et al., 1979). The prairie grass component in the three sward types showed a steady increase starting from a low in summer and reaching a peak in winter; it remained high in spring. This was most probably a result of less frequent and lesser intense grazing regime compared with the regime used prior to the experiment (Matthews, 1986; Black and Chu, 1989).

The LM and IM swards contained a smaller average proportion of dead matter, (18.6%) than the HM swards (22%); the proportion of green leaf was greater in LM (56%) than in IM or HM swards (average 46%) which contained greater but similar (33%) proportions of stem than the LM swards (26%) (Table 4.2). Differences between the three sward types in the proportions of leaf, stem and dead matter are similar to those reported in other studies (Michell and Fulkerson, 1987; L'Huillier, 1988; Stakelum and Dillon, 1991; Hoogendoorn et al., 1992). The proportions of clover leaf or stem in the three sward types were similar (average 22% and 10% respectively). Except for clover stem all components of the herbage in each sward type varied with season (Table 4.4). This highlights the dangers of instituting a set grazing regime across seasons as the results in terms of feeding value of the herbage may differ from season to season.

The differences between sward types in the proportions of leaf or stem were greater in the summer and spring periods than at other times (Tables 4.3 and 4.4), and as was reported by previous workers (Santamaria and McGowan, 1982; Michell and Fulkerson, 1987; L'Huillier, 1987c; Holmes et al., 1982). Contrary to previous reports (ibid) the LM and IM swards in the present study contained a greater proportion of leaf and a smaller proportion of dead matter in winter compared with the HM swards. This was probably caused by the larger difference in herbage mass between the low and high mass swards of the present experiment compared with the perennial ryegrass swards used in previous studies. Furthermore, the similarity among the three sward types in the proportion of dead matter in the summer and spring periods, which was contrary to previous reports (Michell and Fulkerson, 1987; L'Huillier, 1987c; Stakelum and Dillon, 1991; Holmes et al., 1992), may have been caused by a more intense pre-experimental grazing regime (see Section 4.2.1), and by the very high spring herbage masses.

4.4.3 Herbage quality

The differences in the average component composition of the three sward types (cut to ground level) were reflected in the lower apparent OMD and N concentration of herbage from the HM swards (Table 4.6). OMD of the HM swards was lower by 2% units *vs* IM swards, and by 4% units *vs* LM swards. Nitrogen concentration in HM swards was lower by 0.3% units *vs* IM and by 0.5% units *vs* LM swards. Similar differences in OMD and N have been reported by Michell and Fulkerson (1987), Stakelum and Dillon (1991), Holmes et al., (1992) and Hoogendoorn et al., (1992).

On the other hand, differences in the component composition of the three sward types were generally not reflected in the OMD and N concentration (in OM) of whole Matua prairie grass plants. Plants from the LM, IM or HM swards contained similar concentrations of N (average 2.6%). OMD was higher in LM plants (78%) than in IM and HM plants, which had similar OMDs (average 72%). The average concentrations of N in the Matua plants were low (average 2.6%), probably reflecting (i) the high proportion of stem relative to leaf in the plant; and (ii) the increasing maturity of these with increasing herbage mass (Hacker and Minson, 1981; Hoogendoorn et al., 1988). OMD of LM Matua plants was higher than those of IM and HM plants by 6% units. This suggests that the lower OMD of the total herbage from the IM and HM swards compared with that of LM swards was probably caused by the higher proportion of stem of increasing maturity relative to leaf, and the higher proportion of dead matter at the base of the sward and on the plant (Ulyatt, 1981; Hacker and Minson, 1981).

The differences in the OMD or estimated ME values between the total pasture and those of Matua whole plants were large (Table 4.6). The differences in OMD between Matua plants from LM, IM and HM treatments, respectively, and that of corresponding total pasture were 9, 5 and 7% units. This suggests that the proportion of dead matter in the total herbage, or that of red clover stem may have had a more adverse effect on the OMD of the total herbage than the proportion of stem per se in the Matua plant (Thomson et al., 1984; Hume, 1990b, 1991d). This suggestion was tested by correlation analysis using data from subsequent experiments, and the results will be discussed in Chapter 7.

Other workers have reported digestibilities of Matua plants that are similar to those of intensively grazed perennial ryegrass (Crush et al., 1989; Pawlus et al., 1988), or annual ryegrasses (Wilson and Grace, 1978, Hume 1990b, 1991d) despite the greater proportion of stem and cell wall polysaccharides in the Matua plants compared with the ryegrasses. The general conclusion was that the nutritive value of Matua prairie grass decreased more slowly with increasing maturity, following defoliation, compared with other common perennial pasture species.

No data could be found in the literature that compares the composition and digestibility of prairie grass pastures managed to create compositional differences, or data that make comparisons with other perennial pasture species in a pastoral production system. Nevertheless, the concentrations of N and DOMD, and OMDs of the herbage measured in the present trial were low, probably because of the age of the swards, and the associated changes in their botanical composition (low Matua, high red clover and other species content of increasing maturity), and high herbage masses. However, the compositional differences of the herbage were consistent with work published previously using pasture species other than prairie grass (e.g. Stakelum and Dillon, 1991; Holmes et al., 1992; Hoogendoorn et al., 1992).

However, the seasonal trends in the concentrations of N and OMD of the herbage, but not of whole plants, were generally not consistent with those reported by Bryant and Trigg (1982) and Crush et al., (1989); but the OMD and DOMD or ME concentrations of the herbage showed large seasonal differences irrespective of sward type (Tables 4.8 and 4.9). Percent N of the herbage was high in autumn and winter, decreased in summer and decreased more steeply in spring. The steep spring decrease in % N was unusual, and was a result of higher than usual spring herbage masses. OMD of herbage, which normally peaks in winter and remains high in spring (Bryant and Trigg, 1982; Holmes, 1987b) was lowest during these periods in the present study, probably because of (i) high winter soil moisture which increases the rate of death of leaf tissue in prairie grass plants grazed infrequently (Rumball, 1974; Mwebaze, 1986; Eccles et al., 1990), (ii) the high proportion of dead matter evident in IM and HM swards probably carried over from autumn (Table 4.3) and (iii) the high herbage masses in spring.

4.4.3 Conclusions

The Matua prairie grass pasture used for the present study contained, at the start of the present study, a low concentration of prairie grass and a high concentration of red clover, probably because of changes in botanical composition associated with sward age, and intense grazing prior to the experiment. Herbage masses during summer and spring were higher than was intended. The following conclusions can be made:

1. Sward treatment (low, intermediate or high mass) had no effect on rates of net herbage production. This may have been a result of the relatively high pre-grazing herbage masses in all treatments.

2. There were no treatment differences in the concentrations of prairie grass, red clover

or other species in the herbage; there were within and between sward type seasonal effects on concentrations of prairie grass and red clover.

3. There was a general progressive increase with time in the proportions of prairie grass and other species; and a progressive decrease in the proportions of red clover in the herbage, probably because of a lower intensity of experimental grazing compared with the previous managements.

4. The low mass swards contained greater concentrations of green leaf, and smaller concentrations of dead matter and stem than the intermediate or high mass swards, which contained similar proportions of these components.

5. Differences in the component composition of the herbage were generally evident in summer and spring.

6. Total nitrogen and apparent digestibility of organic matter in the herbage was greater in the low mass than the intermediate or high mass swards; the concentration of N in whole Matua plants from the three sward types was similar, while OMD was greater in low mass than the intermediate or high mass plants.

7. There were large differences between the OMD of the total herbage and that of Matua whole plants (OMD was higher in the Matua plants), suggesting that the proportion of dead matter in the swards, and probably or to a smaller extent, that of stem in the total herbage had the dominant influence on herbage quality. Seasonal trends in herbage quality, except spring, were generally similar to those reported in the literature.

8. The influence of red clover on the component composition and nutritive value of the herbage was not clear, probably because of the high initial concentrations of this component in the herbage, and because the digestibility of red clover was not measured. The role of red clover grown in association with Matua prairie grass requires further investigation. However, it appears that the long intervals between defoliations (> 4 weeks) required for prairie grass swards may lead to high accumulations of red clover stem in summer and autumn which may be carried over into winter, thus reducing the nutritive value of Matua prairie grass based pastures at this time. This suggestion may be of consequence on town-supply dairy farms or sheep farms where 'autumn pasture clean up' is not feasible.

Table 4.2 Mean values for pre- and post-grazing herbage mass (t DM/ha), net herbage production (kg DM/ha/day), sward surface height (cm), and herbage composition (% of DM) of the three treatments, averaged across the four periods of measurement (Experiment 1).

	Sward type				
	LM	IM	HM	S.E.M.	Sign.
Herbage mass (t DM/ha)					
Pre-grazing	4.4^{b}	6.5^{a}	6.7^{a}	0.26	**
Post-grazing	1.9^{b}	2.6^{b}	3.5^{a}	0.20	**
NHP[1] (kg DM/ha/day)	65.5	64.3	58.3	4.24	NS
Sward height (cm)					
Pre-grazing	24.3^{b}	28.2^{ab}	32.0^{a}	1.65	NS
Post-grazing	7.0^{b}	9.1^{b}	12.1^{a}	0.63	**
Botanical composition (% DM)					
Prairie grass	38.8	40.9	35.2	5.30	NS
Red clover	33.5	31.4	31.0	3.91	NS
Other species	9.4	7.2	12.0	1.84	NS
Dead matter	18.3^{b}	18.9^{b}	22.2^{a}	0.64	*
Morphological composition (% DM)					
Green leaf[2]	56.2^{a}	47.0^{b}	43.8^{b}	1.11	**
Green stem[2]	25.5^{b}	32.4^{a}	34.3^{a}	1.03	**
Seedhead (grass)	2.3	5.3	4.4	0.85	NS
Clover leaf	25.2	21.6	19.4	2.58	NS
Clover stem[3]	8.3	9.8	11.6	1.43	NS
Leaf:stem ratio	2.5^{a}	2.2^{a}	1.7^{b}	0.13	*

[1] NHP = Net herbage production

[2] In the total herbage

[3] Includes seedhead

[a,b] Means within a row bearing unlike superscripts differ significantly ($P < 0.05$)

Table 4.3 Effects of season and treatment (sward type) on the botanical composition (% of dry matter) of herbage (Experiment 1).

		Herbage component			
Season/ Treatment		Prairie grass (% DM)	Red clover (% DM)	Others (% DM)	Dead matter (% DM)
Summer	LM	26.5	55.0	2.9	15.7
	IM	17.3	58.4	1.1	16.5
	HM	25.3	55.6	2.2	18.6
Autumn	LM	30.1	43.0	3.9	22.6
	IM	32.1	40.7	4.1	23.2
	HM	23.4	47.3	4.0	25.0
Winter	LM	53.6	25.5^{a}	11.5	9.4^{b}
	IM	50.7	24.4^{a}	8.6	16.3^{ab}
	HM	52.5	10.3^{b}	13.9	23.4^{a}
Spring	LM	45.0^{b}	10.5^{a}	19.3^{ab}	25.4
	IM	63.4^{a}	2.1^{b}	14.8^{b}	19.7
	HM	39.7^{b}	10.7^{a}	27.8^{a}	21.8
S.E.M.		3.27	2.85	3.18	2.47
Effects					
Block		*	**	NS	NS
Season		**	***	***	*
Treatment		NS	NS	NS	*
Season x treatment		**	*	NS	NS

a,b Means within a season bearing unlike superscripts differ significantly ($P < 0.05$)

Table 4.4 Effects of season and treatment (sward type) on the morphological composition (% of dry matter) of herbage (Experiment 1).

		Herbage component					
Season/ Treatment		Green leaf[1] (% DM)	Green stem[1] (% DM)	Seed-head[2] (%DM)	Clover leaf (%DM)	Clover stem (% DM)	Leaf: stem ratio
Summer	LM	55.4^{a}	29.0^{b}	2.0^{b}	36.2^{a}	18.8^{b}	1.9^{a}
	IM	46.3^{b}	30.6^{b}	1.1^{b}	33.2^{a}	25.2^{a}	1.6^{ab}
	HM	40.5^{b}	42.6^{a}	6.7^{a}	26.6^{b}	39.0^{a}	1.0^{b}
Autumn	LM	60.2	16.8	0.4	35.1	7.9	3.7^{a}
	IM	60.1	16.8	Nil	31.9	8.7	3.7^{a}
	HM	55.8	18.9	0.2	36.3	11.0	3.0^{b}
Winter	LM	69.2^{a}	21.4	Nil	21.1^{a}	4.4	3.4^{a}
	IM	63.7^{a}	20.0	Nil	19.2^{a}	5.2	3.2^{a}
	HM	53.0^{b}	23.7	Nil	7.7^{b}	2.6	2.3^{b}
Spring	LM	39.9^{a}	34.9^{c}	6.6^{c}	8.5^{a}	2.0	1.2^{a}
	IM	18.0^{c}	62.3^{a}	20.0^{a}	2.0^{b}	0.1	0.3^{b}
	HM	26.1^{b}	52.1^{b}	10.9^{b}	7.0^{a}	3.6	0.5^{b}
S.E.M.		2.88	2.67	1.28	1.83	2.16	0.22
Effects							
Block		NS	NS	NS	***	NS	**
Season		***	***	***	***	***	**
Treatment		**	**	NS	NS	NS	*
Season x Treatment		*	***	***	**	NS	NS

[1] In total herbage

[2] Excludes clover seedhead

a,b,c Means within a season bearing unlike superscripts differ significant ($P < 0.05$)

Table 4.5 Effects of season on the botanical and morphological composition (% of DM) of herbage, averaged across the three treatments (Experiment 1).

	Season					
Herbage component	Summer	Autumn	Winter	Spring	S.E.M.	Sign.
Botanical composition (% DM)						
Prairie grass	23.0^b	28.5^b	52.3^a	49.3^a	2.89	**
Red clover	56.3^a	43.7^b	20.1^c	7.8^d	2.34	***
Other species	2.1^c	4.0^c	11.3^b	20.6^a	0.76	***
Dead matter	16.9^b	23.6^a	16.4^b	22.3^a	1.54	*
Morphological composition (% DM)						
Green leaf (total)	49.4^b	58.7^a	62.0^a	28.0^c	1.24	***
Green stem (total)[1]	34.0^b	17.5^d	21.7^c	49.7^a	1.05	***
Seedhead (grass)	3.3^b	0.2^c	0.0^c	12.5^a	0.51	***
Clover leaf	32.0^a	34.4^a	16.0^b	5.8^c	1.62	***
Clover stem[2]	24.3^a	9.2^b	4.1^c	1.9^c	1.35	***
Leaf:stem ratio	1.5^c	3.5^a	2.9^b	0.7^d	0.15	**

^{a,b,c,d} Means within a row bearing unlike superscripts differ significantly ($P < 0.05$)

[1] Includes grass seedhead

[2] Includes clover seedhead

Table 4.6 Mean values (%) for total nitrogen, ash, digestibility *in vitro*, and masses of nitrogen (in DM) and digestible organic matter of herbage (g/m^2) from the three treatments, averaged across the four periods of measurement (Experiment 1).

	Treatment				
	LM	IM	HM	S.E.M.	Sign.
Chemical composition					
Total herbage					
Nitrogen (% OM)	2.8^a	2.6^b	2.3^c	0.03	***
Ash (% DM)	12.5^a	8.8^b	11.7^a	0.54	**
Prairie grass					
Nitrogen (% OM)	2.8	2.5	2.5	0.08	NS
Ash (% DM)	13.8	12.4	13.1	0.47	NS
Digestibility (%)					
Total herbage					
Organic matter	69.3^a	67.5^b	65.2^c	0.25	***
Digestible organic matter (DOMD)	60.9^a	61.2^a	56.9^b	0.31	***
ME (MJ/kg DM)	9.9^a	10.0^a	9.3^b	0.05	***
Prairie grass					
Organic matter	78.2^a	72.8^b	71.9^b	0.56	**
Digestible organic matter (DOMD)	67.4^a	63.4^b	62.9^b	0.49	**
ME (MJ/kg DM)	11.0^a	10.3^b	10.2^b	0.08	**
Mass of components (g/m^2)[1]					
Total nitrogen	13.0^b	15.5^{ab}	15.8^a	0.72	NS
Digestible organic matter	273^b	392^a	382^a	15.4	**

[a,b,c] Means within a row bearing unlike superscripts differ significantly ($P < 0.05$)

[1] Mass at any one sampling time.

Table 4.7 Effects of season and treatment (sward type) on the concentration of nitrogen (% OM) and digestibility *in vitro* of pasture herbage (Experiment 1).

Season/ Treatment		Herbage composition and digestibility			
		Nitrogen (% OM)	OMD (%)	DOMD (%)	ME (MJ/kg DM)
Summer	LM	2.3	72.9^{a}	65.2^{a}	10.6^{a}
	IM	2.3	70.9^{a}	63.9^{a}	10.4^{a}
	HM	2.3	66.4^{b}	59.8^{b}	9.7^{b}
Autumn	LM	2.7^{b}	73.8	60.4^{b}	9.8^{b}
	IM	3.2^{a}	73.2	65.0^{a}	10.6^{a}
	HM	2.5^{b}	72.1	58.5^{b}	9.5^{b}
Winter	LM	4.0^{a}	64.4^{a}	58.9^{a}	9.6^{a}
	IM	3.7^{a}	63.6^{a}	58.4^{a}	9.5^{a}
	HM	3.2^{b}	57.7^{b}	53.3^{b}	8.7^{b}
Spring	LM	2.3^{a}	66.2^{a}	59.1	9.6
	IM	1.4^{b}	62.5^{b}	57.8	9.4
	HM	1.4^{b}	60.6^{b}	56.1	9.2
S.E.M.		0.12	0.95	1.06	0.17
Effects					
Block		NS	NS	NS	NS
Season		***	***	**	**
Treatment		***	***	***	***
Season x Treatment		***	NS	NS	NS

^{a,b,c} Means within a season bearing unlike superscripts differ significantly ($P < 0.05$)

Table 4.8 Effects of season and treatment (sward type) on the concentration of nitrogen (% OM) and digestibility *in vitro* of Matua prairie grass plants (Experiment 1).

		Herbage composition and digestibility			
Season/ Treatment		Nitrogen (% OM)	OMD (%)	DOMD (%)	ME (MJ/kg DM)
Summer	LM	2.3^{a}	79.1^{a}	69.1^{a}	11.3^{a}
	IM	2.3^{a}	75.9^{a}	65.4^{b}	10.7^{b}
	HM	1.8^{b}	68.9^{b}	61.2^{c}	10.0^{c}
Autumn	LM	2.9	84.4^{a}	71.4^{a}	11.7^{a}
	IM	3.0	74.9^{b}	65.9^{c}	10.8^{c}
	HM	3.4	84.0^{a}	68.7^{b}	11.2^{b}
Winter	LM	3.7	82.6^{a}	68.9	11.1
	IM	3.7	81.2^{a}	67.3	11.0
	HM	3.5	77.5^{b}	68.8	11.2
Spring	LM	2.2^{a}	66.7^{a}	60.3^{a}	9.8^{a}
	IM	1.3^{b}	59.4^{b}	54.8^{b}	8.9^{b}
	HM	1.4^{b}	57.1^{b}	52.8^{b}	8.6^{b}
S.E.M.		0.14	1.29	0.92	0.15
Effects					
Block		NS	*	**	**
Season		***	***	***	***
Treatment		NS	**	**	**
Season x Treatment		**	***	**	**

^{a,b,c} Means within a season bearing unlike superscripts differ significantly ($P < 0.05$)

Table 4.9 Effects of season on the concentration of nitrogen (% OM) and digestibility *in vitro* of pasture herbage and Matua prairie grass plants, averaged across the three treatments (Experiment 1).

	Season					
Herbage component	Summer	Autumn	Winter	Spring	S.E.M.	Sign.
Total herbage						
Nitrogen (% OM)	2.3^c	2.8^b	3.6^a	1.7^d	0.11	***
Digestibility of organic matter (% OMD)	70.0^b	73.0^a	61.9^c	63.2^c	0.62	***
DOMD (%)	63.0^a	61.3^a	56.8^b	57.7^b	0.93	**
ME (MJ/kgDM)	10.3^a	10.0^a	9.3^b	9.4^b	0.15	**
Prairie grass plants						
Nitrogen (% OM)	2.1^c	3.1^b	3.6^a	1.6^d	0.07	***
Digestibility of organic matter (% OMD)	74.6^b	81.1^a	80.4^a	61.1^c	0.98	***
DOMD (%)	65.3^a	68.7^a	68.3^a	56.0^b	1.19	***
ME (MJ/kgDM)	11.6^a	11.2^a	11.1^a	9.1^b	0.19	***

^{a,b,c,d} Means within a row bearing unlike superscripts differ significantly ($P < 0.05$)

Plate 4 1 Red clover dominance in the summer (January) of a high mass Matua prairie grass/red clover sward irrigated during the previous December Prairie grass seedhead can be seen above the sward canopy

CHAPTER 5

EFFECTS OF GRAZING REGIME AND SEASON ON THE COMPOSITION OF PRAIRIE GRASS AND RYEGRASS SWARDS GROWN WITH WHITE CLOVER (EXPERIMENT 2)

5.1 INTRODUCTION

Herbage from grazed pasture contains many different constituents which can vary widely in composition and digestibility (Terry and Tilley, 1964; Hacker and Minson, 1981). Grazing management and season can influence the proportions of the various components of the sward and their nutritive value (Bryant and Trigg, 1982; Santamaria and McGowan, 1982; L'Huillier, 1987b; Holmes et al., 1992), and these would be expected therefore also to influence the feeding value of the herbage (Ulyatt, 1981; Michell and Fulkerson, 1987; Stakelum and Dillon, 1991). The majority of studies on the influence of grazing regime and of season on the composition and feeding value for milk production of temperate pasture herbage have focused on ryegrass/clover swards (Thomson et al., 1984, 1989; Bryant and L'Huiller, 1986; L'Huillier, 1987b, c; Hoogendoorn et al., 1985, 1987, 1988; Michell and Fulkerson, 1987; Stakelum and Dillon, 1991). There is a paucity of information on the influence of grazing regime on the composition of pasture herbage dominated by the newer grass cultivars such as Matua prairie grass (*Bromus willdenowii* Kunth), which in New Zealand is the main non-ryegrass species that has generated considerable interest amongst dairy farmers (Lancashire, 1985a, b; Thom and Prestidge, 1988; Belgrave et al., 1990).

Prairie grass cv. Grasslands Matua is a forage grass valued for its high nutritive value and high summer production (Rumball, 1974; Wilson and Grace, 1978; Fraser, 1985), and also in New Zealand, for high autumn/winter production (Baars and Cranston, 1978; Rys et al., 1978; Burgess et al., 1986; Hume and Lucas, 1987). Prairie grass, however, has a low tillering capacity, which is accentuated by intense/frequent grazing, and when it is grown in poorly drained soils (Rumball, 1974; Hill and Pearson, 1985; Mwebaze, 1986; Black and Chu, 1989). The species is also susceptible to insect and disease damage, which has contributed to the prevailing doubt on the perenniality and persistence of Matua prairie grass (Falloon and Hume, 1988; Falloon and Rolston, 1990; Thom et al., 1989, 1990; Boom and Sheath, 1990). Furthermore, the originally suggested lax and/or infrequent grazing regimes for the species (4 to 6 weeks grazing interval) (Rumball, 1974), and extended reproductive growth (mid spring to autumn), have raised questions on the feeding value of prairie grass swards, and the harvesting efficiency of the extra dry matter produced (Brookes and Holmes, 1986; Cosgrove and Brougham, 1988; Hume, 1991d). However, experimental evidence on the influence of grazing regime upon the composition and nutritive value of the herbage or herbage components of Matua prairie grass dominant pasture is lacking, both in dairy production situations, and in comparison to conventional perennial ryegrass swards (Sellars, 1988; Thom and Prestidge, 1988; Crush et al., 1989).

The objectives of the current study were to measure, under a dairy production system and over a range of seasons, the aspects of pasture characteristics and composition which have important effects on the feeding value of the herbage off Matua prairie grass/white clover swards, maintained at low or high pregrazing herbage mass, and to compare them with those of 'conventional' perennial ryegrass/white clover pastures.

5.2 EXPERIMENTAL PROCEDURE

5.2.1 Scope of the experiment

The composition of herbage from perennial ryegrass (RG), low mass Matua (LM) and high mass Matua (HM) swards was measured during eight short-term (approximately 14 days) grazing trials, over two lactations (1987/88 and 1988/89) during early spring, late spring, summer and autumn, as defined in Section 3.3. The three sward types contained white clover, and their preparation is described in Section 5.2.2. The present chapter describes the sward characteristics and herbage composition, while the details of animal production are reported in Chapter 6.

5.2.2 Experimental swards

5.2.2.1 Establishment of Matua pastures

In mid October 1986 four perennial ryegrass-white clover paddocks of approximately 0.8 ha each, in close proximity to each other, were grazed intensely (approximately 1000 kg DM/ha post-grazing herbage mass) by lactating cows. The swards were grazed laxly after two weeks of regrowth, and were immediately sprayed with glyphosate (Roundup herbicide at 2 litres/ha). Deawned (McCaw, 1986) and head smut treated prairie grass cv. Grasslands Matua seed and white clover cv. Grasslands Pitau were cross-drilled at seed rates of 40 and 5 kg/ha, respectively, using Massey University's Bioblade Direct Drill. Mesurol was broadcast at 10 kg/ha following drilling to control slugs. Sward germination, approximately 10 days after drilling, was excellent.

5.2.2.2 Management of Matua swards post-establishment

The newly established Matua swards were grazed laxly for the first time by heifer calves during the first week of January 1987, at an average sward height of 17 cm. The swards were grazed by lactating cows two weeks later, and at intervals of 5 to 6 weeks thereafter, to 2000-2500 Kg DM/ha post-grazing herbage mass (estimated with a rising plate pasture meter). Differential grazing management of Matua swards was commenced in early September 1987 to create two sward types of different pre-grazing herbage mass in preparation for the first grazing trial in mid October 1987. Urea was applied at 25 kg N/ha in late August 1987 and at similar rates thereafter during autumn and early spring. Phosphatic fertilizer was applied to all paddocks on the farm as outlined in Section 3.1.

5.2.2.3 Pre-experimental preparation of Matua swards

In late August 1987, each of the four Matua paddocks was fenced into two sub-paddocks in order to create low and high mass Matua sward types by differential defoliation; the low mass sward type occupied approximately 56% of the total paddock area. The low and high mass Matua treatments were assigned to the sub-paddocks at random within a paddock prior to subdivision.

Low and high mass Matua swards were initiated during the first week of September 1987 by grazing the sub-paddocks with lactating cows to target residual herbage mass (as defined in Section 5.2.3.1) for each sward type. The first grazing trial started five weeks later (Table 5.2). The low and high mass Matua sub-paddocks within each of the four Matua paddocks were grazed on the same day. Where necessary, the low mass swards were regrazed, or regrazed and mechanically topped to a mean sward height of 5 cm (approximately 1500 kg DM/ha residual herbage mass), after the experimental cows had grazed them at a generous allowance. As much of the topped stubble as possible was removed from the swards immediately after topping.

Regrazing, with or without mechanical topping, was done within 24 hours following initial grazing by the experimental cows or by the entire herd between trials. High mass Matua swards were never regrazed or topped during the two year experimental period; and it was considered necessary to top the low mass swards only on three occasions, during the differential grazing period in mid September, and in early December (1987) and mid March (1988). The ryegrass swards were topped only once in early summer 1987.

5.2.2.4 Perennial ryegrass swards

Eight perennial ryegrass-white clover paddocks (approximately 0.8 ha each), located adjacent to the Matua prairie grass paddocks (Section 5.2.2.1.), were used in various parts of this study. In half the trials, however, only three of these ryegrass paddocks were required, as all experimental paddocks were sequentially grazed, with the quantity of available Matua herbage determining the duration of each trial.

The perennial ryegrass pastures were 13-15 years old, and were generally grazed at intervals of 15-21 days except during winter when the intervals were 60-90 days. Pre-grazing herbage mass rarely exceeded 3500 kg DM/ha, unless paddocks had been closed for conservation in late spring; average post-grazing mass was 1200 kg DM/ha but falling to 700 kg DM/ha in late autumn and winter when grazed by non lactating cows on a restricted level of feeding.

5.2.3 Experimental period

5.2.3.1 Design and treatments

The experimental design was a split-plot in time with sward types as main plots and seasons as sub-plots. The design was balanced during four of the grazing trials, with each of the three sward types (treatments) having four replications (paddocks). During the other four trials, Matua sward types were replicated four times but the ryegrass sward type had three replications, resulting in an unbalanced design. Individual paddocks constituted the experimental units and replicates.

The three treatments (swards types) with their respective target pre- and post-grazing herbage masses are outlined in Table 5.1. The target herbage masses indicated for each sward type were considered typical of perennial ryegrass (Holmes and Wilson, 1984) and Matua swards (Brookes and Holmes, 1986; Matthews, 1986; Ridler, 1985, 1986) grazed by generously fed cows in the Manawatu region of New Zealand. The specific dates and duration of each grazing trial are shown in Table 5.2 (results section).

5.2.3.2 Grazing management

During each of the eight measurement periods the three sward types (prepared as described above) were grazed by three groups of lactating cows (8 per treatment). Two weeks before each grazing trial, twenty-four spring (August/September) calving cows, in their second or subsequent lactation and of predominantly high breeding index (approximately 125), were selected. The majority of the experimental cows were Friesian with occasional Friesian x Jersey crosses. The cows selected for each grazing trial continued to graze with the milking herd during the two weeks pre-experimental period on predominantly ryegrass-white clover pasture at a generous herbage allowance (1200-1400 kg DM/ha RHM). During this period, the yields of milk and milk solids were measured for covariance analysis on two days each week. Further details on animal measurements are presented in Chapter 6. The experimental cows were allocated at random to the three treatments. The selection of cows and their allocation at random to the treatment groups were carried out anew for each of the eight measurement periods.

Cows on all three treatments were given a common herbage allowance of approximately 50 kg DM/cow per day in daily breaks during the experimental periods, using movable electric fences. The replicate paddocks of each sward type were grazed in sequence. Low and high mass Matua swards were allowed similar regrowth periods between successive grazings of approximately 35 days. Grazing intervals were approximately 25 days for ryegrass swards during the measurement seasons. In the periods between grazing trials, the Matua swards were grazed to the experimental target RHM by the milking herd (dry herd during late autumn through winter) at average intervals of 35 days, and at intervals of 50-60 days during winter. Corresponding grazing intervals for ryegrass swards were 15-25 days and 60-90 days during winter. Care was taken to minimise pugging on all swards during very wet days in winter by restricting grazing time or by feeding silage on a concrete pad, and then confining the cows in a 'loafing' paddock for the rest of the day.

5.2.4 Sward measurements

Unless indicated otherwise, the techniques and equipment used to make the measurements described below during each grazing trial are as previously detailed in Section 3.4.

5.2.4.1 Herbage mass and sward height

Pre- and post-grazing herbage mass (kg DM/ha) was assessed by cutting herbage within a 0.247 m^2 quadrat to ground level. Eight such quadrats were placed at equal intervals along a diagonal transect within the area grazed over a period of two days.

Snip samples of pre- and post-grazing herbage adjacent to each quadrat were cut to ground level, bulked, sub-sampled and washed, for dissection into morphological and botanical components of herbage as described in Section 3.4.4, and for assessment of herbage quality as outlined under Section 3.4.7.

Sward surface heights (cm) before and after grazing, were assessed, at two-day intervals, by taking readings with a ruler at 40 evenly spaced points along a diagonal transect. Sward bulk density was derived as defined in Section 3.4.3.

5.2.4.2 Tiller population density

Tiller population density was measured by the author only during the last grazing trial (Autumn, 1989), and only in Matua swards due to time constraints. Herbage within ten 0.18m^2 quadrats, placed at even intervals along a diagonal transect in a paddock, was cut to ground level and the number of tillers present was counted in a laboratory (Jewiss, 1981). Tiller density (tillers / m^2) was then calculated. However, during a concurrent experiment on the same Matua swards (Xia, 1991), tiller and plant population densities were determined using permanent quadrats from early spring through summer of 1988/1989. Individual tiller weights for each of the Matua sward types were determined from the total dry weight of counted tillers per replication divided by the number of tillers.

5.2.4.3 Vertical distribution of sward components

Vertical distribution of sward components before grazing was measured at two positions per paddock during each measurement period. An area of the sward (7.5 cm x 15 cm), where herbage surface height was similar to the mean sward height of two days' breaks, was cut to ground level with one sweep of the hand using a sheep shearing handpiece. Each herbage sample was gathered carefully and secured firmly with rubber bands placed at several points along the vertical plane. Once in the laboratory, the two samples from each paddock were pooled, laid on a table, and cut into four strata using an electric knife, as follows:

Stratum	Height (cm)
1	0-6
2	6-18
3	18-30
4	>30

Herbage from each stratum was dissected into green leaf, stem and senescent matter. Herbage from strata one and two was washed immediately after dissection to reduce soil contamination. The separated herbage components were freeze dried and weighed. The proportion of each component in each stratum was calculated based on the dry weight of herbage from the stratum. The herbage components in each stratum were then pooled within treatments, ground and analysed for total N, ash and digestibility.

The height ranges of the first two strata were selected in anticipation of post-grazing sward heights of the three sward types under a lax defoliation regime; heights for strata 3 and 4 were a reflection of the potential height of prairie grass during different seasons.

5.2.4.4 Nutritive value of herbage

Pre-grazing herbage was sampled for determination of herbage composition (nutrient concentrations and digestibility) as was explained in Section 5.2.4.1; protocols for sample processing and chemical analyses were as described in Section 3.4. Total herbage on offer, and whole plants of perennial ryegrass or Matua prairie grass from each of the three sward types (RG, LM and HM), were analysed for total N, NDF, ADF, lignin, gross energy, ash and digestibility of dry matter (DMD)and organic matter (OMD). Green leaf, green stem and inflorescence from ryegrass and Matua plants, and senescent matter from each of the three sward types, were analysed for total N, ash, DMD and OMD. The concentration of ME (M/D) in the total herbage and herbage components was estimated from their respective DOMD (D) values (Section 3.4.7.6.). The composition and digestibility of herbage in the various sward horizons (strata) were determined as explained in Section 5.2.4.3.

5.2.5 Statistical analysis

Treatment differences and levels of significance were tested by analysis of variance as described in Section 3.6.2. The proportions of herbage components in each of the four vertical strata were averaged within seasons over the two year period, and treatment differences were tested using a split-plot in space model (sward type as main plots and strata as sub-plots). The t-test was used to test for differences in tiller density, and sward composition data from the higher strata, between the two Matua sward types.

5.3 RESULTS

5.3.1 Experimental dates and duration

The dates, duration and season of measurement of each of the eight grazing trials are shown in Table 5.2. The mean duration of each measurement period was 14 days (range 10-18d) and was largely dictated by the availability of Matua herbage. The early spring trial in Year One did not start until mid October because of logistical problems.

5.3.2 Weather

5.3.2.1 Air temperature

Mean monthly air temperatures (maximum and minimum) during the two year experimental period, and the 30-year averages, are presented in Appendix 5.1a. During Year One (May 1987 to April 1988), mean monthly temperatures were close to the 30-year average (13.5°C *vs* 13.2°C average), but the cool months (May to September) were warmer than usual by 0.6°C. Mean monthly temperatures for Year Two (1988/89) were 1.2°C higher than the 30 year average, with a summer period (December to February) mean of 18.6° compared to the average of 17.4°C.

5.3.2.2 Rainfall and sunshine

Total rainfall (mm) and sunshine hours during each month from May 1987 to April 1989 are shown in Appendix 5.1b. Total rainfall was 26% lower than the 30-year average during Year One (746 *vs* 1010 mm), but was 13% (139 mm) higher than average during Year Two. The rainfall deficit during Year One was spread throughout the year; total precipitation during winter (June-August) was 50% lower than that expected (133 *vs* 271 mm), and only 5 mm of precipitation (normal 77 mm) was recorded in January. During 1988/1989 (Year Two), the winter-early spring (June-September) period was very wet, with 51% more rainfall than average (520 *vs* 345 mm); otherwise, average precipitation prevailed.

Hours of sunshine totalled 1656 and 1810 during Years One and Two, respectively, compared to the 30-year average of 1785 hrs; a major departure from the average was recorded only during the May to July period (229 *vs* 301 hrs average) of Year One.

5.3.3 Herbage mass

Actual mean pre- and post-grazing herbage masses (kg DM/ha), averaged across all eight measurement periods for the RG, LM and HM sward types, are presented in Table 5.3. The mean values of herbage mass before and after grazing, for each sward type during each season (measurement period), are indicated in Appendices 5.2 and 5.3, respectively. Mean pre- and post-grazing herbage masses achieved for each sward type during the entire experimental period were within the range of the nominal target herbage mass values (Table 5.1), except for the HM swards which registered a mean post-grazing mass 144 kg DM/ha above the target range, mainly in the spring of Year One (1987).

There were large variations in pre- and post-grazing herbage masses, both between seasons within a year and between years, for each sward type (Appendices 5.2 and 5.3). The lowest and highest herbage mass values were generally observed during early and late spring, respectively. The ranges of herbage mass observed before grazing, in tonnes DM/ha, were: RG, 2.1-4.2; LM, 2.3-5.5 and HM, 3.8-6.8. Values for post-grazing herbage mass were 1.4-2.9, 1.3-3.2 and 2.6-4.5 t DM/ha for RG, LM and HM swards, respectively. Meaningful comparisons of net herbage accumulation (NHA) could not be made during the first year of the experiment because on several occasions (see Section 5.2.2.3) LM swards were either regrazed or topped mechanically 48 to 72 hrs after experimental grazing. During the second year of the study, NHA for the LM and HM Matua swards was measured during a concurrent experiment (Xia, 1991), using the difference and tissue turnover techniques (Bircham, 1981).

5.3.4 Sward height and bulk density

Sward height

The mean sward surface heights of each of the three sward types before and after grazing, and corresponding sward bulk densities, are shown in Table 5.4. Values for pre- and post grazing sward height during each of the eight experimental periods are presented in Figure 5.1.

HM swards had the highest values for sward height in all seasons, while the values for RG swards were smallest, and LM swards were intermediate for this measurement. Pre- and post- grazing sward height for all sward types was high during spring, but decreased in summer and autumn (Figure 5.1a,b).

Bulk density

Mean sward bulk density, averaged across eight seasons, was generally similar for LM and HM swards, but was significantly greater for RG swards (Table 5.4). The lowest and highest sward bulk densities (kg DM/ha per cm sward surface height) for RG (121 vs 316), LM (93 vs 242) and HM (104 vs 240) were generally observed during the spring and summer/ autumn periods, respectively (Figure 5.1c). There were, however, marked season x sward type effects on sward bulk density (Figure 5.1c). This was most apparent during Year One, when LM swards had a lower bulk density than HM swards during late spring and summer, though both had similar levels in early spring and autumn. Regardless of season, RG swards had a higher bulk density than the Matua swards in Year One. Bulk density during Year Two was generally similar among the three sward types, except during summer, when RG bulk density was significantly greater than that of Matua swards.

5.3.5 Sward composition

5.3.5.1 Botanical composition

Ryegrass / prairie grass

The percentages of perennial ryegrass or Matua prairie grass, white clover and other species in the pre-grazing dry green herbage (excluding senescent matter) of the three sward types (RG, LM and HM), averaged across eight measurement periods, are shown in Table 5.5. Corresponding mean values expressed on total herbage dry matter basis (including senescent matter) are presented in Appendix 5.4.

The proportions of the main grass component (ryegrass or prairie grass) in RG and LM sward types, averaged over the experimental periods, were similar, but that of HM swards was significantly greater (Table 5.5). RG and LM swards also contained similar mean percentages of white clover and other species, but HM swards contained less clover ($P<0.05$) and other species ($P<0.05$ vs LM; $P>0.05$ vs RG). There were, however, significant ($P<0.01$) season x treatment effects on the botanical composition of the three sward types (Figure 5.2). The RG and LM swards contained similar percentages of ryegrass and prairie grass, respectively, during all the seasons of measurement except summer, when the percentages of ryegrass in RG swards (Year One) and prairie grass in LM swards (Year Two) were significantly lower (Figure 5.2a). The proportion of the main grass component in HM swards was significantly greater than that in RG swards in all periods of Year One, except the summer, and in the early spring of Year Two; it was similar to that of RG swards in the summer of Year One, and in the late spring and summer of Year Two; but was significantly lower in the autumn of Year Two.

The percentage of Matua prairie grass in LM swards declined progressively, from 84% during the first grazing trial (Year One) to 46% of the green herbage dry matter in the final grazing trial (Year Two). The proportion of Matua in HM swards also declined by a similar magnitude as in the LM treatment, but the decline was steeper in Year Two of the study, particularly during summer and autumn. The LM and HM swards contained similar proportions (Figure 5.2a) of prairie grass during the first two trials (early and late spring of Year One) and at the end of the experiment (autumn Year Two).

White clover

Averaged over the whole experimental period, the mean percentage of clover was significantly lower ($P<0.05$) in HM swards (12%) than in the other sward types, which had a similar content (17%) of clover (Table 5.5). The differences between swards were not significant in most individual seasons, although HM swards had significantly less clover than the other swards during the summer and autumn of Year Two (Figure 5.2b).

Other species

The percentage of other species in the herbage, averaged across all measurement periods, was significantly higher in LM than in HM swards ($P<0.05$) (22.6 vs 15.9%); it was intermediate (17.9%) in RG swards, but this was not significantly different from that of LM or HM swards types (Table 5.5). Perennial ryegrass, *Poa* spp., and to a lesser extent cocksfoot, phalaris and dock weed were the main invaders, depending on the previous swards in each paddock. There was a gradual increase of the other grass species and weed component of all the experimental sward types during the two year measurement period, but no significant differences between sward types were observed during Year One of the experiment (Figure 5.2c). However, starting in early spring of Year Two, the percentage of other species (including weeds) in LM swards increased steeply in comparison to HM swards, and was approximately twice that of HM swards during early spring (25 vs 13%), late spring (28 vs 18%) and summer (49 vs 26%); but values were similar during autumn (31%).

Seasonal trends

The influence of season on the botanical composition of herbage, averaged across the three sward types, is illustrated in Table 5.6. The proportion of the main grass component (ryegrass or prairie grass) of the green herbage tended to decline between late spring and autumn, with summer and autumn values being significantly lower than the early and late spring values. The concentration of clover of the three sward types was stable during early and late spring, but increased steeply during summer and remained high in autumn. Similarly, the percentage of other species in all the swards increased considerably above spring values during summer and autumn, and swards contained about twice the level of other species in Year Two compared with Year One.

5.3.5.2 Morphological composition before grazing

Effects of sward type

Mean percentages of green leaf, green stem, dead matter and inflorescence in the total herbage, and leaf:stem ratio of each sward type before grazing, averaged across measurement periods, are presented in Table 5.5. The influence of season and sward type on the morphological composition of herbage on offer is illustrated in Figure 5.3 and Appendix 5.5. Averaged over the whole experimental period, RG swards contained a greater percentage of green leaf, but smaller percentages of green stem, dead matter and inflorescence, than the LM and HM swards. Within the Matua swards, LM herbage contained a higher percentage of green leaf and a lower percentage of dead matter than HM swards, but HM and LM swards contained similar percentages of green stem and inflorescence.

Green leaf and stem

The influence of sward type on the percentage composition of green leaf, green stem, dead matter and inflorescence in the pre-grazing herbage were modified by season effects (Figure 5.3; Appendix 5.5). RG swards contained higher percentages of green leaf than LM and HM swards during most seasons, but, during the autumn of Year Two, RG and LM swards contained similar percentages of leaf, and these were slightly greater than that in HM swards (Figure 5.3a). Matua swards (LM and HM) contained similar percentages of green leaf during late spring (in both years), and during the summer and autumn of Year Two; but the percentage of leaf in LM swards was larger than that in HM swards in early spring. The percentages of stem did not differ significantly between sward types in summer and autumn (Figure 5.3b), and were also similar between Matua swards during early and late spring, when they were greater than that of RG swards.

Dead matter

The percentage of senescent matter in the herbage on offer was significantly larger in HM swards than in RG and LM swards during seven of the eight seasons of measurement (Figure 5.3c); that of RG swards was the smallest during the summer and autumn of Year One and during the early spring and summer of Year Two. RG and LM swards contained similar percentages of dead matter during late spring (both years) and during the autumn of Year Two. The lowest and highest percentages of dead matter were observed in RG swards (8 and 38%) during the early spring of Year Two and the summer of Year One, and in LM swards (13 and 50%) and HM swards (20 and 53%) during the early spring and autumn of Year One, respectively.

Seedhead

The RG swards contained few or no inflorescences during early spring and autumn (Figure 5.3d); whereas during late spring and summer, inflorescences constituted 1-6% and 0-2%, respectively, of the herbage dry matter, depending on the year. Emerged inflorescences were observed in Matua swards from early spring (mid September) to late autumn (mid May), and constituted 9-18% of the herbage dry matter during peak reproductive growth in late spring.

Leaf:stem ratio

The leaf:stem ratio of herbage, averaged over eight seasons of measurement (Table 5.5), was highest, intermediate and lowest in RG, LM and HM treatments, respectively; and the mean differences between RG swards and the Matua swards were highly significant ($P<0.01$), with RG swards containing 40-50% more leaf relative to stem than the Matua swards. The leaf:stem ratios of pre-grazing RG pasture were significantly greater than those of LM and HM pasture in all periods of measurement, except during the summer and autumn of Year One, when those of RG and LM swards were similar. The leaf:stem ratios of Matua sward types and plants did not differ significantly in most of the experimental periods (Figures 5.4a,b), but LM swards tended to have greater proportions of leaf relative to stem.

Seasonal trends

The influence of season on the morphological composition of herbage before grazing, averaged across sward types, is shown in Table 5.7. The percentage of green leaf in the herbage generally declined during late spring and summer but increased to early spring levels during autumn. The percentage of green stem was generally high during early and late spring but declined considerably throughout summer and autumn, with autumn values being smaller than those of early spring. Dead matter concentration of the herbage increased sharply during summer and remained high during autumn; the proportion of seedheads was highest during late spring but was considerably lower during the remaining seasons. Leaf:stem ratio was smallest during late spring, was intermediate during early spring and summer, and increased sharply during autumn.

5.3.5.3 Morphological composition post-grazing

Green leaf,green stem and dead matter

Mean percentages of the morphological components, and leaf:stem ratio, in herbage post-grazing, are presented in Table 5.8. Over the whole experimental period, sward type had a significant effect on the concentration of green leaf in the residual herbage, with RG, LM and HM swards having the greatest, intermediate and smallest concentrations of green leaf, respectively. Averaged across measurement periods, RG and HM swards had similar mean percentages of stem, which were significantly lower than that of LM residual herbage.
The proportion of dead matter in residual herbage was lowest in RG swards, intermediate in LM swards and highest in HM swards. Post-grazing herbage had a lower leaf:stem ratio, and contained a greater proportion of dead material, than pre-grazing herbage in all three swards types. The implications of these observations in relation to the composition of the diet consumed by the cows are discussed in Chapter 6.

5.3.5.4 Vertical distribution of herbage components

The distribution of herbage components leaf, stem and dead matter in four vertical strata of the three sward types in four periods of measurement , and averaged over two years, is presented in Figure 5.5 and Appendix 5.15A. RG swards contained greater proportions of leaf (19%) and stem (59%) , and a smaller proportion of of dead matter (22%) in the lowest sward horizon (0-6cm) than those of both the Matua sward types (averages, 5, 46 and 49% respectively) in all periods of measurement. In all swards, the proportion of green leaf increased with increasing sward height, but the increase was steeper in RG than the Matua swards, and was steeper in LM than HM swards. Dead matter was found in greater proportions in the upper sward horizons in all Matua swards compared with perennial ryegrass swards, which contained no dead matter above 18cm sward height, and was generally greater in HM than LM swards. The proportion of stem in both the Matua swards was greater than that in the RG swards in all horizons above 6cm, and was generally similar between the two Matua sward types.

5.3.5.5 Tiller density, tiller weight and plant population density in Matua swards

The tiller population density and individual tiller weights, measured by the author in autumn, and by Xia (1991) during other periods (early spring, late spring and summer) of Year Two, are shown in Appendix 5.16. Tiller population density differed significantly between periods ($P < 0.05$), and the HM treatment generally had a higher tiller population density than the LM treatment ($P = 0.06$). Averaged across periods, the mean values were LM, 491 and HM 564 tillers/m^2. The tiller population density per m^2 generally increased over time in the HM swards but not in the LM swards, except in the autumn when tiller densities for the LM swards were slightly greater ($P > 0.05$) than the HM swards. The increase in tiller population density was most apparent in the summer and autumn periods, but the treatment x period interactions were not significant.

The dry weights (mg/tiller) of individual pre-grazing tillers (Appendix 5.16) for the HM swards were significantly greater than those for the LM swards during early spring ($P < 0.05$), late spring ($P < 0.01$) and autumn ($P < 0.05$), but not during the summer ($P > 0.05$), when there was no significant difference between the two sward types. There was a substantial decline in dry weight per tiller over time in both the two Matua sward types, with no significant period x sward type interactions. Much of the decline in individual tiller weights was observed during the summer to autumn period. The range in individual tiller weights was 132-678 and 103-322 mg/tiller for the HM and LM treatments, respectively.

Plant population densities and number of tillers per plant for the LM and HM sward types are also shown in Appendix 5.16 (Xia, 1991). Plant population densities were greater in the LM (18 plants/m^2) than in the HM (13 plants/m^2) treatment ($P < 0.05$), decreased from early spring to late spring and summer ($P < 0.001$), and the declines were steeper in LM than in HM swards; the interaction between treatment and period was significant ($P < 0.01$). Tiller numbers per plant were significantly higher in summer than in early and late spring ($P < 0.05$), and tended to be greater ($P = 0.08$) in HM (37 tillers/plant) than LM (24 tillers/plant) swards; the interaction between period and treatment was not significant.

5.3.5.6 Herbage accumulation for Matua swards

The rates of green and total herbage accumulation per unit area between grazings during Year Two are shown in Appendix 5.16 (Xia, 1991). The rate of herbage accumulation was significantly different between periods, both for green and total herbage, being highest in early/mid spring (September-November) and lowest in late spring/early summer (November-December) for both the LM and HM treatments (Appendix 5.16). The differences between treatments were significant over all periods for total herbage accumulation ($P < 0.001$), and for green herbage accumulation ($P < 0.05$). Average values for the LM and HM treatments were, respectively, 2.2 and 1.9 g DM/m^2 daily for total herbage accumulation, and 1.6 and

2.7 g DM/m^2daily for green herbage accumulation. The interaction between treatment and period was not significant for rate of total herbage accumulation, but it was significant for green herbage accumulation ($P < 0.01$).

The rate of net herbage production per unit area was significantly different between treatments and between periods, but treatment x period interactions were not significant (Appendix 5.16). The HM treatment had a higher net production rate for total herbage than the LM treatment (2.9 *vs* 1.2 g DM/m^2 daily). The highest net herbage production for both treatments was during the September to November periods, and net herbage production was lowest during the late spring/early summer period (November-December).

5.3.6 Nutritive value of herbage

The nutritive values of total herbage on offer, ryegrass and prairie grass whole plants, green leaf, green stem, inflorescence and dead matter, are considered in terms of percentage of chemical components in the organic matter or dry matter (as specified), digestibility (DMD and OMD), ME content and yields of chemical components, DDM and DOMD (g/ m^2).

The main points regarding herbage quality are highlighted in the following brief summary, in order to assist the reader to progress through the large mass of data and differences between treatments when averaged across all periods.

* % N in total herbage : RG > LM > HM
* % N in whole plants : RG = LM > HM
* % N in green leaf and stem : no significant difference
* % OMD and ME in total herbage : RG > LM > HM
* % OMD and ME in whole plants : RG = LM > HM
* % OMD and ME in green leaf and stem : RG > HM (LM not significantly different from either RG or HM)
* leaf:stem ratio: RG > LM > HM (herbage and plants cut to ground level)

The above comparisons (with corresponding data) are also presented in a tabular form in Appendix 7.1a (Table 2) and Appendix 7.1b (Tables 1 and 2).

5.3.6.1 Total herbage before grazing

Chemical composition

Effect of sward type on %N

The chemical composition and digestibility of the total herbage before grazing, averaged across the seasons of measurement, are presented in Table 5.9. The concentration of N (% in OM) in the herbage was influenced by both sward type and season of measurement independently ($P<0.001$; Appendix 5.6). Herbage from RG, LM and HM swards showed highest, intermediate and lowest values for percentage N, respectively. However, RG and LM swards contained similar % N during five of the eight seasons of measurement (Appendix 5.7). The concentration of N in the three sward types was greater in early spring and autumn than late spring or summer (Table 5.10).

Seasonal trends: ADF, lignin, ash

The concentrations of acid detergent fibre (ADF) and lignin (% OM) in the herbage, presented as simple means and averaged across seasons, were generally higher in HM swards than in RG swards; values for LM swards were intermediate (Table 5.9). ADF and lignin values in the three swards varied only slightly between seasons, but were generally smallest in early spring and greatest in summer (Figure 5.6a,b). Percent ash in the herbage dry matter, averaged across the whole experimental period, was significantly greater in RG than HM herbage ($P<0.05$), but % ash in LM herbage did not differ significantly from the remaining swards (Table 5.9). However, RG swards generally contained greater concentrations of ash than LM and HM swards during early and late spring, whereas % ash in LM swards was greater than that of RG and HM swards during summer and autumn, although during these seasons the differences between means were generally not significant (Figure 5.6c). The significance of these trends in relation to the mineral composition of Matua relative to perennial ryegrass herbage will be discussed in Section 5.4.

Chemical composition of herbage (DM basis)

The chemical composition of pre-grazing herbage (% DM basis) and GE values for each sward type during each season of measurement are presented in Appendix 5.7

Digestibility

Effects of sward type

Apparent digestiblities of the herbage DM and OM (predicted from in vitro digestibility values), and the levels of DOMD (%) and ME (MJ/kg DM) averaged across the experimental periods, differed significantly between sward types ($P<0.001$), with RG, LM and HM swards showing the highest, intermediate and the lowest digestibilities, respectively (Table 5.9). Mean GE contents of the herbage were generally similar between sward types and showed little variation between seasons (range 17.7 - 19.4 MJ/kg DM; Appendix 5.7).

Season x sward type interactions

The effects of sward type on both % OMD and DOMD of the herbage on offer were modified by seasonal effects (Figure 5.8; Appendix 5.6). The OMD percentages of RG and LM swards did not differ significantly in the early and late spring of Year One and in the autumn of Year Two, mean values for each period were 74.9, 71.2 and 76.3% respectively); % OMD was greater in RG than LM swards in the remaining seasons of measurement (Figure 5.6a). The highest OMD value (78.3%) was observed in RG swards in the early spring of Year Two, while the lowest value (67.4%) was observed in HM swards in the summer of Year Two. Of the three sward types, HM swards showed the lowest % OMD ($P<0.01$) during each of the eight seasons of measurement. Percent DOMD in the three sward types followed a similar pattern to that of OMD, but the three treatments contained similar % DOMD in the late spring of Year One (mean, 61.5%), and RG and LM swards also contained similar DOMD concentrations (mean 69.6%) in the early spring of Year Two (Figure 5.8b). Percent DMD and the estimated levels of ME of the pre-grazing herbage in the three sward types during each measurement period are shown in Appendix 5.8a & b.

Seasonal trends

The seasonal trends in the apparent digestibilities of DM and OM, and the levels of DOMD (%) and ME (MJ/kg DM) of the herbage before grazing, averaged across sward types, are demonstrated in Table 5.10. Percent OMD and DOMD in the herbage were generally greatest in early spring and smallest in summer; late spring and autumn values were intermediate.

5.3.6.2 Ryegrass and Matua whole plants

Chemical composition

Effects of sward type

Mean values for the chemical composition and gross energy of perennial ryegrass and Matua whole plants (LM & HM), averaged across the whole experimental period, are presented in Table 5.11. The % N (OM basis) in RG and LM plants was similar, but it was significantly smaller in HM plants ($P<0.01$). RG plants contained the lowest percentages (OM basis) of ADF and lignin, LM values were intermediate, while HM plants had the highest values. Ash % was slightly smaller ($P<0.05$) in LM and HM plants than in RG plants. Mean values for GE of ryegrass and Matua plants were similar (18.4 MJ/kg DM).

Season x sward type effects

Significant season x sward type interactions modified the concentrations of the various chemical components in whole plants between the seasons (Appendix 5.9). RG plants contained greater concentrations of total N than the LM and HM swards in early and late spring, and this was more evident in Year Two (Figure 5.7a). Percent N was similar in the three sward types during summer (both years), while % N in LM plants tended to be greater than that in RG or HM whole plants during autumn.

The data for the concentrations of ADF and lignin of whole plants from the three sward types were not analysed statistically because the samples were not replicated, and only the general trends of the concentrations of these herbage components will be mentioned here. LM and HM plants generally contained similar percentages of ADF during late spring and summer in both years (30.7 - 37.1%), and these were considerably greater than the RG plant values (26.7-33.0%) during the same periods; but in early spring and autumn, LM plants contained smaller proportions of ADF than RG or HM plants (Figure 5.7b). Similarly, the concentrations of lignin in LM and HM plants were generally similar, and were greater than the RG plant values throughout late spring and summer; however in early spring and autumn the differences in lignin concentration between swards were not consistent in both years (Figure 5.7c). In comparison to ryegrass plants, LM and HM Matua plants contained smaller concentrations of ash in early and late spring, but % ash was greater in Matua plants during summer and autumn (Figure 5.7d). The chemical composition (DM basis) and GE values of whole ryegrass and Matua plants in the three sward types during each period of measurement are presented in Appendix 5.10.

Digestibility

Effects of sward type

Values for the digestibility and energy content of ryegrass and Matua whole plants, averaged across the measurement periods, are shown in Table 5.11. Percentages of DMD, OMD and DOMD, and the levels of ME, in RG and LM plants were similar (mean 71.3, 76.0, 67.2% and 11.0 MJ/kg DM, respectively); but corresponding values for HM plants were significantly lower ($P<0.01$) than the other treatments.

Season x sward type effects

Season x sward type interaction effects on % OMD and DOMD of whole plants from RG, LM and HM swards were highly significant ($P<0.001$) (Appendix 5.9), and are illustrated in Figure 5.9. Similar effects on % DMD and ME levels are depicted in Appendix 5.8c & d. Percent OMD did not differ significantly between RG and LM plants in early spring (75.6 *vs* 76.9%) or late spring (73.4 *vs* 73.9%) of Year One, but that of HM plants was significantly lower in early spring (72.9%) and was greater in late spring (75.6%) than those of RG and LM plants (Figure 5.9a). Percent OMD for LM plants, however, declined significantly relative to that of RG plants during early spring (76.7 *vs* 79.7%) and late spring (70.6 *vs* 77.7%) of Year Two, and was similar to that of HM plants, which averaged 75.7 and 68.8% during the early and late spring, respectively. Whole plants in the three sward types had similar organic matter digestibilities during summer, when the mean OMD values were 73.4% in Year One and 75.0% in Year Two; during autumn, however, the mean OMD values for LM plants (78.8% in Year One and 81.3% in Year Two) were generally greater than those of plants in the remaining treatments (RG, 76.5 and 76.4% and HM, 75.5 and 80.9%, for Year One and Two, respectively) (Figure 5.9a).

The overall DOMD levels in LM and HM Matua plants were either similar to (Year One) or smaller (Year Two) than that of RG plants (Figure 5.9b). Differences in the DOMD levels of whole plants between the three sward types were not significant in the summer of Year One. In the summer of Year Two, the levels of DOMD of LM and HM plants were similar, but they were significantly smaller than that of RG plants.

Seasonal trends

The influence of season on the nitrogen, ash, DOMD and ME contents, and the apparent digestibility, of whole plants in the three sward types are shown in Table 5.12. The concentrations of N and ash of the grasses were generally stable from early spring to summer, but increased considerably in autumn. Apparent digestibility, DOMD and estimated ME levels of the grasses were generally greatest in autumn, and next highest in early spring. There was a marked effect of year on the digestibility and DOMD values of the grasses such that late spring values were slightly greater than the summer values in Year One, whereas during the following year summer values were considerably greater than those of late spring.

The leaf:stem ratios of the plants averaged across the measurement periods (Table 5.11), closely resembled those of total pasture herbage (Table 5.5), as did their seasonal variations (Section 5.3.5.2, Figure 5.4a,b), which were generally minor. The mean proportion of green leaf:stem in ryegrass plants was 40 and 50% greater than that of LM and HM plants, respectively.

5.3.6.3 Leaf and stem

Chemical composition

There were no significant differences between the three sward types in the concentrations of total N, averaged across measurement periods, in either the green leaf (Table 5.13) or green stem (Table 5.14). Similarly, the mean concentrations of ash in either the green leaf (Table 5.13) or green stem did not differ between sward types. Percent N for green leaf was twice that of stem, and that of ash was also greater for leaf than for stem.

Significant ($P<0.05$) season x sward type effects on % N of green leaf were apparent only in Year One (Figure 5.10a, Appendix 5.11). In Year One, % N for leaf of LM plants was greater in late spring than for RG or HM leaf, and % N for LM and HM leaf was greater in autumn than for RG leaf. Differences between swards in % N for leaf were generally not significant during the remaining seasons of measurement, although RG leaf tended to contain less % N during summer than LM and HM leaf.

Similarly, percent N for green stem was influenced by season x sward type interactions (Figure 5.10b, Appendix 5.12). RG stem contained a greater % N than LM and HM stem in early spring (P<0.01) of Year One and in late spring (P<0.001) of Year Two. Otherwise, % N for stem was generally similar in all swards, but tended to be greater for Matua than ryegrass stem during summer and autumn.

Digestibility

Apparent digestibility (DMD or OMD) of both green leaf (Table 5.13) and green stem (Table 5.14) was significantly higher in RG than in HM plants, while mean values for LM plants were not significantly different from either RG or HM values. The values were generally slightly higher (1-2% units) for green leaf than for green stem. Mean levels of DOMD and ME in green leaf in the three swards followed a pattern similar to that of apparent digestibility, whereas for green stem DOMD, and ME in RG and LM plants were similar, but significantly greater than in HM plants.

Differences in green leaf % OMD and DOMD between the three sward types (Figure 5.11), arising from season x sward type interactions (Appendix 5.11), were only apparent during the autumn of Year One (LM > RG & HM) and the late spring of Year Two (RG > LM & HM). For green stem, % OMD and DOMD of RG and LM plants (Figure 5.12, Appendix 5.12) were similar during most seasons, except during late spring and summer of Year Two when values for LM were lower than those of RG. HM leaf and stem tended to have the smallest values for % OMD or DOMD, particularly during late spring and summer.

General seasonal trends in the concentrations of N and ash for green leaf (Appendix 5.13) and green stem (Appendix 5.14) were similar to those for whole plants, as described in Section 5.3.6.2 (Table 5.12). Seasonal trends for % OMD, % DOMD and ME for green leaf (Appendix 5.13) or stem (Appendix 5.14) also resembled those of whole plants, except that the values were greatest in early spring, and not in autumn as for whole plants (Table 5.12).

5.3.6.4 Seedheads and dead matter

Mean concentrations of nitrogen for inflorescences in the three sward types were generally similar (Table 5.15). The concentration of ash in RG seedheads was generally greater than that of LM and HM seedheads, which contained similar values (Table 5.15). Apparent digestibility, % DOMD and the ME content of RG seedheads tended to be greater than those of Matua, with HM inflorescence showing the lowest values (Table 5.15).

Mean concentrations of N in the dead matter of RG and LM swards were similar, and tended to be higher than that of dead matter from the HM swards (Table 5.16). Percent ash for senescent matter was generally highest, intermediate and lowest in RG, LM and HM swards, respectively (Table 5.16). The concentrations of N in the dead matter of the swards closely resembled those of green stem, while those of ash were generally greater than the corresponding values for whole plants (Table 5.11) and plant components (Tables 5.13 and 5.14), irrespective of sward type. Mean values for apparent digestibility and the levels of DOMD and ME of senescent matter in the three sward types were smaller than the values for other sward components; and were generally highest for RG swards and intermediate for LM swards, with HM swards showing the lowest values (Table 5.16)

5.4. DISCUSSION

5.4.1 Herbage mass and height

Mean pre- and post-grazing herbage masses in kg DM/ha were, respectively, RG 3170 and 2086, LM 4206 and 2237, and HM 5685 and 3644 (Table 5.3). These values were typical for the two grass species when grazed laxly and infrequently, i.e. every 3-4 weeks for ryegrass (Bryant, 1980a; Stockdale, 1985a; Stakelum and Dillon, 1991; Hoogendoorn et al., in press), and 5-6 weeks for prairie grass (Brookes and Holmes, 1986; Cosgrove and Brougham, 1988; Ridler et al., 1988). The low average grazing efficiency (41%) observed from the three sward types was expected because of the high herbage allowance given to the cows, but it would normally be unacceptable in a farming situation.

Pre-grazing herbage masses, for all the three sward types, declined substantially during the second experimental year relative to the first year (Appendix 5.2). This decline was most evident in the early spring of Year Two, was steeper for both the Matua swards, and was steeper for the LM than HM sward type. The second year early spring grazing trial started a month earlier (mid September *vs* mid October) compared with the previous year, which partly explains the low herbage masses during this period.

However, the very wet winter of 1988 (50% above average rainfall, Appendix 5.1) may have caused most of the poor early spring herbage growth, especially for the Matua swards. These swards also had a greater concentration of dead herbage compared to that of the previous spring (Figure 5.3), and the LM swards showed considerable yellowing during this period (Plate 5.1). It is possible, therefore, that the subsequent treatment effects, and performance of the Matua sward types were influenced by the wet winter/early spring conditions. Previous reports have indicated that Matua prairie grass does not tolerate wet soil conditions (Rumball, 1974; Chu et al., 1979; Anon., 1982; Hill and Pearson, 1985; Eccles et al., 1990).

Pre- and post-grazing sward heights of the three treatments varied considerably with season (Figure 5.1). Mean values for pre-grazing sward height (RG, 16 cm; LM, 28 cm; HM, 36 cm) were similar to those reported previously for ryegrass and Matua prairie grass under infrequent and lax grazing regimes (Hoogendoorn, 1986; Ridler, 1986). In Matua swards the high values for sward height were associated with low mean values for sward bulk density relative to RG swards (Table 5.4; RG > LM = HM; 211 > 172 = 179 kg DM/ha per cm respectively, $P < 0.001$) (Hoogendoorn, 1986; Mitchell et al., 1991). Bulk density for LM and HM swards was similar despite the 8 cm difference in mean sward height. This suggests that, in Matua pastures, the high values for sward height relative to ryegrass may not necessarily reduce dry matter intake, because of the generally high density of the pasture (Stobbs, 1975b; Chacon and Stobbs, 1976; Mursan et al., 1989; Hughes et al., 1991).

The high average post-grazing sward heights of the three sward types (9, 12 and 15 cm for RG, LM and HM treatments respectively), indicate the high feeding level achieved in the present study. Feed intake by rotationally grazed lactating dairy cows is reported to decline below 8-12 cm post-grazing sward height for perennial ryegrass swards (Le Du et al., 1979; Mayne and Wright, 1988; Stakelum and Dillon 1991). For prairie grass swards, the effects of post-grazing sward height on feed intake, milk yield and subsequent pasture yield and composition are unknown. However, the relatively smaller milk yields observed from the high mass Matua swards in the current study (Chapter 6), suggest that reductions in milk production from these swards may be substantial at lower residual sward heights or herbage allowances than those of the current study.

5.4.2 Botanical and morphological composition of pasture

Botanical composition of herbage

The proportions of ryegrass for RG swards and prairie grass for LM swards, averaged across periods, were similar, and were smaller than that of prairie grass for HM swards (62 *vs* 72%; Table 5.5). The RG and LM treatments contained similar proportions of white clover (17%). Percent other species was slightly greater for LM than RG swards (23 *vs*

18%; P > 0.05). The HM swards contained a smaller percentage of clover (12%) than the remaining sward types; that of other species (16%) was significantly smaller relative to the LM swards, but did not differ significantly with that for RG swards.

Differences in the botanical composition of the LM and HM swards were consistent with most, but not all reports, which showed that lax or infrequent grazing reduced the clover content, and increased the proportion and persistence of Matua prairie grass pastures; and reduced the proportion of 'unsown' species (Alexander, 1985; Bell and Ritchie, 1989; Black and Chu, 1989). Previous reports also showed that, intense and/or frequent defoliation or set stocking reduced the proportion of Matua prairie grass, increased that of 'unsown' species, and caused Matua to disappear from the swards within two to four years (ibid; Lancashire and Brock, 1983; Stevens and Hickey, 1989; Webby et al., 1990).

The proportion of prairie grass in HM and LM swards decreased from 85% to a mean of 48%, and that of other species (mainly perennial ryegrass and Poa spp.) increased from 8% to 32% between the start and conclusion of the experiment (two year period). Differences between the two Matua swards in the proportions of these components were not significant at the begining and termination of the experiment (Figure 5.2a & c). These changes were progressive for LM swards, but for HM swards significant changes occurred during Year 2 (Figure 5.2 a & c). The proportion of clover in the Matua swards also declined in Year 2, but more steeply for HM than LM (Plate 5.2). The progressive decline in the proportion of Matua herbage in the LM swards was in accordance with previous reports, which showed that intense or frequent grazing of Matua swards resulted in sward deteriation (Rumball, 1974; Fraser, 1985). In the present study, long grazing intervals of five to six weeks did not reduce the decline in the proportion of Matua herbage in both the LM and HM swards. In the HM swards, a long grazing interval only delayed the onset of sward decline until the third year post-establishment. A similar observation was reported by Black and Chu (1989).

Persistence of Matua pastures was improved when grazing was lax or delayed until replacement tillers appeared at the base of the sward, followed by hard grazing to the height of the new tillers (ibid; Hume 1990a; Matthew et al., in press). This observation, and reports that tiller density in Matua pasture is maintained mainly by tillers from reproductive rather than vegetative plants (ibid, Hume, 1990b, 1991c), and not by self seeding (Hume, 1990a), suggest that physiological mechanisms and disease and pest damage (Thom et al., 1989; Black and Chu, 1989; Hume, 1991c), rather than intensity and frequency of grazing per se, may be the major determinants of persistence of Matua prairie grass.

Morphological composition of herbage

Averaged across periods, the proportion of green leaf was greater in RG than in LM or HM swards, and was generally greater in LM than HM swards (means 51 > 39 > 33% respectively). The proportions of stem, seedhead and dead matter were smaller in RG swards than in LM and HM swards, which had similar proportions of green stem and seedheads, but the proportion of dead matter was greater in HM than LM swards (Table 5.5). The difference between the RG and both the Matua swards in the proportion of dead matter was largest in the summer period (Plate 5.2). Average component compositions for RG, LM and HM treatments were, respectively, green stem, 27 *vs* 33 *vs* 32%; seed heads 1 *vs* 7 *vs* 7%; dead matter, 23 *vs* 28 *vs* 36%. Similar trends in the component compositions of perennial ryegrass and high mass Matua pastures grazed by dairy cows were reported by Brookes and Holmes (1986), and compared with low mass ryegrass swards, high mass ryegrass swards contained greater proportions of stem and dead matter and lower proportions of green leaf and were always less digestible (Michell and Fulkerson, 1987; Holmes et al., in press; Stakelum and Dillon, (1991).

Differences in the component compositions of the three sward types in the current study were reflected in the lower N concentration and % OMD of herbage on offer from the HM and LM treatments in comparison to the RG swards. Herbage quality will be discussed in Section 5.4.5.

5.4.3. Tiller population density and herbage accumulation of Matua pasture

In the present experiment, the rate of net herbage production per unit area decreased substantially from early spring through summer (Appendix 5.16). The tiller population density increased over the period, but this effect was more than offset by the decrease of individual tiller weights (Appendix 5.16) and tiller net production rates (Xia, 1991). The highest rate of tiller population increase occurred in the late spring period, but this coincided with the lowest rate of net herbage production per unit area as a result of increasing rates of senescence (Appendix 5.16, Xia, 1991). During the late spring/early summer period, the stem accounted for 50% of the total net herbage production Xia, 1991). Hume, (1990a; 1991c) reported a rapid increase in dry matter accumulation associated with reproductive growth, and that reduction in reproductive development may reduce natural reseeding in prairie grass and so reduce sward persistence.

The rates of herbage growth and net production, and tiller population density and individual tiller weight were significantly greater in HM than LM swards (Appendix 5.16). Black and Chu (1989) reported that lax grazing permitted sward persistence and higher tiller population density but resulted in only 56% grazing efficiency. Hard grazing at 75% grazing efficiency resulted in less total herbage harvested and lower tiller population density, owing primarily to sward decline (ibid).

The seasonal effects on pasture production are the results of variation in climate and plant physiology. In the present study, the decline in the proportions of the primary grass species in the herbage (ryegrass or prairie grass) and in net herbage production in Matua pastures, may have resulted from the excessively wet soil conditions experienced in the winter to early spring period of 1988. During this period the rainfall was 50% higher than the 30-year average, and the succeeding dry summer, with December rainfall 40% below average, and higher temperatures than the average for the period (Appendix 5.1). However, there were consistent treatment effects, suggesting that climate did not influence the differences between treatments unduly.

5.4.4 Herbage quality

5.4.4.1 Total herbage quality

The quality of the herbage on offer reflected differences in the component compositions of the three sward types. Total N in the organic matter (Table 5.9) was greater in RG than LM or HM swards, and was greater in LM than HM swards (means, 2.7 *vs* 2.6 *vs* 2.3, $P < 0.001$). Percent N was smallest in HM swards in all periods of measurement (Figure 5.7). It was similar for RG and LM swards in most periods, except in late spring, when % N was smaller in LM swards, probably due to a sharp decline in Year Two of % green leaf and leaf:stem ratio of both Matua sward types (Figure 5.3a and 5.4a). The low N content of HM swards reflected the smaller clover, and high dead matter concentrations of the herbage from this treatment compared to the remaining treatments (Figures 5.2b and 5.3c). During autumn, % N was generally greater in LM than RG swards, which was surprising in view of the similarity in the proportions of leaf, stem, dead matter and clover of the two sward types during this period (Figures 5.2 and 5.3).

Apparent digestibility of organic matter, averaged across periods, was highest in RG (75%), intermidate in LM (73%) and lowest in HM (71%) swards. Differences in % OMD between sward types were significant ($P < 0.001$; Table 5.9). RG and LM swards had similar % OMD in early and late spring of Year one and autumn of Year Two; at other times % OMD was smaller in LM than HM swards, and showed a sharper decline in late spring of Yeat Two compared with RG swards (Figure 5.8a). Percent OMD for HM swards was consistently smaller than the remaining sward types. Differences between swards in % OMD resulted in significantly greater average DOM and ME concentrations for RG than either LM or HM herbage (ME means, 10.7; 10.4, 10.0 MJ ME/kg DM; Table 5.9, Appendix 5.8b). On the other hand, Crush et al. (1989) reported similar average digestibility of ryegrass and Matua pastures of similar herbage mass grazed by young bulls over the whole year.

These results are in close agreement with previous reports which showed smaller % N, and lower digestibility of herbage from high compared to low mass swards of lower concentrations of dead and higher concentrations of green matter (Hoogendoorn, 1986; Michell and Fulkerson, 1987). However, the relatively small difference (2% units) in the average OMD of herbage from LM and RG swards showing a large difference in average pregrazing herbage mass (1 tonne DM/ha), proportions of green leaf (12% units) and acid detergent fibre and lignin (Table 5.9) confirm previous reports that the nutritive value of prairie grass declines less rapidly with increasing herbage mass and maturity (Anon, 1982; Crush et al., 1989; Hume, 1990b, 1991d).

5.4.4.2 Nutritive value of whole plants and plant components

Despite a greater leaf:stem ratio of ryegrass plants compared to that of low mass Matua plants, % N, % OMD and ME concentration, averaged across periods, were similar for these plants, but were significantly smaller for the high mass Matua plants (Table 5.11). Percent N in green leaf or stem from ryegrass and both Matua sward types was similar; % OMD of green leaf or stem from RG and LM swards was similar, but that of HM was significantly smaller compared with RG leaf or stem, and was similar to that of LM leaf or stem. Mean values for % N for RG or LM and HM treatments were, respectively, whole plant, 2.6 *vs* 2.3%; green leaf 3.5 *vs* 3.5%; and green stem 1.8 *vs* 1.7%. Corresponding values for % OMD were whole plant, 76.0 *vs* 74.5%; green leaf, 76.8 *vs* 76.2%; and stem, 75.5 *vs* 73.8%. Compared with RG swards, % OMD for whole plants, green leaf and stem from both the Matua swards decreased substantially in the late spring/summer period of Year Two. This was probably caused by the decline in the leaf:stem ratio of the latter than the former swards (Figure 5.4).

Differences between treatments in the quality of the herbage components were generally larger for dead matter (Table 5.16) and seedhead (Table 5.15), however, the data presented for these components are simple means. Generally, % OMD of dead matter from the RG swards was greater by 3 and 7% units compared with that of LM and HM treatments, respectively. In view of the substantial amounts of the seedhead and dead matter components of low digestibility in both the Matua sward types compared to the ryegrass swards (Table 5.5), these, and to a lesser extent, stem, are likely to have contributed to the overall poor quality and feeding value of herbage from the high mass prairie grass pasture, and of low mass prairie grass pasture during the summer period. There are very limited data on the nutritive value of plant components from prairie grass with which to compare the present data. Hume (1991d) reported from the Netherlands similar average values for % N in the DM in Matua reproductive stem (1.7%) and inflorescence (2.7%) which were greater than those of Westerwolds ryegrass. He (ibid) also observed similar digestibilities of cell wall and % OMD in Matua plants and Westerwolds ryegrass despite greater concentrations of cell wall in Matua plants.

5.4.5 Conclusions

1. Matua prairie grass pastures maintained at either low or high pregrazing herbage mass for two years showed a substantial decline in the proportion of prairie grass in the herbage. The decline in the Matua component of the pasture was immediate for the low mass swards, but it was evident in the high mass swards in the second experimental year (3rd year post establishment).

2. The low mass Matua and perennial ryegrass swards contained, on average, similar proportions of white clover, the high mass swards contained a significantly lower proportion of this component.

3. The proportion of green leaf was consistently greater in perennial ryegrass swards, it was intermediate in low mass swards, and was smallest for high mass Matua swards. The opposite was observed for dead matter, with the LM swards showed an intermediate value for this component. The two Matua sward types had similar proportions of stem, which were greater than that of perennial ryegrass swards. Compared with ryegrass, prairie grass plants showed a steady decline in the leaf:stem ratio over the experimental period. This did not appear to influence the nutritive value of the herbage in Year One, but reduced herbage quality the following year, except in the autumn, and reduced rates of net herbage production.

4. Tiller population density and tiller weights declined substantially over time in both Matua sward types, but this decline was steeper in the low mass Matua swards.

5. The digestibility of herbage from low mass Matua swards was similar to that of perennial ryegrass swards in three of the eight periods of measurement, but it was significantly lower at other times; that of high mass Matua swards was consistently the lowest during the duration of the study. It appears that the poor quality of Matua herbage was caused mainly by the greater concentrations of dead matter and seedheads of lower digestibility than for ryegrass swards, especially in the late spring/early summer period; since, on the average, the organic matter digestibility of whole plants or of leaf and stem from ryegrass or low mass Matua sward types were similar; and the actual difference in digestibility between these and those of high mass Matua herbage was small - although statistically significant.

Table 5.1 Nominal target values for pre- and post-grazing herbage masses (kg DM/ha) for the three sward types.[1]

Sward type	Pre-grazing	Post-grazing
Perennial ryegrass (RG)	2000 - 3500	1000 - 2000
Low mass Matua (LM)	3000 - 4500	1500 - 2500
High mass Matua (HM)	4500 - 6000	2500 - 3500

[1] Actual mean pre- and post-grazing herbage masses for the three sward types averaged across all eight seasons are presented in Table 5.3.

Table 5.2 Experimental dates during each of the eight periods of measurement.

	Dates		
Season	Start	End	Number of days[1]
1987/88			
Early spring	16 October 1987	1 November 1987	17
Late spring	20 November 1987	7 December 1987	18
Summer	29 January 1988	14 February 1988	17
Autumn	9 April 1988	20 April 1988	12
1988/89			
Early spring	23 September 1988	2 October 1988	10
Late spring	5 November 1988	18 November 1988	14
Summer	13 January 1989	27 January 1989	15
Autumn	8 April 1989	21 April 1989	14
Mean (± SD)			14.6 ± 2.6

[1] Duration of grazing trial during each period of measurement.

Table 5.3 Mean values (± SD) for actual pre- and post-grazing herbage masses (kg DM/ha) for the three sward types averaged across all eight seasons.[1,2]

Sward type	Pre-grazing $\bar{x}$	Pre-grazing SD	Post-grazing $\bar{x}$	Post-grazing SD
Perennial ryegrass (RG)	3170	738	2086	529
Low mass Matua (LM)	4206	1093	2237	775
High mass Matua (HM)	5685	1090	3644	787

[1] Values are raw means ± standard deviation (SD).

[2] Mean herbage masses for the three sward types during each of the eight seasons are presented in Appendices 5.2 and 5.3

Table 5.4 Mean sward surface height (cm) and bulk densities (kg DM/ha per cm sward surface height) of the three sward types (RG, LM and HM) averaged across all eight seasons.

	Sward type RG	LM	HM	S.E.	Sign.
Sward height[1] (cm)					
Pre-grazing	16.0±4.4	27.8±12.3	35.7±15.5	NA	NA
Post-grazing	8.7±2.6	12.3±5.6	15.4±6.4	NA	NA
Bulk density ($kg\ DM\ ha^{-1}\ cm^{-1}$)	211^{a}	172^{b}	179^{b}	3.5	***

[1] Values are raw means ± standard deviations.

[a,b] Means within a row bearing different superscripts differ significantly (P<0.05).

Table 5.5 Mean values for botanical and morphological composition (% dry weight) and leaf:stem ratio of the pre-grazing herbage from the three sward types, averaged across all eight periods of measurement.

Herbage component	Sward type RG	LM	HM	S.E.	Sign.
Botanical composition[1]					
Grass[2] (%)	63.5^{b}	61.0^{b}	71.9^{a}	1.80	**
Clover (%)	16.9^{a}	16.5^{a}	12.2^{b}	0.94	*
Other species[3] (%)	17.9^{ab}	22.6^{a}	15.9^{b}	1.86	+
Morphological components[4]					
Green leaf (%)	50.5^{a}	38.7^{b}	32.5^{c}	1.13	***
Green stem[5] (%)	26.6^{b}	33.4^{a}	32.1^{a}	0.48	***
Dead matter (%)	23.2^{c}	28.0^{b}	36.4^{a}	1.19	***
Inflorescence (%)	1.2^{b}	6.9^{a}	6.7^{a}	0.43	***
Leaf:stem	2.3^{a}	1.5^{b}	1.2^{c}	0.03	***

[1] Values are presented on dry weight basis of green biomass (excludes dead matter).

[2] Ryegrass or Matua prairie grass.

[3] Includes weeds.

[4] Percentage of total dry matter

[5] Includes inflorescence

[a,b,c] Means within a row with different letters differ significantly (P < 0.05).

+ Significant at P < 0.10.

Table 5.6 Mean values for botanical composition (% dry weight) of pre-grazing herbage during each of the eight measuring periods, averaged across all three sward types (RG, LM & HM).

	Herbage component		
Season	Grass[1]	Clover	Others[2]
<u>1987/88</u>			
Early spring	81.9^{a}	8.8^{c}	9.3^{b}
Late spring	74.2^{b}	11.6^{c}	14.2^{a}
Summer	64.1^{c}	26.4^{a}	9.5^{b}
Autumn	65.7^{c}	19.5^{b}	14.8^{a}
<u>1988/89</u>			
Early spring	71.3^{a}	8.0^{b}	20.7^{b}
Late spring	69.5^{a}	8.8^{b}	21.7^{b}
Summer	50.7^{b}	17.1^{a}	32.3^{a}
Autumn	51.1^{b}	21.2^{a}	27.7^{a}
S.E.	3.1	1.8	2.0
Sign. level	***	***	***

[1] Ryegrass and Matua prairie grass
[2] Other plants, including weeds
[a,b,c] Values in a column within a year bearing different superscripts differ significantly ($P < 0.05$). Values in this and other similar tables are expressed on dry weight basis of green biomass (excluding dead matter).

Table 5.7 Mean values for morphological components (% dry weight) of pre-grazing herbage during each of the eight measurement periods, averaged across all three sward types (RG< LM & HM).

	Herbage component				
Season	Leaf	Stem[1]	Dead	Seedhead	Leaf:Stem
1987/88					
Early spring	38.7^a	43.5^a	17.8^c	6.7^b	1.0^{bc}
Late spring	31.0^b	41.6^a	27.5^b	9.7^a	0.8^c
Summer	29.6^b	25.7^b	44.7^a	4.5^b	1.2^b
Autumn	35.9^a	18.3^c	45.9^a	1.5^c	2.1^a
1988/89					
Early spring	56.5^a	25.0^b	18.7^c	0.0^c	2.4^b
Late spring	38.3^b	48.1^a	16.7^c	12.6^a	0.9^d
Summer	40.2^b	24.8^b	35.1^a	3.0^{bc}	1.7^c
Autumn	54.1^a	18.7^c	27.4^b	1.3^c	3.2^a
S.E.	1.8	1.5	1.7	1.1	0.1
Sign. level	***	***	***	***	***

[1] Includes seedheads

[a,b,c,d] Values in a column within a year bearing different letters differ significantly (P < 0.05)

Table 5.8 Mean values for morphological composition (% dry weight) and leaf:stem ratio in the post-grazing herbage from the three sward types, averaged across all eight seasons.

	Sward type				
Herbage component	RG	LM	HM	S.E.	Sign.
Green leaf (%)	33.7^a	24.9^b	17.4^c	0.93	***
Green stem (%)	32.7^b	35.8^a	32.1^b	0.66	**
Dead material (%)	33.7^c	39.4^b	50.5^a	1.38	***
Inflorescence (%)	0.0^b	2.5^a	2.6^a	0.23	***
Leaf:stem ratio	1.1^a	0.8^b	0.7^b	0.04	***

[a,b,c] Means within a row bearing different letters differ significantly at P < 0.05.

Table 5.9 Mean values for chemical composition (% OM) *in vitro* digestibility and energy concentration of pre-grazing herbage from the three sward types, averaged across all eight periods of measurement.

	Sward type				
Herbage parameter	RG	LM	HM	S.E.	Sign.
Chemical composition					
Nitrogen (% OM)	2.7^a	2.6^b	2.3^c	0.04	***
ADF[1] (% OM)	29.3 ± 2.2	32.0 ± 2.9	34.6 ± 2.4	NA	NA
Lignin[1] (% OM)	3.5 ± 0.6	4.3 ± 0.6	4.5 ± 0.7	NA	NA
Ash (% DM)	10.0^a	9.7^{ab}	9.0^b	0.30	+
Digestibility					
Dry matter (%)	69.4^a	67.3^b	64.3^c	0.19	***
Organic matter (%)	74.7^a	73.1^b	70.7^c	0.20	***
DOMD (%)	65.7^a	63.8^b	61.3^c	0.20	***
Energy concentration					
GE[1] (MJ kg DM^{-1})	18.4 ± 0.5	18.3 ± 0.3	18.3 ± 0.3	NA	NA
ME (MJ kg DM^{-1})	10.7^a	10.4^b	10.0^c	0.03	***

NA = Not applicable.

[1] Values are means (± SD) of samples bulked within each sward type during each season (n=8).

[a,b,c] Means within a row bearing different letters differ significantly at $P < 0.05$.

+ Significant at $P < 0.10$.

Table 5.10 Mean values for nitrogen, ash and metabolisable energy concentration, and *in vitro* digestibility of pre-grazing herbage during each of the eight seasons, averaged across all three sward types (RG, LM & HM).

	Herbage parameter						
Season	Nitrogen % DM	 % OM	Ash % DM	DMD %	OMD %	DOMD %	ME[1]
1987/88							
Early spring	2.1^{b}	2.4^{b}	10.0^{b}	68.8^{a}	73.9^{a}	64.7^{a}	10.6^{a}
Late spring	1.9^{b}	2.1^{c}	9.8^{b}	65.3^{b}	71.2^{b}	61.5^{b}	10.0^{b}
Summer	1.9^{b}	2.2^{c}	9.4^{b}	62.9^{c}	70.0^{c}	60.4^{b}	9.8^{b}
Autumn	2.5^{a}	2.8^{a}	11.5^{a}	65.1^{b}	71.7^{b}	61.6^{b}	10.1^{b}
1988/89							
Early spring	2.8^{a}	3.1^{a}	8.6^{b}	71.5^{a}	76.4^{a}	68.4^{a}	11.1^{a}
Late spring	2.0^{b}	2.2^{b}	7.9^{c}	67.6^{b}	73.3^{b}	64.7^{c}	10.5^{c}
Summer	2.2^{b}	2.4^{b}	9.1^{b}	64.5^{c}	70.7^{c}	60.8^{d}	9.9^{d}
Autumn	2.9^{a}	3.2^{a}	10.4^{a}	70.5^{a}	75.6^{a}	66.8^{b}	10.9^{b}
S.E.	0.07	0.08	0.40	0.58	0.42	0.52	0.08
Sign. level	***	***	***	***	***	***	***

[a,b,c] Means in a column within a year bearing different letters differ significantly at $P < 0.05$

[1] MJ/kg DM.

Table 5.11 Mean values for chemical composition (% OM), *in vitro* digestibility, energy concentration and leaf:stem ratio (dry weight basis) of ryegrass and prairie grass whole plants from the three sward types, averaged across all eight seasons.

	Sward type				
Herbage parameter	RG	LM	HM	S.E.	Sign.
Leaf:stem ratio	2.3^a	1.4^b	1.1^c	0.04	***
Chemical composition					
Nitrogen (% OM)	2.6^a	2.5^a	2.3^b	0.05	**
ADF[1] (% OM)	28.6 ± 1.7	29.4 ± 3.9	32.2 ± 2.2	NA	NA
Lignin[1] (% OM)	3.5 ± 0.6	4.3 ± 0.6	4.5 ± 0.7	NA	NA
Ash (% DM)	9.3	9.1	9.0	0.24	NS
Digestibility					
Dry matter (%)	71.4^a	71.1^a	69.4^b	0.29	**
Organic matter (%)	76.2^a	75.8^a	74.5^b	0.23	**
DOMD (%)	67.4^a	66.9^a	65.5^b	0.33	**
Energy concentration					
GE[1] (MJ kg DM^{-1})	18.5 ± 0.32	18.5 ± 0.26	18.2 ± 0.25	NA	NA
ME (MJ kg DM^{-1})	11.0^a	10.9^a	10.7^b	0.05	**

NA = Not applicable.

[a,b,c] Means within a row bearing different letters differ significantly at $P < 0.05$.

[1] Values are means (± SD) of samples bulked within each sward type during each season (n=8).

Table 5.12 Mean values for nitrogen, ash and metabolisable energy concentrations, and *in vitro* digestibility of ryegrass and prairie grass whole plants during the eight measurement periods, averaged across all three sward types (RG, LM & HM).

	Herbage parameter						
Season	Nitrogen % DM	Nitrogen % OM	Ash % DM	DMD %	OMD %	DOMD %	ME[1]
1987/88							
Early spring	2.0^{b}	2.2^{b}	9.0^{b}	70.2^{b}	75.1^{b}	65.8^{ab}	10.7^{ab}
Late spring	1.8^{b}	2.0^{b}	9.0^{b}	68.9^{bc}	74.3^{b}	65.0^{bc}	10.6^{bc}
Summer	1.9^{b}	2.1^{b}	9.6^{b}	68.2^{c}	73.4^{bc}	63.9^{c}	10.4^{c}
Autumn	2.8^{a}	3.1^{a}	10.5^{a}	72.6^{a}	76.9^{a}	67.4^{a}	11.0^{a}
1988/89							
Early spring	2.6^{b}	2.7^{b}	7.1^{c}	73.1^{b}	77.4^{b}	70.1^{a}	11.4^{a}
Late spring	1.8^{d}	1.9^{c}	7.1^{c}	66.7^{d}	72.4^{d}	63.7^{c}	10.4^{c}
Summer	2.2^{c}	2.5^{b}	9.5^{b}	70.1^{c}	75.0^{c}	66.1^{b}	10.8^{b}
Autumn	2.9^{a}	3.2^{a}	10.9^{a}	75.5^{a}	79.2^{a}	71.1^{a}	11.6^{a}
S.E.	0.08	0.10	0.25	0.64	0.50	0.58	0.09
Sign. level	***	***	***	***	***	***	***

[a,b,c,d] Means within a column within a year bearing different letters differ significantly at $P < 0.05$.

[1] MJ/kg DM.

Table 5.13 Mean values for chemical composition, *in vitro* digestibility and metabolisable energy concentration of green leaf of ryegrass and prairie grass from the three sward types, averaged across all eight seasons.

	Sward type				
Herbage parameter	RG	LM	HM	S.E.	Sign.
<u>Chemical composition</u>					
Nitrogen (% OM)	3.4	3.5	3.5	0.07	NS
Nitrogen (% DM)	3.0	3.2	3.1	0.06	NS
Ash (% DM)	9.8	10.2	10.1	0.14	NS
<u>Digestibility</u>					
Dry matter (%)	72.4^{a}	71.9^{ab}	71.5^{b}	0.28	+
Organic matter (%)	77.0^{a}	76.6^{ab}	76.2^{b}	0.22	+
DOMD (%)	68.8^{a}	68.1^{ab}	67.6^{b}	0.33	+
ME (MJ/kg DM)	11.2^{a}	11.1^{ab}	11.0^{b}	0.05	+

^{a,b} Means bearing different letters differ significantly at $P < 0.05$.
+ = $P < 0.10$
NS = Not significant at $P < 0.05$.

Table 5.14 Mean values for chemical composition, *in vitro* digestibility and energy concentration of green stem of ryegrass and prairie grass from the three sward types, averaged across all eight periods of measurement.

	Sward type				
Herbage parameter	RG	LM	HM	S.E.	Sign.
<u>Chemical composition</u>					
Nitrogen (% OM)	1.7	1.8	1.7	0.05	NS
Nitrogen (% DM)	1.6	1.6	1.5	0.05	NS
Ash (% DM)	7.3	7.2	7.2	0.21	NS
<u>Digestibility</u>					
Dry matter (%)	70.8^{a}	69.7^{ab}	68.4^{b}	0.39	**
Organic matter (%)	75.9^{a}	75.0^{ab}	73.8^{b}	0.33	**
DOMD (%)	68.7^{a}	67.6^{a}	66.3^{b}	0.46	*
ME (MJ/kg DM)	11.2^{a}	11.0^{a}	10.8^{b}	0.06	*

^{a,b} Means bearing different letters differ significantly at $P < 0.05$.

Table 5.15 Mean values (± SD) for chemical composition, *in vitro* digestibility and energy concentrations of inflorescences of ryegrass and prairie grass from the three sward types, averaged across all eight periods of measurement.[1]

	Sward type		
Herbage parameter	RG	LM	HM
Nitrogen (% OM)	2.1 ± 0.4	2.0 ± 0.3	2.0 ± 0.3
Nitrogen (% DM)	2.0 ± 0.0	1.9 ± 0.2	1.9 ± 0.3
Ash (% DM)	7.0 ± 1.5	5.3 ± 0.4	5.6 ± 0.5
DMD (%)	67.8 ± 10.4	64.1 ± 3.5	61.4 ± 4.5
OMD (%)	73.4 ± 8.5	70.4 ± 3.1	68.2 ± 4.0
DOMD %	66.0 ± 8.9	63.4 ± 2.9	60.7 ± 3.8
ME (MJ/kg DM)	10.8 ± 1.5	10.3 ± 0.5	9.9 ± 0.6
n[2]	3	7	7

[1] Values are raw means of samples pooled on seasonal basis.

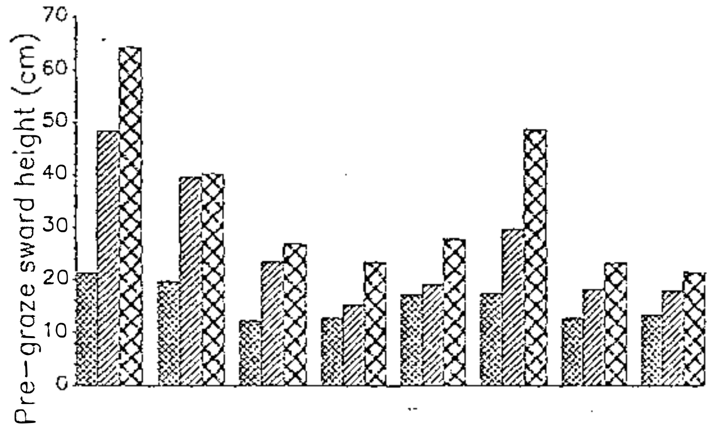
[2] Number of seasons during which inflorescence was available for sampling.

Table 5.16 Mean values (± SD) for chemical composition, *in vitro* digestibility and energy concentrations of senescent matter from the three sward types, averaged across all eight seasons.[1]

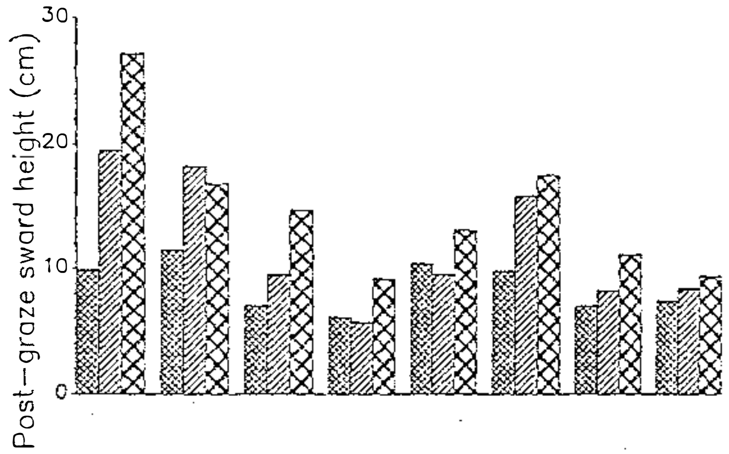
	Sward type		
Herbage parameter	RG	LM	HM
Nitrogen (% OM)	1.8 ± 0.3	1.8 ± 0.3	1.6 ± 0.2
Nitrogen (% DM)	1.6 ± 0.2	1.6 ± 0.2	1.4 ± 0.2
Ash (% DM)	11.1 ± 1.4	10.5 ± 1.5	9.3 ± 1.2
DMD (%)	50.3 ± 1.9	47.9 ± 1.6	45.3 ± 2.1
OMD (%)	48.1 ± 2.8	44.9 ± 2.5	41.3 ± 2.7
DOMD %	42.9 ± 2.8	40.5 ± 2.5	37.7 ± 2.3
ME (MJ/kg DM)	7.0 ± 0.5	6.6 ± 0.4	6.1 ± 0.4

[1] Values are raw means of samples bulked on treatment basis within each season.

(a) Pre-grazing sward height



(b) Post-grazing sward height



(c) Sward bulk density

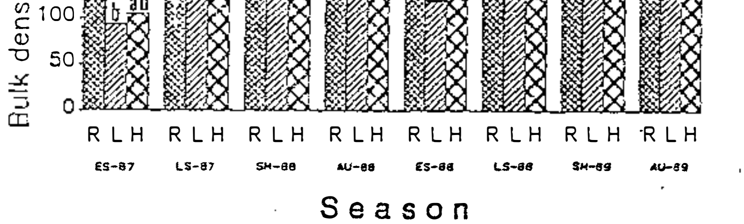
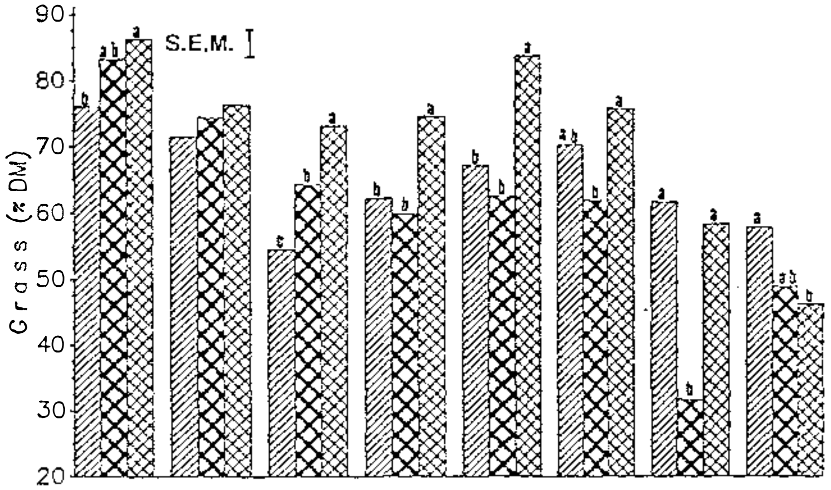


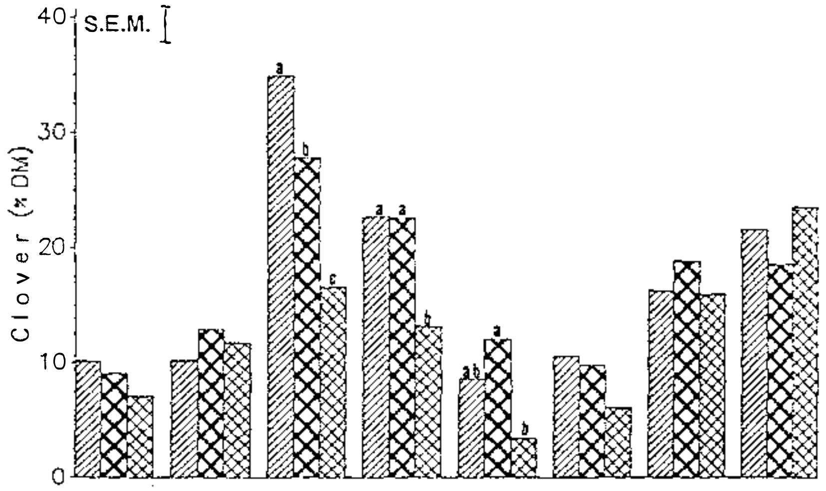
Figure 5.1 Mean values for (a) pre-grazing sward height, (b) post-grazing sward height, and (c) sward bulk density of the three sward types for each period of measurement. Values for (a) and (b) are raw means.

Note: For this Figure and all subsequent Figures in the present chapter, unless indicated otherwise, vertical bars denote the largest standard error of the means (S.E.M.); within each period, means that differ significantly ($P < 0.05$) bear different letters (a, b or c); R=ryegrass swards, L=low mass Matua swards, H=high mass Matua swards; and ES=early spring, LS=late spring, SM=summer, and AU=autumn.

(a) Grass



(b) White clover



(c) Other species

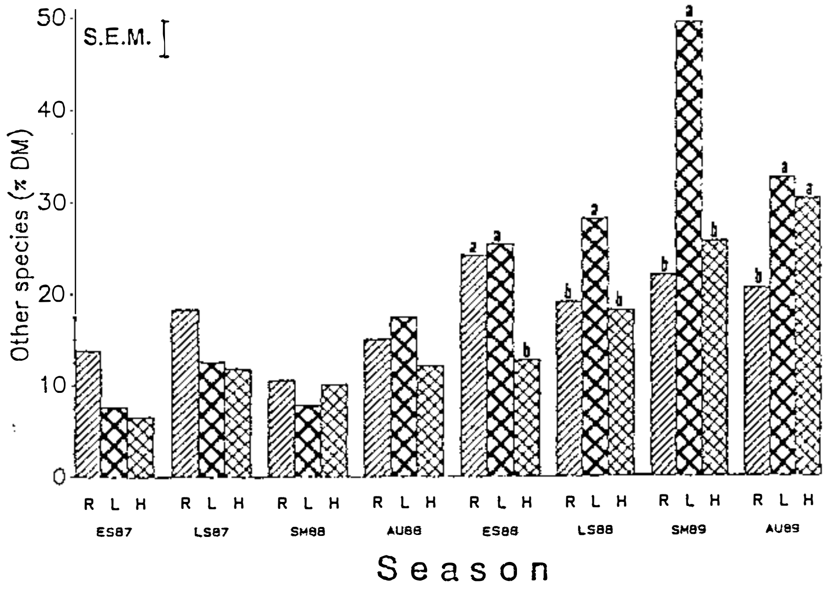
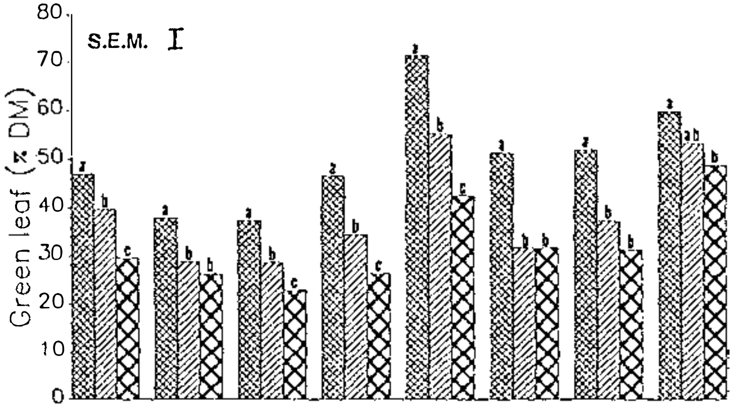
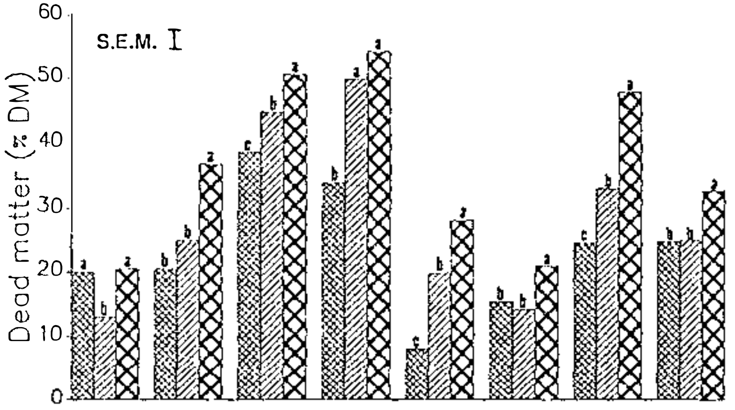


Figure 5.2 Mean values for botanical composition (% dry weight) of the pre-grazing herbage from the three sward types during each of the eight periods of measurement: (a) grass (perennial ryegrass or prairie grass); (b) white clover; (c) others.

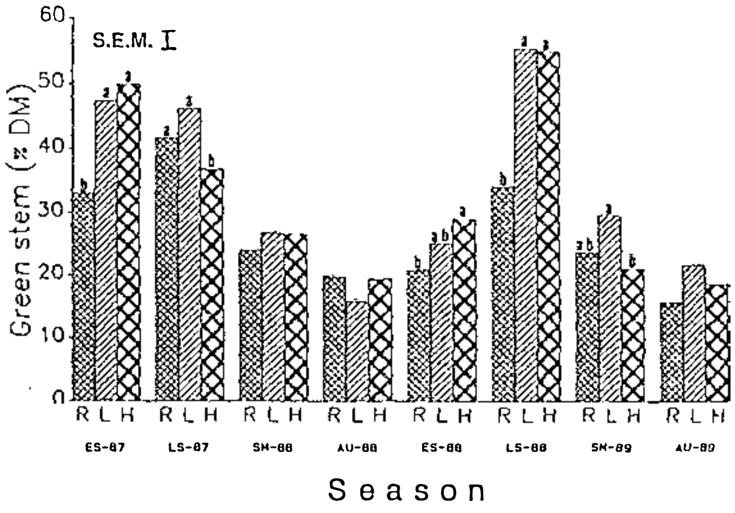
(a) Green leaf



(c) Dead matter



(b) Green stem



(d) Seed head

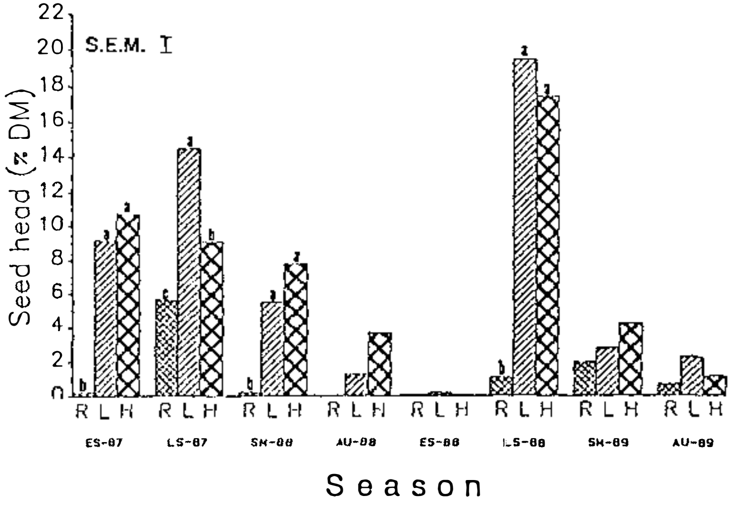
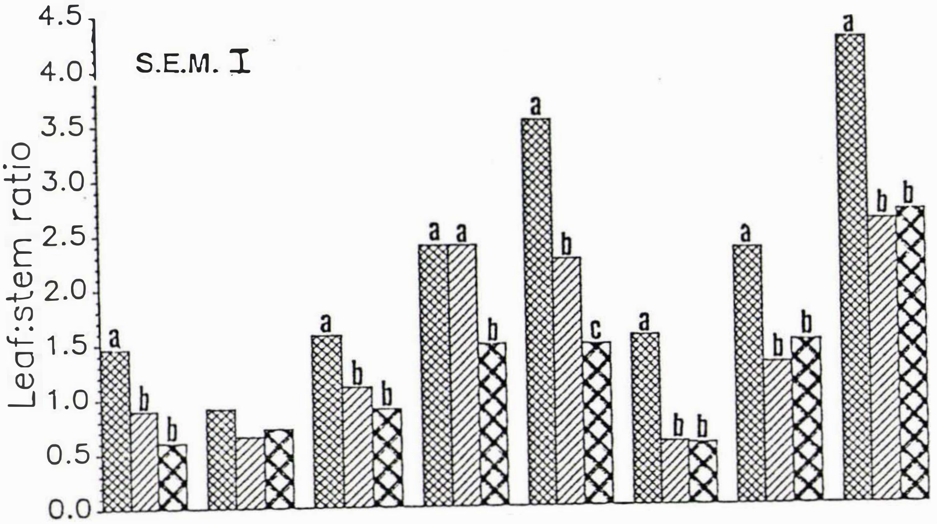


Figure 5.3 Mean values for morphological components (% dry weight) of the pre-grazing herbage from the three sward types during each of the eight seasons: (a) green leaf; (b) green stem; (c) dead matter; (d) seedhead.

(a) Pasture (pre-grazing)



(b) Plant (pre-grazing)

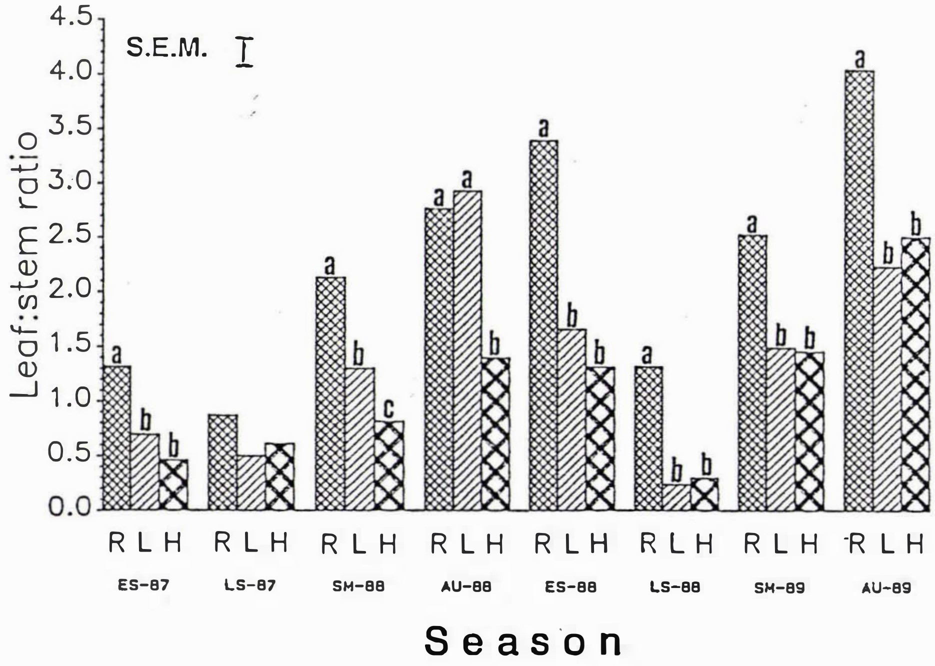


Figure 5.4 Mean values for leaf:stem ratio of the pre-grazing herbage from the three sward types during each of the eight periods of measurement.

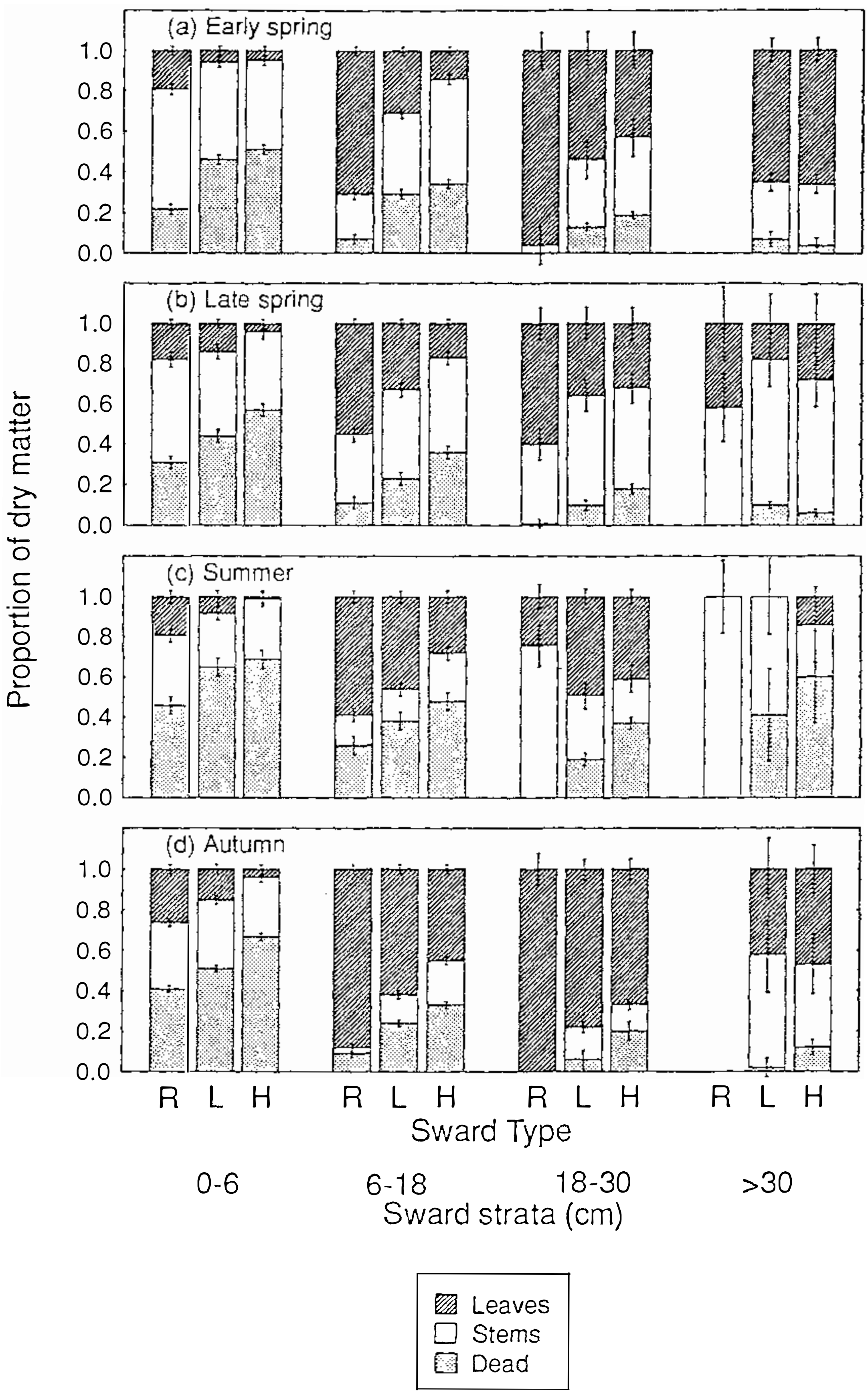
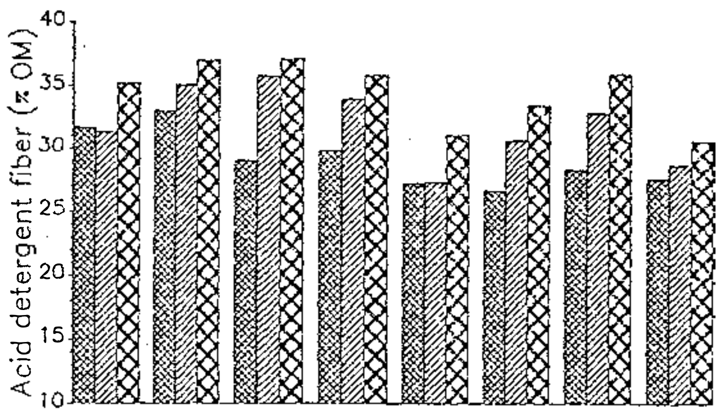
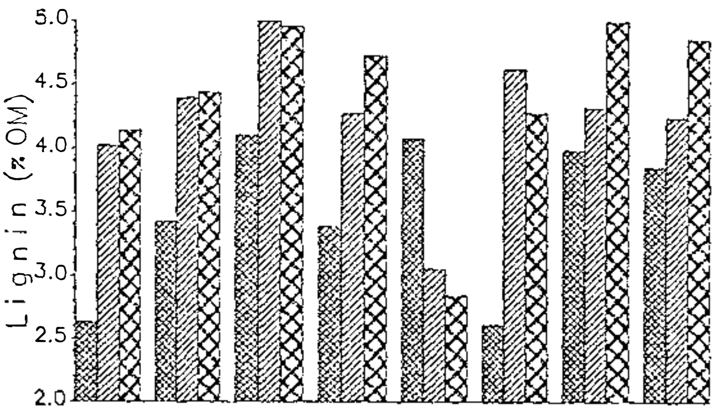


Figure 5.5 Effect of sward type (R = ryegrass, L = low mass Matua and H = high mass Matua) and season on the distribution of the herbage components dead, stem and leaves (base, middle and upper section of each bar) in four vertical sward horizons. Vertical lines indicate the standard error of the mean.

(a) Acid detergent fiber



(b) Lignin



(c) Ash

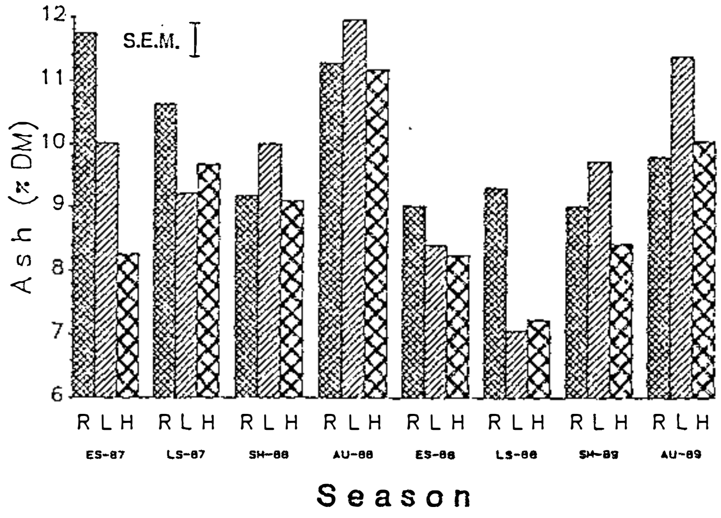


Figure 5.6 Mean values for concentrations of (a) acid-detergent fibre and (b) lignin (% OM), and ash (% DM) in the pre-grazing herbage from each of the three sward types during each of the eight periods of measurement. Values for (a) and (b) are raw means of samples pooled across replications.

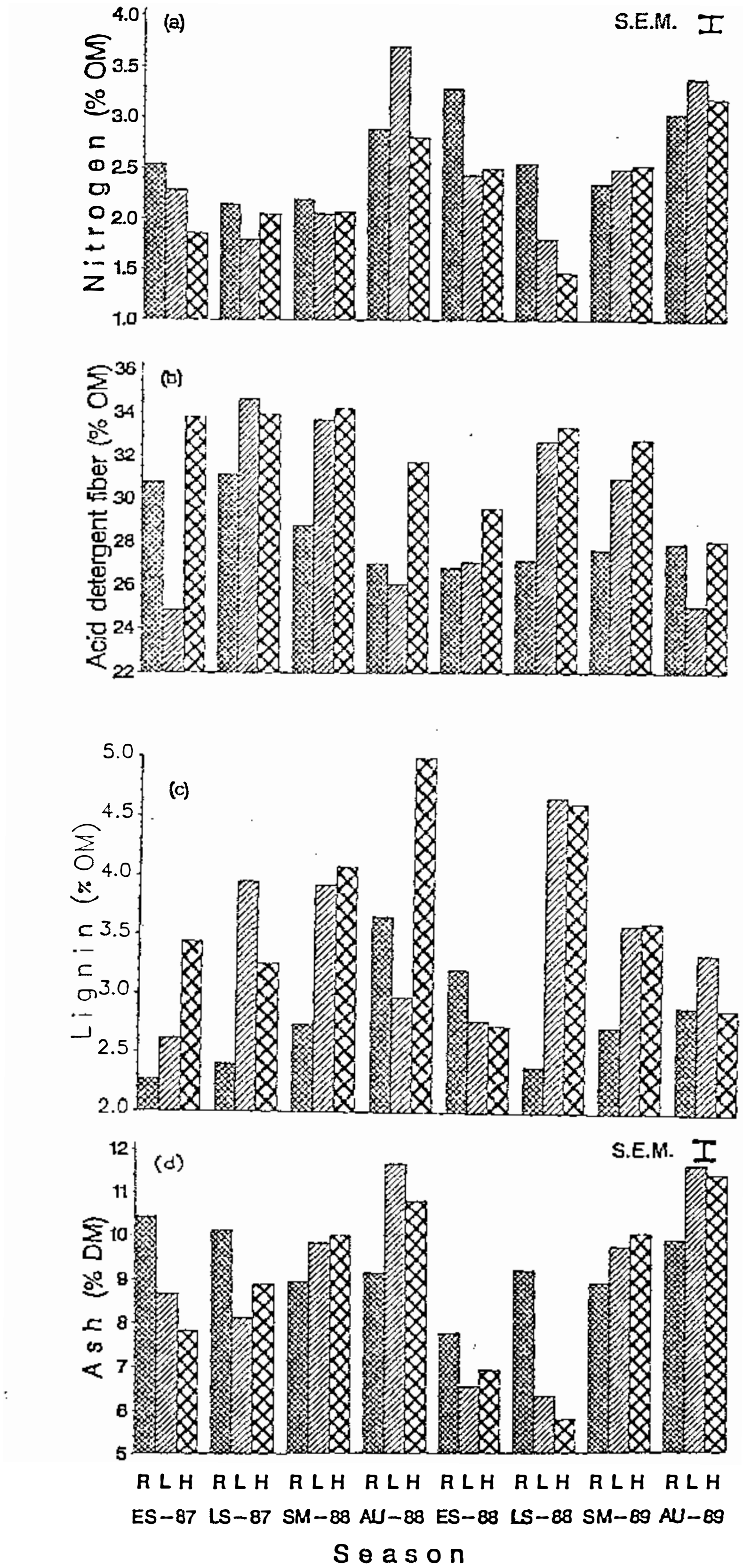


Figure 5.7 Mean values for concentrations of (a) nitrogen, (b) acid detergent fibre[1], (c) lignin (% OM)[1], and (d) ash (% DM) in ryegrass and prairie grass whole plants from the three sward types during each of the eight periods of measurement.

[1] Values are raw data from samples bulked within sward types during each of the eight seasons.

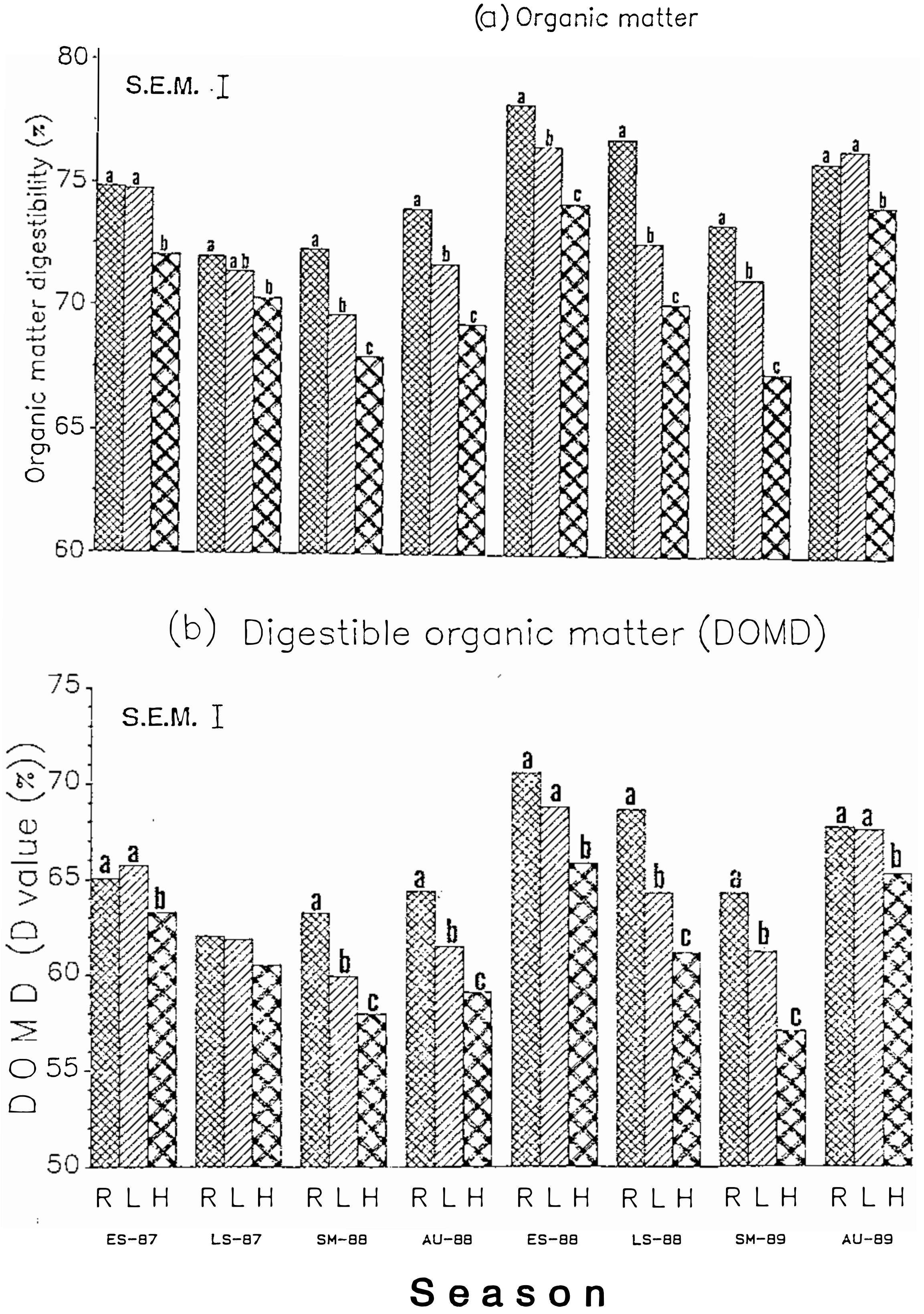
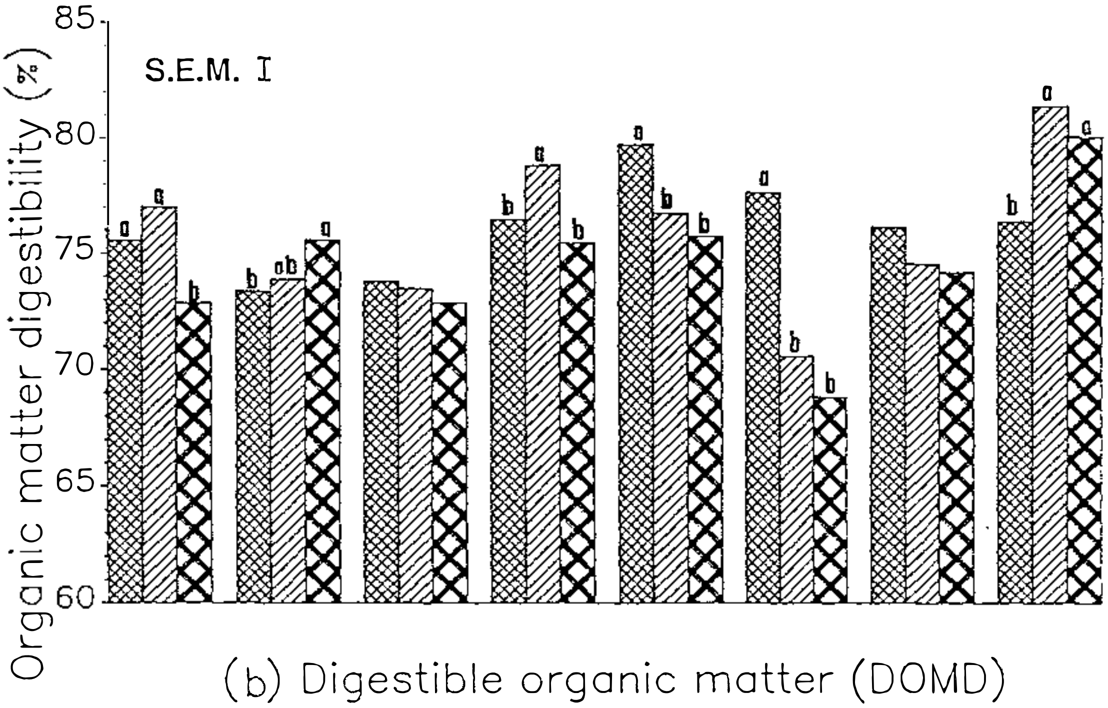


Figure 5.8 Mean values for *in vitro* digestibility of (a) organic matter (%) and (b) concentrations of DOM (%) in the pre-grazing herbage from the three sward types during each of the eight periods of measurement.

(a) Organic matter



(b) Digestible organic matter (DOMD)

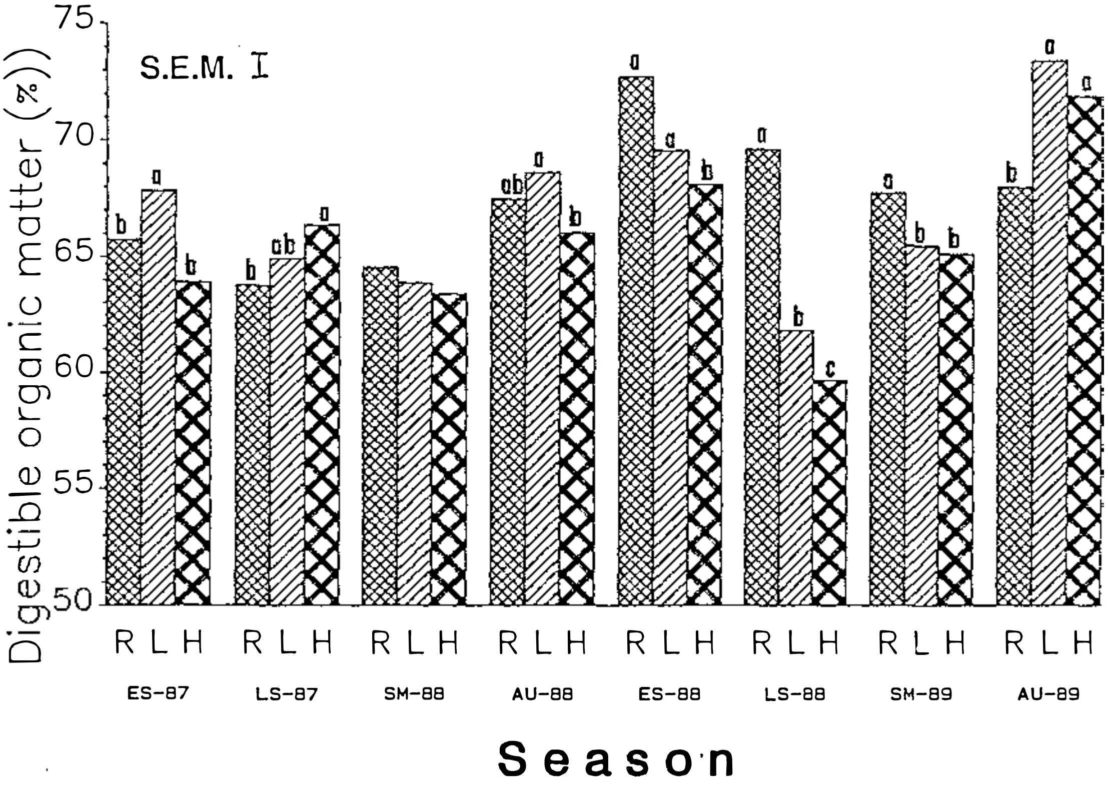
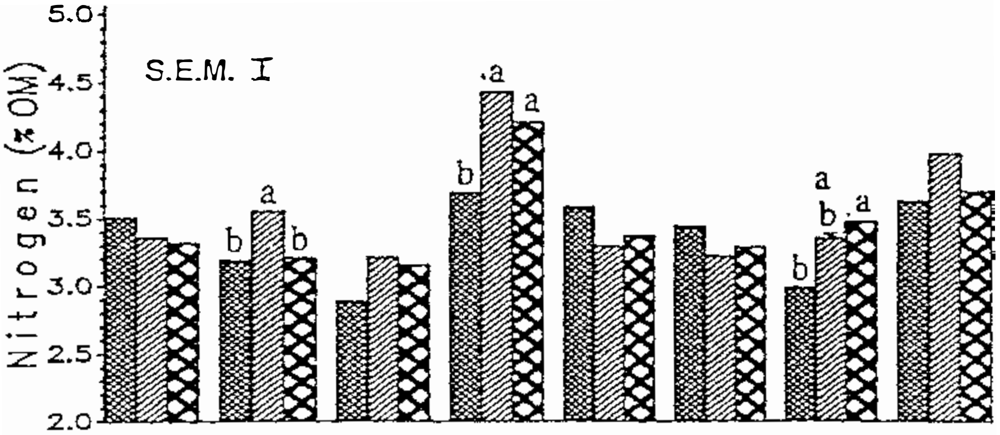


Figure 5.9 Mean values for *in vitro* digestibility of (a) organic matter (%), and (b) concentrations of DOMD (%) in ryegrass and prairie grass whole plants from the three sward types during each of the eight periods of measurement.

(a) LEAF



(b) STEM

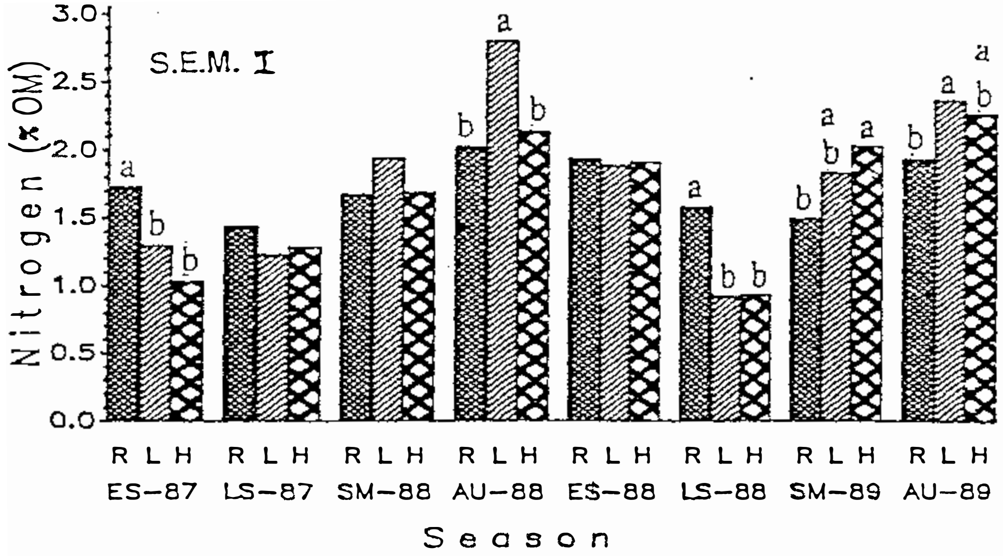
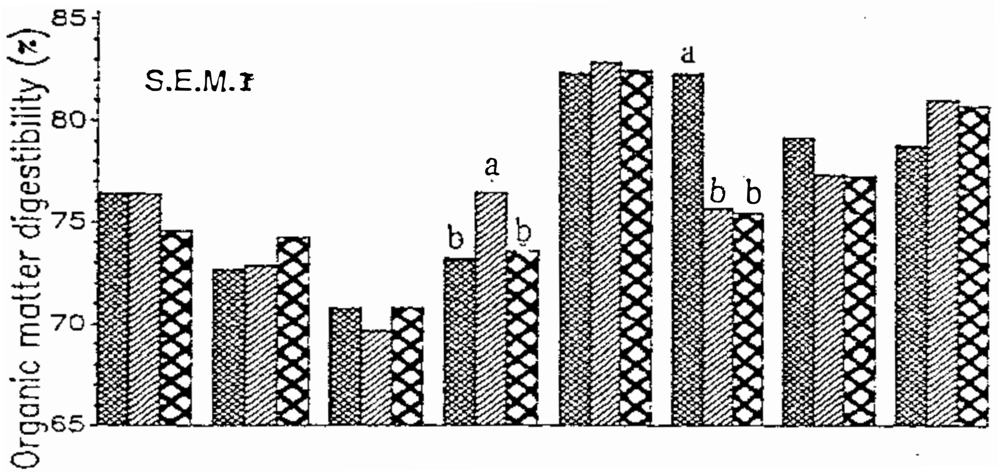


Figure 5.10 Mean values for concentrations of nitrogen (% OM) in (a) green leaf, and (b) green stem fom ryegrass and prairie grass plants from the three sward types during each of the eight periods of measurement.

(a) Organic matter



(b) DOM

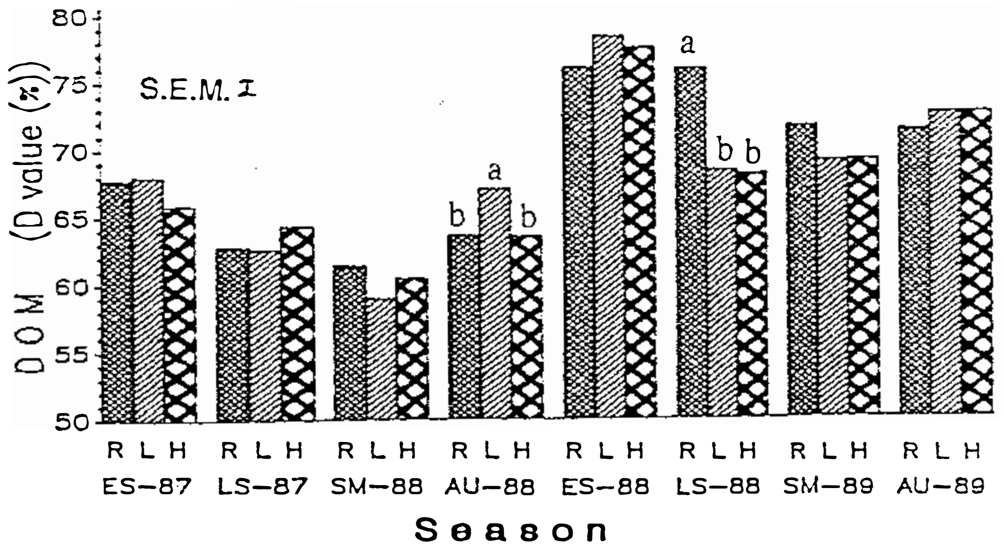
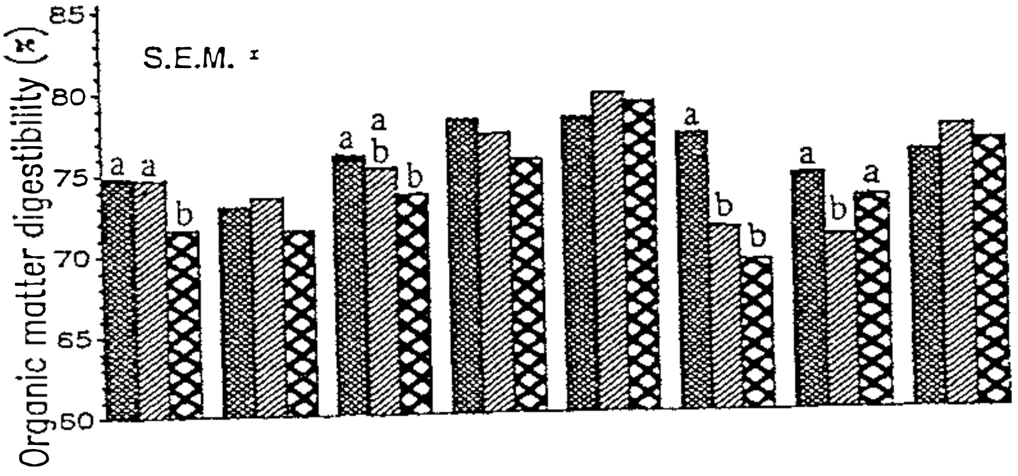


Figure 5.11 Mean values for *in vitro* digestibility of (a) organic matter (%) and (b) and DOMD concentration (%) of green leaf from the three sward types during each of the eight periods of measurement.

(a) Organic matter



(b) DOM

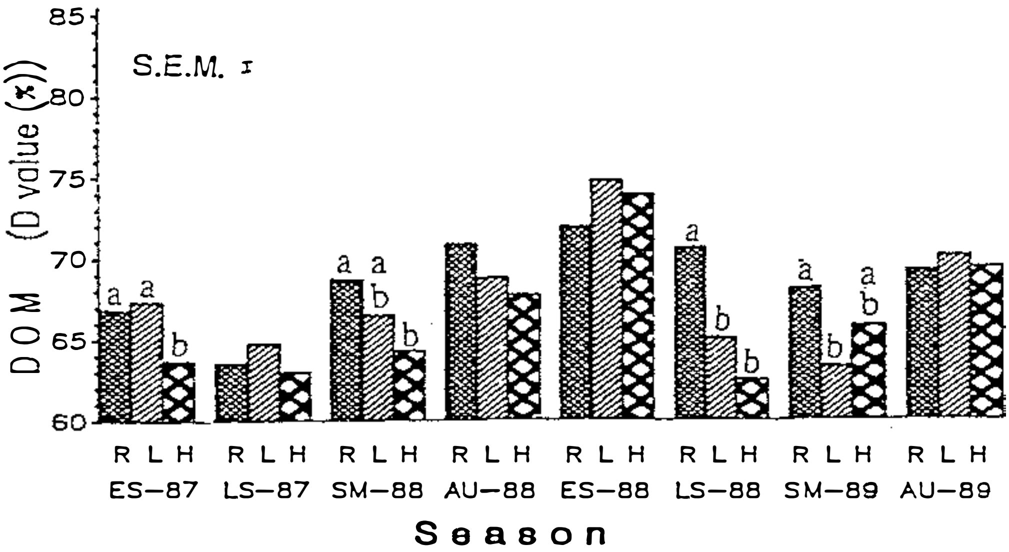


Figure 5.12 Mean values for *in vitro* digestibility of (a) organic matter (%) and (b) and DOMD concentration (%) of green stem from the three sward types during each of the eight periods of measurement.

Plate 5 1 Substantial yellowing of herbage in low mass (top left) and some yellowing in high mass (top right) Matua prairie grass swards, and accumulation of dead matter in high mass Matua swards (bottom) during early spring (September) following a very wet winter

Plate 5 2 Low mass Matua prairie grass sward (top) showing a higher content of white clover and a lower content of dead matter during the summer compared with a high mass Matua sward (bottom)

CHAPTER 6

EFFECTS OF GRAZING REGIME AND SEASON ON THE FEEDING VALUE FOR MILK PRODUCTION OF PRAIRIE GRASS SWARDS GROWN WITH WHITE CLOVER

(EXPERIMENT 2)

6.1 INTRODUCTION

Prairie grass (*Bromus willdenowii* Kunth) is potentially a valuable temperate pasture species for dairy cows both in New Zealand (Rumball, 1974; Belgrave et al., 1990) and elsewhere (Anon., 1982; Parneix, 1982; G.A. Jung, pers. com.). The cultivar 'Grasslands Matua', which is in current use in New Zealand, was released in 1975 as a winter and summer season active, and high nutritive value pasture cultivar most suited to lax-infrequent grazing on well drained, high fertility dairy farms (Rumball, 1974). Previous work showed that cows grazing 'pure' Matua swards of low herbage mass (< 2.5t DM/ha) in spring produced similar quantities of milk and milkfat to cows grazing 'pure' Westerwolds ryegrass or mixed ryegrass/white clover pastures, when offered a generous herbage allowance (Wilson and Grace, 1978). However, subsequent observations with sheep (Alexander, 1985; Fraser, 1985), dairy cows (Brookes and Holmes, 1986; Thom and Prestidge, 1988; Sellars, 1988), or young bulls (Cosgrove and Brougham, 1988; Crush et al., 1989; Webby et al., 1990) have raised questions on Matua's feeding value, levels of consumption of the herbage grown and persistence, under the originally recommended management. The current thinking is that Matua prairie grass can be grazed more intensively with long rest periods (Fraser, 1985; Matthews, 1986), or after replacement tillers have emerged at the base of the sward (Black and Chu, 1989). Such management may lead to significant improvements in the feeding value of Matua prairie grass pastures, and in animal and sward productivity, but this has not been assessed under an applied dairy farming system.

The objectives of the present study were to measure over a range of seasons, the effects of differences in pasture composition and feeding value on the performance of dairy cows grazed on Matua prairie grass/white clover swards maintained at low or high pregrazing herbage mass; and to compare these with milk production data from cows grazed simultaneously on 'conventional' perennial ryegrass/white clover pastures.

6.2 EXPERIMENTAL PROCEDURE

6.2.1 Scope of the experiment

The feeding value for milk production of perennial ryegrass (RG), low mass Matua prairie grass (LM) and high mass Matua prairie grass (HM) swards was measured, during eight short term grazing trials, over two lactations (1987/88 and 1988/89), during early spring, late spring, summer and autumn. The three sward types were grown in association with white clover, and were prepared for this investigation as was explained in Chapter 5, Section 5.2.2. The present chapter describes the feeding value of herbage from the three swards, and details of animal production by the cows grazing on the swards. The details of sward composition have already been described in Chapter 5.

6.2.2 Swards and treatments

The low mass and high mass Matua prairie grass swards were created, and maintained through differential defoliation by dairy cows, at target pre-grazing herbage mass and target post-grazing herbage mass as was defined in Table 5.1 (Section 5.2.3.1).

The three treatments or sward types, perennial ryegrass (RG), low mass Matua (LM) and high mass Matua (HM), were grazed by three groups of lactating cows as described in Sections 5.2.3.2 and 6.2.6.1. The actual dates of experimental grazing of the swards, duration of each grazing trial (days), and the season of measurement were shown in Table 5.2 of the previous chapter. The seasons during which measurements were made were defined in Chapter 3, Section 3.3.

6.2.3 Experimental animals

The selection of cows (predominantly Friesian), selection criteria and management of the animals before each grazing trial were explained in Chapter 5, Section 5.2.3.2.

6.2.4 Experimental design

In each of the eight grazing trials, the differences between the three sward types during each measurement period, and during the entire experimental period, were assessed according to a completely randomized design (Cochran and Cox 1957), with eight cows per treatment.

The problem of inadequate replication in grazing experiments with cattle has been discussed by several workers (Blight et al., 1984; Hoekstra, 1987) and remains a contentious issue, mainly because of resource constraints. For the same reasons the three groups of cows in the current study (each group and its associated paddock constituting the experimental unit) grazed the three sward types without further cow group replication. Statistically, this was of major consequence only in the estimation of feed intake, because failure to isolate within-treatment between-animal and between-paddock (group) variation inflates the random experimental error, and reduces the power of the tests of significance. Where individual animal measurements were taken (e.g. liveweight and milk yields), cows within a treatment group were treated as replications, with animal-within-paddock variation providing the error term. Although the three sward types were replicated in four paddocks, the paddocks within each treatment were grazed in sequence with the same group of cows, at herbage regrowth intervals which were as similar as was practically possible.

6.2.5 Management of experimental animals

During the experimental period, experimental cows were managed in separate groups according to their designated treatments. The cows were milked at 0600 and 1600 hours, spending approximately 2 hours each day away from pasture. The cows were offered their daily herbage allowance, after the morning milking, as one area of fresh pasture, surrounded by electric fences. The cows had access to water at all times.

In early spring all cows were drenched daily with Bloatenz (Economics Lab. N.Z. Limited) at the morning milking, and depending on sward condition during other measurement periods, as a prophylactic measure against bloat. Cows exhibiting oestrus during late spring were inseminated or served by a bull after the morning milking. There were no major health problems during the two year experimental period. The cows had access to mineral block in the milking shed.

6.2.6 Measurements taken

6.2.6.1 Sward measurements

Herbage mass, sward surface height, and morphological composition of herbage before and after grazing, and herbage quality before grazing, were measured as was described in

Chapters 3 and 5 (Section 5.2.4.). Procedures used in estimating herbage allowance (HA), dry matter intake (DMI) and the composition of the diet consumed are outlined below.

Herbage allowance

The area of pasture required to meet the common daily herbage allowance of 50 kg DM/cow (11 kg DM/100 kg liveweight) for each 24 hr period of grazing was determined from the measured pre-grazing herbage mass (from herbage cuts taken 36 hours previously). No account was made for herbage accumulating or disappearing over the 36 hours between the cutting and commencement of grazing.

Dry matter intake

Apparent herbage dry matter intakes were estimated from the difference between pre- and post-grazing herbage masses for each 24 hour break. The amount of herbage which disappeared during the grazing process was presumed to have been eaten by the cows. No attempt was made to correct this value for net herbage accumulation during the grazing period.

Diet composition

The masses of each component calculated to be contained in the sward, both before and after grazing for each break, were used to estimate, by difference, the amount of each component which disappeared during the grazing process. These amounts were assumed to have been eaten by the cows.

6.2.6.2 Animal measurements

The following cow measurements were taken during each grazing trial (on an individual cow basis):

(i) unfasted liveweight and condition score
(ii) daily yields of milk, milkfat, milk protein and lactose
(iii) milk composition (% milkfat, milk protein and lactose)

Cows were weighed after the morning milking (between 0700 and 0800 hours) on two consecutive days immediately prior to the commencement of each measurement period, and on two consecutive days commencing 48 hrs after each grazing trial had terminated. The 48 hour interval between termination of the experimental period and first weighing of the cows was allowed in an attempt to minimize bias due to possible differential gut fill between the treatment groups. The unfasted liveweight of each animal before and after each measurement period was the mean of the two consecutive weights.

The condition score of each cow (Earle, 1976) was assessed visually at the same times that the cows were weighed.

Milk yields for each cow were measured at both milkings on two or three consecutive days per week during the 2 week covariate and the 2-3 week trial periods, respectively. Milk sampling meters (Tru-test Distributors Ltd.), which sample a proportion of the milk flow of each cow, were used to measure milk yield. Daily milk yield was taken as the sum of the yields at the evening milking and at the following morning's milking. Aliquots of milk from each milking were analysed for fat, protein and lactose concentration by infra-red absorption (Milko Scan 104, A/S N. Foss Electric, Denmark). Milk, milkfat, milk protein and lactose yields were calculated for each cow and the figures averaged for the two or three days to give a mean value for daily yield per cow for each week.

6.2.7 Statistical analyses

The effects of sward type and season on the daily allowance of green matter and green leaf, and on daily feed intake, were subjected to univariate analysis of variance for a completely randomized design in a factorial arrangement, as paddock effects were dropped from the model because they were not significant. The effects of sward type and season on the composition of the diet consumed by the cows were subjected to univariate analysis of variance for a split-plot in time design using a linear model described in Section 3.6.2.

The effects of sward type and season on the final unfasted liveweights and condition score, and on changes in liveweight and condition score of the cows at the end of the experimental period (8 trials), were examined by analysis of covariance according to a completely randomized design, with the initial measurements (liveweight and condition score, respectively) nested within seasons as covariates.

Data for daily yields of milk, milkfat, milk protein and lactose, and data for the concentrations of milk fat, milk protein and lactose, were subjected to repeated measures analysis of covariance (variables were measured repeatedly at different times on the same individuals), at the conclusion of each grazing trial. This was to test, by orthogonal contrasts, the effects of time (in weeks) on the response of cows, within and between groups, to the three treatments or sward types. Repeated measures analysis of correlated measurements, a form of multivariate analysis, takes into account the different error structure that exists, within and between animals, across measurement periods (Gill and Hafs, 1971; Bryant and Gillings, 1985). The null hypothesis that the treatment effects are similar are tested within each time period (ibid).

The milk production data were also pooled and subjected to univariate analysis of covariance, with pre-experimental measurements, nested within seasons, as covariates, in order to examine the effects of sward type and season on the various milk production parameters. All data for milk production were analysed according to a completely randomized design.

The following general linear models were used to describe the data for:

(i) green matter, green leaf, total OM and total DOMD allowance (kg/cow daily; dry weight basis), and feed intake:

$$Y_{ij} = \mu + T_i + S_j + (TS)_{ij} + e_{ij}$$

where Y_{ij} = observation in the j^{th} season from the i^{th} sward type

μ = overall mean

T_i = effect of the i^{th} sward type; i = 1,2,3

S_j = effect of the j^{th} season; j = 1,...,8

$(TS)_{ij}$ = interaction between the j^{th} season and the i^{th} sward type

e_{ij} = random residual error associated with the j^{th} season and the i^{th} sward type, and is assumed to be normally distributed with mean 0 and variance σ^2.

(ii) final and change in liveweight and condition score of the cows; and yields of milk, milkfat, milk protein and lactose, and the concentrations of milk solids over the whole experimental period:

$$Y_{ijk} = \mu + T_i + S_j + \beta x_{ik(j)} + (TS)_{ij} + e_{ijk}$$

where Y_{ijk} = observation on cow k in season j on sward type i

μ = overall mean

T_i = effect of the i^{th} sward type; i = 1,2,3

S_j = effect of the j^{th} season; j = 1,...,8

β = regression coefficient associated with $x_{ik(j)}$

$x_{ik(j)}$ = initial observation of the variable concerned on the k^{th} cow within the j^{th} season on the i^{th} sward type

$(TS)_{ij}$ = interaction between the j^{th} season and the i^{th} sward type

e_{ijk} = random error associated with the k^{th} cow in the j^{th} season on the i^{th} sward type, and is assumed to be randomly distributed with mean 0 and variance σ^2.

(iii) milk, milkfat, milk protein and lactose yields with covariates during each measurement period or season (repeated measurements analysis):

$$Y_{ikp} = \mu_p + T_{ip} + \beta x_{ik} + e_{ikp}$$

where Y_{ikp} = observation on the k^{th} cow on the i^{th} sward type in period (week) p

μ = mean of the p^{th} week

T_{ip} = effect of the i^{th} sward type in the p^{th} week; i=1,2,3; p = 1,2,3

β = regression coefficient associated with x_{ik}

x_{ik} = initial observation of the k^{th} cow on the i^{th} sward type before each measurement period commenced

e_{ikp} = random error associated with the k^{th} cow on the i^{th} sward type during the p^{th} week, and is assumed to be normally distributed with mean 0 and variance σ^2 but there being covariance across weeks.

6.3 RESULTS

6.3.1 Herbage allowance and intake

6.3.1.1 Herbage allowance

The values for daily allowance of total herbage (HA), green matter (GMA), green leaf (GLA), organic matter (OMA) and digestible organic matter in the dry matter (DOMA), for cows grazing either RG, LM or HM swards, averaged across the eight experimental periods, are presented in Table 6.1a. The daily HA actually given to the cows on each of the three swards (mean, 50.2 kg DM/cow; $P>0.05$) agreed closely with the nominal target of 50 kg DM/cow. Similarly, there were no significant differences between the cow groups ($P>0.05$) in the mean daily OMA in the dry herbage (mean, 45.4 kg/cow). There were, however, significant differences between the swards ($P<0.001$) in the masses of green matter, green leaf and DOM presented to the cows daily (Table 6.1a; Appendix 6.1a). In comparison to the LM and HM swards, green matter allowance for the cows on RG swards was greater by 8 and 19%, green leaf allowance was greater by 25 and 37%, and digestible organic matter allowance was greater by 7 and 8%, respectively.

Seasonal variations in the masses of the various sward components presented to the cows daily, arising from interactions between season and sward type, are illustrated in Figure 6.1 and Appendix 6.1a.

Green matter allowance

Cows on the HM treatment received the smallest green matter allowance during all the experimental periods, except in early spring when GMA was similar to that for cows on the RG swards (Year One) or the LM swards (Year Two) (Figure 6.1a). Cows on the LM swards received less GMA than those on the RG swards during five of the eight periods of measurement; at other times GMA was similar on the two swards.

Green leaf allowance

During all the experimental periods, green leaf allowance was greatest for RG, intermediate for LM swards and smallest for HM swards, and differences between the treatments were significant (Figure 6.1b).

Organic matter allowance

The daily allowance of organic matter did not differ significantly between the sward types throughout Year One of the experiment, while differences between sward types during Year Two were inconsistent (Figure 6.1c).

Digestible organic matter allowance

The daily DOMA for cows on the RG and LM swards was similar during five of the eight measurement periods, but that for cows on the HM sward type was generally the smallest, and this difference was most apparent between late spring and autumn of Year Two (Figure 6.1d).

Seasonal trends

Green mass allowance for all swards tended to decline during summer and autumn, but GLA was smallest in late spring and summer; while DOMA varied very little between seasons but was smallest in summer (Figure 6.1a,b,d, respectively; Appendix 6.2). The differences in GMA, GLA and DOMA arose because of differences in composition of herbage from the three swards, and despite the similarities in DMA and OMA (see Section 5.3.5.2; Table 5.5).

6.3.1.2 Herbage intake

Apparent daily intakes of herbage dry matter, averaged across the seasons of measurement, were similar for cows on the RG and HM swards (mean, 17.3 kg/cow daily), while intake from LM swards was greater (P = 0.001 *vs* RG, P = 0.03 *vs* HM) (Table 6.1a). Daily herbage intake as a percentage of liveweight followed a pattern similar to that for DM intake (Table 6.1a). There were no significant (P > 0.05) season or season x sward type effects on apparent herbage intake (Appendices 6.1a & c and 6.2).

6.3.1.3 Composition and metabolizable energy concentration of the diets

The calculated mean compositions of the diets and the corresponding estimates of ME concentrations are presented in in Tables 6.1b and 6.1c, respectively. The values presented were not analysed statistically. Nevertheless, these values provide an indication of the diets likely to have been consumed by the cows grazing on each of the three sward types , and their estimated ME concentrations.

The diet consumed from the RG swards contained, generally, a greater proportion of green leaf and smaller proportions of stem and dead matter, and the concentration of ME tended to be higher than that of diets from the LM and HM sward types. The diets consumed from the LM and HM treatments showed only small differences in the proportions of the dietary components. Diets from the RG, LM and HM treatments contained, respectively, green leaf, 83, 61 and 58%; green stem, 15, 30 and 31%; and dead matter, 2, 9 and 11%; corresponding values for ME concentration were 11.2, 10.7 and 10.4 MJ ME/kg DM.

6.3.2 Animal production

The main points regarding animal production are highlighted in the following brief summary, in order to assist the reader to progress through the data and the differences between treatments:

Milk yield
(kg/cow daily) : RG > LM > HM, averaged across periods.

: RG > HM; LM not different from either RG or HM in early spring Yr 1.

: RG = LM > HM in autumn Yr 1, early and late spring Yr 2.

: RG > LM > HM in summer Yr 1 and 2.

: RG = LM = HM in late spring Yr 1 and autumn Yr 2.

Milk yield fat
(kg/cow daily) : RG = LM > HM, averaged across periods.

: RG = LM > HM in early spring and autumn Yr 1, and late spring Yr 2.

	:	RG ≈ LM = HM in early spring and autumn Yr 2.
	:	RG ≈ HM < LM in late spring Yr 1.
	:	RG > LM > HM in summer Yr 1 and 2.
Milk protein (kg/cow daily)	:	RG > LM > HM, averaged across periods.
	:	RG ≈ LM > HM in early spring Yr 1, and late spring and autumn Yr 2.
	:	RG > HM, LM not different from either RG or HM in late spring Yr 1 and early spring Yr 2.
	:	RG > LM > HM in summer Yr 1 and 2 and autumn Yr 1.
Lactose yield (kg/cow daily)	:	RG > LM > HM, averaged across periods.
	:	RG ≈ LM > HM in early spring and autumn Yr 1, and late spring and summer Yr 2.
	:	RG ≈ LM = HM in late spring Yr 1 and autumn Yr 2.
	:	RG > LM > HM in summer Yr 1.
	:	RG > HM, LM not different from either RG or HM in early spring Yr 2.

% milkfat : RG = LM = HM, averaged across periods.

: RG = LM = HM except in summer Yr 2 when RG > HM, LM not different from either RG or HM.

% milk protein : RG = LM > HM, averaged across periods.

: RG = LM = HM in late spring Yr 1 and 2, summer Yr 1, and early spring and autumn Yr 2.

: RG = LM > HM in early spring Yr 1.

: RG > LM, HM not different from either RG or LM in autumn Yr 1.

: RG > HM, LM not different from either RG or HM in summer Yr 2.

% lactose : RG = LM = HM, averaged across periods.

LW change (kg/cow per day) : RG = LM = HM, averaged across periods.

Condition score change : RG > HM, LM not different from either RG or HM, averaged across periods.

6.3.2.1 Milk production and composition within experimental periods

Milk yield

Mean daily yields of milk, milkfat, milk protein and lactose of cows on each of the three swards for each period of measurement, and the effects of time (in weeks) on the treatments on these yields within each trial period are presented in Tables 6.2, 6.3, 6.4 and 6.5, respectively. Milk production trends, when compared across seasons are illustrated in Figure 6.2.; milk production averaged across experimental periods is shown in Table 6.7a. Sward type exerted significant effects on the daily yields of milk in six of the eight experimental seasons (Table 6.2). The LM group produced 5 to 8% less milk ($P < 0.05$) during summer (both years) than the RG group; at other times daily milk yields did not differ significantly between the two treatment groups. During six of the eight experimental periods, milk yields of HM cows were smaller than those of the RG and LM groups by 8 to 19% and by 6 to 15%, respectively. However, in two of the eight trials (late spring of Year One and autumn of Year Two), the differences in daily milk production between the three treatment groups were not significant ($P > 0.05$), even though yields from the HM group were again the smallest. The difference in milk yield between the HM group and the other groups was largest in late spring and summer.

Time effects, during each experimental period, on the daily production of milk and milk solids, were tested by repeated measures analysis. This was to examine whether animal production response, within and between treatments, was affected by time on the trial; whereby weekly yields of milk and milk solids were compared within and between sward types, as was described in Section 6.2.7.

There were no significant time effects, within each experimental period, on the milk yield response of the cows grazing on the three swards types. Treatment-group x time interactions were inconsistent between years (Table 6.2), which made further examination of their nature not worthwhile. Similarly, within treatment yields of milkfat, milk protein and lactose (Tables 6.3, 6.4, 6.5, respectively) did not vary significantly between weeks during the course of each trial; and the treatment x time interactions were generally not significant within each measurement period .

Milkfat yield

As for milk yield, daily yields of milkfat were significantly affected by sward type in all the experimental seasons, except during early spring and autumn of Year Two when yields for the three treatment groups were similar (Table 6.3). While the RG and LM groups produced similar milkfat yields in early spring, summer and autumn of Year One, yields for the LM group were significantly greater ($P < 0.05$) than those for the RG group in late spring (both years), whereas in the summer of Year Two the reverse was observed. Milkfat yields for the HM group were consistently smaller than those of the RG and LM treatments (by 6 to 21%), and the differences between means were significant during six of the eight grazing trials (Table 6.3). Once again, the magnitude of the difference in milkfat yield between the HM group and the remaining treatment groups was largest during the summer in both years.

Milk protein and lactose yields

Daily yields of milk protein for the HM group were consistently smaller than those of the RG group (by 5-21%) and the LM group (by 5-15%), and these differences were generally significant (Table 6.4). The RG and LM groups produced similar yields of milk protein in early and late spring (both years), but during the summer and autumn, protein yields for the LM group were approximately 6% smaller (Table 6.4).

Daily yields of lactose did not differ significantly between the three treatment groups during the late spring of Year One and the autumn of Year Two; at all other times yields by cows grazing on the HM swards were significantly smaller than those of the RG and LM groups (Table 6.5). Yields of lactose for the RG and LM groups were generally similar throughout the study.

Milk composition

Sward type had no significant effect ($P > 0.05$) on either percent milkfat or milk protein in most periods of measurement, however, % milk protein tended to be smaller on HM swards (Tables 6.6 a,b). The percentages, in the milk, of both milk fat and protein generally increased with advancing stage of lactation (Tables 6.6a & b).

6.3.2.2 Milk production and composition averaged across measurement periods

The effects of sward type on daily yields of milk and milk components and on milk composition, averaged across the experimental periods, are presented in Table 6.7a.

Milk production

When compared to the RG group, mean values for daily milk yields were smaller for the LM and HM treatments by 3% ($P < 0.01$) and 11% ($P < 0.001$), respectively; while milk yield for the LM group was 9% greater ($P < 0.001$) than that of the HM group. Milkfat yields for the RG and LM treatments did not differ significantly ($P > 0.05$), whereas milkfat yield for the HM group was 12% smaller ($P < 0.001$) in comparison to the remaining treatments. Daily yields of milk protein for the RG treatment were 3% ($P < 0.001$) and 14% ($P < 0.001$) greater than yields for the LM and HM groups, respectively. Similarly, lactose yield for the RG group was 2% ($P < 0.01$) and 11% ($P < 0.001$) greater than yields for the LM and HM treatments, respectively. The differences between the LM and HM treatment means for yields of milk protein and lactose were 11 and 9% ($P < 0.001$), respectively, in favour of the LM treatment.

When the data for daily yields of milk and milk solids were compared across the seasons of measurement (Figure 6.2, Appendix 6.3), significant season x sward type effects caused only slight changes in the pattern of milk yield responses between seasons as was described in Section 6.3.2.1. Whereas milk yields for RG and LM groups differed significantly only during summer (both years) in the seasonal analyses of variance (Table 6.2), milk yield for the LM group in the pooled analysis was significantly smaller in the early spring and summer of Year One, and values for the RG and LM groups remained similar for the remaining seasons (Figure 6.2a). The cows on the HM swards produced significantly less milk than those on RG or LM swards during six of the eight periods of measurement (Figure 6.2a), as was observed from the within period analyses (Table 6.2). Milk yields from the three sward types were similar during the late spring of Year One for both within- and across-period analyses. They were also similar in the autumn of Year Two for the within-period analysis, but those from HM and LM swards for the same period, tended to be smaller than those from RG swards for the combined analysis (Figure 6.2a).

When the data for milkfat yields from each experimental period were compared in a pooled analysis of variance, there were considerable changes in the response patterns of the treatment groups for milkfat yield (Figure 6.2b) in comparison to those shown in Table 6.3 (Section 6.3.2.1). Milkfat yields for the RG and LM treatments, when compared both within and across periods, were similar during five of the eight seasons of measurement. In the latter, analysis differences in milkfat yields between these two groups of cows (RG and LM) occurred only in the late spring (RG < LM) and summer (RG > LM) of Year One (Figure 6.2b), while in the former analysis the differences occurred in the late spring of both years

(LM > RG) and in the summer of Year Two (RG > LM) (Table 6.3). Milkfat yields from HM swards were the smallest in both analyses during all periods of measurement, except in the autumn of Year Two when yields from the three swards were similar.

The effects of season and sward type on the daily yields of milk protein are illustrated in Figure 6.2c. The presence of significant season x sward type interaction effects on the yields of milk protein did not alter the within- or between-season yield response patterns of the three treatment groups presented in Section 6.3.2.1 and in Table 6.4. In general, yields of milk protein for the RG and LM treatments were similar in early and late spring (both years), but yields were smaller for the LM treatment during summer and, to a lesser degree, during autumn. Again, daily yields of milk protein for the HM group were generally the smallest.

Similarly, daily yields of lactose by cows on the three sward types, followed the same seasonal pattern (Figure 6.2d) as that presented for the within period data (Section 6.3.9.1, Table 6.5).

The influence of season on the daily yields of milk and milk constituents, averaged across all three sward types, is demonstrated in Table 6.7b and Appendix 6.3. The simple effects of season on the yield of milk, milk protein and lactose were not significant ($P > 0.05$), although yields were generally greater in the early and late spring than in summer or autumn. Milkfat yields, however, were high in early and late spring but declined significantly in the summer-autumn period.

Milk composition

Sward type had no significant effect ($P > 0.05$) on milk composition for percent milkfat or lactose (Table 6.7a; Appendix 6.3). Mean compositions, averaged across the experimental periods, were milkfat, 4.5% and lactose, 4.7%. Percent milk protein, however, was significantly smaller ($P < 0.01$) for the HM treatment (3.5%) than either the RG or HM values, which did not differ significantly (mean, 3.6%; Table 6.6c). There were no significant season x sward type effects on fat or protein percentages in the milk, but the effects of season on milk composition, averaged across the treatments, were significant (Table 6.7b; Appendix 6.3). Generally, % milkfat was greater but % protein was smaller in the late spring-summer period in comparison to early spring and autumn values. The confounded effects of season and stage of lactation on % milkfat and milk protein were presented in Section 6.3.2.1 (Tables 6.6a,b), whereby the concentrations of both milk components generally increased with advancing stage of lactation.

6.3.2.3 Liveweight and condition score

The initial unfasted mean liveweights and body condition scores of cows grazing each of the three experimental swards, and changes in these parameters, averaged over the entire experimental period, are presented in Table 6.7a. The mean initial liveweight of the cows was 459 ± 51 kg/cow, while the initial mean body condition score was 4.6 ± 0.7. Sward type had no significant effect on either the mean change or rate of change in liveweight of individual cows averaged across the periods of measurement, and the actual change in liveweight was negligible (mean, +1.0 kg/cow over 15 ± 3 days or +112 g/cow per day). However, there was a significant difference between RG and HM cows in the mean change in body condition (+ 0.1 for RG and - 0.1 for HM cows), that of the LM cows did not differ significantly from the remaining groups.

There were no significant season or season x sward type effects on the change in liveweight of the cows, while significant season effects but not season x sward type interactions were observed on the change in condition score (Table 6.8; Appendix 6.4). The cows generally experienced a larger negative change in liveweight and body condition during summer compared to the other periods, and this corresponded to the period of lowest herbage quality (see Section 5.3.6.1).

6.4 DISCUSSION

6.4.1. Pasture allowance and intake

6.4.1.1 Pasture allowance

The output of milk from pasture depends upon the combined effects of the quality and quantity of pasture grown, and the efficiencies with which the pasture is harvested and converted into milk by the grazing cow. In this respect, herbage allowance (HA) is an important determinant of the intake and performance of grazing dairy cows (Le Du et al., 1979; Stockdale, 1985b; Stakelum and Dillon, 1991; see also Sections 2.4.3.4 and 2.4.4.2). In the present study, the choice of the target daily HA (50 kg DM/cow or 11 kg DM/100 kg liveweight) was intended to facilitate maximal (ad libitum) herbage intake by the cows. The objective was to provide an environment unconstrained by herbage availability under which the feeding value, for milk production, of Matua prairie grass pastures differing in composition would be evaluated, and compared with that of conventional perennial ryegrass pasture.

Total herbage allowance

The actual daily herbage allowances given to the cows grazing on the three sward types (RG, LM and HM), averaged across the treatment periods, were similar (average 50.2 kg DM/cow; Table 6.1a). This similarity, and the high absolute value of the herbage allowance given to the cows suggests that the dry matter intakes (DMIs) (17 to 19 kg DM/cow) measured in the present study (Table 6.1a) were close to maximal. Previous studies have shown that the DMI of lactating dairy cows grazing on temperate swards is usually maximised when herbage allowance is 2.5 to 4 times intake (Combellas and Hodgson, 1979; Bryant, 1980; Glassey et al., 1980; Stockdale, 1985a). For example, Glassey et al. (1980) and Bryant (1980) observed early lactation (early spring) DMIs of 16.3 and 13.3kg DM/cow (4.8 and 3.6kg DM/100kg liveweight), respectively, at a daily HA of approximately 53 kg DM/cow (16 and 14kg DM/100kg liveweight respectively). These DMIs were close to the maximum, since intakes increased very little above herbage allowances of 33-40 kg DM/cow (10-11kg DM/100kg liveweight; Figure 2.7a).

Actual herbage allowances varied between 43.3 and 53.9kg DM/cow throughout the study, probably because of the errors associated with the preliminary estimation of herbage mass when daily grazing areas were allocated (Appendix 6.1b), but it is unlikely that the small differences in HA affected the results for intake (Appendix 6.1a & c) or milk production.

Green matter allowance and green leaf allowance

The daily allowances of green matter (GMA) and green leaf (GLA), averaged across the experimental periods, did differ between treatments. They were smaller for cows grazing on the HM than on the RG swards (Table 6.1a). Corresponding allowances for the LM swards were intermediate, and showed considerable seasonal variation (Figure 6.1; Appendix 6.1a). The daily GMA and GLA for the LM swards (means 35.8 and 19.1 kg DM/cow respectively) were, respectively, 8 and 25% smaller than those for the RG swards; and were 19 and 37% greater than those for the HM swards. The greater allowances of GMA and GLA for the RG swards occurred because the RG swards contained greater concentrations of green leaf (by 12-18 percent units), and smaller concentrations of stem and dead matter (by 6 and 5-13 percent units respectively) than both the Matua sward types. Both the Matua swards had similar concentrations of stem, but the HM swards contained a greater concentration of dead matter, by 8 percent units, while the concentration of green leaf for the LM swards was greater by 6 percent units (Chapter 5, Table 5.5). These differences in the component compositions of the swards were generally consistent during the study period (Chapter 5, Figure 5.3).

For all the three sward types GMA declined during the summer and autumn, while GLA decreased during the late spring/summer period (Appendix 6.2); however, the magnitude of decline for these parameters was greater for the Matua swards, with that of HM being greater than LM. These trends reflected the greater rates of stem accumulation during the late spring/summer period (smaller GLA) and of dead matter accumulation (smaller GMA) during the summer/autumn period (Korte et al, 1984; L'Huillier, 1987b; Hoogendoorn et al., 1988); and the greater rates of stem and dead matter accumulation in the HM than LM swards (Xia, 1991), and of Matua prairie grass than ryegrass (Hume, 1991c,d).

Results from previous studies show that at a common, generous HA the DMIs of grazing dairy cattle were increased by higher green matter or green leaf allowances; conversely DMIs were similar when a common GLA was offered from swards of differing mass and composition (Hoogendoorn et al., 1988; Stakelum and Dillon, 1991). The possible reasons for the observed differences in DMI between the sward types in the present study are discussed in Section 6.4.1.2.

Digestible organic matter allowance

In view of the large differences in the morphological compositions of the three sward types, it was interesting that the DOMA allowances for the RG and LM sward types (means 33.2 and 31.8 kg/cow respectively, $P > 0.05$) were similar. This was true during six of the eight trials, with very little seasonal variation (Figure 6.1), except during the summer (both years) when the DOMA was smaller for the LM swards. The possible explanation for these observations will follow shortly. The summer period coincided with the greatest concentration of dead matter in the Matua swards (Chapter 5), but DMIs from these swards were highest during the summer period (Table 6.1a), which was unexpected (see Section 6.4.1.2 for a possible explanation).

Furthermore, it would have been expected that the greater concentrations of stem and dead matter of the Matua swards in comparison to the RG swards would generate smaller DOMAs from the former than the latter swards. The very small differences actually observed in the OMD of green leaf and stem between the RG and LM swards (Chapter 5,

Table 5.9), and the smaller proportion of dead matter in the LM than HM swards, may account for the similarity of DOMA between the RG and LM swards; and despite the large difference (1 ton DM/ha) in pregrazing herbage mass between the two sward types.

However, the DMI for the LM swards (18.6 kg DM/cow or 16.8 kg OM/cow) measured in the present study was greater than the DMIs for the remaining sward types, which were similar (17.3 kg DM/cow or 16 kg OM/cow). The greater or similar DMIs for the Matua swards (LM & HM) when compared to the RG swards, were unexpected (probable explanation in Section 6.4.1.2).

6.4.1.2 Herbage intake, diet composition and metabolisable energy intake.

Limitations of estimating herbage intake at pasture

Apparent herbage dry matter intakes (DMIs) were estimated by the difference technique, with the assumption that the difference between herbage mass before and after grazing, i.e. herbage disappearing during the grazing process, had been consumed by the animals (Meijs, 1981; Leaver, 1982). The limitations of this technique for estimation of DMIs of grazing animals have been extensively reviewed (ibid), while those of estimating pasture mass were reviewed by t'Mannetje (1978) and Frame (1981). One particular problem is the high standard errors associated with the method, even when the pre- and post- grazing cuts are made daily, during the course of a grazing trial (Hoogendoorn, 1986). The problem of high standard errors surrounding the DMI means is compounded by the very high herbage masses observed for prairie grass in the present investigation (up to 7 t DM/ha). High herbage masses are associated with considerable herbage trampling (Alexander, 1985),which may cause an under-estimation of residual herbage mass, thus an over-estimation of DMI. In view of these limitations, the values for DMI and MEI (metabolisable energy intake) reported in the present investigation should be taken with caution, as they are probably slightly over-estimated.

The composition of the diets eaten by the cows were calculated from the masses of each herbage component (green leaf, stem and dead matter) contained in the pre- and post-grazing herbage, the difference in each being assumed to constitute a corresponding proportion of the total diet. The potential cumulative errors associated with such an approach to diet estimation are obvious. The use of oesophageal fistulae to estimate diet composition was impracticable under the conditions of the present study.

Dry matter intake

Averaged across periods, the apparent DMI for the LM cows (Table 6.1a) was 8% greater than that of the RG and HM groups which registered similar intakes (mean 17.3 kg DM/cow per day). The DMIs of the three cow groups did not vary significantly between seasons (Appendix 6.1a). The intake values measured corresponded to 3.8, 4.1 and 3.8 kg DM/100kg liveweight for the RG, LM and HM treatments, respectively, levels which are similar to intakes of 3.7 to 4.5kg DM/100kg liveweight reported by Glassey et al., (1980) and Bryant and Trigg (1982) for lactating dairy cows given high pasture allowances.

A number of previous studies have demonstrated differences in the DMIs and milk yields by cows grazing perennial ryegrass dominant swards differing in pre-grazing herbage mass or height, and hence pasture composition, at common, but generous, herbage allowances (Combellas and Hodgson, 1979; Le Du et al., 1979; Stakelum and Dillon, 1991; Holmes et al., 1992; Hoogendoorn et al., 1992). It is therefore, somewhat surprising that, in the present study, intakes from the three swards were generally high despite large differences between swards in:

- pre- and post-grazing herbage masses
- pre- and post-grazing sward height
- and in sward bulk densities

Cows grazing on high mass ryegrass/clover swards in previous studies had lower yields of milkfat than those on low mass swards; the corresponding difference in DMI was apparent only at a high HA and not at a low HA (Hoogendoorn et al., 1988; 1992).

In Matua prairie grass swards, there was very little green leaf below 6cm sward height (Chapter 5, Figure 5.5). L'Huillier et al. (1986) made a similar observation. In the present study, the concentration of green leaf in the 0-6 cm sward horizon ranged from 2-16% of the DM for both the Matua swards (LM and HM) compared to 17-26% for the ryegrass swards (Figure 5.5, Appendix 5.15a). Compared with the ryegrass swards, a greater proportion of the Matua leaf was distributed in the upper sward horizons. This trend in the distribution of green leaf and the erect nature of prairie grass may have contributed to the relatively high DMIs from both the Matua sward types (L'Huillier et al., 1986).

Diet composition

Compared with the diet of cows receiving the RG treatment, the average diets of the cows grazing the LM or HM swards contained twice the percentage of stem (31 *vs* 15%), and four times that of dead matter (9.0 *vs* 2.4%), while the percentage of green leaf was smaller by 22-25 units (means 83%, RG; 61%, LM; 58%, HM; Table 6.1b). These differences in the component composition of the diets of the cows grazing on the three sward types account for the general trend in the M/D values of the diets consumed (Table 6.1c). For the three treatments, the diets of the cows contained greater proportions of leaf and smaller proportions of stem and dead matter than those of the herbage on offer. This agrees with previous reports that grazing animals given a generous HA will ingest a diet that contains greater proportions of green matter and smaller proportions of dead herbage, and is 3-10% higher in digestibility than the average of that on offer (Hodgson and Jamieson, 1981, L'Huillier et al., 1986; Michell and Fulkerson, 1987).

Metabolisable energy intake

The concentrations of ME in the herbage consumed by the cows were estimated from the DOMD values of the individual components of leaf, stem and dead matter of the herbage on offer (Chapter 5; Tables 5.13, 5.14, 5.16), the sum of the products of the component MEs and the proportions of the components in the diet (Table 6.1b). However, it is realized that using the ME concentrations of individual herbage components sampled to ground level to derive the ME concentration of the diet, will tend to bias the latter values downwards. In this respect, using the ME values of herbage from the grazed sward horizons might have improved the accuracy of the dietary ME predictions. In the present study, the contributions of the various sward strata (horizons) to the total herbage mass, and to the diets consumed were not assessed, thus eliminating the use of the ME concentration of the herbage components disappearing from the grazed sward horizons to estimate dietary ME.

The estimated ME concentrations of the cows' diets (MJ ME/kg DM), averaged across all the eight grazing trials, were 11.2, RG; 10.7, LM; and 10.4, HM (Table 6.1c). These dietary ME values were higher than those of the herbage on offer by 0.3 - 0.5 MJ/kg DM (Chapter 5, Table 5.9). Within the limitations of estimating herbage intake from pasture and the ME concentration of the diet, the estimated daily MEI, averaged across periods, were 190, 199 and 183 MJ ME/kg DM for RG, LM and HM cows, respectively (Table 6.1c). These MEIs were greater by 34-41 MJ ME/kg DM, than the daily ME requirements calculated according to MAFF (1975), and were 39-52 MJ ME/kg DM greater than the requirements according to Holmes and Wilson (1984) for cows grazing on temperate pastures (Appendix 6.5a & b).

The differences between the ME requirements and the apparent ME intakes by the cows suggest that the liveweights of the cows and maintenance requirements were under-estimated , or that apparent DMIs were over-estimated. Most probably the DMIs were slightly over-estimated because of the trampling of herbage which was greater in the LM and HM than RG swards.

When other factors are held constant, grazing animals will increase their DMI in response to the deficit between energy demand and supply (Weston, 1985; Gherardi and Black, 1989). In the present study, the LM cows appear to have increased their DMI through the energy deficit mechanism, and this was probably facilitated by a more favourable LM sward structure compared to that of the HM swards (Figure5.5d). In which case, either the preferred green component of the LM swards was more accessible in the grazed horizons, or because the grazed horizons contained more digestible herbage (Appendix5.15b), and contained less dead matter than the HM swards (Figure 5.5d; Appendix 5.15a).

There is very little information in the literature showing the potential DMIs and MEIs of lactating dairy cows grazing on Matua pastures differing in composition with which to compare the intakes measured in the current study. Data on the comparative feeding values for milk production of prairie grass and perennial ryegrass pastures , at a common or differing herbage allowances are also scarce (see Section 6.4.2).

6.4.2 Animal performance

6.4.2.1 Milk production and composition

Milk and milk solids yield

Despite generally greater apparent DMIs off the LM treatment, there were no significant differences in daily milk yields of cows receiving the RG or LM treatments during all the experimental periods, except in the summer (both years) when milk yields were significantly smaller (by 7%) on the LM than the RG treatment (Table 6.2). Cows receiving the HM treatment produced 8-19% and 6-15% less milk than the RG and LM cows, respectively, in six of the eight trials. Milk yields for the three treatments were similar in late spring of Year One and autumn of Year Two (Table 6.2). Averaged across periods, the LM and HM cows produced 3% and 11% less milk, respectively, than the RG cows. These differences in yields were significant, and occurred despite the greater apparent DMIs of the LM cows, or similar DMI of the HM cows relative to that of the RG cows (Table 6.1a) Averaged across periods, milk yields were 17.9, RG; 17.4, LM; and 15.9, HM (Table 6.6c).

The mean values for milk production for all the three sward types were lower than could be theoretically supported by the MEIs achieved (Appendix 6.5a & b). The probable reasons for this apparent contradiction were discussed in the previous section (Section 6.4.1.2). The smaller milk yields of cows receiving the HM treatment relative to the RG treatment, despite the similar DMIs, may be accounted for by the smaller probable concentration of ME in the diet of these animals, due to the greater concentrations of stem, seedheads and dead matter of lower digestibility in the herbage on offer and the diet (Tables 5.14 - 5.16 and 6.1b).

The milk production data suggest that, at a generous herbage allowance, the feeding value of the low mass prairie grass pastures was similar to that of "conventional" perennial ryegrass pastures during all periods, other than summer when the LM group produced less milk and milk solids (Tables 6.2 - 6.5). The HM cows produced smaller yields of milkfat (by 5-21%) than the RG and LM groups in all periods except early spring and autumn of Year Two when yields were similar for the three treatment groups (Table 6.3).

Averaged across periods, the yields of milkfat, milk protein and lactose were approximately 12% and 9% smaller on the HM than RG and LM treatments, respectively. The 3% difference in the yields of milkfat, protein and lactose between the LM and RG cows was not statistically significant for milkfat ($P > 0.05$), but was significant for milk protein and lactose. (Table 6.7a).

The cows receiving the LM treatment tended to produce more milkfat in late spring ($P < 0.05$ Year One; $P > 0.05$ Year Two; Table 6.3 and Figure 6.2b) than the RG group, which may have compensated for the smaller summer yields of the LM group; such that the overall milkfat yields were similar for the RG and LM treatments. The LM and RG herbage contained similar proportions of dead matter during late spring, which suggests that reproductive development of the swards during this period (Figure 5.2b,c and d) may have caused a greater reduction in milkfat production from the RG than the LM treatments, but this reduction was most apparent in Year One. Matua seedheads, unlike those of ryegrass, are consumed readily by the cows (Plate 6.1), which, together with a greater proportion of stem of comparable digestibility in the diet of the LM cows (Tables 5.14 & 6.1b), may have promoted a rumen fermentation more conducive to milkfat synthesis for the LM than the RG treatment during the late spring period (Sutton and Morant, 1989) (Table 6.6a, also see discussion on milk composition).

In the current study, the concentrations of N and clover of the HM herbage, averaged across periods, were smaller than for the remaining sward types (Table 5.4 and 5.9). This may have contributed to the poor overall performance of the HM cows, by affecting the amount of undegraded N reaching the duodenum (Rogers et al., 1980; Thomas and Chamberlain, 1990), despite the small (0.3-0.4% units) but significant difference in % N of the total herbage between the HM and the remaining sward types (Table 5.9). The degradability of N of mixed perennial ryegrass pasture relative to Matua prairie grass pastures differing in composition, and its effects on milk production are unknown, and warrant further research.

Wilson and Grace (1978) reported, from a New Zealand study, similar milk and milkfat yields by identical twinmates of various breeds grazing on either 'pure' stands of Matua prairie grass or Westerwolds ryegrass (Lolium multiflorum Lam), or on mixed ryegrass/white clover pasture. The above experiment (ibid) was conducted in early spring, and the cows were fed to ensure ad libitum intake. However, the results of Wilson and Grace (1978) are not exactly comparable to those of the current study, since the Matua pastures were 'pure', and herbage masses or DMIs were not reported. In another New Zealand study (Thom and Prestidge, 1988) a small reduction (3%) in milkfat production per hectare and per cow was observed from 50:50 Matua/perennial ryegrass swards grown with white clover relative to new or well established perennial ryegrass/white clover swards. The stocking rate of 3.9 cows/ha (ibid) was high, suggesting that the pastures were intensely grazed and of low mass. Again, milk production data from farmlet trials, such as that of Thom and Prestidge (1988) may not be strictly comparable to results obtained from controlled component studies such as those ones being reported in the present thesis. Nevertheless, the results of Wilson and Grace (1978) and Thom and Prestidge (1988) generally agree with those of the present study, that, in the short term, there is very little actual difference in milk and milk solids production between generously fed cows grazing on 'conventional' (intensely grazed) perennial ryegrass/white clover, or low mass Matua prairie grass/white clover pastures.

Summer milk production

Brookes and Holmes, (1986), using herbage masses similar to those of the present study, approximately 4 t DM/ha for perennial ryegrass pasture and 6t DM/ha for Matua pastures, observed a 20% decline in milkfat yields by cows grazing on Matua/white clover pastures in summer relative to those ones from perennial ryegrass/white clover swards. The smaller milkfat yields were observed at both low or high herbage allowances (27 or 52 kg DM/cow daily), and despite greater apparent DMI (by approximately 9%) from the Matua swards at each herbage allowance. The difference in milkfat production was attributed to the higher concentrations of stem and low clover content of the Matua pastures than in the ryegrass pastures of smaller herbage mass.

In the present study, summer milkfat yields were, on average, 22% and 8% smaller for the HM and LM treatments, respectively, compared to the RG treatment. Corresponding reductions in summer milk or milk protein yields were 20% and 7%. The reduction in summer milkfat production by the HM cows relative to RG cows agrees closely with that reported by Brookes and Holmes (1986). Furthermore, the differences in summer milk, milkfat and milk protein yield between the RG, LM and HM treatments were generally similar to the differences which would have been expected if all three sward types had been low, medium and high mass perennial ryegrass swards of, respectively, high, moderate and low digestibility, or green herbage availability (Thomson et al., 1984; Michell and Fulkerson, 1987; Stakelum and Dillon, 1991; Holmes et al., 1992; Hoogendoorn et al., 1992).

Milk composition

Averaged across periods, there were no significant treatment effects on milk composition for % milkfat (mean 4.5%) and lactose (mean 4.7%); % milk protein was significantly smaller for the HM treatment (mean 3.5%) than the remaining sward types (mean 3.6%) (Tables 6.6a & b, 6.6c, Appendix 6.3). Sward type x period effects were not significant for % milkfat or % protein. The similarity of % milkfat and lactose, and the small actual difference for % milk protein between the HM swards and the remaining sward types, agree with previous reports that for pasture fed cows, milk composition is generally not influenced significantly by level or quality of nutrition. This is true over a wide range of stocking rates, or variations in grazing management (L'Huillier, 1987c, 1988; Thomson, 1988; Sutton and Morant, 1989; Stakelum and Dillon, 1991; Kolver and Bryant, 1992).

However, it would be expected that the greater concentrations of fiber in the total herbage and diet from both the Matua sward types relative to ryegrass swards (Tables 5.9 and 6.1b), would result in greater concentrations of milkfat for cows receiving the LM and HM treatments (Sutton and Morant, 1989). Percent milkfat during the late spring period showed a greater, but non-significant, increase for the LM but not for the HM cows relative to that of RG cows (Table 6.6a). It is probable that, despite the high fiber content, the high soluble carbohydrate content of prairie grass relative to ryegrass (Wilson and Grace, 1978; Anon; 1982; Hume, 1990b) may have a diluting effect on the acetate:propionate ratio. In which case, milkfat synthesis may not be enhanced by feeding prairie grass pastures. More work is required on the comparative patterns of ruminal volatile fatty acid production of perennial ryegrass and prairie grass dominant pastures, and their role in milkfat synthesis.

6.4.2.2 Liveweight and condition score

There were no significant effects of sward type on the liveweight change or on the rate of liveweight change within and across experimental periods (Tables 6.7a and 6.8). These results were not surprising in view of the short duration of each period of measurement (< 3 weeks). This may have made small changes in the liveweight of the cows, because of differences in herbage composition, difficult to detect due to variations in gut fill, and despite weights being taken on two consecutive days (Hoogendoorn, 1986). Furthermore, the coefficients of variation for the liveweight parameters were very large (> 100%). For all the treatments, the rate of liveweight change of the cows was negative during both summers (Table 6.8), which was probably a reflection of the poor quality of the herbage during these periods (Figure 5.8). Sward type x period interactions were not significant for rate of liveweight change in the present study, but other workers (Cosgrove and Brougham, 1988) have reported poor summer liveweight performance by young bulls grazing on Matua dominant pastures relative to perennial ryegrass dominant swards.

Averaged across periods, the HM cows showed a slight, but significant, decline in body condition score relative to RG but not to LM cows (Table 6.7a). The overall smaller yields by the HM cows of milk and milk solids, and the loss of body condition relative to the remaining groups for cows, reinforces the suggestion that the intake of digestible nutrients by cows receiving the HM treatment was smaller (see Table 6.1c). This may have been caused by differences in the composition of the herbage on offer, and in the nutritive value of herbage consumed, since the actual difference in the apparent DMIs of the three cow groups was small.

6.4.3 Implications of results to dairy farming

For cows at pasture, high herbage allowances, like those provided in the present study, are associated with high post-grazing herbage masses, although the long term consequences of such management on farm productivity may be difficult to predict (Bryant, 1980a; Glassey et al., 1980; Stockdale and King, 1980; Stakelum and Dillon, 1991; Hoogendoorn et al., 1992). However, the results of the eight grazing trials in the current study were consistent with those of other workers (Michell and Fulkerson, 1987; Stakelum and Dillon, 1991; Hoogendoorn et al., 1992) in showing that the changes in herbage composition associated with increases in herbage mass decreased herbage feeding value and animal performance in the short term, despite a high HA and selection opportunity. However, these effects were most evident for the HM sward type, and may have been accentuated by the very high residual herbage masses recorded for this treatment (Chapter 5; see also Section 2.4.4.4).

In the present study, milk and milk fat yields were generally similar from the low mass prairie grass and the perennial ryegrass swards, even though the prairie grass swards had a higher pregrazing herbage mass (4.2 vs 3.2 t DM/ha). This suggests that it may be possible, in the short term, to maintain the feeding value of prairie grass pastures up to higher herbage masses than can be achieved in ryegrass pastures. However, the relatively slow decline in the feeding value of low mass Matua pasture with increasing herbage mass, or the greater herbage yields may not necessarily lead to increases in milk production per cow or per hectare. The need to control herbage growth in the late spring/ early summer period, in order to maintain herbage quality during this and the subsequent summer period may result in a large decline in production per cow and per hectare from Matua swards. This suggestion is supported by the results of the present study, and by those of Brookes and Holmes (1986) which showed that, relative to ryegrass swards, summer milk production was smaller from Matua swards, and showed a sharp decline when HA fell below 35 kg DM/cow daily. Relative to the RG swards, the lowest horizon (< 6 cm) in both the Matua swards contained smaller proportions of leaf and greater proportions of stem and dead matter, and the herbage was less digestible. The OMD of the herbage from this horizon, averaged across periods, was HM, 49%; LM, 55%; and RG 61% (Figure 5.5; Appendix 5.15a and b). A similar difference between the digestibility of low mass Matua and ryegrass herbage shortly after grazing was reported by Savage et al. (1985), and may explain the poor animal performance that is likely to result from restrictions in HA as often practiced on New Zealand dairy farms, for animals grazing on Matua pastures, thus forcing them to graze into the lower horizons containing little or no leaf.

In addition, the grazing management strategies commonly used with perennial ryegrass dominant pastures to promote late spring/summer herbage quality, tiller density, and herbage accumulation (Korte et al., 1984; Michell and Fulkerson, 1987; L'Huillier 1987 a-c, 1988; L'Huillier and Bryant, 1987; Hoogendoorn et al., 1992), may not be applicable to Matua prairie grass pastures. Recent reports indicated that perennation in Matua pastures was promoted by lax grazing or delaying grazing during the mid/late spring period until replacement tillers have emerged mainly from reproductive tillers, and then followed by hard grazing or topping (Black and Chu, 1989; Matthew et al., in press; C. Black, pers. com.). Such management may lead to large reductions in milk production, arising from the failure to control spring reproductive development of the swards, and/or large losses of herbage dry matter from topping.

Clearly then, more work on the effects of herbage allowance, or intensity and timing of spring grazing on the feeding value for milk production, herbage accumulation and perennation of Matua prairie grass pastures is still necessary.

6.4.4 Conclusions

From the results of the current study, the following conclusions can be made:

1. Yields of milk and milk solids (milkfat, milk protein and lactose), averaged across periods, were 11 and 12% smaller ($P < 0.001$) from the high mass Matua prairie grass pasture, and were, except milkfat, 3% smaller ($P < 0.05$) from low mass Matua pasture compared to perennial ryegrass pasture. Mean yields of milkfat for the low mass Matua and perennial ryegrass treatments were similar. Differences between low mass Matua and ryegrass swards in the yield of milk and milk solids were evident only during the summer period.

2. In the summer, yields of milk, milkfat, and milk protein were, respectively, 20, 22 and 20% smaller ($P < 0.001$) from high mass Matua swards, and were 7, 8 and 7% smaller ($P < 0.05$) from low mass Matua swards compared with ryegrass swards.

3. Milk composition was not significantly affected by sward type within and across periods for % milkfat and % lactose; % milk protein was significantly smaller for the high mass Matua swards than the remaining sward types for which % protein was similar.

4. Averaged across periods, there were no significant sward type effects on the liveweight change or rate of liveweight change of the cows, and there was little actual change in liveweight. There was no difference between the low mass Matua and ryegrass treatments in the mean change in body condition score of the cows, but cows receiving the high mass Matua treatment showed a significant loss in body condition compared with the remaining treatment groups.

5. Compared with perennial ryegrass swards, changes in herbage composition, particularly those of dead matter, stem and seedheads, and in the digestibility of these (Chapter 5) associated with increases in herbage mass, caused a significant decrease in the feeding value and animal production from the high mass Matua swards. This occured during all eight periods of measurement. The feeding value of low mass Matua pasture and animal production from these pastures were generally not affected by compositional changes of the herbage, except during the summer period. This suggests that it may be possible to maintain the feeding value of prairie grass pastures up to higher herbage masses than can be done in perennial ryegrass pastures.

6. It appears that spring grazing regimes developed for perennial ryegrass to promote tiller density and herbage accumulation, and to prevent a sharp decline in the feeding value and milk production during the summer period, may not necessarily apply to Matua prairie grass pastures. Further information about the factors which affect the successful perennation of Matua prairie grass is required before appropriate spring grazing regimes for prairie grass pastures can be recommended.

Table 6.1a Mean values for daily allowance (kg DM/cow) of total herbage, green matter, green leaf, organic matter, and digestible organic matter (DOMD); and daily herbage intake (kg/cow) of cows grazing on the three sward types, averaged across all eight seasons of measurement.

	Sward type				
Herbage component	RG	LM	HM	S.E.	Sign.
Daily herbage allowance					
Dry matter (kg/cow)	50.7	50.0	49.9	0.38	NS
Organic matter (kg/cow)	45.6	45.1	45.4	0.34	NS
Green matter (kg DM/cow)	38.8^a	35.8^b	31.6^c	0.28	***
Green leaf (kg DM/cow)	25.4^a	19.1^b	16.1^c	0.16	***
DOM (kg/cow)	33.2^a	31.8^b	30.6^c	0.24	***
Daily herbage intake					
Dry matter (kg/cow)	17.0^b	18.6^a	17.6^b	0.35	**
Apparent DMI as % LW[1]	3.8^b	4.1^a	3.8^b	0.08	***

[a,b,c] Means within a row bearing different letters differ significantly at $P < 0.05$.

[1] Mean liveweights of the experimental cows on each treatment are shown in Table 6.7a.

Table 6.1b Mean values (% dry weight) of the composition of the cows' diet from each of the three sward types, averaged across all eight measurement periods[1].

Diet component	Sward type		
	RG	LM	HM
Green leaf (%)	82.8	61.4	58.3
Green stem (%)	14.8	29.9	31.1
Dead matter (%)	2.4	8.7	10.6
Total (%)	100.0	100.0	100.0

[1] Composition of the diet calculated from measurements of dry masses of individual herbage components constituting the pre- and post grazing herbage, the difference in the masses of these components being assumed to have been consumed by the cows.

Table 6.1c Calculated metabolisable energy concentrations (MJ ME/kg DM) of the cows' diets, and the daily intake of metabolisable energy (MJ ME/cow), averaged across all eight periods of measurement.

Parameter	Sward type		
	RG	LM	HM
Dietary ME (MJ ME/kg DM)[1]	11.2	10.7	10.4
Feed intake (kg DM/cow per day)	17.0	18.6	17.6
Daily ME intake (MJ ME per cow)	190	199	183

[1] ME concentration estimated from the digestible organic matter in the dry matter (Section 3.4.7.6) of the individual diet components (Table 6.1b). Sample calculations of the daily ME requirements and intake of the cows are shown in Appendix 6.5a & b.

Table 6.2 Mean values for daily milk production (kg/cow) of cows grazing on each sward type during each experimental period (season).

	Sward type				Sign. level		
Season	RG	LM	HM	S.E.	Group[1]	Time[2]	Group x Time
1987/88							
Early spring	22.9^{a}	22.0^{ab}	20.9^{b}	0.41	**	NS	***
Late spring	18.1	18.6	17.9	0.28	NS	NS	NS
Summer	15.4^{a}	14.1^{b}	12.4^{c}	0.34	***	NS	NS
Autumn	13.2^{a}	12.5^{a}	11.3^{b}	0.29	***	NS	***
1988/89							
Early spring	22.6^{a}	22.1^{a}	20.8^{b}	0.39	*	NS	NS
Late spring	21.0^{a}	20.9^{a}	17.7^{b}	0.34	***	NS	NS
Summer	16.5^{a}	15.7^{b}	13.5^{c}	0.24	***	NS	NS
Autumn	11.8	11.5	10.8	0.38	NS	NS	NS

[1] Treatment group.
[2] Time effects refer to differences in the yield response by cows between any two weeks within a treatment during each period of measurement.
a,b,c Means within a row bearing different letters differ significantly at $P < 0.05$.

Table 6.3 Mean values for daily milkfat production (kg/cow) of cows grazing on each sward type during each experimental period (season).

	Sward type				Sign. level		
Season	RG	LM	HM	S.E.	Group[1]	Time[2]	Group x Time
<u>1987/88</u>							
Early spring	0.96^a	0.93^a	0.85^b	0.023	*	NS	*
Late spring	0.78^b	0.83^a	0.77^b	0.018	*	NS	*
Summer	0.67^a	0.61^a	0.52^b	0.022	***	NS	*
Autumn	0.58^a	0.55^a	0.49^b	0.012	***	NS	NS
<u>1988/89</u>							
Early spring	0.96	0.95	0.90	0.029	NS	NS	NS
Late spring	0.95^b	0.96^a	0.81^c	0.018	***	NS	NS
Summer	0.75^a	0.70^b	0.59^c	0.014	***	NS	NS
Autumn	0.58	0.57	0.54	0.016	NS	**	NS

[1] Treatment group.

[2] Time effects refer to differences in the yield response by cows between any two weeks within a treatment during each period of measurement.

a,b,c Means within a row bearing different letters differ significantly at $P < 0.05$.

Table 6.4 Mean values for daily production of milk protein (kg/cow) of cows grazing on each sward type during each experimental period (season).

	Sward type				Sign. level		
Season	RG	LM	HM	S.E.	Group[1]	Time[2]	Group x Time
1987/88							
Early spring	0.83^{a}	0.81^{a}	0.72^{b}	0.012	***	NS	***
Late spring	0.64^{a}	0.64^{ab}	0.61^{b}	0.009	+	NS	NS
Summer	0.50^{a}	0.46^{b}	0.40^{c}	0.012	***	*	NS
Autumn	0.52^{a}	0.48^{b}	0.44^{c}	0.011	***	NS	***
1988/89							
Early spring	0.77^{a}	0.76^{ab}	0.71^{b}	0.018	+	NS	NS
Late spring	0.78^{a}	0.75^{a}	0.64^{b}	0.014	***	NS	NS
Summer	0.56^{a}	0.53^{b}	0.45^{c}	0.009	***	NS	NS
Autumn	0.47^{a}	0.47^{a}	0.43^{b}	0.015	+	NS	NS

[1] Treatment group.

[2] Time effects refer to differences in the yield response by cows between any two weeks within a treatment during each period of measurement.

[a,b,c] Means within a row bearing different letters differ significantly at $P < 0.05$.

+ Not significant at $P < 0.05$ but significant at $P < 0.10$.

Table 6.5 Mean values for daily production of lactose (kg/cow) of cows grazing on each sward type during each experimental period (season).

	Sward type				Sign. level		
Season	RG	LM	HM	S.E.	Group[1]	Time[2]	Group x Time
1987/88							
Early spring	1.11^{a}	1.09^{a}	1.02^{b}	0.019	**	NS	***
Late spring	0.87	0.90	0.85	0.015	NS	NS	NS
Summer	0.69^{a}	0.63^{b}	0.56^{c}	0.017	***	NS	NS
Autumn	0.60^{a}	0.56^{a}	0.51^{b}	0.014	***	NS	***
1988/89							
Early spring	1.13^{a}	1.08^{ab}	1.04^{b}	0.018	*	NS	NS
Late spring	1.03^{a}	1.04^{a}	0.88^{b}	0.020	***	NS	NS
Summer	0.76^{a}	0.73^{a}	0.62^{b}	0.012	***	NS	NS
Autumn	0.53	0.52	0.49	0.018	NS	NS	NS

[1] Treatment group.

[2] Time effects refer to differences in the yield response by cows between any two weeks within a treatment during each period of measurement.

[a,b,c] Means within a row bearing different letters differ significantly at $P < 0.05$.

Table 6.6a Mean values for milk composition for each sward type during each experimental period (season): Percent milkfat.

	Sward type				
Season	RG	LM	HM	S.E.	Sign.
1987/88					
Early spring	4.18	4.24	4.12	0.075	NS
Late spring	4.29	4.52	4.29	0.087	NS
Summer	4.39	4.33	4.18	0.104	NS
Autumn	4.44	4.42	4.39	0.087	NS
1988/89					
Early spring	4.25	4.34	4.33	0.106	NS
Late spring	4.57	4.60	4.61	0.096	NS
Summer	4.57^{a}	4.44^{ab}	4.40^{b}	0.056	+
Autumn	5.02	4.99	5.08	0.078	NS

[a,b] Means within a row bearing different letters differ significantly at $P < 0.05$.
\+ Not significant at $P < 0.05$ but significant at $P < 0.10$.

Table 6.6b Mean values for milk composition for each sward type during each experimental period (season): Percent milk protein.

	Sward type				
Season	RG	LM	HM	S.E.	Sign.
1987/88					
Early spring	3.62^{a}	3.67^{a}	3.51^{b}	0.036	*
Late spring	3.54	3.44	3.44	0.040	NS
Summer	3.26	3.29	3.25	0.037	NS
Autumn	4.00^{a}	3.87^{b}	3.90^{ab}	0.045	+
1988/89					
Early spring	3.36	3.48	3.41	0.067	NS
Late spring	3.73	3.62	3.60	0.046	NS
Summer	3.41^{a}	3.34^{ab}	3.30^{b}	0.031	*
Autumn	4.06	4.11	3.98	0.047	NS

[a,b,c] Means within a row bearing different letters differ significantly at $P < 0.05$.
\+ Not significant at $P < 0.05$ but significant at $P < 0.10$.

Table 6.7a Mean values for daily milk production (kg/cow), milk composition, initial liveweight and liveweight change (kg/cow) and initial condition score and condition score change of cows on the three sward types, averaged across all eight periods of measurement.

	Sward type				
	RG	LM	HM	S.E.	Sign.
Milk production					
Milk (kg/d)	17.9^{a}	17.4^{b}	15.9^{c}	0.20	***
Milkfat (kg/d)	0.79^{a}	0.77^{a}	0.69^{b}	0.01	***
Milk protein (kg/d)	0.64^{a}	0.62^{b}	0.55^{c}	0.008	***
Lactose (kg/d)	0.84^{a}	0.82^{b}	0.75^{c}	0.010	***
Milk composition					
Fat (%)	4.46	4.48	4.42	0.033	NS
Protein (%)	3.60^{a}	3.57^{a}	3.52^{b}	0.017	**
Lactose (%)	4.71	4.73	4.74	0.012	NS
Liveweight (LW)					
Initial (kg/cow)[1]	457 ± 56	454 ± 54	465 ± 41	NA	NA
LW change (kg/cow)[2]	+ 1.8	+ 1.0	+ 0.3	0.08	NS
Rate of LW change (g/cow per day)	151	113	73	77	NS
Condition score					
Initial (per cow)[1]	4.6 ± 0.75	4.6 ± 0.72	4.6 ± 0.62	NA	NA
Change (per cow)[2]	$+ 0.07^{a}$	$+ 0.01^{ab}$	$- 0.08^{b}$	0.037	*

[1] Values are means ± standard deviation.

[2] Change in liveweight or condition score of cows averaged across eight experimental (measurement) periods of approximately 15 days each (see Table 5.2 for exact duration of each period).

NA = Not analysed statistically.

[a,b,c] Means within a row bearing different letters differ significantly at $P < 0.05$.

Table 6.7b Adjusted mean values for daily production of milk and milk solids (kg/cow per day) and milk composition (%) during each of the eight experimental periods (seasons), averaged across all three sward types.[1]

	Yield parameter					
Season	Milk (kg/d)	Milkfat (kg/d)	Protein (kg/d)	Lactose (kg/d)	Fat (%)	Protein (%)
1987/88						
Early spring	17.0	0.80^a	0.64	0.82	4.4^b	3.6^a
Late spring	16.5	0.76^a	0.57	0.78	4.6^a	3.4^b
Summer	15.8	0.63^b	0.53	0.74	4.2^b	3.5^b
Autumn	15.8	0.62^b	0.56	0.72	4.0^c	3.7^a
1988/89						
Early spring	18.8	0.86^a	0.70	0.93	4.5^b	3.5^b
Late spring	17.7	0.83^a	0.65	0.84	4.8^a	3.7^a
Summer	16.7	0.76^b	0.57	0.78	4.7^a	3.4^c
Autumn	17.8	0.78^b	0.62	0.82	4.4^b	3.7^a
S.E.	0.43	0.020	0.018	0.024	0.06	0.03
Sign. level	NS	*	NS	NS	*	***

^{a,b,c} Means within a column within a year bearing different letters differ significantly at $P < 0.05$.

[1] Mean values were adjusted by analysis of covariance (see Tables 6.2-6.5) in order to illustrate the simple effects of season (present table) and season x sward type interaction effects (Figure 6.2) on the production of milk and milk solids, unconfounded by the effects of stage of lactation over two lactations.

Table 6.8 Mean values for change in liveweight and condition score of individual cows during each experimental period, averaged across all three sward types.

	Liveweight change kg/ cow per cow^1	LW change g/cow daily	Condition score change per cow^1
1987/88			
Early spring	19.2	1132	0.19^a
Late spring	-1.5	-83	0.01^b
Summer	-23.8	-1399	-0.05^b
Autumn	4.9	404	0.05^{ab}
1988/89			
Early spring	4.7	465	-0.06^a
Late spring	9.5	680	0.10^a
Summer	-3.4	-227	-0.16^b
Autumn	-1.0	-73	-0.08^b
S.E.	1.80	130	0.060
Sign. level	NS	NS	*

[a,b,c] Means within a column within a year bearing different letters differ significantly at $P < 0.05$.

[1] Table 5.2 shows the duration of each experimental period (average 15d each).

Plate 6 1 High mass Matua prairie grass sward (top right) showing a greater content of maturing seedheads during late spring compared with a low mass Matua sward (top left), which are readily grazed by cows (bottom)

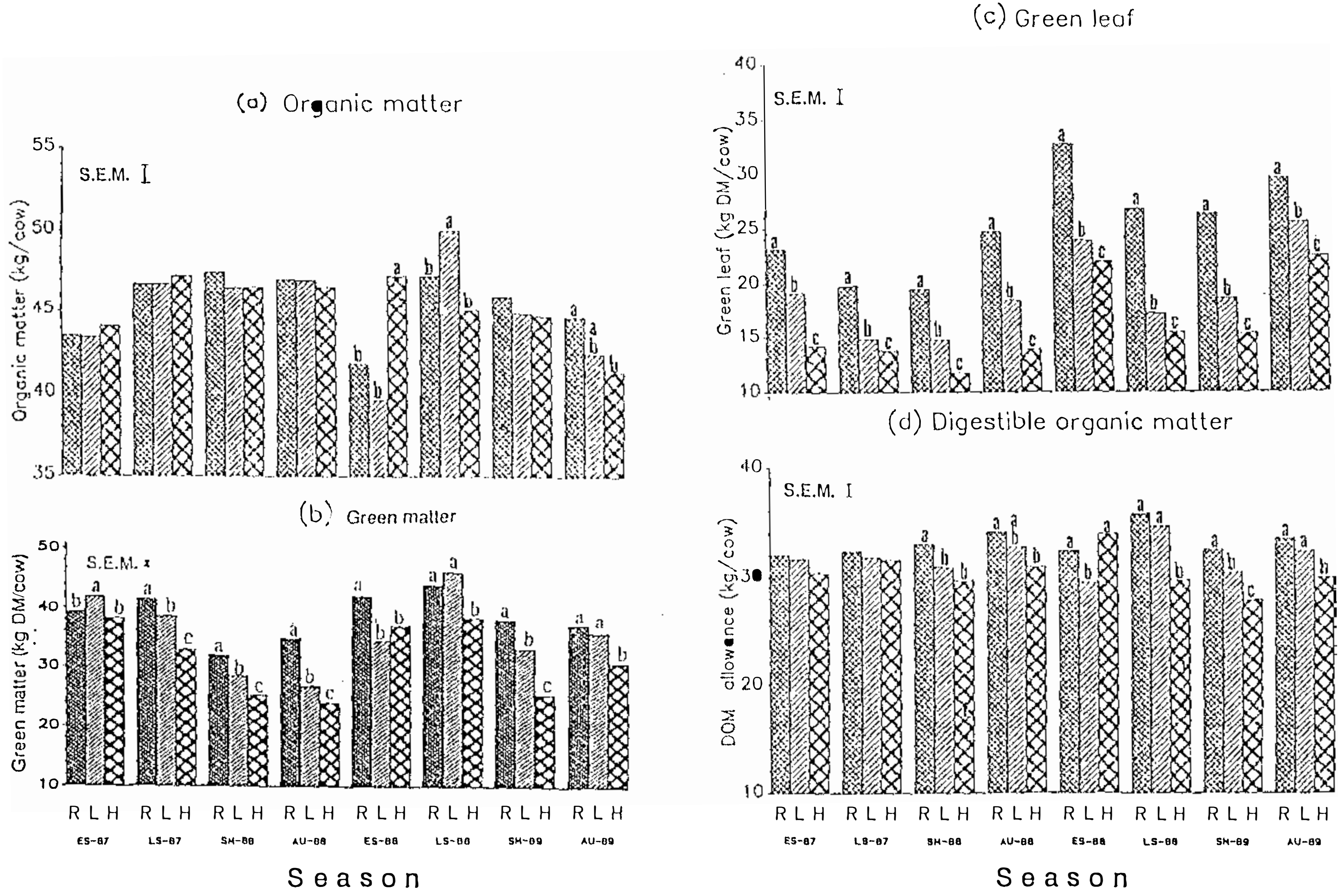
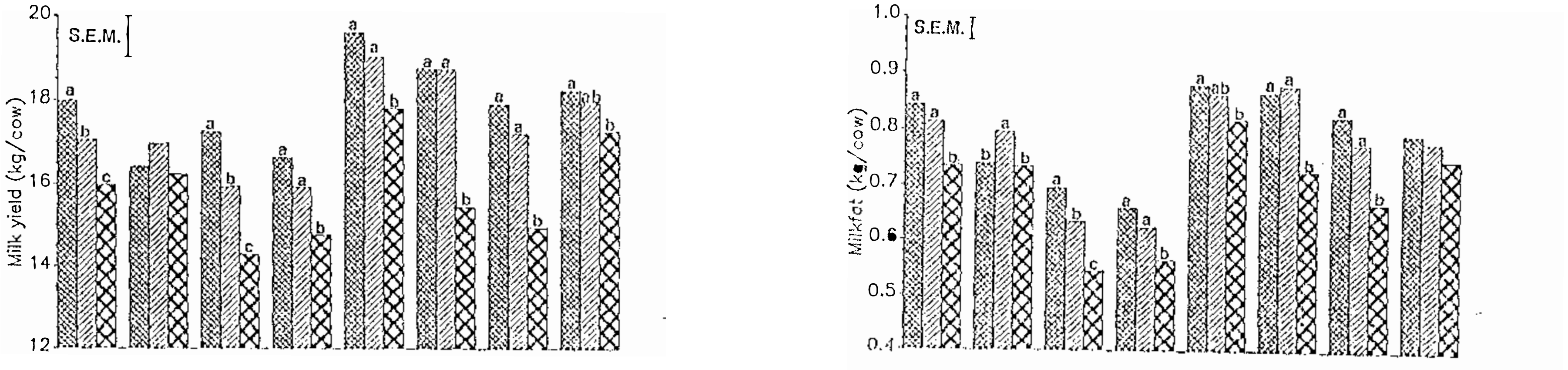


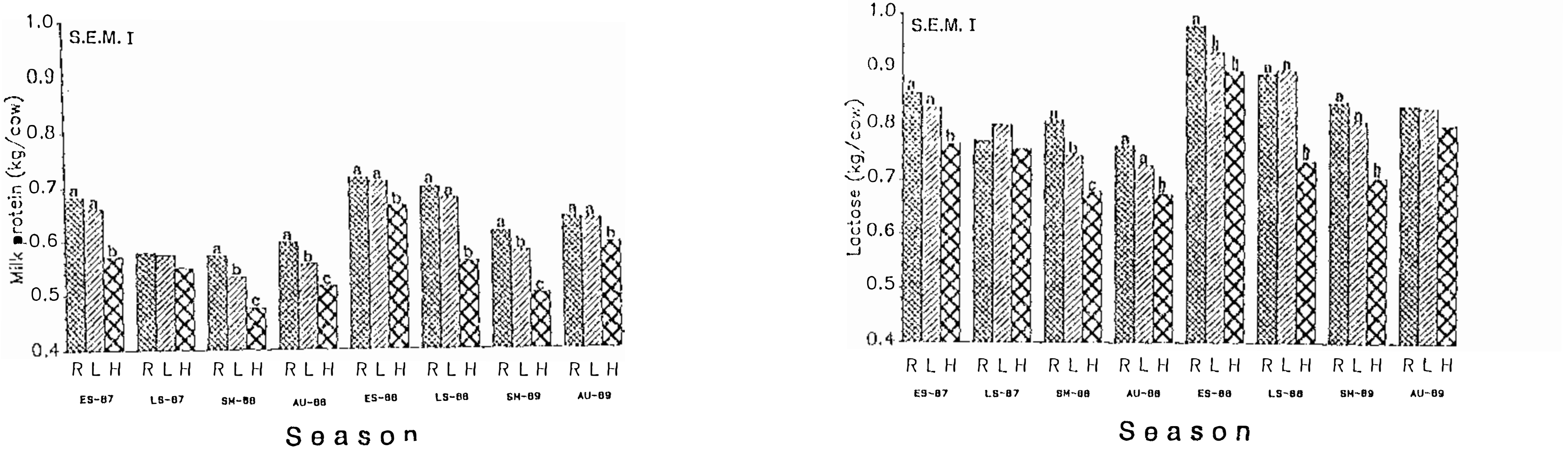
Figure 6.1 Mean values for daily allowance (kg/cow, dry weight basis) of (a) organic matter, (b) green matter, (c) green leaf and (d) digestible organic matter (DOM) for cows grazing on the three sward types during each of the eight periods of measurement.

Note: For Figures 6.1 and 6.2 vertical bars denote the largest standard error of the means (S.E.M.); within each period, means that differ significantly ($P < 0.05$) bear different letters (a, b or c); R=ryegrass swards, L=low mass Matua swards, H=high mass Matua swards; and ES=early spring, LS=late spring, SM=summer, and AU=autumn.



(a) Milk yield

(b) Milkfat yield



(c) Milk protein yield

(d) Lactose yield

Figure 6.2 Adjusted mean values (kg/cow per day) for yields of (a) milk, (b) milkfat, (c) milk protein and (d) lactose by cows grazing on the three sward types during each of the eight periods of measurement (see footnote on page 190)

CHAPTER 7

GENERAL DISCUSSION AND CONCLUSIONS

7.1 INTRODUCTION

The overall objective of the present investigations was to assess the suggestion that intense but infrequent grazing (5-6 weeks recovery period) of Matua prairie grass pastures may improve herbage quality and production per animal, without causing a significant decrease in sward persistence and herbage production. The suggestion was consequent to the original recommendation that Matua prairie grass was best suited for well drained dairy farms under lax and infrequent grazing management, and the subsequent questions on the feeding value and harvesting efficiency of the herbage grown under these grazing management conditions.

The aim of this chapter is to briefly review results and conclusions obtained, collate the results with the most relevant published work, consider briefly some problems associated with the measurements made, relate the relevance of results obtained in this study to the potential role of Matua prairie grass in dairy farming in the Manawatu Region and probably in New Zealand; and finally suggest areas for further research.

The more specific objectives were to measure, over a range of seasons, aspects of herbage composition, including digestibility, and the effects of these on the feeding value of the herbage, and on milk production from Matua prairie grass/clover pastures maintained at different pregrazing herbage masses; and to compare these with conventional perennial ryegrass/clover pastures.

7.2. RESUME OF RESULTS AND CONCLUSIONS

In Experiment 1 the composition, including digestibility, of herbage from prairie grass cv. Grasslands Matua pasture maintained at low herbage mass (LM), intermediate mass (IM) and high mass (HM) was measured over summer, autumn, winter and spring. The Matua swards were grown in association with red clover. Differences in herbage masses between the three sward types were created and maintained by differential grazing management with lactating dairy cows (dry cows in winter).

There were no significant differences between sward types in the concentrations of prairie grass, red clover or other (unsown) species in the herbage. The low mass swards contained a greater proportion of green leaf, but smaller proportions of stem and dead matter. The apparent digestibility (OMD) and concentrations of total nitrogen in the herbage from the intermediate or high mass swards were lower than those of low mass swards. Whole prairie grass plants from the low mass swards contained a greater concentration of nitrogen and had much higher OMD than those of the intermediate or high mass sward types. The OMD of whole plants from the three sward types were much higher than the corresponding values for total herbage. There were no treatment differences in the rates of net herbage production.

Overall, the initial proportion of red clover in the herbage was high; that of prairie grass was low but tended to increase over time. The actual herbage masses achieved were higher than was intended, partly because the grazing intervals were longer than was probably necessary. This, and the high clover content of the herbage may have caused the small differences in botanical composition observed between sward types when compared with previous reports.

The effects of season on the component composition and digestibility of herbage were large, and were observed for the majority of the variables measured. These often interacted with sward type, but the differences between sward types in the component concentrations and OMD described above were generally consistent.

The second experiment (Chapters 5 and 6) consisted of a series of eight short-term (2-3 weeks) grazing experiments with lactating dairy cows, conducted over a two year period in early and late spring, summer and autumn. The cows were grazed, at a generous herbage allowance (50 kgDM/cow daily), on one of three sward types; low mass prairie (LM) high mass prairie (HM) and conventional ryegrass (RG). All swards contained white clover. The three sward types were created and maintained by suitable grazing pressures and mechanical mowing, if required. The prairie grass swards were one year old at the start of the experiment while the ryegrass swards were well established.

Mean pre-grazing and post-grazing herbage masses, over the two year period, were, respectively, RG 3.2 and 2.1, LM 4.2 and 2.2, and HM 5.6 and 3.6t DM/ha. At a common grazing interval of 4-6 weeks for the Matua sward types and 3-4 weeks for the ryegrass swards, significant differences occurred in the composition of the herbage from the three sward types. The proportion of green leaf was greater in perennial ryegrass herbage, it was intermediate in the low mass Matua herbage and was smallest in the high mass Matua herbage. The proportion of green stem was smaller in ryegrass swards than that in the two Matua sward types, which contained similar proportions of this component.

The HM swards contained a greater concentration of dead matter than the low mass swards; the ryegrass swards contained the smallest proportion of dead matter. The low mass Matua and ryegrass swards contained a similar concentration of clover, which was greater than that in the high mass Matua swards.

There was a substantial decrease over time in the proportion of prairie grass, tiller density and tiller weight in both Matua sward treatments, but the decrease was faster in the low mass treatment. Rates of net herbage production were smaller in low mass than high mass Matua swards.

Differences between the three sward types in the proportions of herbage components were reflected in the nutritive value of the herbage. Nitrogen concentration and apparent digestibility of organic matter were lower in the high mass Matua swards than those of the RG or LM swards, irrespective of season of measurement. Herbage from the ryegrass sward was more digestible, and the concentration of nitrogen was greater than that in low mass Matua swards. However, differences between the ryegrass and low mass Matua swards in the quality of herbage were most pronounced in the late spring/summer period. At these times, the proportions of stem and dead matter increased steeply in the low and high mass Matua swards compared with the ryegrass swards.

Differences between treatments in the concentrations of nitrogen and the OMD of the individual whole plant, leaf or stem, were surprisingly small, given the large differences in herbage mass and proportions of green leaf in the herbage. In general, whole plants, green leaf and stem from ryegrass and low mass Matua herbage were equally digestible and contained similar N concentrations; differences between the high mass and low mass Matua swards in the nutritive value of herbage components were small, but they were larger between the high mass and ryegrass treatments. The digestibility of dead matter and seedhead tended to be lower in the Matua herbage than that of ryegrass, and was much lower on the high mass Matua treatment.

Daily yields of milk and milk solids from the ryegrass and low mass Matua swards were similar in all periods of measurement except in the summer, when yields from the low mass Matua treatment were smaller. Yields of milk and milk solids from the high mass Matua swards were the smallest in most periods. Sward type had no effect on milk composition, except that protein concentration was smaller in the high mass Matua swards.

Voluntary feed intake was high from all the three sward types. However, the smaller yields of milk and milk solids from the high mass swards in comparison with the other two sward types indicate that the intake of digestible nutrients from these swards was smaller.

7.3. LIMITATIONS OF THE PRESENT STUDY

Several sward measurements were associated with high coefficients of variation (CV), particularly the proportions of clover in the herbage (CV 30-50%), other species (CV 50-60%) and seedhead (CV 60%). CVs for other herbage components were generally below 20%. The high CVs observed for measurements of the above components may be attributed to the heterogeneous spatial distribution of these components, and the large seasonal effects on their concentrations in the herbage (Meijs, 1981). Consequently, demonstration of significant differences between treatment means for these variables, because of the large standard errors surrounding the means, required large differences between them.

Measurements of pre-grazing herbage mass and feed intake were made with CVs of 10-20% which were within the range reported in the literature (Meijs, 1981; Leaver, 1982). However, measurements of post-grazing herbage mass had a CV of approximately 30%. This may explain the greater apparent DMI measured in the present study from the low mass Matua swards compared with the ryegrass treatment but without an increase in milk production.

The absence of satisfactory but cheap methods for measuring herbage intake and its digestibility by the grazing animal has almost certainly hampered progress in grassland utilization (Leaver, 1982). This topic was discussed in Chapters Two and Six of the present thesis and will not be dealt with further. However, the introduction of tall, less dense pasture species of high growth potential, (e.g. prairie grass and tall fescue) into intensively grazed temperate pastures, makes the need to develop more accurate methods of estimating pasture mass and comparative feeding value more acute. Cutting, the pasture probe (capacitance pasture meter) or the rising plate pasture meter have inherent limitations in themselves when used to estimate herbage mass, and these methods are even more inadequate for use in high herbage mass, tall and erect, heterogeneous pastures.

The use of inert internal markers, e.g. chromic oxide in gelatin capsules (Hodgson et al., 1977) or in controlled slow release capsules (CRC) (Parker et al., 1990, 1991), and natural or synthetic alkanes (Mayes et al., 1986; Dove et al., 1989, 1990) to estimate faecal DM output and feed intake was not feasible under the conditions of the present study. These methods often show variation in accuracy, and the results may not justify the high resource requirements (faecal and diet sampling; marker and digestibility assays)(Leaver, 1982). CRC and n-alkane methods may be less labour intensive, and are reported to produce more accurate estimates of feed intake in sheep, because of reduced diurnal variations in marker recovery, and more accurate estimates of herbage digestibility in individual animals, respectively. CRCs and alkanes also have their limitations, in addition to the very limited available data on their use to estimate feed intake of grazing lactating cows; however their future role in animal feeding research looks promising.

7.4 DISCUSSION OF RESULTS AND THEIR IMPLICATIONS TO DAIRY FARMING

The results of the present study were consistent in showing that high herbage mass swards (> 4t DM/ha) were less digestible and contained smaller concentrations of nitrogen compared with more intensely or frequently grazed swards (< 4t DM/ha). The feeding value of the herbage in terms of milk production per head was reduced, on average, by 12% (20% in summer) by a grazing regime that encouraged high herbage accumulations. Rates of net herbage production were similar for low and high mass swards because of high losses to senescence in the high mass swards (Bircham & Hodgson, 1983b; Xia, 1991). These results are consistent with those of similar studies reported previously (L'Huillier and Bryant, 1987; Michell and Fulkerson, 1987; Holmes et al., 1992; Hoogendoorn et al., 1992).

High rates of accumulation of dead matter and the high proportion of this component in the herbage and diet of grazing cows, appear to be the major reason for decreases in the feeding value of herbage - especially in the late spring/summer period (Thomson et al., 1984; Michell and Fulkerson, 1987).

With Matua prairie grass/clover pasture (Experiment 2) a grazing regime, including topping when required, which maintained low mass swards (average 4.0 t DM/ha) increased herbage quality and its feeding value as reported previously with perennial ryegrass swards (Bryant, 1982b; Hoogendoorn et al., 1992; Stakelum and Dillon, 1991). Milk production from these swards, except in summer, was similar to that from conventional perennial ryegrass/ clover swards. However, such grazing management led to sward decline (decreases in proportion of prairie grass), which was steeper than that observed when high herbage masses were maintained. A similar average reduction in milk production from intensively grazed prairie grass: ryegrass/clover pastures (50:50) compared to conventional ryegrass pasture was reported from Ruakura (Thom and Prestidge, 1988; A.M. Bryant, pers. com.). In the present study, average milkfat production from ryegrass and low mass prairie grass swards was similar, but milk and milk protein yields were 3% smaller ($P < 0.05$) from low mass Matua swards - as was observed at Ruakura. It is probable that reductions in milk yield compared to yields from ryegrass swards may be much greater at restricted herbage allowances, particularly in late spring/summer (present experiment) from intensely grazed Matua/clover swards (not sown with ryegrass e.g. Ruakura). Experimental evidence, however, is lacking.

Recent physiological studies of prairie grass cv. Grasslands Matua showed persistence and tillering was improved if intense grazing was delayed until after seedhead emergence (Hume, 1990a; Matthew et al., in press), or after replacement tillers appeared at the base of the sward which was then grazed to tiller height (Black and Chu, 1989). What effect does such a grazing regime have on short term (spring/summer) or long term production per animal and per hectare? Does Matua prairie grass still retain its annual dry matter production advantage (in terms of animal production) over perennial ryegrass under such grazing management practice?

What evidence is there to suggest that delayed grazing of Matua prairie grass swards, until post seedhead emergence, will halt sward deterioration in the long term (beyond 3 or 4 years)? Answers to these questions need to be provided through research before prairie grass can be recommended for incorporation into perennial pastures on dairy farms in New Zealand.

The Matua prairie grass plant (with a minimum of attached dead matter) has a very high nutritive value which decreases slowly with maturity (Cruickshank et al., 1985; Hume, 1990a, 1991d). Simple correlation analysis of the present data showed that the apparent OMD of Matua prairie grass herbage was not correlated to pregrazing herbage mass ($r = -0.2$, NS), sward surface height ($r = -0.3$, NS) (Experiment 1), or proportion of stem in the herbage ($r = -0.1$, NS; Experiment 2); but that it was highly correlated to the proportion of green leaf ($r = 0.9^{***}$) and to the proportion of dead matter ($r = -0.9^{***}$) in the pregrazing herbage (Appendix 7.2).

In perennial ryegrass pasture the r values for proportions of herbage components *vs* OMD were leaf, $r = 0.9^{***}$; stem, $r = -0.7^{**}$; dead matter, $r = -0.8^{**}$. The lack of correlation between the proportion of stem and OMD of prairie grass herbage suggests that prairie grass may be a suitable special purpose short duration crop (yielding high herbage masses of high digestibility) for use as green fodder (cut and carry), hay or silage. However, the economics and feeding value of Matua herbage under such managements need to be established, and the long term effects of such managements on sward persistence have yet to be assessed.

7.5 CONCLUSIONS AND SUGGESTIONS FOR FURTHER RESEARCH

The general conclusions to be made from the present studies are:

1. Maintenance of Matua swards at low mass improved the feeding value for milk

production of the herbage, which is in agreement with the first part of the working hypothesis. Cows grazing on high mass Matua swards produced approximately 10% less milk and milk solids per cow compared to the low mass swards. Compared to 'conventional' perennial ryegrass swards, low mass Matua swards had similar feeding value in all periods except in the summer, when it was lower in the low mass Matua swards.

2. The proportion of Matua prairie grass in the herbage, tiller densities and tiller weights, decreased in the low mass swards, the decrease was slow in Year One but more rapid in Year Two of the study in the high mass swards. Overall, the loss of prairie grass plants from the sward was more pronounced in the low mass swards. These observations do not support the second part of the hypothesis that increasing grazing pressure of Matua pastures while maintaining long rest periods (5-6 weeks) will maintain sward persistence.

3. Prairie grass is potentially a high nutritive value, short duration perennial (3-5 years) pasture species, despite the high proportion of stem in the herbage and reproductive activity which occurs for a major part of the year. The feeding value of Matua prairie grass herbage appears to be affected more by the proportions of green leaf and dead matter in the herbage than that of stem per se when compared with perennial ryegrass. This suggests that grazing regimes that reduce the proportion of dead herbage in the pasture may exploit the high feeding value, growth and herbage production potential of Matua prairie grass. However, in the cultivar's present form, such management will reduce sward persistence.

   These data and reports from other parts of New Zealand that Matua prairie grass persistence was reduced severely by disease and insect damage (anthracnose and Hessian fly), suggest that recommendations for inclusion of Matua prairie grass in a dairy production system in New Zealand can only be made in very limited circumstances.

The following areas are suggested for further research:

1. Basic plant breeding and selection research to improve perennation and persistence of Matua prairie grass. The species and cultivar contain valuable germ plasm for high dry matter production during critical periods, of high nutritive value and acceptability by the cows; which needs to be preserved while selecting for persistence and insect and disease tolerance. This is a long term priority research requiring the collaboration of agronomists and animal nutritionists.

Matua prairie grass, because of its relatively slow rate of decrease in herbage quality with increasing herbage mass and maturity, and because it has no vernalization requirement, is potentially a valuable pasture species for the subtropics and tropical highlands where the relatively warm climate causes fast decreases in herbage quality by accelerating lignification. However, the adoption of prairie grass in those environments will depend on the progress made in improving its persistence and pest tolerance.

2. Effects of a range of restricted herbage allowances, over a range of seasons, on the composition of herbage, herbage production, and milk production (per cow and per hectare) from low mass prairie grass dominant pastures (in comparison with perennial ryegrass pastures). Such a study would provide information on the comparative feeding value of prairie grass, under conditions of restricted feeding which are frequently encountered in practical farming.

3. Comparative feed intake assessment (indoors and at pasture) to determine the efficiency of feed conversion for milkfat and milk protein yield; and studies on the effects of Matua's sward structure on the composition of the diet ingested, and ingestive behavior of cows grazing Matua swards.

4. Effects, during mid/late spring, of grazing intensity and frequency (involving intermittent and set-stocking) of Matua pastures, and of conservation policy on the composition and feeding value of the herbage (including conserved herbage) at that time and in summer. Tiller dynamics, perennation and rates of net herbage accumulation should be monitored simultaneously.

5. Farmlet type studies, over several years and involving predominantly prairie grass, ryegrass or other common pasture species and mixtures of these, to investigate sward and dairy cow performance in an applied dairy production system.

6. Basic research on the competitive ability of prairie grass grown with other grasses and/or legumes; and detailed nutrition studies on herbage shear strength, ruminal degradation characteristics, e.g. N degradation, DM outflow rates and retention times, and patterns of volatile fatty acid production. These studies would be best done along-side the plant selection studies mentioned in (1) above.

APPENDICES

Appendix 2.1 Effects of defoliation regime and season on herbage growth and accumulation : a review

2.1.1 Herbage growth

2.1.1.1 Introduction

Defoliation is the complete or partial removal of the above-ground parts of plants by grazing animals, fire, mechanical or chemical means (Harris, 1978). Regrowth of herbage, defined as the development and increase in size and weight of new leaf and stem tissue (Hodgson, 1979) when successive defoliations are imposed, is one essential feature of a pasture plant. In contrast with cutting, animals selectively graze and tread pastures, deposit dung and urine, and disperse seed, which have an influence on herbage growth, persistency and utilization (Edmond, 1970; Watkin and Clements, 1978; Curll and Wilkins, 1983). The effects of treading, excreta return and seed dispersal on herbage growth and composition will not be reviewed here (see reviews by Brown and Evans, 1973; Watkin and Clements, 1978; Charles, 1979; Wolton, 1979; Wilkins and Garwood, 1986; Leaver, 1985; Korte and Harris, 1987). Attention will be directed mainly on the effects of defoliation on leaf and stem growth, tiller density and net herbage accumulation (NHA).

Herbage growth, both initial growth following dormancy and regrowth following intermittent defoliations, follows a sigmoidal pattern regarding time, common to many biological organisms (Brougham 1955, 1959a; Hunt 1970; Wilman et al., 1976a; Bircham and Hodgson, 1983b). A period of initial exponential growth is followed by a period of rapid linear growth, and finally a period when growth declines exponentially until the ceiling mass (plateau) is reached. The beginning of the plateau is the time when growth becomes limited by the light falling on the pasture and by increasing herbage senescence (Hunt, 1970). At that time, the pasture canopy will intercept 95% of the incident light (Brougham, 1955, 1956). The leaf area that will prevent all but 5% of the light from reaching the soil surface is called the critical leaf area and is usually defined by a critical leaf area index. The leaf area index (LAI), a measure of the photosynthetically active tissue in a sward, is the ratio of leaf area of a plant community to the area of land beneath that community, and the critical leaf area index varies with plant species and season (Watson, 1947). As grass plants age and mature the internodes elongate, the leaf arrangement becomes more open, and an increased leaf area is required to intercept 95% of the light falling on the canopy (Walton, 1983). Critical LAI therefore changes with season.

An important feature of the regrowth pattern of plants is the inverse relationship between their mass following defoliation and the length of time that passes before growth becomes exponential (Walton, 1983). This may explain why frequent lenient grazing rarely produces maximum herbage growth rates (Brougham, 1959b; Bryant and Blaser, 1961), most probably because grazing animals, under such a defoliation regime, tend to selectively remove the young leaves at the top of the canopy. It has been shown that young leaves are the most efficient, photosynthetically, in promoting further shoot growth in both grasses and legumes (Vickery, 1981). However, severe defoliation of pasture plants will remove not only a substantial amount of dry matter, but also much of the carbohydrate reserves stored in the stem base (Alberda, 1960). Where carbohydrate reserves are low, or where current photosynthesis is inadequate to support regrowth, for example under low light intensities, initial growth could be slow and the total productivity of the stand could be reduced (Ward and Blaser, 1961; Weinmann, 1961). This could be accentuated by a small area of leaf remaining following defoliation (ibid). Nevertheless, carbohydrate reserve is not an important issue for most New Zealand pastures (A.C.P. Chu & C. Matthew, pers. com.).

2.1.1.2 Leaf growth and effects of leaf removal

The tiller is the basic unit of grass and forms the basis of growth and development of the grass plant and the sward. It consists of a pseudostem (leaf sheath) or true stem (reproductive tiller), surrounded by leaf lamina (Davies, 1969). Sward lamina growth per unit area is a function of the tiller density (stolon density for clover), rates of tiller appearance and death, and the rate of leaf production per tiller, which depends on rates of leaf appearance and leaf extension (Davies, 1981). Individual tillers may live from a few weeks to a year depending on when they satisfy the vernalization requirements, a prerequisite to flowering for most temperate grass species (Langer, 1977; Williams, 1980). The lifespan of an individual leaf, assuming rates of leaf appearance of less than a week in summer and up to 3 weeks in winter, is from 4 to 5 weeks in summer and about 8 to 10 weeks in winter (Davies, 1977; Williams, 1980). As with tillers, the rate of leaf appearance is positively related to the moisture (Chu et al., 1979), temperature and light energy to which the plant is exposed; with an optimum temperature range for temperate grasses of 20 to 25°C (McWilliam, 1978; Williams, 1980).

Leaf growth and senescence are closely linked to maintain a constant number of live leaves per vegetative tiller, of approximately 3 to 4, which is made possible by the development of a new leaf, undergoing no further meristematic activity or growth at the time of death of the oldest leaf (Davies, 1977). In some cases there is a concurrent transfer of assimilates from the dying leaf to other parts of the plant (Williams, 1980).

Leaf growth starts from the leaf primordia located on alternate sides of the apical meristem. The leaf primordia have initially two meristematic zones: one at the base of the leaf sheath for sheath growth and another at the base of the leaf blade for growth of leaf lamina (Langer, 1977). Meristematic activity at the base of the leaf lamina ceases once the ligule is differentiated, and further leaf growth is sustained by the meristematic activity at the base of the leaf sheath; making leaf growth possible following defoliation (Williams, 1980). Leaf growth ceases once the ligule is exposed to light (ibid).

There is conflicting evidence on the sensitivity of leaf appearance and leaf growth to defoliation regime. Leaf appearance may be accelerated (Grant et al., 1981) or reduced (Davies, 1974) by close grazing, depending on severity. Grant et al. (1981) found that the effects of defoliation on leaf appearance were largely determined by the interaction of defoliation on leaf extension rates and the length of the sheath tube through which the emerging leaf grows. Higher leaf extension rates are found with larger (Chapman et al., 1983) and older tillers with greater lamina area (Grant et al., 1981), and therefore less severe defoliation increases leaf extension rates (Wilman and Shrestha, 1985). Greater rates of leaf extension (Parsons and Robson, 1980) and leaf appearance (Vine, 1983) are found with reproductive rather than vegetative tillers. Reproductive tillers may suppress the rate of leaf appearance of vegetative tillers associated with them (Davies, 1969). Although reproductive tillers have potentially greater rates of lamina growth, this may be short-lived as the number of leaves on reproductive tillers is limited; that is, once the flag leaf has emerged no more leaves will appear (Davies, 1977). Bircham and Hodgson (1983a, b) noted that leaf growth was much lower in the lower horizons of the sward canopy because of reduced interception of incident light, and this accelerates death and decay of shaded leaves.

The effect of leaf removal on the growth of a plant is dependent on whether the whole or only part of the leaf is removed, the stage of development of the leaf at which it is removed, and the extent to which the leaf area of the plant as a whole is reduced (Tainton, 1981). The importance of maintaining, in the sward, sufficient leaf area to intercept most of the incident light for photosynthesis, and of the rapid recovery of this leaf area after defoliation was demonstrated by the studies of Brougham (1956), in which regrowth increased as the residual LAI increased.

In swards maintained at low LAI, young leaves are expanded in high light, free from shade by old leaves and so could develop a high capacity for photosynthesis (Woledge, 1977). In a sward maintained at LAI 1.0 by continuous grazing, the growing leaves and the youngest fully expanded leaves contributed some 75% to the total photosynthesis of the canopy (Parsons et al., 1983a). Leaf sheaths and clover stolons are also photosynthetically active, but contribute less than 5% to the gross photosynthesis of the sward (Parsons et al., 1983a; Korte and Parsons, 1984) However, at the high stocking rates required to maintain a low LAI, many leaves are defoliated while young (Maclvor and Watkin, 1973). Thus it is a proportion of the most photosynthetically efficient tissue that is removed, and the remaining leaves in the sward tend to be older and less efficient. The reduction in photosynthetic capacity of the plant will invariably affect plant vigour and in particular the growth rates of roots and lateral daughter shoots (Walton, 1983). Frequent leaf removal could therefore reduce the capacity of plants to produce tillers, and will reduce the size and depth of penetration of the root systems (Troughton, 1957; Evans, 1971). However, other investigators (Matthew et al., 1991), have reported root mass and new root development in perennial ryegrass swards to be relatively insensitive to grazing management; seasonal fluctuations in the production of new roots were large in comparison to those produced by contrasting hard and lax grazing regimes. On the other hand, the increased light penetration to the base of the sward resulting from leaf removal may stimulate the development of daughter tillers from basal nodes in many species, or alternatively stimulate the growth of young tillers that have already begun development, which may not have survived in the dense canopy (Tainton, 1981).

2.1.1.3 Stem growth and effects of stem removal

The development of the stem and inflorescence in most temperate grasses, and that of the inflorescence in legumes, is dependent on suitable environmental conditions of low temperature (vernalization) and photoperiodism. Vernalization helps to stimulate the apex of the plant to respond to conditions inductive to flowering i.e., daylength and temperature (McWilliams, 1978). The optimum temperature for thermo-induction ranges from 1-7°C although vernalization can occur over a wide range of -5 to 14°C (ibid); whereas the critical day length is 13-15 hours, below which flowering will not occur (Williams, 1980).

Since the inflorescence of the grass plant develops directly from the apex of the stem, the most obvious effect of removing the apex is that of terminating stem growth and preventing flowering and seed production (Brougham, 1961). Another effect of the removal of the stem apex results from the associated removal of the inhibiting effect of the apex on the development of lateral tillers lower down on the stem, an inhibition that results from the secretion of growth regulators by the apex (Tainton, 1981). The removal of the apex leads to growth in previously dormant tiller initials at the basal nodes of the stem, and this results in an increased tiller density (ibid).

Besides the above effects, the removal of the stem apex in certain species in which it is elevated above grazing or cutting height while it is still in the vegetative growth stage, and therefore still producing leaves, reduces the eventual number of leaves that will be formed (Davies, 1976).

The importance of the location of the apical meristem has long been recognized. During the annual cycle of development some tillers become reproductive and basal internodes begin to elongate, carrying the developing inflorescence upwards and exposing it to decapitation. Once the apex has been removed the tiller stub dies, so regrowth in reproductive swards depends partly on the number and developmental status of any accompanying undecapitated tillers (Davies, 1977). The timing of defoliation during the reproductive phase is thus critical regarding the quantity and character of regrowth. Matthew (1990) suggested that reproductive tillers supply substrate to daughter tillers and help their initial establishment, and that the translocation to daughter tillers was greater where the parent tiller seedhead had been removed than where the parent tiller seedhead had remained intact.

As decapitated tillers cannot continue growth, immediate regrowth depends on the tillers that have escaped decapitation and can continue to form new leaves and/or stem material. New tillers also develop on the defoliated stubs of the decapitated tillers (Matthew, Black & Butler, in press). There is ample evidence to show that when these stubs are cut short, fewer new tillers are formed and regrowth is reduced (Davies et al., 1981). Each reproductive tiller stub in perennial ryegrass swards seems capable of producing two to three new tillers both intravaginally (after decay of subtending sheaths) and extravaginally (breaking through old sheaths) (Davies, et al., 1981); and under favourable conditions the number of living tillers may double in two weeks (Davies, 1981). However, in dry conditions many vegetative tillers in a reproductive sward of perennial ryegrass die before or because of defoliation (Davies, 1988).

Responses to defoliation in the reproductive phase are related both to the duration of the phase and to the percentage of tillers that become reproductive. In swards well supplied with water and nitrogen the loss of old tillers by decapitation is quickly made up for by development of new tillers, though heavy fertilization of a reproductive crop can both increase deaths of non-flowering tillers after defoliation and reduce formation of new tillers

(Dawson et al., 1983).

Autumn and early spring defoliations appear to have little influence on the number of seedheads formed (Roberts, 1965; Johnson and Parsons, 1985), though they may influence the number of vegetative tillers and therefore the percentage of tillers that flower (Davies and Simons, 1979; Johnson and Parsons, 1985). Comparisons of data from different experiments, harvest years and cutting treatments, for S24 perennial ryegrass, confirm that the total number of tillers that become reproductive remains similar over a wide range of circumstances (Davies, 1988). Very frequent close defoliation, however, reduces the total number of reproductive tillers in a way that can not be accounted for by tiller deaths, both in rotationally and continuously grazed swards (ibid).

2.1.2 Tiller populations

The number of tillers present per unit area at any one time depends on the relative rates of formation and death (Langer, 1963). As was mentioned previously (Section 2.2.1.3) tiller formation is stimulated by defoliation, though the number of new tillers initiated, and the rate at which they develop, is likely to be affected by sward conditions both before and after defoliation (Jewiss, 1972). The longevity of tillers is influenced by time of year at which they first appear. Tillers appearing immediately following anthesis tend to survive in a vegetative state through the following winter, form the bulk of inflorescences the following year, and then die (Holmes, 1980). Tillers developing later are subject to competition from previously established tillers, and a proportion of the tillers established in late winter and early spring may succumb to the competitive effects of shading before flowering (Jewiss, 1966).

The rate of tiller death is usually greatest during reproductive growth, due initially to the death of vegetative tillers surrounding the reproductive tillers, and then due to death of the reproductive tillers post anthesis (L'Huillier, 1987a). The death of vegetative tillers is caused by the failure of larger tillers (mainly reproductive) to supply assimilate to smaller heavily shaded vegetative tillers (Ong et al., 1978).

Thus, loss of tillers is increased by both severe shading and by frequent severe defoliation (Brougham, 1959; L'Huillier, 1987a). Changes in tiller density can be extremely rapid over short periods of time (Brougham, 1960; Garwood, 1969), though it may be easier to depress than to increase populations in the short term (Korte, 1982; Korte et al., 1984; Xia et al., 1990).

In general, more frequent or intense defoliations result in a higher tiller density due to greater tiller appearance and survival in conditions of light and reduced assimilate demand by the recently defoliated parent tiller (Baars et al., 1981; Grant and King, 1984; L'Huillier and Bryant, 1987; Xia et al., 1990). Tiller densities are also maintained at a higher level under continuous stocking management than under rotational grazing at comparable stocking rates (Hodgson and Wade, 1978; Tallowin, 1981; L'Huillier, 1987b).

The influence of severity of defoliation is more complex, populations tending to be greatest at intermediate levels of defoliation, but the pattern of response is sensitive to both sward and climatic conditions at the time of defoliation (Brougham, 1960; Jewiss, 1972; Grant et al., 1981a, b).

In a vegetative sward, tiller density and weight per tiller are inversely related (Bircham, 1981; Hodgson et al., 1981; Butler, 1986). This relationship is defined (according to the self-thinning rule) as a thinning line of tiller density plotted against tiller weight (log scale) with a slope of minus 3/2 (Yoda et al., 1963). The self-thinning law does not apply on very short and intensely grazed swards, where tiller density declines due to frequent uprooting and decreased rate of tiller formation; on swards where tiller numbers are increasing; or on mixed pasture (Hodgson et al., 1981; Grant and King, 1984; Davies, 1988).

Swards may respond to defoliation by net gains, net losses or no general changes in tiller populations, depending on initial tiller numbers at the time of defoliation, and time of year (L'Huillier, 1987a). For example, ryegrass tiller density on pastures grazed by sheep has been reported to be greatest in late winter/early spring, declining during reproductive growth and then increasing again in autumn (Harris, 1971; Hunt and Field, 1978; Korte, 1981). In the late spring a sward defoliated intermittently (e.g. every 4 weeks) may develop a stand of tillers sufficiently dense to permit rapid canopy development and suppress further tillering (Davies, 1977; L'Huillier, 1987a). Tillers may be suppressed to the point at which they will die when the sward is defoliated (Alberda, 1966; Tallowin, 1981). Wade (1979) observed that tiller losses in swards were high in the first week after defoliation and that subsequent tiller production was inversely proportional to LAI. When tillers cease to develop, leaf sheaths accumulate, and these may die and persist after the sward has been defoliated. With continued lax defoliation, tubes of dead sheaths may accumulate and suppress further tiller development (Jackson, 1974).

On ryegrass/white clover pastures grazed by dairy cows in New Zealand, tillering activity was greatest during late spring/early summer (October-December), and not in the autumn period as commonly stated (Bryant and L'Huillier, 1986; L'Huillier and Bryant, 1987; L'Huillier 1987a). The rate of tiller death was also greatest during the late spring/early summer period and was greater in low stocked than high stocked swards (2.8 vs 4.3 cows/ha); whereas tiller appearance rate during the same period was not significantly affected by stocking rate (L'Huillier, 1987a). The seasonal pattern of tiller density is reported to be unaffected by grazing management, irrespective of stocking rate; grazing management merely affects the rate and/or extent of the change (Tallowin, 1981; L'Huillier, 1987a).

Tiller density is also influenced by the species of animal grazing the sward and by the nitrogen status of the soil. Greater tiller densities are found with sheep than with cattle grazing at similar intensities (Arosteguy et al., 1983, Sheath et al., 1987). Cattle appear to uproot tillers to a greater extent than sheep do (Briseno de la Hoz and Wilman, 1981), particularly at low grazing intensity (Tallowin, 1985) which may be a function of the difference in method of prehension between the two species. Although tiller density generally increases with nitrogen application (Ball and Field, 1982), the effect is dependent on season and grazing regime imposed. Increases in tiller populations due to N are greatest towards the end of the summer and smallest in early spring; while infrequent defoliation will result in a decreased tiller density probably due to increased shading with fertilized compared to unfertilized swards (ibid).

2.1.3 Pasture production

2.1.3.1 Total herbage production

Two characteristics of the grass crop that are central to understanding the effects of defoliation on production were recently highlighted by Parsons (1988). Firstly, because the grass sward displays a rapid turnover of tissues, any material that remains unharvested is soon lost to death. This turnover is clearly the origin of a considerable potential loss to production. With mean leaf appearance intervals of 11 days, an amount equal to the entire standing live weight of the crop may die each month. So, in contrast with many crops that are harvested once after a single period of growth, the grass crop must be harvested repeatedly. Secondly, it is the photosynthetic tissue, the leaves, that are predominantly harvested. Over the whole year, the repeated defoliation that is essential to harvest a proportion of the grass crop, inevitably reduces the leaf area and light interception of the canopy, interrupts canopy photosynthesis and so reduces the capacity for the production of new leaves. Clearly, then, the way the sward is harvested on any one occasion has a profound effect on the amount grown, as well as on the degree to which the tissue produced is harvested.

The objective of good grassland management must be to strike a compromise between the conflicting demands of the grass plant, which needs to retain leaf area for photosynthesis, and the essential need to harvest leaf tissue for animal consumption to meet specific animal requirements and production objectives (pasture-animal interface). This conflict leads to a dilemma that is central to grassland management (Holmes, 1987; Sheath et al., 1987).

Control over the frequency and severity of defoliation has long been recognised for manipulating the amount of herbage produced over a given period (Smetham; 1975; Holmes, 1980). In most studies, the effects of defoliation on herbage yield have been determined by: (1) the amount of herbage dry matter per unit area determined by cutting (herbage harvested); (2) grazing (herbage consumed); and (3) the amount accumulated between successive grazings (herbage accumulation). These three parameters may differ from each other, and none directly measures pasture growth rate (Hodgson, et al., 1981), which is difficult to quantify in cut or grazed pasture, and is seldom attempted (Korte and Harris, 1987; Korte et al., 1987). Most often the three parameters outlined above are actually measurements of net pasture production (less decay), which will be discussed later.

The effects of defoliation regime on pasture production have been extensively studied, and have been reviewed by several authors (Harris, 1978; Vickery, 1981; Curll, 1982; Korte and Harris, 1987; Simpson and Culvenor, 1987). Herbage DM production is usually reduced by intensive and more frequent defoliation, whether by cutting or grazing (Brougham, 1959b; Pinneiro and Harris, 1978a; Bircham and Hodgson, 1983b; Stockdale, 1986); although herbage yield under grazing may be 1.1-1.2 times that under cutting (Curll and Wilkins, 1983). The adverse effects of more intense defoliation are often reduced by less frequent defoliation (Campbell, 1969; Brougham, 1970; Baars et al., 1981). Sometimes, more frequent or intensive defoliations have increased DM production (Alcock, 1964; Binnie et al., 1980; Hoogendoorn, 1986). In such cases, greater utilization of herbage from the base of the sward, rather than increased growth, may be a major reason for the higher yields obtained (Korte and Harris, 1987). In other reports, intensive rotational grazing by dairy cows at 2.7 to 4.3 cows/ha (McFeely et al., 1975; L'Huillier, 1987b), or at daily herbage allowances of 16 to 32 kg OM/cow (Kristensen, 1988) had no significant effect on annual herbage accumulation (total or green). A similar observation was reported by Rattray

(1978) with pastures grazed by sheep at 28 vs 21 ewes/ha, with early or late lambing, over three years; although lax grazed pastures produced more DM during August-October and less DM during February-May.

Very infrequent defoliation may also reduce herbage production (Brougham, 1970; Baars et al., 1981). Brougham (1970) showed that grazing infrequently with sheep in the winter (126 vs 42 days) reduced yields by 40%. A similar reduction was noted by Baars et al., (1981), when winter pastures were grazed at 4000 rather than 3000 kg DM/ha. On the other hand, Bryant and L'Huillier (1986) reported increased herbage accumulations in July (winter) of 150 kg DM/ha for every 10 day increase in autumn-winter rotations. The stocking rate was 3.7 cows/ha, while rotation lengths were 43-99 days. Santamaria and McGowan (1982) and Hoogendoorn et al., (1987) also reported increased winter-early spring herbage growth rates following long winter rotations of pastures grazed by dairy cows. However, the amount of feed on the farm in August-September positively affects mid- to late-spring herbage growth rates more than grazing intensity or rotation length per se (Carton and Brereton, 1982; Santamaria and McGowan, 1982; Bryant, 1983, 1990a, b; Thomson et al., 1989).

In a review of grazing experiments, Hodgson and Wade (1978) concluded that defoliation at intervals less than 2 weeks may reduce herbage production by 40%. Grazing every 4 weeks consistently increased production 15-17% over 2-3 weekly grazing when the height of grazing was controlled. However, in some experiments with dairy cows, no significant difference in herbage yield was observed between 2-3 vs 4-5 weeks rotations over the grazing season (Leaver, 1975; McFeely et al., 1975).

In other situations, various combinations of defoliation frequency and intensity have had little effect on annual yields (Hodgson and Wade, 1978; Hodgson et al., 1981a). In these cases, although photosynthesis and herbage growth were reduced by more frequent and intense defoliation, death and decay of unharvested herbage was also reduced. However, very intensive or very frequent defoliation (beyond the range of practical interest) does reduce annual yield under both continuous stocking and intermittent defoliation (King and Stockdale, 1980; Hodgson, 1990b).

Herbage growth after severe defoliation is sigmoidal over time (see Section 2.2.1.1). Growth is initially exponential, then linear; growth rates during these two phases are highly dependent on the severity of defoliation , and have a bearing on the ability to match the availability of quality herbage and animal requirements, at least in the short-term.

The conflict in results between studies on the effect of defoliation regime on pasture production can be attributed to differences in and interactions between environments, botanical composition of the pasture, the method of defoliation, measurement technique and species of animals used to graze the pasture. Also the diverse definitions of, and interactions between grazing intensity and frequency, soil nutrient status, and season, contribute substantially to the reported inconsistencies of the results. For example, Brougham (1959b) showed that annual yields were reduced 20% by frequent severe grazing (7.5 cm to 2.5 cm versus 17.5 cm to 7.5 cm). However if grazing frequency was reduced (grazing after growth to a sward height of 22.5 cm down to 2.5 cm versus grazing at 7.5 cm down to 2.5 cm) then no reduction in herbage accumulation eventuated. A common explanation of these results is that less frequent hard grazing enables pastures greater time in the linear phase of growth so that net production is not reduced. However, very similar results were obtained by Brougham (1960) during the spring when there may be little or no exponential phase to the growth curve. Korte (1981) also found during spring that herbage mass appeared to increase linearly between grazing (either hard or lax) and 95% light interception.

The presence of interactions between defoliation regimes and season, and the effects of alternation between lax and intense defoliations on pasture production have been demonstrated by several workers. Infrequent hard grazing in winter outyielded lax grazing (Brougham, 1960) while Tainton (1974b) showed that alternate lax and hard grazing in autumn may outyield hard grazing by 63%. Sheath and Boom (1985) found that hard summer grazing did not lower herbage accumulation, as did Brougham (1960), and attributed this to pastures of predominantly annual species rather than the ryegrass based pastures of Brougham, despite similar moisture status. During dry summers, hard grazing reduced herbage accumulation by 20 - 40%, compared with lax grazing (Brougham, 1960; Tainton, 1974a). Appadurai and Holmes (1964), however, observed that when the soil was maintained close to field capacity, ryegrass/white clover pastures produced 20-41% more under hard (2.5 cm) than lax (7cm) cutting.

Alternate hard and lax grazing has been shown to result in a small increase (10%) in herbage production when previously hard grazed swards were laxly grazed, and a similar drop in production when hard grazing previously lax grazed swards (Baars et al., 1981; Xia et al., 1990); however, changing from lax to hard grazing in early summer increased both total and net herbage production in summer (L'Huillier, 1987a; Xia et al., 1990). Bircham and Hodgson (1984) also found that changing the intensity of grazing from lax to hard under continuous grazing reduced herbage accumulation, but it did not increase when changing from hard to lax grazing. The authors attributed this to fewer tillers and reduced growth per tiller in the hard then lax grazed swards, which is characteristic of low mass (frequently hard grazed) swards.

The effects on herbage accumulation of integrating animal species to take advantage of complementary grazing habits, especially in late-spring-early summer, are not clear. In some reports, herbage accumulation was greater for swards stocked with sheep or sheep with cattle than those stocked only with cattle (Monteath et al., 1977; Boswell and Cranshaw, 1978), which may be a result of associated differences in the degree of treading and defoliation (Sheath et al., 1987), and the change in botanical composition, i.e. more cocksfoot under cattle whereas under sheep there was more ryegrass. However, McCall et al. (1986) did not observe significant differences in green mass accumulation on easy or hill country swards grazed by cattle and sheep in various ratios. Total herbage accumulation was not reported.

2.1.3.2 Spring-summer herbage production

Peak herbage accumulation rates within a year coincide with inflorescence emergence in the spring-early summer period (Leafe et al., 1974). In New Zealand 60-80% of annual growth usually occurs from September to January (Rattray, 1978; Bryant and Sheath, 1987; Bryant, 1990a); consequently many studies have been conducted to assess the effects of grazing management during this period on immediate and subsequent herbage production.

The timing and frequency of defoliation during the spring reproductive growth period may affect the long-term accumulation of herbage in a sward. A reduction in annual herbage accumulation of 20-40% has been reported when reproductive development was interrupted at a leafy stage compared to interruption at full flower emergence (Wilman et al., 1976a, c). Mislevy et al. (1977) reported no effect on total spring or annual herbage accumulation over a 38 week measurement period of defoliation at early culm elongation versus at 30% inflorescence appearance. Apart from the timing of defoliation, increasing the frequency of defoliation during reproductive growth may result in decreased annual herbage production (Wilman et al., 1976 a, c; L'Huillier, 1988). Most of the increase in net herbage accumulation with less frequent grazing during this period can be attributed to increased growth of the stem and inflorescence (Korte et al., 1984; L'Huillier and Bryant, 1987).

Most reports show that lax rather than hard grazing of perennial ryegrass dominant swards during spring increases total spring herbage accumulation (Carton and Brereton, 1983, L'Huillier, 1987b; Michell and Fulkerson, 1987; Thomson et al., 1989). A similar effect has also been reported with long rather than fast rotations or set stocking at comparable stocking rates during mid spring to early summer (L'Huillier, 1988; Thomson et al., 1989). In some reports, however, spring herbage accumulation was decreased by lax compared to intense grazing (Holmes and McClenaghan, 1979; Binnie et al., 1980) or no significant effect was observed (Holmes and Hoogendoorn, 1983; Korte et al., 1982b, 1984). Net or green herbage accumulation in spring may increase (L'Huillier, 1987b; Mayne et al., 1987; Hoogendoorn et al., 1988), or may not be significantly affected (Xia et al., 1990) by lax rather than intense grazing during the same period. Frequent grazing from mid spring (e.g., 12d rotations) or set stocking rather than long rotations (e.g., 30d) may decrease net herbage accumulation, but increase spring tiller density (L'Huillier and Bryant, 1987). This may reflect a greater degree of "control" of reproductive tiller development and thus lower net herbage accumulation of this component and stem (ibid). Such differences may also be due to an interaction between defoliation frequency or intensity and climatic conditions, and the influence this has on treading damage (Wilkins and Garwood, 1986; Mayne et al., 1987).

Spring management may also affect subsequent herbage accumulation. Pastures that are laxly rather than intensely grazed during spring may have reduced (Korte et al., 1982, 1984; Holmes and Hoogendoorn, 1983; Sheath and Bircham, 1983; Sheath et al., 1984; L'Huillier, 1987b), or increased total accumulation during the subsequent summer-autumn period (Carton and Brereton, 1983; Mayne et al., 1987; Thomson et al., 1989; Xia et al., 1990). At high stock rates (e.g., 4 cows/ha), frequent defoliation or set stocking rather than long rotations in spring increased (L'Huillier, 1988) or had no effect on summer herbage accumulation (Thomson et al., 1989). On the other hand, net herbage production during summer may be increased by intense grazing during spring (L'Huillier, 1987b; Michell and Fulkerson, 1987; Hoogendoorn et al., 1988; Xia et al., 1990), which encourages tiller development from the stubs of grazed reproductive tillers.

The higher rates of summer net herbage production following hard grazing in spring may be a result of lower rates of growth being more than balanced by lower senescence losses (Korte et al., 1984; L'Huillier, 1987a, b; Xia et al., 1990). However, moisture status rather than grazing management has the dominant influence on herbage growth during summer (Chu et al., 1979; Sheath and Bircham, 1983; Korte et al., 1987; Bryant, 1990b).

2.1.4 Components of net herbage accumulation

There has long been interest in the degree to which control of sward conditions can be used to influence herbage production and utilization. However, many investigators have concluded that Net Herbage Accumulation (NHA) is relatively insensitive to variations in grazing management or to variations in stocking rate over the range of practical interest (Hodgson and Wade, 1978; L'Huillier 1987b; Grant et al., 1988; Parsons, 1988; Hodgson, 1990b). The absence of substantial differences in animal production per hectare between intermittent and continuous grazing managements supports this view (McMeekan, 1956, 1960; Clark et al., 1982, Bryant, 1984, 1990b; Bryant and L'Huillier, 1986; Bryant and Sheath, 1987; L'Huillier, 1988).

The development of concepts of tissue turnover or tissue flows in grazed swards provided a basis for explanation of this relative insensitivity to variations in grazing management. In summary, the rate at which herbage accumulates for harvesting represents the balance between the rate of growth of new plant tissue and the rate of loss of established tissue to senescence and decomposition (Hodgson et al., 1981, Bircham and Hodgson, 1983a, b). In theory both the rate of growth and the rate of loss can be controlled by cutting or grazing management, but in practice the effects of defoliation on the sward characteristics that determine these rates tend to be self-compensating in the long term (ibid).

The use of NHA as the index of comparison in both cutting and grazing experiments introduces a major difficulty in the interpretation of treatment differences. In the absence of grazing animals, NHA is a function of plant tissue growth (G) and death and decay (D), but when the grazing animal is present, NHA represents the balance between G, D, and herbage consumption (C), all expressed as rates per unit of ground area, (Davies, 1981; Bircham, 1981). Plant tissue flow from the live pool to the dead pool is described as senescence. Thus, growth can be considered as potential production, and decay can be regarded as a measure of the inefficiency of the grazing process.

Net herbage accumulation can thus be described as:

$$\text{NHA} = \text{G} - (\text{D} + \text{C})\text{............}(1)$$

In these circumstances differences in NHA between experimental treatments could be due to differences in G, D or C, or to interactions betweenn two or more variables. Herbage tissue that is not harvested must eventually senesce and die (Vickery, 1981); therefore the efficiency of harvesting the tissue grown is a determinant of NHA. When NHA is zero, as it may be under continuous stocking management, equation (1) can be transformed to equation (2):

$$NP = G - S = C \text{ green} .... (2)$$

whereby NP is the net production of green herbage, and senescence (S), the rate at which live tissue becomes dead tissue, is substituted as an alternative to the parameter D, which is difficult to measure. The measurement of NHA merely accounts for the net result of the processes just described.

The balance between photosynthesis, gross tissue production, herbage intake, and death, that may be achieved in swards maintained at a range of sward states, has been derived from studies of both the carbon balance of the grazed crop (Parsons et al., 1983a, b, 1988; Parsons and Penning, 1988) and from studies of the rates of tissue growth and senescence on individual tillers (Bircham and Hodgson, 1983a, b; Grant et al., 1983, 1988). These studies have shown how rates of photosynthesis and gross tissue production are close to a maximum in swards maintained at high herbage masses, but to sustain this level of green production a large proportion of leaves must remain in the sward to contribute to photosynthesis. As a result, this tissue inevitably causes a high rate of loss of matter to death and decomposition through shading, and the amount harvested is small. In swards maintained at a lower herbage mass, a greater proportion of leaf tissue is removed and photosynthesis and gross tissue production are reduced. However, in terms of animal production per head or per hectare, the increase in the harvesting efficiency of plant tissue of high digestibility usually offsets the decrease in the amount grown (Parsons et al., 1983b; 1988).

Clearly then, maximum harvested herbage yield per hectare is not achieved in swards maintained at high herbage masses to intercept a large proportion of the incident light, but at a lower, intermediate mass, as this allows the best compromise between gross tissue production on the one hand and losses to decomposition and death on the other. Bircham and Hodgson (1983a, b) demonstrated the existence of a 'homeostatic' mechanism in swards continuously grazed by sheep (Figure 2.1), by which compensatory changes in species population density and tissue turnover on individual plant units combine to maintain relatively constant net production of green herbage, over a range of herbage mass, sward surface height or leaf area index levels. At the lower extreme (< 1000 kg OM/ha), herbage growth restricted net production, and at the higher extreme (> 2000 kg OM/ha), rates of senescence would reduce net production. Maximum net herbage production in continuously grazed perennial ryegrass swards is achieved at a sward height of 4-7 cm (Bircham and Hodgson, 1983b; Schlepers and Lantinga, 1985).

Most studies monitoring the effects of grazing regime on NHA have been conducted with sheep or beef cattle while studies with dairy cows are scarce. The limited studies conducted on temperate pastures grazed by dairy cows (Carton and Brereton, 1983; Schlepers and Lantinga, 1985; Hoogendoorn, 1986; Hoogendoorn et al., 1988; L'Huillier and Bryant, 1987; Michell and Fulkerson, 1987; Xia, 1991), which may differ considerably from sheep grazed pastures, were mostly short-term. Short-term NHA in these studies was greater in lax or long rotation than intensely or short rotation grazed swards. However, Schlepers and Lantinga (ibid) and L'Huillier (1987b) did not observe significant differences in NHA due to grazing frequency over the grazing season. The recent conclusion by Bryant (1990b), that, on farms already highly stocked, variations in grazing management account for no more than 10 kg milkfat per cow over the entire lactation, may reflect the minor effects on longterm NHA of variations in grazing management. Bryant (ibid) cautions, however, that grazing management should be used as a fine tuning tool, to maintain sufficient herbage mass on the farm during mid to late spring to encourage high herbage accumulation rates when animal responsiveness is greatest, and to control stem accumulation and promote self-reseeding and sward density in late spring-early summer. This could be achieved through long rotations (about 20d) in early spring, and fast rotations or set stocking during late spring-early summer, with conservation or 'deferred grazing' (Bryant and L'Huillier, 1986; L'Huillier, 1988; Thomson et al., 1989).

Appendix 2.2 Composition of temperate pastures : a review

2.2.1 Botanical composition

Grass species

It is estimated that throughout the world there are approximately 600 grass genera containing some 6,000-10,000 species, about 40 of which account for over 90% of sown pastures (Williams, 1981; Langer, 1990). In each of the temperate and tropical grasslands, 20-25 of these grass species are now in use in cultivated pastures (Mott, 1981; Norton, 1982); most of which having been improved through breeding and selection to give a range of strains and cultivars. The grass genera that constitute most temperate pastures include *Lolium, Bromus, Dactylis, Festuca, Phalaris, Phleum, Agrostis, Holcus* and *Poa* (Langer, 1990). In the warmer parts of the temperate regions a few grass species of tropical and subtropical origin, mainly *Paspalam dilatatum* and *Pennisetum clandestinum*, have shown promising performance as components of pasture leys (Goold, 1979; Rumball and Boyd, 1980).

Forage legumes

Legumes, as a result of their ability to 'fix' atmospheric nitrogen through a symbiotic relationship with appropriate *Rhizobium* bacteria species and strains in root nodules, are an important component of both temperate and tropical pastures. Forage legumes as a group have a higher nutritive and feeding value than any grass species (see Section 2.3.3 for evidence) and when grown with grass, they improve the protein concentration of pasture swards (Minson, 1981a; Ulyatt, 1981; Thomson, 1984). Most important, however, legume forages provide cheap nitrogen for grass growth and improve pasture dry matter yields, especially in temperate grasslands receiving nil or limited N fertilization, e.g., New Zealand (Lancashire, 1985a; Sheath and Harris, 1985;). In New Zealand, nitrogen fixation by clover averages 185 kg/ha per annum (Ball et al., 1979). These characteristics of forage legumes are of special significance in the tropics because of the inherent lower nutritive value of tropical pasture grasses (Minson, 1976, 1981a). Forage legumes that are sown in temperate pastures belong to 20 species, mostly of the genera *Trifolium, Medicago, Lotus* and *Onobrychis* (sainfoins) (Norton, 1982). In the tropics 12 genera have been reported (ibid).

Grass-legume balance

The most important pastoral association in temperate regions is perennial ryegrass and white clover (Williams, 1980; Harris and Chu, 1985). Other grass and legume species, whether sown as pure stands or as grass-legume mixtures, contribute a smaller proportion of the pastures and the dry matter consumption of ruminant animals, mainly as special situation or special purpose forage. Exceptions are lucerne, sown mainly in pure stands, and subterranean clover, which are the dominant legume forages in North America (Stelly, 1972) and the cooler regions of Australia (Wheeler, 1981; Stockdale et al., 1985), respectively.

The proportion of clover in grass-legume swards differs widely in different temperate countries. Reports from the U.K. (Frame, 1981; Snaydon and Baines, 1981) indicate that 80% of pastures surveyed contained less than 5% clover with 80% of the established leys under perennial ryegrass. The situation is probably similar in other parts of Europe, arising from heavy reliance on nitrogen fertilizer, unpredictability of clover performance, and low persistence probably because of extended low temperatures (Frame and Newbould; 1984; Davidson and Robson, 1984). It may also be due to less adapted clover varieties and pasture defoliation practices (ibid). With declining farm profits, due to reduced agricultural support and continuing downward trends in the consumption of dairy cattle derived products, and environmental legislation to reduce N losses from livestock systems, the U.K. is reappraising its N fertilization policies (Leaver, 1991). Furthermore, with average responses of 4-10 kg DM/kg N at mean application rates of 250 kg N/ha annually on grazed dairy farms (Morrison, 1987), the use of white clover is becoming a more attractive option (Phillips, 1989; Leaver, 1991). Similar average response rates to N fertilization have been observed on New Zealand dairy pastures at application rates of 85 to 400 kg N/ha annually (Bryant et al., 1982; Holmes, 1982; Roberts and Thomson, 1989).

The clover content of New Zealand pastures varies from 15 to 40% depending on topography, season and grazing management (Smetham, 1977; Hoglund et al., 1979). However, differences in the botanical composition of pastures on the country's dairy and sheep farms are small, except for prairie grass that is mainly grown by dairy farmers (Lancashire, 1985a, b). Other significant grass species sown, in descending order of occurrence, are cocksfoot, timothy, and more recently tall fescue (Lancashire, 1985a). Legume species, in a similar order of occurrence, are red clover, subterranean clover, lucerne and lotus (ibid). *Poa* spp., *Agrostis* spp. and weeds may form part of the botanical composition of pastures as primary 'colonizers' depending on several factors to be discussed later (Section 2.3.2), and may form an important source of nutrients for grazing animals.

2.2.2 Morphological composition

Grass harvested by the grazing animal or by cutting the sward, comprises leaf blades, leaf sheaths, which form a pseudostem before the initiation of reproductive development, true stem and dead material (Osbourn, 1980). In the forage legumes, leaflets, petioles, stem and inflorescences are readily distinguished, although in white clover, the true stem being prostrate and stoloniferous, only the petioles and laminae stand erect above it (ibid).

As the leaf canopy in a sward increases, the lower leaves begin to senesce and die, resulting in a pasture sward that contains varying proportions of green leaf, dead leaf, stem and inflorescence (Bircham, 1981). The leaf:stem ratio, the proportion of dead material, and the spatial distribution of these components in a pasture sward, vary considerably with season, stage of growth, fertilization and defoliation regime; and have a major influence on the concentration of nutrients, digestibility of the dry matter and feed intake (Raymond, 1969; Norton, 1982; Hoogendoorn et al., 1985). The influence of sward composition on the nutritive value of herbage is discussed in Section 2.3.2.

2.2.3 Nutrient concentrations and digestibility

Chemical composition of herbage

A useful nutritional, and simple empirical, chemical division of plant material is into cell contents and cell-wall constituents (Van Soest, 1967). The cell contents, which are almost entirely digested by the ruminant animal, include most of the plant proteins, peptides, amino acids, nucleic acids, lipids, vitamins, minerals, pectin and α-linked carbohydrates; and all, except minerals and silica, are soluble in neutral detergent (ibid). The cell wall residue is termed neutral detergent fibre (NDF). The cell wall fraction of the plant contains the β-linked structural polysaccharides (hemicellulose and cellulose) that are degraded only by the polysaccharidases produced by microorganisms in the reticulo-rumen of ruminants and in the cecum of hind-gut fermenters (non-ruminant herbivores); and it also contains lignin. The residue, after NDF is boiled in an acid-detergent solution, is the acid detergent fibre (ADF) fraction containing ligno-cellulose and insoluble minerals (Van Soest, 1967).

As plants mature, lignin, which is an extremely stable compound and is not degradable in the animal's digestive system, is deposited in the cell walls. Besides being undegradable, lignin also encrusts the cell wall polysaccharides and forms chemical bonds that prevent the cell walls from swelling (Osbourn, 1980). The swelling of cell walls is a prerequisite for the penetration of microbial cellulases (ibid). Localized lignification of the cell walls of plant tissues renders some parts of otherwise digestible pasture forage totally unhydrolysable (Van Soest, 1983).

In routine nutritional evaluation of herbage, carbohydrates are grouped as non-structural or readily fermentable carbohydrates, and as structural carbohydrates (Bailey et al; 1970). The non-structural carbohydrates include soluble sugars (mono- and di-ssacharides), starch, fructosans and pectin. The structural carbohydrates are composed of hemicellulose, which is partially hydrolysable, and cellulose. Crude protein (N x 6.25), ash and lignin are the other components determined in routine herbage analyses. The term 'crude fibre' is used to designate the structural carbohydrate content of herbage (McDonald et al., 1988). It encompasses lignocellulose but not hemicellulose and pectins (Van Soest, 1983). With the detergent system of fractionating fibre as NDF and ADF, hemicellulose is determined by difference as NDF less ADF (Van Soest, 1967). The carbohydrate fractions of pasture plants are the major source of digestible energy for herbivorous animals.

The chemical composition of New Zealand pasture grasses and legumes has been reported on many occasions (Hutton, 1961, 1962; Wilson and McDowall, 1966; Wilson and Dolby, 1967; Bailey et al., 1970; Ulyatt, 1970, 1971; Rattray and Joyce, 1974; Ulyatt et al., 1976, 1984; Rattray 1978; Bryant and Trigg, 1982; Hoogendoorn, 1986; Crush et al., 1989). However, the majority of this information refers to pastures grazed by sheep. Bryant and Trigg (1982) observed that there were few New Zealand data that quantified either seasonal changes in the nutritive value of pasture grazed by dairy cows or the relationship between nutritive and feeding value for the grazing dairy cow. Similarly, the extent that within-season nutritive value of pasture can be influenced by management had received little attention (ibid). This is still true today, but more so for the former than the latter observation (see Section 2.3.2).

Carbohydrate concentrations

The soluble carbohydrate concentration of temperate forages (DM basis) ranges from 1% in some cocksfoot varieties to over 30% in certain varieties of Italian ryegrass; and the cellulose and hemicellulose concentrations vary from 20 to 30% and 10 to 30%, respectively (Raymond, 1969; Ulyatt, 1973, 1981). Compared to grasses of similar digestibility, legume forages generally have lower concentrations of cell wall- and soluble carbohydrates but equivalent levels of non-structural carbohydrates, higher concentrations (4 to 7%) of pectin (grasses, 1 to 3%), a lower ratio of hemicellulose to cellulose, and a higher concentration of lignin (3 to 12% vs 2 to 7% for grasses) (Ulyatt, 1971; Rattray and Joyce, 1974; Thomson, 1984). The ratios of hemicellulose to cellulose in temperate grasses and legumes are 0.7 to 0.9 : 1 (1.0 to 1.2 : 1 for tropical grasses) and 0.3 to 0.7 : 1, respectively (Osbourn, 1980; Norton, 1982). Temperate grasses and legumes have similar concentrations of crude fibre (20 to 30%), the mean values being 26% for grasses and 25% for legumes (Minson, 1981a). Equivalent values for tropical forages[1] are 34% and 30%, respectively (ibid). Species, variety, stage of growth, rate of growth, and season markedly influence the carbohydrate fractions, and hence the metabolisable energy (ME) concentration, of forages (Minson, 1981a). For example, considerable variation in water soluble carbohydrates has been demonstrated between varieties of temperate pasture species, but differences in chemical composition and digestibility between species are generally small at similar stages of maturity (Wilson and Dolby, 1967).

Protein concentration

The crude protein (CP) concentration of temperature pastures may range from as little as 3% in very mature herbage to over 30% in young grass under heavy N fertilization (Ulyatt, 1971; Le Du et al., 1981; Thomson, 1982). Generally, legumes have higher protein concentrations than grasses in both temperate and tropical environments (Ulyatt, 1971; Rattray and Joyce, 1974; Minson, 1976; Figure 2.2); the higher level of protein in legumes being associated with the 'built-in' nitrogen supply. The amino acid complement of temperate grasses and legumes, however, is similar (Norton, 1982).

Minson (1976) compiled frequency distributions of the crude protein concentrations of temperate and tropical pasture grasses and legumes from 760 cuts of grasses and 492 cuts of legumes. The median CP concentration for legumes was 15 to 18% compared to 6 to 9% in the dry matter for grasses. Temperate and tropical legumes had similar ranges of CP concentration (3 to 33%) with few values less than the 7% level, considered minimum for ruminant requirements, below which feed intake and microbial N supply become limiting (Balch and Campling, 1962). Only 6% and 32% of temperate grasses (22 and 53% for tropical grasses) contained less than 6 and 9% CP, respectively.

---

[1] Values for tropical forages are mainly for comparison purposes

Of the N in herbage, from 10 to 30% is non-protein nitrogen (NPN) (Osbourn, 1980; Mangan, 1982). The NPN fraction includes peptides, amino acids, amines and inorganic nitrate; and this fraction is increased by nitrogen fertilization (Deinum and Dirven, 1975; Mangan, 1982). NPN in forages, besides its potential toxicity, contributes only to the rumen degradable protein (RDP) fraction of the diet (Ørskov, 1982). Considering the high protein degradability (above 0.7) in temperate pastures, RDP is usually oversupplied under most grazing conditions (Leaver, 1985); and unless readily soluble carbohydrates are fed, NPN in forages is inefficiently used by ruminants (Ørskov, 1982).

Undegradable dietary protein (UDP) requirements of lactating cattle depend on the stage of lactation, milk yield, and level of feed intake. However, feed intake is normally low in early lactation, which increases the net tissue protein that is not supplied from microbial sources, and has to be supplied as UDP. The crude protein concentration of temperate forages, although rather high, will normally meet the requirements for low producing dairy cows (15 kg milk/day or less; M/D, 11 MJ ME/kg DM) (Holmes and Wilson, 1984), but may not meet those of high producing cows on pasture especially in early lactation (Brookes, 1982; Bryant and Trigg, 1982; ARC, 1984). Increases in milkfat production of 15-20% per cow have been reported when partially-protected protein or casein were fed or infused abomasally, respectively, to cows in early lactation on high digestibility pasture (Rogers et al., 1980; T.E. Trigg (unpublished data), cited by Bryant and Trigg, 1982).

Mineral concentrations

Several comprehensive reviews have been published on the mineral composition of herbage and the factors that affect it (Fleming, 1973; Reid and Hovath, 1980; Underwood, 1981; Jones and Thomas, 1987; Judson et al., 1987); while reports by Hutton et al. (1965, 1967), Wilson and Grace (1978) and Grace (1983) contain data on the mineral nutrition of lactating cattle grazing New Zealand pastures. The ash content of temperate pastures ranges from 5 to 12%, but higher values, depending on the level of soil contamination, have been reported (Hodgson, 1990b). This subject will not be reviewed any further.

Digestibility and metabolisable energy concentration

Apparent digestibility of pasture herbage is a major determinant of its nutritive value (Raymond, 1969). Nutritive value refers to the concentration of nutrients, particularly of digestible energy, in the herbage dry matter or organic matter, and it can also be expressed as animal production response per unit of feed intake (Ulyatt, 1973, 1981). The nutritive value of a diet thus depends on the proportion of nutrients digested and on the efficiency with which these digested nutrients are absorbed and utilized within the animal's tissues. The feeding value of herbage, on the other hand, is the animal production response to the total herbage consumed, and is thus a function of nutritive value and feed intake (ibid). Therefore, the comparative feeding value of grazed herbage is best assessed in trials where voluntary feed intake is not limited by herbage availability.

Since the gross energy concentration of different herbages of varying maturity is constant at around 18 MJ/kg DM (Raymond, 1969) digestible energy concentration is closely related to the digestibility of dry matter (DMD) or organic matter (OMD). Assessment of the digestibility of these is therefore regarded as an acceptable measurement of the metabolisable energy of herbage, since the proportion of energy losses in urine and fermentation gases also tends to remain constant; with ME averaging 0.82 digestible energy (ARC, 1980). However, potential digestibility may not always be realised if the rate of passage in the gut is accelerated, or if the diet is deficient in essential nutrients such as nitrogen and sulphur, required for efficient microbial fermentation (Balch and Campling, 1962). The nitrogen concentration of temperate pastures, unlike that of tropical pastures, rarely falls below the 1.0 to 1.3% (6 to 8% CP) level, which is considered minimal for sustaining appetite and rumen microbial health (Minson, 1982; Figure 2.2).

The digestibility of temperate pastures can be very high, comparable to values for cereals of 70 to 80% (Minson, 1981a). The apparent digestibility of ryegrass-clover dominant New Zealand pastures has been reported on many occasions (Hutton, 1962; Rattray, 1978; Clark and Brougham, 1979; Bryant and Trigg, 1982; L'Huillier, 1987c; Crush et al., 1989). These reports show a seasonal pattern in pasture digestibility, whereby OMD values are highest (80 to 86%) in winter and early spring (July-September), falling slightly (75 to 78%) in mid spring through early summer (October-December), but declining more sharply (65 to 75%) over most of the summer (January-March), and increasing again to mid spring levels over autumn (April-June). In general, green leaf (70 to 80% DMD) is more digestible than green stem (60-80%) (Hacker and Minson, 1981), while older dead material has digestibilities of 40 to 50% DMD and much less OMD (Francis and Smetham, 1985; Michell and Fulkerson, 1987; Pearce et al., 1987).

Similarly, the metabolisable energy concentration of New Zealand pastures varies with season, with reported mean values of 11.9, 11.2, 10.1 and 10.9 MJ ME/kg DM for winter to early spring, mid spring to early summer, summer, and autumn, respectively (Bryant and Trigg, 1982; Ulyatt et al., 1984). Vegetative grass and clover have similar concentrations of

ME ranging from 11 to 12 MJ ME/kg DM, declining to 8 to 10 MJ ME/kg DM, respectively, as they mature (Waghorn and Barry, 1987).

The importance of digestibility or ME concentration of pasture is because the efficiency of use of ME by the animal varies directly with the ME content of the feed (ARC, 1980), and because digestibility has some effect on intake of DM and ME, as was shown in Section 2.4.3.3 of the main review.

The proportion of stem, in grasses and legumes, increases markedly as the plant matures and enters the reproductive phase. At the same time the digestibility of the stem also declines, whereas the digestibility of leaf remains reasonably constant over the same period. Hacker and Minson (1981) quote a mean daily decline of 0.5 to 0.8 percentage units for stem and 0.1 to 0.4% units for leaf, in a range of temperate grasses. The two-fold effect of an increasing proportion of stem of decreasing digestibility, reduces the digestibility of the whole plant as it matures, and as herbage mass accumulates (Ulyatt, 1981). Some grass species show a relatively slow decline in digestibility with age, and are thus of particular value in tropical pastures (Norton, 1982). Considerable variation in digestibility also exists between early- and late-flowering (-maturing) grass species; early flowering varieties generally being more digestible than late flowering ones at the same growth stage (Raymond, 1969).

The decline in digestibility with maturity is caused by changes in the chemical composition of the plant. Cellulose and hemicellulose, which are digested slowly, increase rapidly in stems and slowly in leaves; lignin that is itself indigestible and clearly associated with cell wall carbohydrates, also increases rapidly in stems and slowly in leaves; the readily fermentable carbohydrates decrease slowly in stems and remain constant in leaves; and crude protein declines more rapidly in stems than leaves (Osbourn, 1980).

Factors that influence the digestibility of pasture herbage have been reviewed by Raymond (1969), Minson (1981a) and Norton (1982), and will not be reviewed here. The overall nutritive value of temperate pastures and factors affecting it have also been extensively reviewed (Raymond, 1969; Ulyatt, 1973, 1981; Ulyatt et al., 1976; Osbourn, 1980; Poppi, 1983; Jones and Wilson, 1987; Waghorn and Barry, 1987; Black, 1990; Thomas and Chamberlain, 1990), and will similarly not be reviewed further.

Appendix 4.1 Grazing dates and grazing intervals in days (d) for each of the three treatments (sward types) during each of the four periods of measurement (Experiment 1).

	Treatment/Grazing dates		
Season	Low mass (LM)	Intermediate mass (IM)	High mass (HM)
Summer	16 January 1987 (41 d)	19 January 1987 (45d)	20 January 1987 (56 d)
	27 February 1987 (31 d)	6 March 1987 (51 d)	18 March 1987 (58 d)
Autumn	3 April 1987 (42 d)	27 April 1987	16 May 1987
	16 May 1987 (47 d)	(66 d)	(81 d)
Winter	3 July 1987 (62 d)	3 July 1987 (60 d)	6 August 1987 (48 d)
	4 September 1987 (39 d)	2 September 1987	24 September 1987
Spring	14 October 1987 (33 d)	(67 d)	(45 d)
	17 November 1987	10 November 1987	8 November 1987
Mean grazing interval (d ± SD)[1]	45 ± 11	60 ± 8	61 ± 13

[1] SD = standard deviation.

Appendix 4.2 Mean values for pre-grazing and residual herbage mass (t DM/ha), pre-grazing and residual sward height (cm), and rates of net herbage production (kg DM/ha daily) of the three sward types during each of the four periods of measurement (Experiment 1).

		Herbage parameter				
Season/ Treatment		PHM (t DM/ha)	RHM (t DM/ha)	PSH (cm)	RSH (cm)	NHP (kg DM/ha/d)
Summer	LM	5.6^c	1.9^c	35	7	103^a
	IM	7.0^b	3.1^b	32	7	81^b
	HM	8.2^a	4.5^a	34	9	67^c
Autumn	LM	2.9^b	1.7^b	15^b	5^{ab}	28
	IM	4.5^a	1.9^{ab}	16^{ab}	4^b	39
	HM	4.9^a	3.0^a	22^a	9^a	32
Winter	LM	2.0^b	0.8^b	15	6	20
	IM	2.7^{ab}	1.0^{ab}	13	6	27
	HM	3.4^a	2.0^a	18	8	18
Spring	LM	7.2^c	3.2^b	33^b	10^b	111
	IM	11.7^a	4.3^{ab}	51^a	19^a	110
	HM	10.1^b	4.7^a	54^a	23^a	116
S.E.M.		0.36	0.39	2.1	1.4	4.7
Effects						
Block		*	NS	**	NS	NS
Season		***	***	***	***	***
Treatment		**	**	NS	**	NS
Season x treatment		**	NS	**	**	NS

^{a,b,c} Means within a season bearing unlike superscripts differ significantly ($P < 0.05$)

PHM = Pre-grazing herbage mass; RHM = residual herbage mass; PSH = pre-grazing sward height; RSH = residual sward height; NHP = net herbage production

Appendix 4.3 Effects of season and treatment (sward type) on the masses of nitrogen and digestible organic matter in the dry matter (g/m^2) of herbage (Experiment 1).

		Herbage component	
Season/Treatment		Nitrogen (g/m^2)^1	DOMD (g/m^2)^1
Summer	LM	14.5^{b}	367^{b}
	IM	17.7^{ab}	448^{a}
	HM	20.3^{a}	491^{a}
Autumn	LM	9.9^{b}	177^{b}
	IM	16.0^{a}	290^{a}
	HM	15.4^{a}	288^{a}
Winter	LM	8.9	119^{b}
	IM	10.6	155^{ab}
	HM	12.1	183^{a}
Spring	LM	18.7	427^{c}
	IM	17.8	676^{a}
	HM	15.5	567^{b}
S.E.M.		1.22	21.5
Effects			
Block		NS	NS
Season		***	***
Treatment		NS	**
Season x Treatment		*	**

^{a,b,c} Means within a season bearing unlike superscripts differ significantly ($P < 0.05$)

[1] Mass at any one sampling time in the herbage dry matter.

Appendix 5.1 Meteorological data for each month from May 1986 to April 1989.

(a) Air Temperature (°C): Mean Maximum and Minimum

	1986/87		1987/88		1988/89		30 yr average	
Month	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
May	15.6	7.0	15.2	7.5	15.7	7.0	15.2	7.1
June	13.3	5.5	13.3	6.0	13.7	6.0	12.8	4.8
July	11.6	2.7	12.3	4.2	13.5	5.7	12.1	4.0
August	12.2	4.4	15.1	6.8	13.8	5.7	13.3	5.2
September	14.3	6.6	15.4	7.1	15.6	9.4	15.0	6.9
October	16.9	9.8	17.4	8.6	17.1	10.2	16.8	8.4
November	18.6	10.3	19.6	11.3	19.8	10.9	18.7	10.1
December	20.9	11.8	21.0	12.6	22.9	13.4	20.8	11.9
January	23.5	13.6	22.4	12.7	24.1	15.2	22.3	13.1
February	21.6	12.3	22.9	14.6	23.1	12.9	22.9	13.2
March	19.9	10.9	20.3	11.0	22.0	12.4	21.4	12.2
April	17.8	9.9	17.9	8.1	19.2	9.8	18.4	9.7

(b) Total Rainfall (mm) and Sunshine (hrs)

	1986/87		1987/88		1988/89		30 yr average	
Month	Rain	Sun	Rain	Sun	Rain	Sun	Rain	Sun
May	70	126	54	75	110	124	93	108
June	76	99	68	65	119	67	87	93
July	135	99	33	89	163	99	98	100
August	98	135	32	131	94	143	86	118
September	78	119	67	122	144	69	74	129
October	108	112	93	159	98	138	87	158
November	32	149	62	199	63	182	82	172
December	23	187	96	145	57	225	102	190
January	74	230	5	240	93	223	77	207
February	63	200	150	135	75	193	77	207
March	123	153	41	130	89	172	72	167
April	124	143	45	166	44	175	75	136

Appendix 5.2 Mean values (± SD) for actual pre-grazing herbage masses (kg DM/ha) for the three sward types during each of the eight experimental periods.

	Sward Type					
	RG		LM		HM	
Year/Season	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD
1987/88						
Early spring	2534	402	4578	1100	6759	436
Late spring	4215	320	5495	536	6823	809
Summer	3799	329	4526	278	5916	410
Autumn	3496	456	3325	311	5239	277
1988/89						
Early spring	2103	337	2256	639	3829	393
Late spring	2650	288	4814	704	6074	426
Summer	3179	226	3883	250	5163	512
Autumn	2825	214	3592	765	4517	726

Appendix 5.3 Mean values (± SD) for actual post-grazing herbage masses (kg DM/ha) for the three sward types during each of the eight seasons.

	Sward Type					
	RG		LM		HM	
Year/Season	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD
1987/88						
Early spring	1639	339	2903	743	4337	632
Late spring	2877	203	3228	494	4511	478
Summer	2547	241	2832	340	3755	263
Autumn	2406	258	2252	304	3376	362
1988/89						
Early spring	1348	35	1293	466	2552	200
Late spring	1751	194	3120	345	3952	671
Summer	2029	175	2279	276	3142	404
Autumn	1813	184	2205	486	2917	559

Appendix 5.4 Mean values for botanical composition (% dry weight of total herbage biomass) of the pre-grazing herbage from the three sward types, averaged across all eight seasons.

Botanical component	Sward type RG	LM	HM	S.E.	Sign.
Grass[1]	50.8^{a}	44.5^{b}	46.4^{b}	1.3	*
Clover	12.5^{a}	11.2^{ab}	8.3^{b}	1.3	+
Other[2]	13.8^{ab}	16.4^{a}	9.9^{b}	1.5	*
Dead matter	23.2^{c}	28.0^{b}	36.4^{a}	1.3	***

[a,b,c] Means within a row bearing different letters differ significantly at $P < 0.05$

[1] Ryegrass or prairie grass

[2] Other grass species and weeds

Appendix 5.5 Mean values for morphological components (% dry weight) of post-grazing herbage from each of the eight seasons, averaged across all three sward types.

Season	Herbage component Leaf %	Stem %	Dead %	Seedhead %	Leaf:Stem
<u>1987/88</u>					
Early spring	24.3	48.6	27.2	2.1	0.5
Late spring	22.0	38.1	40.1	4.2	0.6
Summer	20.0	20.7	59.3	0.4	1.0
Autumn	19.9	23.8	56.3	0.1	0.8
<u>1988/89</u>					
Early spring	33.4	38.5	28.1	0.0	0.9
Late spring	26.8	45.8	27.4	6.2	0.6
Summer	23.5	27.2	49.3	0.5	0.9
Autumn	32.6	25.6	41.7	0.2	1.3
S.E.	1.2	1.8	1.3	0.91	0.09
Sign. level	***	***	***	***	***

Appendix 5.6 ANOVA table for total nitrogen (% OM) and metabolisable energy concentrations, and *in vitro* digestibility of pre-grazing herbage from the three sward types (RG< LM & HM) averaged across all eight measurement periods.

		Herbage parameter									
Source of variation	df	Nitrogen		DMD		OMD		DOMD		ME	
		F	Sign.	F	Sign.	F	Sign.	F	Sign.	F	Sign.
Block	3	3.2	*	1.3	NS	1.3	NS	1.2	NS	1.2	NS
Season	7	25.2	***	29.6	***	32.4	***	35.2	***	35.2	***
Block x Seas.	21	2.1	*	2.6	**	2.1	*	2.0	*	2.0	*
Sward type	2	47.3	***	231.9	***	122.5	***	161.8	***	161.8	***
Block x Sward type	6	1.0	NS	0.6	NS	1.0	NS	0.6	NS	0.6	NS
Season x Sward type	14	1.7	NS	5.3	***	4.6	***	4.4	***	4.4	***
Residual	38										

Total number of observations = 92

Appendix 5.7 Mean values for chemical composition (% DM) and gross energy concentration (MJ/kg DM) of pre-grazing herbage from the three sward types (RG, LM & HM) during each of the eight periods of measurement.

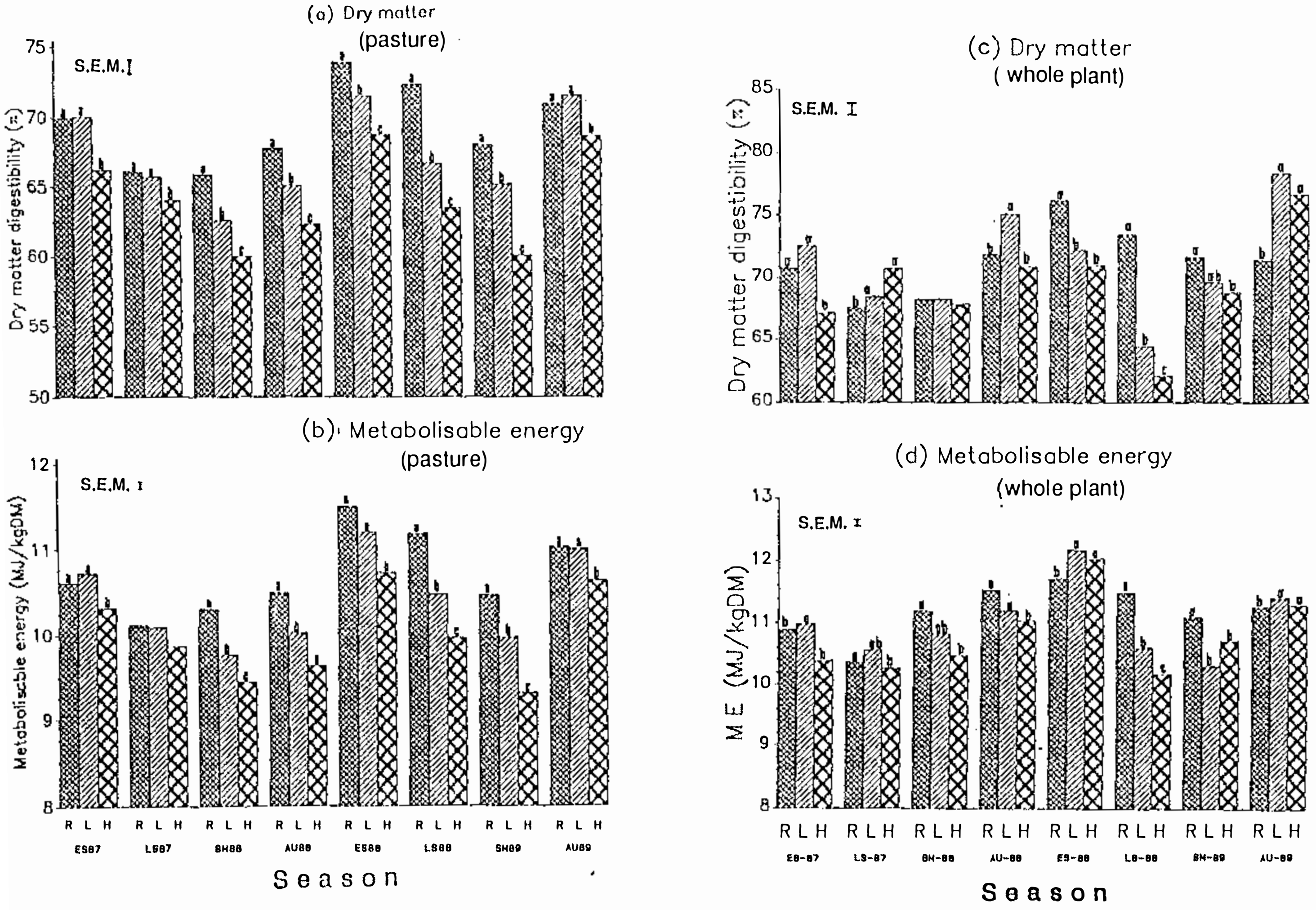
		Herbage parameter					
Season	Sward type	N %	Ash %	NDF[1] %	ADF[1] %	Lignin[1] %	GE[1] MJ/kg
1987/88							
Early spring	RG	2.3	11.7	56.1	27.9	2.4	17.7
	LM	2.1	10.0	58.1	28.2	3.6	17.9
	HM	1.9	8.3	62.7	32.3	3.8	18.1
Late spring	RG	1.9	10.6	55.5	29.5	3.1	18.1
	LM	2.0	9.2	57.5	31.9	4.0	18.0
	HM	1.8	9.7	60.0	33.5	4.0	18.2
Summer	RG	2.2	9.2	51.9	26.4	3.7	18.5
	LM	1.9	10.0	60.6	32.2	4.6	18.4
	HM	1.7	9.1	64.7	33.8	4.5	18.2
Autumn	RG	2.6	11.3	51.8	26.5	3.1	18.0
	LM	2.6	12.0	56.7	29.9	3.8	18.3
	HM	2.3	11.2	60.1	31.8	4.2	17.9
1988/89							
Early spring	RG	3.1	9.0	46.2	24.6	3.7	19.0
	LM	2.8	8.4	47.3	25.4	2.8	18.6
	HM	2.5	8.3	54.8	28.5	2.6	18.6
Late spring	RG	2.4	9.3	47.0	24.2	2.4	18.2
	LM	2.0	7.1	54.6	28.5	4.3	18.6
	HM	1.8	7.2	58.8	31.0	4.0	18.5
Summer	RG	2.2	9.0	50.5	25.6	3.6	18.5
	LM	2.3	9.7	55.4	29.7	3.9	18.3
	HM	2.0	8.4	62.2	32.9	5.3	18.1
Autumn	RG	3.0	9.8	50.0	24.8	3.5	19.4
	LM	2.9	11.4	46.8	25.5	3.8	18.5
	HM	2.7	10.1	50.3	27.6	4.4	18.7
S.E.		0.09	0.45	NA	NA	NA	NA
Effects							
Block		NS	NS	NA	NA	NA	NA
Season		***	***	NA	NA	NA	NA
Sward type		***	NS	NA	NA	NA	NA
Season x Sward type		NS	***	NA	NA	NA	NA

---

[1] Values are raw means from samples bulked on treatment basis.

NA = Not applicable.

Appendix 5.8 Mean values for in vitro digestibility (% DMD) and estimated metabolisable energy concentration ((a) and (b) respectively) of pre-grazing herbage, and of whole plant ((c) and (d) respectively) from each of the three sward types during each of the eight periods of measurement. (R = ryegrass swards, L = low mass Matua and H = high mass Matua swards; ES = early spring, LS = late spring, SM = summer, AU = autumn).



S.E.M. = largest standard error of the means.

Within a season means bearing unlike letters (a, b, c) are significantly (P < 0.05) different.

Appendix 5.9 ANOVA table for total nitrogen (% OM), metabolisable energy concentrations, and *in vitro* digestibility of ryegrass and prairie grass whole plants from the three sward types averaged across all eight seasons of measurement.

		Herbage parameter									
		Nitrogen		DMD		OMD		DOMD		ME	
Source of variation	df	F	Sign.	F	Sign.	F	Sign.	F	Sign.	F	Sign.
Block	3	2.0	NS	2.6	+	2.8	*	3.4	*	3.4	*
Season	7	24.7	***	18.1	***	18.2	***	23.1	***	23.1	***
Block x Season	21	2.1	*	1.7	+	1.7	+	1.8	+	1.8	+
Sward type	2	14.8	*	19.4	*	20.8	**	11.3	**	11.3	**
Block x Sward type	6	0.9	NS	0.6	NS	0.6	NS	1.3	NS	1.3	NS
Season x Sward type	14	7.8	***	11.2	***	10.9	***	11.9	***	11.9	***
Residual	38										

Total number of observations = 92

+ Not significant at $P < 0.05$ but significant at $P < 0.10$.

Appendix 5.10 Mean values (% DM) for chemical composition and gross energy concentration of ryegrass and prairie grass whole plants for each of the three sward types during each of the eight seasons of measurement.

		Herbage parameter					
Season	Sward type	N %	Ash %	NDF[1] %	ADF[1] %	Lignin[1] %	GE[1,2]
1987/88							
Early spring	RG	2.3	10.4	53.7	27.6	2.0	18.4
	LM	2.1	8.7	53.8	22.7	2.4	18.4
	HM	1.7	7.8	60.7	31.2	3.2	18.1
Late spring	RG	1.9	10.1	56.1	28.0	2.2	18.2
	LM	1.7	8.1	59.1	31.8	3.6	18.3
	HM	1.9	8.9	58.1	31.0	3.0	18.4
Summer	RG	2.0	8.9	54.2	26.2	2.5	18.4
	LM	1.9	9.9	58.9	30.4	3.7	18.2
	HM	1.9	10.0	59.4	30.8	3.7	18.2
Autumn	RG	2.6	9.1	50.2	24.5	3.2	18.3
	LM	3.3	11.6	50.6	23.0	2.6	18.4
	HM	2.5	10.8	55.4	28.3	5.4	17.8
1988/89							
Early spring	RG	3.0	7.8	47.4	24.7	3.0	19.3
	LM	2.3	6.5	51.2	25.3	2.6	19.1
	HM	2.3	6.9	54.1	27.5	2.6	18.6
Late spring	RG	2.3	9.2	48.5	24.7	2.2	18.5
	LM	1.4	6.3	58.3	30.6	4.4	18.5
	HM	1.4	5.8	59.3	31.4	4.4	18.3
Summer	RG	2.2	8.9	50.6	25.1	2.5	18.2
	LM	2.3	9.7	54.7	28.0	3.3	18.3
	HM	2.3	10.0	56.4	29.5	3.3	18.3
Autumn	RG	2.7	9.9	49.7	25.1	2.6	18.5
	LM	3.0	11.6	44.7	22.2	3.0	18.5
	HM	2.8	11.4	46.9	24.9	2.6	18.2
S.E.		0.10	0.30	NA	NA	NA	NA
Effects							
Block		NS	NS	NA	NA	NA	NA
Season		***	***	NA	NA	NA	NA
Sward type		**	NS	NA	NA	NA	NA
Season x Sward type		***	***	NA	NA	NA	NA

[1] Values are raw means of samples pooled on sward type basis.
[2] MJ/kg DM.
NA = Not applicable.

Appendix 5.11 ANOVA table for total nitrogen (OM basis), metabolisable energy concentration, and digestibility of green leaf of ryegrass and prairie grass from the three sward types ((RG, LM & HM) averaged across all eight seasons of measurement.

		Herbage parameter									
Source of variation	df	Nitrogen		DMD		OMD		DOMD		ME	
		F	Sign.	F	Sign.	F	Sign.	F	Sign.	F	Sign.
Block	3	3.0	*	1.3	NS	1.5	NS	1.8	NS	1.8	NS
Season	7	9.0	***	46.8	***	53.4	***	72.7	***	72.7	***
Block x Season	21	2.0	*	1.1	NS	1.2	NS	1.1	NS	1.1	NS
Sward type	2	2.0	NS	3.6	+	4.1	+	3.6	+	3.6	+
Block x Sward type	6	1.9	NS	0.4	NS	0.4	NS	0.6	NS	0.6	NS
Season x Sward type	14	2.3	*	3.7	***	4.4	***	4.0	***	4.0	***
Residual	38										

Total number of observations = 92; + Not significant at $P < 0.05$ but significant at $P < 0.10$.

Appendix 5.12 ANOVA table for total nitrogen (% OM), metabolisable energy concentration, and *in vitro* digestibility of green stem of ryegrass and prairie grass from the three sward types during all eight seasons of measurement.

		Herbage parameter									
Source of variation	df	Nitrogen		DMD		OMD		DOMD		ME	
		F	Sign.	F	Sign.	F	Sign.	F	Sign.	F	Sign.
Bloc	3	4.1	*	0.9	NS	0.9	NS	0.7	NS	0.7	NS
Season	7	21.7	***	16.7	***	15.5	***	16.6	***	16.6	***
Block x Season	2	1.7	NS	1.4	NS	1.5	NS	1.4	NS	1.4	NS
Sward type	2	1.8	NS	11.8	**	13.3	***	8.7	*	8.7	*
Block x Sward type	6	1.3	NS	0.8	NS	0.9	NS	1.1	NS	1.1	NS
Season x Sward type	14	5.4	***	3.9	***	3.9	***	3.2	***	3.2	**
Residual	38										

Total number of observations = 92

Appendix 5.13 Mean values for nitrogen, ash and metabolisable energy concentration, and *in vitro* digestibility of green leaf of ryegrass and prairie grass during the eight seasons of measurement , averaged across all three sward types (RG, LM and HM).

	Herbage parameter						
	Nitrogen		Ash	DMD	OMD	DOMD	ME[1]
Season	% DM	% OM	% DM	%	%	%	
1987/88							
Early spring	3.1^{b}	3.4^{b}	9.9^{b}	71.4^{a}	75.8^{a}	67.2^{a}	11.0^{a}
Late spring	3.0^{bc}	3.3^{bc}	10.9^{a}	67.5^{b}	73.3^{b}	63.2^{b}	10.3^{b}
Summer	2.7^{c}	3.1^{c}	11.0^{a}	64.6^{c}	70.5^{c}	60.3^{c}	9.8^{c}
Autumn	3.7^{a}	4.1^{a}	10.9^{a}	69.5^{a}	74.5^{ab}	64.7^{b}	10.5^{b}
1988/89							
Early spring	3.2^{ab}	3.4^{b}	7.9^{c}	78.8^{a}	82.6^{a}	77.2^{a}	12.6^{a}
Late spring	3.0^{b}	3.3^{b}	8.7^{b}	73.5^{c}	77.9^{c}	70.7^{bc}	11.5^{bc}
Summer	2.9^{b}	3.3^{b}	10.3^{a}	73.7^{c}	77.9^{c}	69.8^{c}	11.4^{c}
Autumn	3.4^{a}	3.8^{a}	10.5^{a}	76.5^{b}	80.2^{b}	72.0^{b}	11.7^{b}
S.E.	0.10	0.11	0.27	0.70	0.56	0.66	0.11
Sign. level	***	***	***	***	***	***	***

[a,b,c] Means within a column within a year bearing different letters differ significantly at $P < 0.05$.

[1] MJ/kg DM.

Appendix 5.14 Mean values for nitrogen, ash and metabolisable energy concentration and *in vitro* digestibility of green stem of ryegrass and prairie grass during the eight seasons of measurement, averaged across all three sward types (RG, LM and HM).

Season	Herbage parameter						
	Nitrogen % DM	Nitrogen % OM	Ash % DM	DMD %	OMD %	DOMD %	ME^{1}
1987/88							
Early spring	1.3^{c}	1.4^{c}	7.1^{c}	68.6^{b}	73.7^{bc}	66.0^{b}	10.8^{b}
Late spring	1.2^{c}	1.3^{c}	7.5^{bc}	66.1^{c}	72.6^{c}	63.8^{c}	10.4^{c}
Summer	1.6^{b}	1.8^{b}	7.8^{ab}	68.9^{b}	74.9^{b}	66.5^{b}	10.8^{b}
Autumn	2.1^{a}	2.3^{a}	8.2^{a}	72.5^{a}	76.9^{a}	69.1^{a}	11.3^{a}
1988/89							
Early spring	1.8^{ab}	1.9^{b}	6.3^{c}	74.1^{a}	78.9^{a}	73.5^{a}	12.0^{a}
Late spring	1.1^{c}	1.2^{c}	5.5^{d}	66.8^{b}	72.5^{c}	66.0^{c}	10.8^{c}
Summer	1.7^{b}	1.8^{b}	7.4^{b}	67.6^{b}	72.8^{c}	65.7^{c}	10.7^{c}
Autumn	2.0^{a}	2.2^{a}	8.3^{a}	72.3^{a}	76.6^{b}	69.6^{b}	11.3^{b}
S.E.	0.08	0.09	0.18	0.68	0.60	0.73	0.12
Sign. level	***	***	***	***	***	***	***

^{a,b,c,d} Means within a column within a year bearing different letters differ significantly at $P < 0.05$.

[1] MJ/kg DM.

Appendix 5.15 A Proportions of leaf, stem and dead material contained in four vertical strata (expressed as % of DM) during (a) early spring, (b) late spring, (c) summer and (d) autumn, averaged across two years.

(a) Early Spring

Stratum/Herbage component		Sward type			S.E.	Sign.
		RG	LM	HM		
0-6 cm	Leaf	0.19^a	0.06^b	0.04^b	0.022	***
	Stem	0.59^a	0.48^b	0.44^b	0.026	*
	Dead	0.22^c	0.46^b	0.51^a	0.023	***
6-18 cm	Leaf	0.72^a	0.31^b	0.15^c	0.020	***
	Stem	0.22^c	0.40^a	0.52^a	0.026	*
	Dead	0.07^b	0.29^b	0.34^a	0.023	***
18-30 cm	Leaf	0.96^a	0.55^b	0.43^b	0.092	*
	Stem	0.04^b	0.33^{ab}	0.38^a	0.095	NS
	Dead	Nil	0.13^a	0.19^a	0.019	***
30 + cm	Leaf	Nil	0.65	0.67	0.058	NS
	Stem	Nil	0.28	0.30	0.045	NS
	Dead	Nil	0.07	0.04	0.038	NS

[a,b,c]In this table and the next three tables means in a row with unlike superscripts differ significantly ($P < 0.05$).

+, $P < 0.10$; *, $P < 0.05$; **, $P < 0.01$; ***, $P < 0.001$ for this table

(b) Late Spring

Stratum/Herbage component		Sward type			S.E.	Sign.
		RG	LM	HM		
0-6 cm	Leaf	0.17^a	0.14^a	0.03^b	0.022	**
	Stem	0.51^a	0.42^a	0.39^a	0.038	NS
	Dead	0.31^c	0.44^b	0.57a	0.031	***
6-18 cm	Leaf	0.54^a	0.33^b	0.17^c	0.022	**
	Stem	0.34^a	0.44^a	0.47^a	0.038	NS
	Dead	0.11^c	0.23^b	0.36^a	0.031	***
18-30 cm	Leaf	0.60^a	0.36^b	0.32^b	0.079	NS $P = 0.09$
	Stem	0.39	0.54	0.50	0.078	NS
	Dead	0.01^b	0.10^a	0.18^a	0.025	**
30 + cm	Leaf	0.42	0.18	0.28	0.182	NS
	Stem	0.57	0.72	0.66	0.137	NS
	Dead	0.01^b	0.10^a	0.06^{ab}	0.017	*

Appendix 5.15A(continued)

(c) Summer

Stratum/Herbage component		Sward type			S.E.	Sign.
		RG	LM	HM		
0 - 6 cm	Leaf	0.19^{a}	0.08^{b}	0.02^{b}	0.031	*
	Stem	0.35	0.27	0.30	0.035	NS
	Dead	0.46^{b}	0.65^{a}	0.69^{a}	0.045	+
6 - 18 cm	Leaf	0.59^{a}	0.46^{b}	0.29^{c}	0.031	*
	Stem	0.15	0.16	0.24	0.035	NS
	Dead	0.26^{b}	0.38^{a}	0.48^{a}	0.045	+
18 - 30 cm	Leaf	0.27^{b}	0.49^{a}	0.41^{a}	0.039	+
	Stem	0.76^{a}	0.32^{b}	0.22^{b}	0.068	*
	Dead	Nil	0.19^{b}	0.37^{a}	0.031	**
30 + cm	Leaf	Nil	Nil	0.14	0.109	NS
	Stem	1.00	0.59	0.26	0.438	NS
	Dead	Nil	0.41	0.60	0.540	NS

(d) Autumn

Stratum/Herbage component		Sward type			S.E.	Sign.
		RG	LM	HM		
0 - 6 cm	Leaf	0.26^{a}	0.16^{a}	0.04^{c}	0.022	**
	Stem	0.33	0.34	0.29	0.020	NS
	Dead	0.41^{c}	0.51^{b}	0.67^{a}	0.017	**
6 - 18 cm	Leaf	0.88^{a}	0.63^{b}	0.45^{c}	0.022	**
	Stem	0.03^{c}	0.14^{b}	0.22^{a}	0.020	*
	Dead	0.09^{c}	0.24^{b}	0.33^{a}	0.017	**
18 - 30 cm	Leaf	1.00^{a}	0.77^{b}	0.68^{b}	0.049	*
	Stem	Nil	0.16^{a}	0.13^{a}	0.026	*
	Dead	0.04	0.06	0.20	0.075	NS
30 + cm	Leaf	Nil	0.42	0.47	0.108	NS
	Stem	Nil	0.56	0.41	0.109	NS
	Dead	Nil	0.02	0.12	0.046	NS

Appendix 5.15 B The digestibility and concentration of nitrogen (% dry weight) of the pre-grazing herbage from four vertical strata of the three sward types (RG, LM & HM), averaged across two years of measurement (Values are raw means).

Stratum	Herbage parameter/Sward type								
	% N			% OMD			% DOMD		
	RG	LM	HM	RG	LM	HM	RG	LM	HM
Early Spring									
0-6 cm	2.1	2.0	1.5	65.4	54.7	48.9	60.1	51.8	46.9
6-18 cm	3.3	2.9	2.0	75.9	74.5	65.2	68.8	67.8	60.0
18-30 cm	4.0	2.9	2.4	85.4	78.2	77.0	76.3	71.2	69.8
> 30 cm	NIL	2.8	2.5	NIL	74.7	78.0	NIL	68.2	70.6
Late Spring									
0-6 cm	1.4	1.7	1.5	58.4	56.1	48.5	54.6	53.2	47.0
6-18 cm	2.1	2.1	1.8	69.7	70.1	63.5	63.8	64.5	59.2
18-30 cm	2.6	2.4	2.2	76.0	74.3	67.9	68.7	67.9	62.4
> 30 cm	NIL	2.7	2.0	NIL	74.3	66.1	NIL	68.2	61.6
Summer									
0-6 cm	1.9	1.8	1.7	62.2	49.2	48.1	57.8	46.8	45.9
6-18 cm	2.7	2.4	1.9	75.3	64.4	60.0	68.1	58.4	54.6
18-30 cm	1.9	2.4	1.9	65.7	69.6	63.0	60.4	62.6	56.6
> 30 cm	NIL	2.0	1.7	NIL	60.2	63.4	NIL	56.0	58.1
Autumn									
0-6 cm	2.0	2.4	1.7	59.2	57.7	51.0	54.1	52.7	47.0
6-18 cm	3.2	3.5	2.4	74.9	78.0	69.2	67.4	68.9	61.9
18-30 cm	NIL	4.0	3.0	NIL	80.7	73.6	NIL	69.8	65.5
> 30 cm	NIL	NIL	2.4	NIL	NIL	72.1	NIL	NIL	64.6

Appendix 5.16 Effects of sward type and period of measurement on tiller and plant population density, tiller weight, tillers per plant, net herbage production (NHP), rate of green herbage accumulation (GHA), and rate of total herbage accumulation (THA) of Matua prairie grass pastures. (Largely adapted from Xia, 1991).

Period	Sward type	Tillers/ m^2	Plants/ m^2	Tillers/ Plant	Weight/ tiller (mg)	NHP g DM/m^2 daily	GHA g DM/m^2 daily	THA g DM/m^2 daily
ESP	LM	447	25	24.4	322	2.4	2.6	2.6
	HM	457	16	33.3	678	5.6	4.4	4.6
	(S.E.)				(58.2)*			
LSP	LM	394	14	19.8	103	0.2	0.2	-0.1
	HM	496	12	33.6	398	1.4	0.6	0.9
	(S.E.)				(17.3)**			
SMR	LM	408	14	26.2	116	0.9	2.0	2.0
	HM	647	12	44.9	148	1.6	3.1	2.3
	(S.E.)				(16.4) NS			
AUT	LM	713	NM	NM	116	NM	NM	NM
	HM	654	NM	NM	132	NM	NM	NM
	(S.E.)				(4.1)			
Pooled S.E.		65	1.0	2.3		0.49	0.10	0.34
Treatment		+	*	+		*	*	***
Period		*	***	*		***	***	*
Treatment x Period		NS	**	NS		NS	**	NS

Footnotes ESP: early spring (Sep-Nov); LSP: late spring (Nov-Dec); SMR: Summer (Jan-Feb); AUT: Autumn (March-Apr); NM: Not measured.

+: $P < 0.10$; *: $P < 0.05$; **: $P < 0.01$; ***: $P < 0.001$; NS: No significant difference ($P > 0.05$).

Appendix 6.1a ANOVA table for daily herbage allowance and apparent herbage intake (kg/cow) of cows from the three sward types, averaged across all eight seasons of measurement.

		Herbage allowance											
		DM		OM		Green[1]		Leaf[2]		DOMD		Intake	
Source of variation	df	F	Sign.	F	Sign.	F	Sign.	F	Sign.	F	Sign.	F	Sign.
Season	7	12.1	***	12.1	***	133.4	***	235.5	***	5.6	***	1.9	NS
Sward type	2	1.2	NS	0.5	NS	163.8	***	899.9	***	30.8	***	5.5	**
Season x Sward type	14	2.9	***	3.2	***	10.1	***	9.5	***	4.0	***	0.6	NS
Residual	327												

[1] Green matter
[2] Green leaf

Total number of observations = 351

Appendix 6.1b Mean values for daily pasture allowance (kg DM/cow) given to the cows grazing on each of the three sward types during each of the eight periods of measurement.

Season	Sward type			S.E.	Sign. level
	RG	LM	HM		
1987/88					
ESP	49.3	48.2	48.1	0.97	NS
LSP	52.3	51.5	52.3	0.94	NS
SMR	52.3	51.7	51.2	0.97	NS
AUT	53.0	53.4	52.5	1.16	NS
1988/89					
ESP	46.0^{b}	43.3^{b}	51.6^{a}	1.27	**
LSP	52.2^{a}	53.9^{a}	48.7^{b}	1.07	*
SMR	50.6	49.8	48.9	1.03	NS
AUT	49.6^{a}	47.9^{ab}	46.1	1.07	*

a,b Means in a row with unlike superscripts differ significantly ($P < 0.05$).

ESP = Early spring; LSP = Late spring; SMR = Summer; AUT = Autumn

*, $P < 0.05$; **, $P < 0.01$; NS, not significant ($P > 0.05$).

Appendix 6.1c Mean values for daily apparent dry matter intake (kg DM/cow) by cows grazing on each of the three sward types, during each of the eight periods of measurement.

Season	Sward type			S.E.	Sign. level
	RG	LM	HM		
1987/88					
ESP	16.8	17.7	16.9	0.88	NS
LSP	16.4	18.2	17.3	0.91	NS
SMR	17.2	19.4	18.6	0.88	NS
AUT	16.4	17.3	18.7	1.05	NS
1988/89					
ESP	15.8^{b}	18.7^{a}	16.9^{ab}	1.15	+
LSP	17.7	18.9	17.0	0.97	NS
SMR	18.4	20.5	19.0	0.94	NS
AUT	17.8^{ab}	18.3^{a}	16.1^{b}	0.97	+

a,b Means in a row with unlike superscripts differ significantly ($P < 0.05$).

ESP = Early spring; LSP = Late spring; SMR = Summer; AUT = Autumn

+,$P < 0.10$; NS, not significant ($P > 0.05$)

Appendix 6.2 Mean values for daily herbage allowance and apparent feed intake (kg/cow) during the eight experimental periods (seasons), averaged across the three sward types (RM, LM & HM).

	Herbage allowance					
Seasons	DM kg/cow	OM kg/cow	Green[1] kg DM/cow	Leaf[2] kg DM/cow	DOMD kg/cow	Intake kg DM/cow
1987/88						
Early spring	48.5^b	43.7^b	39.9^a	18.8^a	31.4^b	17.2
Late spring	52.0^a	46.9^a	37.7^b	16.1^b	32.0^{ab}	17.3
Summer	51.7^a	46.9^a	28.7^c	15.3^c	31.2^b	18.4
Autumn	53.0^a	46.9^a	28.7^c	19.0^a	32.7^a	17.4
1988/89						
Early spring	46.9^c	42.9^c	38.0^b	26.3^a	32.0^b	17.1
Late spring	51.6^a	47.5^a	43.0^a	19.8^b	33.4^a	17.9
Summer	49.8^b	45.2^b	32.4^d	20.1^b	30.3^c	19.3
Autumn	47.8^c	42.8^c	34.8^c	25.9^a	32.0^b	17.4
S.E.	0.60	0.55	0.46	0.26	0.40	0.66
Sign. level	***	***	***	***	***	NS

a,b,c,d Means within a column within a year bearing different letters differ significantly at $P < 0.05$

[1] Green matter

[2] Green leaf

Appendix 6.3 ANOVA table for daily yields of milk and milk solids (kg/cow), and composition of milk (%) from the three sward types (RG, LM & HM), averaged across all eight seasons of measurement.

		Milk production								Milk composition			
		Milk		Fat		Protein		Lactose		Fat		Protein	
Source of variation	df	F	Sign.	F	Sign.	F	Sign.	F	Sign.	F	Sign.	F	Sign.
Season	7	0.6	NS	2.1	*	1.0	NS	1.0	NS	2.1	*	7.3	***
Sward type	2	75.3	***	50.8	***	92.4	***	63.7	***	0.9	NS	5.8	**
Season x Sward type	14	3.2	***	2.6	**	2.7	**	3.0	***	0.7	NS	1.4	NS
Covariance (season)	8	76.8	***	48.1	***	45.4	***	68.2	***	69.5	***	75.8	***
Residual	160												

Total number of observations = 192

Appendix 6.4 ANOVA table for change in liveweight (kg/cow) and condition score of cows on the three sward types during each experimental period, averaged across all eight seasons of measurement.

		Liveweight change		Condition score change	
Source of variation	df	F	Sign.	F	Sign.
Season	7	0.9	NS	2.4	*
Sward type	2	0.5	NS	3.8	*
Season x Sward type	14	1.4	NS	1.0	NS
Covariance (season)	8	3.9	***	2.6	**
Residual	160				

Total number of observations = 192

Appendix 6.5a Calculation of ME (MJ/cow daily) required to sustain animal production levels achieved, averaged over all the eight measurement periods (After MAFF, 1975).

ME allowance = $M_m + M_l + M_g$ (MAFF, 1975)

Whereby M_m = maintenance requirement (+ activity and safety margin)

= $8.3 + 0.091W$

M_l = requirement for milk production

= FCM x 5.31

M_g = requirement for liveweight gain

= + 34 MJ/kg gain
- 28 MJ/kg loss

and W = liveweight of cow (kg)

FCM = fat corrected milk

= 0.4 MY + 15 FY

MY = milk yield (kg)

FY = milk fat yield

Parameter	Sward type		
	RG	LM	HM
Liveweight (kg/cow)	459	455	465
Liveweight gain (kg/d)	0.151	0.113	0.073
Milk yield (kg/d)	17.9	17.4	15.9
Milk fat yield (kg/d)	0.79	0.77	0.69
M_m (MJ ME)	50.1	49.7	50.6
M_l (MJ ME)	100.9	98.2	88.7
M_g (MJ ME)	+ 5.1	+ 3.8	+ 2.5
ME requirement (MJ/d)	156.1	151.7	141.8
ME of diet (M/D)[1]	11.2	10.7	10.4
DMI requirement (kg/d)	13.9	14.2	13.6
DMI estimate (kg/d)	17	18.6	17.6
ME[1] (MJ/d)	190	197	183
ME[1] above requirements (MJ/d)	34	47	41

[1] ME concentration of diet was estimated from the ME concentrations of individual diet components (Table 6.1b) as calculated from their respective DOMD values (Tables 5.13, 5.14 and 5.16) (MAFF, 1984), when sampled at ground level.

Appendix 6.5b Calculation of daily metabolisable energy requirements of cows grazing on the three sward types, averaged across periods. (Assumptions according to Holmes and Wilson, 1984)

	Sward type		
	RG	LM	HM
Liveweight (kg) (Friesian)	459	455	465
Metabolic weight (LW $^{0.75}$)	99.7	98.8	101
Assumptions			
ME maintenance (ME_m)	59.8	59.3	60.6
= 0.6 MJ x $LW^{0.75}$			
ME gain (ME_g)	+5.8	+ 4.4	+2.8
= 38.5 MJ/kg LW gain			
(32 MJ/kg LW loss)	85.9	83.5	76.3
ME lactation (ME_l)			
(4.8 MJ/kg milk - Friesian)			
(5.7 MJ/kg milk - Jersey)			
MEI and DMI requirements			
ME requirements (MJ/cow/d) (ME_m + ME_g + ME_l)	151.5	147.2	139.7
ME of diet (MJ/kg DM)	11.2	10.7	10.4
DMI requirements (kg/cow/d)	13.5	13.8	13.4
DMI (kg/cow/d)	17.0	18.6	17.6
MEI (MJ/cow/d)	190	197	183
MEI above requirements (MJ/cow/d)	39	52	43
DMI above requirements (kg DM/cow/d)	3.5	4.8	4.2

Appendix 7.1a

Proceedings of the New Zealand Society of Animal Production 1990, Vol 50 ~~269~~

Milk production by cows grazing on Matua prairie grass (*Bromus willdenowii* Kunth) pastures maintained under different managements

V.K. RUGAMBWA, C.W. HOLMES, A.C.P. CHU AND H. VARELA-ALVAREZ

Massey University, Palmerston North

ABSTRACT

Perennial ryegrass (RG) and Matua prairie grass swards of low (LMPG) and high (HMPG) pre-grazing herbage masses were compared in 8 grazing trials (2-3 weeks) during early spring, late spring, summer and autumn (1987/88 and 1988/89) to assess their feeding values. Pre-grazing masses were approximately 3000, 4000 and 5500 kg DM/ha for RG, LMPG and HMPG treatments, respectively. Friesian cows (8 per treatment) were allowed 50 kg DM/cow/d. Mean concentrations of N (% in OM) and OMD (%) for RG, LMPG and HMPG herbage were 2.7, 2.6, 2.3 (s.e.lsm 0.04, $P < 0.001$); and 74.7, 73.1 and 70.7 (s.e. 0.18, $P < 0.001$), respectively. HMPG values were lowest during all seasons and were influenced by high compositions of dead material, low leaf:stem ratios and low compositions of clover in the swards.

Daily yields of milk and protein on RG swards were 3% higher ($P < 0.05$) than LMPG yields, and 11 and 13% higher ($P < 0.001$), respectively than those of HMPG swards. Milkfat yields were similar on RG and LMPG swards, but were 11% lower ($P < 0.001$) on the HMPG treatment. The results indicate that leafy prairie grass and leafy ryegrass swards have similar feeding and productive values. Further research is needed on Matua's persistence under grazing.

Keywords Matua prairie grass; ryegrass; herbage mass; season; sward composition; milk production.

INTRODUCTION

'Grasslands Matua' prairie grass (*Bromus willdenowii* Kunth) was released in New Zealand as a high yielding, cool and summer season active, high nutritive value pasture cultivar most suited to lax-infrequent grazing (Rumball, 1974). More recent work with sheep (Frazer, 1985; Alexander, 1985), dairy cows (Brookes and Holmes, 1986) and with bull beef (Cosgrove and Brougham, 1988) has raised questions on Matua's feeding value, and on levels of pasture utilization when grazed laxly to ensure persistence. The current practice has been to graze more intensively with long rest periods (Alexander, 1985; Matthews, 1986) or to graze intensively only after replacement tillers have emerged at the base of the sward (Black and Chu, 1989).

There is very little information on the effects of grazing regime on Matua's persistence, herbage composition, and production per cow or per hectare in dairying situations. The limited data available show that production of milk and milk solids from cows fully fed on Matua/clover pasture is either equal to (Wilson and Grace, 1978) or lower than that of cows equally fed on perennial ryegrass/clover pastures (Brookes and Holmes, 1986; Sellars, 1988). This paper is a preliminary report of results from a two year comparative study of the composition of Matua prairie grass/white clover swards maintained under two grazing managements and of perennial ryegrass/clover pasture; and of milk production by cows grazed generously on the three sward types.

MATERIALS AND METHODS

Swards and Treatments

Eight short term grazing trials were conducted at Massey University's Dairy Cattle Research Unit between October 1987 and April 1989 with spring calving Friesian cows. The experimental swards comprised of well established perennial ryegrass (*Lolium perenne L.*) swards grown with white clover (*Trifolium repens L.*), and one year old Matua prairie grass/white clover pasture on a well drained Tokomaru silt loam soil. Each of four Matua paddocks (0.8 ha each) were divided into two parts in late August 1987. Differential grazing was imposed in early September in order to create and maintain either low mass, LMPG (1.5-2.5 t DM/ha residual herbage mass (RHM)) or high mass, HMPG (2.5-3.5 t RHM) Matua prairie grass sward types. Four similar size ryegrass paddocks, previously subjected to conventional management and adjacent to the Matua swards, constituted the control treatment, RG (1.0-2.0 t/ha RHM). Target pre-grazing herbage masses for RG, LMPG and HMPG were 2.0-3.5, 3.0-4.5 and 4.5-6.0 t/ha, respectively. When deemed necessary, LMPG paddocks were either regrazed, topped or both to approximately 1.5 t/ha RHM (5 cm height) within 24 h after experimental grazing. One dressing of 15% potassic superphosphate (375 kg/ha) and two of urea (25 kg N/ha each) were applied in autumn and during autumn and early spring (1987 and 1988), respectively.

During each of two years the three sward types prepared as described above were grazed by three groups of lactating cows (8 per treatment), for 2-3 weeks in early spring (September/October), late spring (October/November), summer (December/February) and autumn (March/May). The cows were selected before each trial and grazed as a group on ryegrass/clover pasture for a two week covariate period, and thereafter randomly allocated to the treatments. A common herbage allowance of 50 kg DM/cow/d was given in daily breaks during the experimental periods.

Measurements

Herbage mass was estimated every two days within 36 h before and after grazing by cutting (to ground level) eight 0.247 m^2 quadrats along a transect using a motor powered shearing handpiece. Cut herbage was immediately washed, dried at 80°C for 36-48 h and weighed. Snip samples of pre- and post-grazing herbage adjacent to each quadrat were cut to ground level, sub-sampled and washed for determination of chemical composition and morphological components. Chemical analyses and *in vitro* DMD and OMD determinations (Roughan and Holland, 1977) were performed on freeze dried samples ground through a 1 mm sieve and bulked within replications. Total N and ash were measured by the Kjeldahl technique and by incineration in a muffle furnace at 500°C for 16-18 h, respectively. Acid detergent fibre (ADF) and lignin were estimated according to Robertson and Van Soest (1981).

Milk yields for each animal were measured twice daily on 2 and 3 consecutive days per week during the two week covariate and the experimental periods, respectively, using a proportioning Milk Meter (TruTest Co., N.Z.). Milk composition was assessed by infra-red absorption (Milk-O-Scan, A.S NFoss, Denmark). Cows were weighed and condition scored on two consecutive days at the start and end of each experimental period. Apparent herbage intakes were estimated from the difference between pre- and post-grazing herbage masses.

Statistical analysis

Data for sward measurements, herbage intake and individual animal performance were examined by analysis of variance or covariance (liveweight and condition score change with initial measurements as covariates). Milk yield and milk constituent data were analysed on seasonal basis by repeated measures analysis with covariance and on pooled basis by analysis of covariance. Unless otherwise stated, data are presented as least squares means.

RESULTS

Sward characteristics

Mean pre- and post-grazing herbage masses for each treatment are presented in Table 1. Herbage allowance was similar ($P > 0.05$) at 50.7, 50.0 and 49.9 (s.e.lsm 0.4) kg DM/cow/day for ryegrass, low mass and high mass prairie grass treatments, respectively.

The mean botanical composition and morphological components of the swards are also shown in Table 1. There were significant ($P < 0.001$) treatment x season effects on the proportion of green leaf relative to stem of the herbage on offer. The ryegrass swards had the largest ($P < 0.01$) proportion of leaf (23 and 36% higher *vs* LMPG and HMPG, respectively) during all seasons except in late spring when low mass Matua had a similar (Year One) or a higher, $P < 0.001$, Year Two leaf:stem ratio compared to ryegrass swards. The leaf:stem ratio was lower in high mass than low mass Matua treatments, and was lowest in the LMPG treatment during summer. The proportion of dead material in the swards was greatest ($P < 0.05$) in the HMPG treatment irrespective of season; that of RG swards but lowest in most seasons but was similar to the LMPG treatment ($P > 0.05$) during late spring.

Chemical composition

The mean chemical composition of herbage on offer is presented in Table 2, with data on the pattern of OM digestibility in Figure 1. The OM digestibility of ryegrass and low mass Matua swards was similar (P > 0.05) during spring (Year One) and during autumn (Year Two); otherwise it was greater (P < 0.05) on the RG treatment during the other seasons, the mean difference, however, was small (Table 2). The HMPG treatment had the lowest values for OM digestibility (P < 0.01) during all seasons, while that of Matua swards dropped markedly during summer in comparison to ryegrass pastures. The nitrogen concentration of the herbage in RG and LMPG treatments was similar (P > 0.05) during five of the eight seasons, and the difference between means was small (P = 0.04) in favour of RG swards (Table 2). The high mass Matua treatment had the lowest (P < 0.01) concentration of N throughout the experiment.

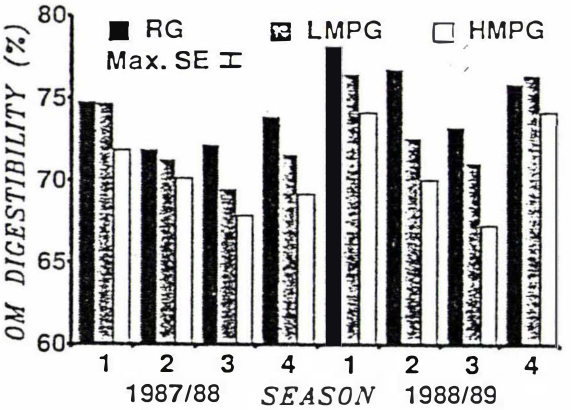


FIG 1 Influence of sward type and season on the OM digestibility of herbage on offer (1, early spring; 2, late spring; 3, summer; 4, autumn).

Animal performance

The effects of sward type on milk production are given in Table 3. The seasonal milkfat yields are shown in Figure 2. Yields of milk, milkfat, protein and lactose were, respectively, 11, 12, 13 and 11% less (P < 0.001) on the high mass Matua treatment, and were, except milkfat, (3% not 9% and P < 0.05 not 0.01) on low mass Matua compared to the ryegrass treatment. Milkfat yields on the RG and LMPG swards were similar (P > 0.05) during all seasons except during late spring when LMPG yields were higher in Year One (P < 0.05). The 3% decline in mean yields of milk, milk protein and lactose on the low mass Matua treatment relative to the ryegrass yields was generally insignificant except during summer. Repeated measures analysis of milk production data failed to detect any time effects or consistent time x treatment interactions on the response of cows to the treatments during each season.

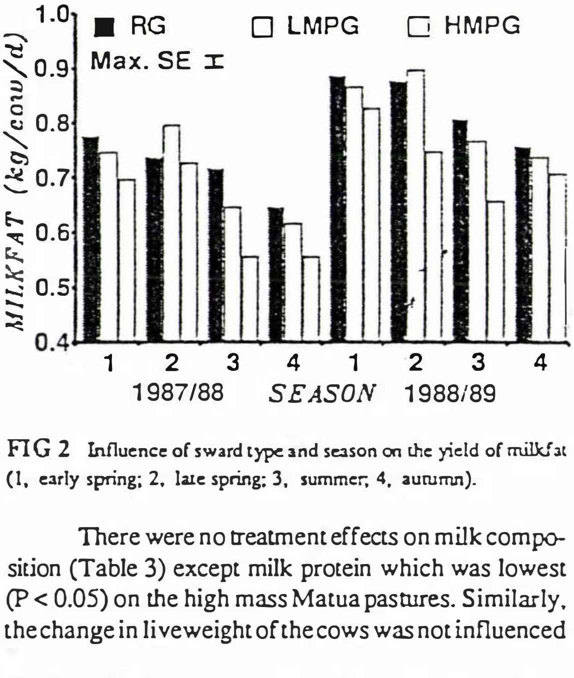


FIG 2 Influence of sward type and season on the yield of milkfat (1, early spring; 2, late spring; 3, summer; 4, autumn).

There were no treatment effects on milk composition (Table 3) except milk protein which was lowest (P < 0.05) on the high mass Matua pastures. Similarly, the change in liveweight of the cows was not influenced

TABLE 2 Mean chemical composition of herbage on offer

	Sward type			
	RG	LMPG	HMPG	SEM
DM digestibility (%)	69.4	67.3	64.3	0.17***
OM digestibility (%)	74.7	73.1	70.7	0.18***
Nitrogen (% of OM)	2.7	2.6	2.3	0.04***
Ash (% of DM)	10.0	9.7	9.0	0.25NS
ADF (% of DM)	29.2	32.0	34.6	0.92**
Lignin (% of DM)	3.5	4.3	4.5	0.24*
ME (MJ/kg DM)[1]	10.7	10.4	10.0	0.03***

[1] ME = %DOMD x 0.163 (MAFF, 1984)

TABLE 3 Mean animal production data

	Sward type			
	RG	LMPG	HMPG	SEM
Milk yield (l/cow/d)	17.7	17.2	15.7	0.12***
Milk constituent yields				
Fat (kg/cow/d)	0.78	0.76	0.69	0.012***
Protein (kg/cow/d)	0.63	0.61	0.55	0.004***
Lactose (kg/cow/d)	0.84	0.82	0.75	0.006***
Milk composition				
Fat (%)	4.46	4.48	4.43	0.03NS
Protein (%)	3.63	3.60	3.55	0.02**
Lactose (%)	4.71	4.73	4.74	0.01NS
Liveweight change (kg/cow)	+1.4	+0.2	+0.2	1.04NS
Condition score change	+0.1	0.0	-0.1	0.04*
Feed intake (kg DM/cow/d)	~~16.6~~ 17.0	18.8	17.6	~~0.75NS~~ 0.35*

TABLE 1 Mean botanical composition and morphological components of pasture on offer (% of DM), and sward herbage masses (t DM/ha (± SD)).

	Sward type			
	RG	LMPG	HMPG	SEM
Botanical composition				
Grass	65.3	61.0	71.9	1.90**
White clover	16.9	16.5	12.2	0.94*
Other species[1]	17.9	22.6	15.9	1.86*
Morphological components				
Live leaf	50.5	38.7	32.5	1.13***
Live stem	26.6	33.4	32.1	0.48***
Leaf:stem	2.3:1	1.5:1	1.2:1	0.03***
Dead material	23.2	28.0	36.7	1.19***
Herbage mass				
Pre-grazing	3.2(0.7)	4.2(1.1)	5.7(1.1)	
Post-grazing	2.1(0.5)	2.2(0.8)	3.6(0.8)	

[1] Other grasses and weeds

by the sward types. The condition of cows on the HMPG treatment, however, decreased slightly ($P < 0.05$) in comparison to the RG group (Table 3). The initial liveweights and condition score of the cows on the three treatments were similar $P > 0.05$, (mean 459 ± 51 kg/cow and 4.6 ± 0.7, respectively). Apparent feed intakes did not differ significantly ($P > 0.05$) probably because of the high C.V. (19%), but tended to be greater on the Matua swards.

DISCUSSION

The differences in component composition, in particular leaf:stem ratio and dead material, were reflected in the lower N concentration and OMD of herbage on offer from the HMPG and LMPG treatments in comparison to the RG swards. The absolute differences between the RG and LMPG swards, especially during late spring and autumn, were small. Similar trends in Matua's nutritive value have been reported by Hume (1990) under a cutting management. The nutritive value of Matua swards was lowest during summer and was much lower than RG swards. Cosgrove and Brougham (1988) have reported poor performance of bull calves grazing Matua based pastures during summer, in the North Island, while Fraser (1985) working with sheep observed good summer growth in the South Island. The summer period coincided with peak concentrations of dead material, stem and other species in the Matua swards, which may explain the marked decline in herbage quality.

The daily herbage allowance (50 kg DM/cow) was generous and was planned to minimise restrictions on the cows' DMI. Dry matter intakes were slightly, ~~but not significantly~~, higher on the Matua swards. Prairie grass has a greater proportion of leaf in the upper sward horizons (L'Huillier *et al.*, 1986) and has a shorter rumen retention time (Cruickshank *et al.*, 1985) than perennial ryegrass, which may have contributed to the slightly higher intakes off the Matua swards.

Cows on the HMPG swards produced lower yields of milk, fat, protein and lactose in both years, which may have been caused by differences in the nutritive value of herbage consumed since DMI did not differ significantly between the treatments. The feeding value of low mass Matua pastures, measured in terms of yields of milk, fat and protein was practically similar to that of perennial ryegrass pasture, particularly during late spring.

CONCLUSION

Grazing Matua prairie grass at pre-grazing herbage masses above 4 t DM/ha resulted in swards with the highest concentrations of stem and dead material; and the lowest levels of white clover and pasture quality. Milk yields were depressed on these swards. At low pre-grazing masses, however, Matua swards were comparable to perennial ryegrass swards in herbage quality and milk production. It appears that the feeding value of Matua pastures declines more slowly with reproductive growth and increasing herbage mass in relation to ryegrass swards. This suggests that prairie grass may be a suitable grass species under silage, hay or 'cut and carry' feeding systems in both cool and warm environments. Thus Matua would be suitable as a special purpose pasture. Further work on the management of Matua pasture is required. Again, grazing studies under different environments are still needed to exploit Matua's high feeding and growth qualities.

ACKNOWLEDGEMENTS

D.A. Hamilton, Y.F. Moore, R.M. Watson and M. Scott assisted with the laboratory analyses; A. Whitton and M. Chesterfield helped in managing the cows and pastures; The Ministry of External Relations and Trade and The Miss E.L. Hellaby Trust provided financial assistance.

REFERENCES

Alexander, R.T. 1985. Effects of sheep grazing regime on performance of Matua prairie grass. *Proceedings of the New Zealand Grassland Association 46*: 151-156.

Black, C.K.; Chu, A.C.P. 1989. Searching for an alternative way to manage prairie grass. *Proceedings of the New Zealand Grassland Association 50*: 219-223.

Brookes, I.M.; Holmes, C.W. 1986. The effect of herbage allowance on dry matter intake and milk production of cows grazing Matua prairie grass swards. *Massey Farm Series 3*: 7-11. Massey University.

Cosgrove, G.P.; Brougham, R.W. 1988. Pasture strategies for dairy beef production. *Proceedings of the New Zealand Grassland Association 49*: 57-62.

Cruickshank, G.P.; Poppi, D.P.; Sykes, A.R. 1985. Intake and duodenal protein flow in early weaned lambs grazing white clover, lucerne, ryegrass and prairie grass. *Proceedings of the New Zealand Society of Animal Production 45:* 113-116.

Fraser, T.J. 1985. Role of Matua prairie grass in prime lamb production. *Proceedings of the New Zealand Grassland Association 46*: 157-161.

Hume, D.E. 1990. Morphological and physiological studies of prairie grass. *PhD Thesis*, Agricultural University, Wageningen.

L'Huillier, P.J.; Poppi, D.P.; Fraser, T.S. 1986. Influence of structure and composition of ryegrass and prairie grass-white clover swards on the grazed horizon and diet harvested by sheep. *Grass and Forage Science 41*: 259-267.

Matthews, P.N.P. 1986. Matua prairie grass: Changes in approach. *Massey Farm Series* 3: 12-14, Massey University.

Ministry of Agriculture, Fisheries and Food. 1984. Energy allowances and feeding systems for ruminants. *Technical Bulletin 33*. HMOS, London.

Robertson, J.B.; Van Soest, P.J. 1981. The detergent system of analysis and its application to human foods. In: *Basic and Clinical Nutrition* Eds . James, W.P. and Theander, O., *3*: 123-158.

Roughan, P.G.; Holland, R. 1977. Predicting *in vivo* digestibilities of herbage by exhaustive enzymatic hydrolysis of cell walls. *Journal of the Science of Food and Agriculture 28*: 1057-1064.

Rumball, W. 1974. 'Grasslands Matua' prairie grass (*Bromus catharticus* Vahl). *New Zealand Journal of Experimental Agriculture 2*: 1-5.

Sellars, M.D. 1988. Manawatu dairy farmers experiences with Matua prairie grass. *Proceedings of the New Zealand Grassland Association 49*: 185-186.

Wilson, G.F.; Grace, N. 1978. Pasture magnesium levels and milk production in dairy cows. *New Zealand Journal of Experimental Agriculture 6*: 267-269.

Proceedings of the New Zealand Society of Animal Production 1991. Vol 51

The effects of season and herbage mass on the nutritive value of prairie grass cv. Grasslands Matua and perennial ryegrass

V.K. RUGAMBWA, C.W. HOLMES AND A.C.P. CHU

Massey University, Palmerston North, New Zealand.

ABSTRACT

The nutritive value of perennial ryegrass (RG), low mass Matua prairie grass (LM) and high mass Matua prairie grass (HM) swards were measured during early spring, late spring, summer and autumn of 1987/88 and 1988/89. Pre-grazing herbage masses were approximately 3000, 4000 and 5500 kgDM/ha for RG, LM and HM swards, respectively. Lactating cows on a common herbage allowance (50 kg DM/cow daily), grazed the ryegrass and Matua swards at mean intervals of 25 and 35 d, respectively.

Values for the concentration of N (% OM) and DMD in whole plants, averaged across all seasons, were (%N) 2.6, 2.5 and 2.3, and (% DMD) 71.4, 71.1 and 69.4, respectively, for RG, LM and HM. The values for HM were significantly lower than those for the other two treatments. Values for the concentration of N and DMD in green grass leaf were (%N) 3.4, 3.5 and 3.5, and (% DMD) 72.4, 71.9 and 71.5, respectively, for RG, LM and HM. There were no significant differences in % N between the three treatments; the difference in % DMD between RG and HM was significant. During the autumn in both years, the LM treatment had a higher value for DMD % than the RG treatment (by 3 to 6% units).

These results indicate that even at high pre-grazing herbage masses (4-5 tDM/ha) Matua prairie grass plants maintained relatively high nutritive values in green leaf and stem.

Keywords Matua prairie grass, ryegrass, whole plant, plant components, nutritive value, season.

INTRODUCTION

Herbage produced by prairie grass (*Bromus willdenowii* Kunth cv. Matua) is reputed to be highly palatable and highly digestible (Rumball, 1974; Hume, 1990 a,b), and there is some data for its chemical composition (Rumball *et al.*, 1972; Rys *et al.*, 1978; Crush *et al.*, 1989; Hopkins *et al.*, 1989; Hume, 1990 a,b; Thom *et al.*, 1990). However there is little information about the composition of Matua Prairie grass grazed by dairy cattle.

The present report is based on a two year study involving perennial ryegrass swards maintained at a moderate herbage mass, and Matua prairie grass swards maintained at either low or high pre-grazing herbage masses. All the three sward types were grown in association with white clover. This paper presents results for the nutritive value, in terms of digestibility and nutrient concentrations (Ulyatt, 1981), of whole plants and plant components of Matua prairie grass as compared to perennial ryegrass under field conditions. Data for botanical and morphological compositions and feeding value for milk production were reported by Rugambwa *et al.* (1990).

MATERIALS AND METHODS

The Swards

The nutritive values of whole plants and plant components from two Matua prairie grass and one perennial ryegrass (*Lolium perenne* L.) swards were assessed at Massey University's Dairy Cattle Research Unit between October 1987 and April 1989. The three sward types, ryegrass (RG), low mass Matua (LM) and high mass Matua (HM), were grazed by lactating Friesian cows at pre-grazing herbage masses of approximately 3200, 4200 and 5500 kg DM/ha, respectively. Mean post-grazing herbage masses were RG 2100, LM 2200 and HM 3500 kg DM/ha. The swards were grazed at intervals of approximately 25 days for ryegrass and 35 days for Matua, during the periods of the experiments (spring to autumn). The cows were fed generously (daily herbage allowance 50 kg DM/cow) during each of the eight grazing trials, each lasting for 2 to 3 weeks, during early and late spring, summer and autumn over the two year period. Details of the establishment and management of the swards before and during the experimental period, herbage mass estimations, herbage sampling, and sample processing protocols were reported by Rugambwa *et al.* (1990).

Design and Statistical Analysis

The experimental design used and statistical methods employed to test the treatment differences were described by Rugambwa *et al.* (1990). The results are presented as least squares means (LSM) with corresponding standard errors ($S.E_{LSM}$), unless indicated otherwise.

Measurements

Fresh herbage sub-samples from RG, LM and HM sward types were dissected into either ryegrass or Matua plants (retaining senescent matter attached to the plant), or into plant components (green leaf laminae, green stem or pseudostem, inflorescence (above flag leaf) and dead matter. These sward components, except inflorescence (seedhead) and dead matter, were bulked within replications during each season after being washed, freeze-dried and ground; and were analysed for concentrations of total nitrogen (N), ash, acid detergent fibre (ADF), lignin, gross energy (GE), and for *in vitro* digestibility as was described previously (Rugambwa *et al.*, 1990). Results for ADF, lignin and gross energy concentrations, and for all analyses performed on seedheads and dead matter are simple means (± standard deviations) of sub-samples bulked within sward types during each season. The concentrations of metabolizable energy of the various pasture components were estimated from their respective values of digestible organic matter in the dry matter (DOMD) according to MAFF (1975), with slight modifications to suit New Zealand pasture herbage (Ulyatt *et al.*, 1984).

RESULTS

Chemical Composition of Whole Plants

Mean values for the chemical composition of perennial ryegrass (RG), low mass Matua (LM) and high mass Matua (HM) whole plants, averaged across all eight experimental periods, are presented in Table 1. The concentrations of total N in RG and LM plants were similar, while that of HM plants was significantly lower. RG plants had the lowest concentrations of ADF and lignin, LM values were intermediate, and HM plants had the highest values. Mean concentrations of lignin in Matua plants were higher than those of ryegrass values by about 1% unit.

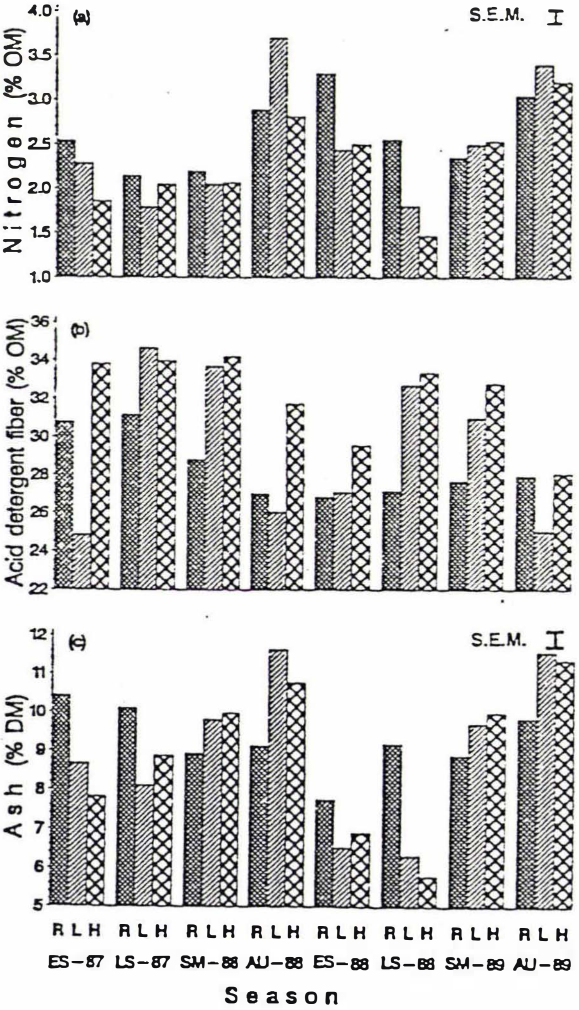


FIG 1 Influence of sward type and season on the concentration of (a) nitrogen, (b) acid detergent fibre and (c) ash of whole plants. (R = ryegrass, L = Low mass Matua, H = high mass Matua; ES = early spring, LS = late spring, SM = summer, AU = autumn 1987-1989; S.E.M.: highest standard error of means).

TABLE 1 Mean values for chemical composition of whole ryegrass and prairie grass plants and their components from the three sward types, averaged across eight seasons (unless stated otherwise, n=32).

Herbage parameter	Herbage component	Sward type			S.E.	P < 0.01
		RG	LM	HM		
N (% OM)						
	Whole plant	2.6	2.5	2.3	0.05	**
	Green leaf	3.4	3.5	3.5	0.07	NS
	Green stem	1.7	1.8	1.7	0.05	NS
	Inflorescence[1]	2.1 ± 0.4	2.0 ± 0.3	2.0 ± 0.3	NA	NA
	Dead matter[2]	1.8 ± 0.3	1.8 ± 0.3	1.6 ± 0.2	NA	NA
ADF (% OM)[2]						
	Whole plant	28.6 ± 1.7	29.4 ± 3.9	32.2 ± 2.2	NA	NA
Lignin (% OM)[2]	Whole plant	2.7 ± 0.4	3.5 ± 0.7	3.8 ± 1.0	NA	NA
Ash (% DM)	Whole plant	9.3	9.1	9.0	0.24	NS
	Green leaf	9.8	10.2	10.1	0.14	NS
	Green stem	7.3	7.2	7.2	0.21	NS
	Inflorescence[1]	7.0 ± 1.5	5.3 ± 0.4	5.6 ± 0.5	NA	NA
	Dead matter[2]	11.1 ± 1.4	10.5 ± 1.5	9.3 ± 201.2	NA	NA

NA = Not analysed statistically.

[1] Values are means (± SD) of samples bulked within each sward type during each season with n=3 for RG and n=7 for LM and HM.

[2] Values are means (± SD) of samples bulked within each sward type during each season with n=8.

NS = Non significant ($P>0.05$).

The concentration of ash tended to be lower in Matua, relative to ryegrass, but the differences were not significant. There were, however, highly significant sward type x season interactions in the proportions of N and ash of plants from the three sward types (Fig. 1). Ryegrass had the highest proportion of total N in the organic matter during early and late spring (Fig. 1a), while plants from all three swards had similar values for % N during summer. The proportion of ADF in LM plants was either equal to or lower than that of ryegrass during early spring and autumn (Fig. 1b) whereas HM plants had the highest ADF values during most seasons. Compared to ryegrass, Matua plants had lower concentrations of ash during early and late spring (Fig. 1c), but higher values during summer and autumn.

Digestibility of Whole Plants

Mean values for *in vitro* digestibility and energy concentrations of whole plants in the three sward types are shown in Table 2. RG and LM plants had similar values for DMD and similar DOMD and ME concentrations, but values for HM plants were significantly lower. There were no differences in GE between the three treatments. Seasonal trends in the *in vitro* DMD for ryegrass and Matua plants are illustrated in Figure 2a. RG and LM plants had similar mean DMD values in Year One except during autumn when the digestibility of LM plants was significantly greater. In Year Two, however, the DMD of LM plants was consistently lower than that of RG, except again during autumn when the DMD of LM plants was significantly

TABLE 2 Mean values for in vitro digestibility and energy concentration of whole ryegrass and prairie grass plants and plant components, and of leaf:stem ratios from the three sward types, averaged across eight seasons (unless stated otherwise, n=32).

Herbage parameter	Herbage component	Sward type RG	LM	HM	S.E.	Sign.
DMD (%)	Whole plant	71.4	71.1	69.4	0.29	**
	Green leaf	72.4	71.9	71.5	0.28	+
	Green stem	70.8	69.7	68.4	0.39	**
	Inflorescence[1]	67.8 ± 10.4	64.1 ± 3.5	61.4 ± 4.5	NA	NA
	Dead matter[2]	50.3 ±1.9	47.9 ± 1.6	45.3 ± 2.1	NA	NA
DOMD (%)	Whole plant	67.4	66.9	65.5	0.33	**
	Green leaf	68.8	68.1	67.6	0.33	+
	Green stem	68.7	67.6	66.3	0.46	*
	Inflorescence[1]	66.0 ± 8.9	63.4 ± 2.9	60.7 ± 3.8	NA	NA
	Dead matter[2]	42.9 ± 2.8	40.5 ± 2.5	37.7 ± 2.3	NA	NA
GE[2] (MJ kg DM^{-1})	Whole plant	18.5 ± 0.32	18.5 ±0.26	18.2 ± 0.25	NA	NA
ME (MJ kg DM^{-1})	Whole plant	11.0	10.9	10.7	0.05	**
	Green leaf	11.2	11.1	11.0	0.05	+
	Green stem	11.2	11.0	10.8	0.06	*
	Inflorescence[1]	10.8 ± 1.5	10.3 ± 0.5	9.9 ± 0.6	NA	NA
	Dead matter[2]	7.0 ± 0.5	6.6 ± 0.4	6.1 ± 0.4	NA	NA
Leaf:stem ratio		2.3	1.4	1.1	0.04	***

* = $P < 0.05$, ** = $P < 0.01$, *** = $P < 0.001$
+ = $P < 0.1$

NA = Not analysed statistically.

[1] Values are means (± SD) of samples bulked within each sward type per season with n=3 for RG and n=7 for LM and HM.

[2] Values are means (± SD) of samples bulked within each sward type per season with n=8.

higher than that of RG plants.

Leaf and Stem

There were no significant differences between the swards in the mean concentrations of total N (Table 1) in either the green leaf or green stem. Similarly, the proportions of ash in either the green leaf or green stem did not differ between sward types. The concentrations of N and of ash were higher for green leaf than for green stem.

In vitro DMD of both green leaf and stem was significantly higher in RG than in HM plants, values for LM plants were intermediate and not significantly different from either RG or HM values (Table 2). The values were generally slightly higher for green leaf than for green stem.

Differences between the three swards in the *in vitro* DMD of leaf (Fig. 2b) were only apparent during autumn (Year One) and late spring (Year Two), when LM and RG green leaf had significantly higher values than HM green leaf. The DMD values in the green stem of RG and LM plants (Fig. 2c) were similar during most seasons, except during late spring and summer of Year Two when LM values were lower than those of RG. Stem from HM plants tended to have the lowest DMD values, particularly during late spring and summer.

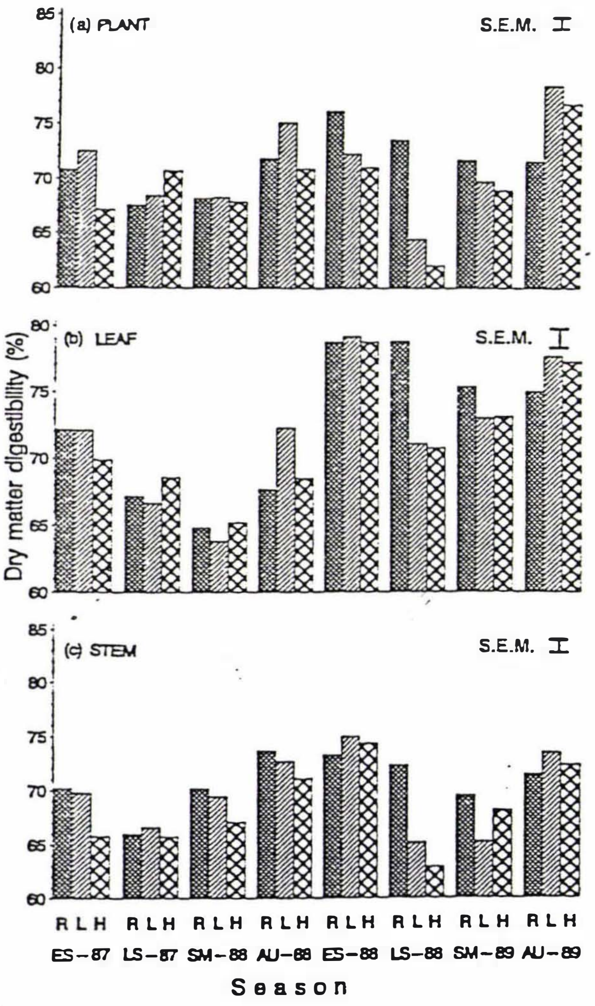


FIG 2 Influence of sward type and season on the *in vitro* dry matter digestibility of (a) whole plant, (b) green leaf and (c) green stem. (R = ryegrass, L = low mass Matua, H = high mass Matua; ES = early spring, LS = late spring, SM = summer, AU = autumn (1988-1989; S.E.M.: highest standard error of means).

SeedHeads and Dead Matter

Seedheads from the three sward types had similar concentrations of N (Table 1). The concentration of ash in RG seedheads was considerably higher than that of LM and HM seedheads (Table 1). *In vitro* DMD and ME values of RG seedheads were higher than those of Matua, with HM swards showing the lowest values.

The concentration of N in the dead matter of the three sward types was similar to that of green stem (Table 1). The proportions of ash in the dead matter (Table 1) were higher than those of whole plants and plant components, regardless of sward type. Dead matter in all sward types had the lowest *in vitro* digestibilities and ME concentrations relative to other sward components.

The mean proportion of green leaf:stem in ryegrass plants (Table 2) was 40 and 50% greater than that of LM and HM plants, respectively, with minor seasonal variations.

DISCUSSION

The average values for digestibility and the changes in these values between seasons, are similar to those reported by previous authors (Rattray, 1978; Crush *et al.*, 1989). The values of DMD were similar for ryegrass and low mass Matua plants, but these were higher than the values for high mass Matua plants (by about 1.5% units). The exception to this general finding was that in autumn, digestibilities of plants from both Matua treatments were higher than ryegrass plants as has been reported by Crush *et al.* (1989).

In general, digestibility of plant material decreases with increases in maturity and mass (Osbourn, 1980) due to increases in stem:leaf ratio, cell wall carbohydrates and lignin concentrations (Ulyatt, 1981; Waghorn and Barry, 1987), and proportion of dead matter (Bircham and Hodgson, 1983). In the present experiment the Matua swards had much larger pre-grazing herbage masses than the ryegrass swards (by 1 to 2.5 t DM/ha), and had longer periods for regrowth between successive grazings. Therefore the similarity in DMD between LM and RG plants, the relatively small difference between RG and HM plants, and the absence of any difference in % N between the swards, are surprising. It is interesting to note that, at a similar stage of maturity, the digestibility of cell walls and the concentration of water soluble carbohydrates were greater for Matua plants than for Westerwolds annual ryegrass plants, despite higher concentrations of cell wall polysaccharides in Matua (Hume, 1990b).

The differences in DMD between RG and HM swards were, however, larger for inflorescence and dead material (about 5% units). These are likely to have contributed to the poorer feeding value of HM swards reported by Rugambwa *et al*. (1990).

CONCLUSION

Low mass Matua and perennial ryegrass whole plants had similar average nutritive values, which were higher than that of high mass Matua. Only small differences between sward types were observed for digestibility of green leaf or stem, despite large differences in herbage mass between swards. The digestibility and ME concentration of dead matter was lower in Matua than in ryegrass.

ACKNOWLEDGEMENTS

We are grateful to H. Valera-Alvarez for computing advice; the staff of Massey University's Animal Nutrition Laboratory and Dairy Cattle Research Unit, C.M. Jenkinson and D.L. Burnham for technical help; and to The Miss E.L. Hellaby Indigenous Grasslands Research Trust and M.E.R.T., Wellington for financial assistance.

REFERENCES

Bircham, J.S. and Hodgson, J. 1983. The influence of sward condition on rates of herbage growth and senescence in mixed swards under continuous stocking management. *Grass and Forage Science 38*: 323-331.

Crush, J.R.; Evans, J.P.M. and Cosgrove, G.P. 1989. Chemical composition of ryegrass (*Lolium perenne L.*) and prairie grass (*Bromus willdenowii* Kunth) pastures. *New Zealand Journal of Agricultural Research 32*: 461-468.

Hopkins, A.; Murray, P.J. and Patefield, W.M. 1989. A comparison of the herbage productivity of Bromus willdenowii cv. Grasslands Matua with four cultivars of *Lolium perenne* when grown in association with *Trifolium repens*. *Grass and Forage Science 44*: 31-39.

Hume, D.E. 1990a. Morphological and physiological studies of prairie grass. *Ph.D. Thesis*, Agricultural University, Wageningen.

Hume, D.E. 1990b. Growth of prairie grass (*Bromus willdenowii* Kunth) and Westerwolds ryegrass *Lolium multiflorum* Lam.) at Wageningen, The Netherlands. *Grass and Forage Science 45*: 403-411.

Ministry of Agriculture Fisheries and Food (MAFF). 1975. Energy allowances and feeding systems for ruminants. *Technical Bulletin 33*: HMOS, London.

Osbourn, D.F. 1980. The feeding value of grass and grass products. In: *Grass-Its Production and Utilization*. Ed. W. Holmes. British Grassland Society pp 70-123.

Rattray, P.V. 1978. Effect of lambing date on production from breeding ewes and on pasture allowance and intake. *Proceedings of the New Zealand Grasslands Association 9*: 98-107.

Rugambwa, V.K.; Holmes, C.W.; Chu, A.C.P. and Varela-Alvarez, H. 1990. Milk production by cows grazing on Matua prairie grass (*Bromus willdenowii* Kunth) pastures maintained under different managements. *Proceedings of the New Zealand Society of Animal Production 50*: 269-273.

Rumball, W. 1974. 'Grasslands Matua' prairie grass (*Bromus catharticus* Vahl). *New Zealand Journal of Experimental Agriculture 2*: 1-5.

Rumball, W.; Butler, G.W. and Jackman, R.H. 1972. Variation in nitrogen and mineral composition in populations of prairie grass (*Bromus unioloides* H.B.K.). *New Zealand Journal of Agricultural Research 15*: 33-42.

Rys, G.J.; Ritchie, I.M.; Smith, R.G.; Thomson, N.A.; Crouchley, G and Stiefel, W. 1978. The performance of 'Grasslands Matua' prairie grass in the Southern North Island. *Proceedings of the New Zealand Grasslands Association 39*: 148-155.

Thom, E.R.; Taylor, M.J. and Wildermoth, D.D. 1990. Effects of establishment method, seeding rate and soil fertility on the growth and persistence of a prairie grass pasture in Waikato. *Proceedings of the New Zealand Grasslands Association 51*: 79-84.

Ulyatt, M.J. 1981. The feeding value of temperate pastures. In: *Grazing Animals*. Ed. F.H.W. Morley. Elsevier Publishing Co., Amsterdam. pp. 125-141.

Ulyatt, M.J.; Fenessy, P.F.; Rattray, P.V. and Jagusch, K.T. 1984. The nutritive value of supplements. In: Supplementary Feeding. Eds. K.R. Drew and P.F. Fennessy. *New Zealand Society of Animal Production Occasional Publication No. 7*: 157-184.

Waghorn, G.C. and Barry, T.N. 1987. Pasture as a nutrient source. In: Livestock Feeding on Pasture. Ed. E.M. Nicol. *New Zealand Society of Animal Production Occasional Publication No. 10*: 21-37.

Appendix 7.2 Correlation matrices between pregrazing herbage mass (premass), sward height (preht), and the concentrations of leaf (pcleaf), stem (pcstem), dead matter (pcdead) in prairie grass and ryegrass swards and the digestibility of organic matter of the herbage (OMD).

(a) Low, intermediate, and high mass prairie grass/red clover swards (Experiment 1). The data were pooled across sward types because of similar inter-correlations (n=36).

	PREMASS	PREHT	PCOMD
PREMASS	1.00000 0.0	0.94220 0.0001	-0.21820 0.2011
PREHT	0.94220 0.0001	1.00000 0.0	-0.25120 0.1395
PCOMD	-0.21820 0.2011	-0.25120 0.1395	1.00000 0.0

(b) Perennial ryegrass/white clover swards (n=16).

	PCLEAF	PCSTEM	PCDEAD	OMD
PCLEAF	1.00000 0.0	-0.79058 0.0022	-0.72912 0.0109	0.92518 0.0001
PCSTEM	-0.79058 0.0022	1.00000 0.0	0.20043 0.5546	-0.65586 0.0284
PCDEAD	-0.72912 0.0109	0.20043 0.5546	1.00000 0.0	-0.83882 0.0024
OMD	0.92518 0.0001	-0.65586 0.0284	-0.83882 0.0024	1.00000 0.0

(c) Low mass prairie grass/white clover swards (n=16).

	PCLEAF	PCSTEM	PCDEAD	OMD
PCLEAF	1.00000 0.0	-0.54540 0.0355	-0.69325 0.0042	0.79898 0.0006
PCSTEM	-0.54540 0.0355	1.00000 0.0	-0.14228 0.5991	-0.14106 0.6160
PCDEAD	-0.69325 0.0042	-0.14228 0.5991	1.00000 0.0	-0.92545 0.0001
OMD	0.79898 0.0006	-0.14106 0.6160	-0.92545 0.0001	1.00000 0.0

(d) High mass prairie grass/white clover swards (n=16).

	PCLEAF	PCSTEM	PCDEAD	OMD
PCLEAF	1.00000 0.0	-0.34028 0.1972	-0.78844 0.0003	0.87759 0.0001
PCSTEM	-0.34028 0.1972	1.00000 0.0	-0.30954 0.2433	-0.04548 0.8672
PCDEAD	-0.78844 0.0003	-0.30954 0.2433	1.00000 0.0	-0.85533 0.0001
OMD	0.87759 0.0001	-0.04548 0.8672	-0.85533 0.0001	1.00000 0.0

REFERENCES

Agricultural Research Council (ARC). 1980. The Nutrient Requirements of Ruminant Livestock. Commonwealth Agricultural Bureaux, Slough.

Agricultural Research Council (ARC). 1984. Nutrient Requirements of Farm Livestock, Supplement No. 1. Commonwealth Agricultural Bureaux, Slough.

Ahlborn, G. and Bryant, A.M. 1992. Production, economic performance and optimum stocking rates of Holstein-Friesian and Jersey cows. Proceedings of the New Zealand Society of Animal Production 52: (in press).

Alberda, Th. 1960. The effect of nitrate nutrition on the carbohydrate content of *Lolium perenne. Proceedings of the VIII International Grassland Congress,* Reading, pp 612-617.

Alberda, Th. 1986. The influence of reserve substances on dry matter production after defoliation. *Proceedings of the X International Grassland Congress, Helsinki,* pp 140-147.

Alcock, M.B. 1964. The physiological significance of defoliation on the subsequent regrowth of grass-clover mixtures and cereals. *In*: British Ecological Society, Symposium No. 4, B.J. Crisp (ed), pp 25-41.

Alexander, R.T. 1985. Effects of sheep grazing regime on performance of Matua prairie grass. *Proceedings of the New Zealand Grassland Association* 46: 151-156.

Allden, W.G. and Whittaker, I.A.McD. 1970. The determinants of herbage intake by grazing sheep: the interrelationships of factors influencing herbage intake and availability. *Australian Journal of Agricultural Research* 21: 755-766.

Anon. 1982. *Latest Technical Information on Bromus catharticus.* Bureau de Promotion de Varietes Fourrageres, Paris.

Appadurai, R.R. and Holmes, W. 1964. The influence of stage of growth, closeness of defoliation, and moisture on the growth and productivity of a ryegrass-white clover sward. *Journal of Agricultural Science, Cambridge* 62: 327-332.

Arosteguy, J.C., Hodgson, J., Souter, W.G. and Barthram, G.T. 1983. Herbage growth and utilisation on swards grazed by cattle and sheep. *In*: Efficient Grassland Farming, A.J. Corrall (ed). British Grassland Society Occasional Symposium No. 14, pp 155-158.

Association of Official Agricultural Chemists. 1975. Official Methods of Analysis, A.O.A.C., Washington, D.C.

Baars, J.A. and Cranston, A. 1977. Performance of Grasslands Matua prairie grass under close mowing in the Central North Island. *Proceedings of the New Zealand Grassland Association* 39: 139-147.

Baars, J.A., Jagusch, K.T., Dyson, C.B. and Farquhar, P.A. 1981. Pasture production and sward dynamics under sheep grazing. *Proceedings of the New Zealand Society of Animal Production* 41: 101-111.

Baile, C.A. and Della-Fera, M.A. 1988. Physiology of control of food intake and regulation of energy balance in dairy cows. *In*: Nutrition and lactation in the dairy cow, P.C. Garnsworthy (ed). Butterworths, London, pp 251-261.

Bailey, R.W., Allison, R.M. and O'Connor, K.I. 1970. Protein and carbohydrate composition of lucerne grown in Canterbury. *Proceedings of the New Zealand Grassland Association* 32:

127-136.

Baines, R.N., Grieshaber-Otto, J.H. and Snaydon, R.W. 1983. Factors affecting the performance of white clover in swards. *In*: Efficient Grassland Farming, A.J. Corrall (Ed). British Grassland Society, Occasional Symposium No. 14, pp 217-221.

Baker, A-M.C. and Leaver, D. 1986. Effect of stocking rate in early season on dairy cow performance and sward characteristics. *Grass and Forage Science* 41: 333-340.

Baker, R.D., Alvarez, F. and Le Du, Y.L.P. 1981a. The effect of herbage allowance upon the herbage intake and performance of suckler cows. *Grass and Forage Science* 36: 189-199.

Baker, R.D., Le Du, Y.L.P. and Alvarez, F. 1981b. The herbage intake and performance of set stocked suckler cows and calves. *Grass and Forage Science* 36: 201-210.

Balch, C.C. and Campling, R.C. 1962. Regulation of voluntary feed intake in ruminants. *Nutrition Abstracts and Reviews* 32: 669-686.

Baldwin, G. and Holmes, C.W. 1990. The performance and problems of winter-milk dairy farms. *Massey Dairyfarming Annual* 42: 59-63.

Ball, R., Brougham, R.W., Brock, J.L., Crush, J.R., Hoglund, J.H. and Carran, R.A. 1979. Nitrogen fixation in pastures. *New Zealand Journal of Experimental Agriculture* 7: 1-15.

Ball, P.F. and Field, T.R.O. 1982. Responses to Nitrogen as affected by pasture characteristics, season and grazing management. *In*: Nitrogen Fertilizers in New Zealand Agriculture, P.B. Lynch (ed). New Zealand Institute of Agricultural Science, Wellington, pp 45-63.

Barry, T.N. 1976. Effects of intraperitoneal injections of DL-methionine on the voluntary intake and wool growth of sheep fed sole diets of hay, silage and pasture differing in digestibility. *Journal of Agricultural Science* 86: 141-149.

Barry, T.N. and Blaney, B.J. 1987. Secondary compounds of forages. *In*: The nutrition of herbivores, J.B. Hacker and J.H. Ternouth (eds). Academic Press, Sydney, pp 91-119.

Barry, T.N. and Reid, C.S.W. 1985. Nutritional effects attributable to condensed tannins, cyanogenic glycosidases and oestrogenic compounds in New Zealand forages. *In*: Forage Legumes for Energy-Efficient Animal Production. United States Department of Agriculture, Agricultural Research Service, pp. 246-259.

Bartholomew, P.W., McLauchlan, W. and Chestnut, D.M.B. 1981. An assessment of the influence of net herbage accumulation, herbage consumption and individual animal performance of two lengths of grazing rotation and three herbage allowances for grazing beef cattle. *Journal of Agricultural Science, Cambridge* 96: 363-373.

Beever, D.E., Sutton, J.D and Phipps, R.H. 1991. The principles and practices of feeding for quality milk. *In*: Management issues for the grassland farmer, C.S. Mayne (ed). British Grassland Society Occasional Symposium No. 25, pp 102-118.

Belgrave, B.R., Watt, P.C., Brock, J.L., Wewala S. and Sedcole, J.R. 1990. A survey of farmer knowledge and use of pasture cultivars in New Zealand. *New Zealand Journal of Agricultural Research* 33: 199-211

Bell, C.C. and Ritchie, I.M. 1989. The effect of frequency and height of defoliation on the production and persistence of 'Grasslands Matua' prairie grass. *Grass and Forage Science* 44: 245-248.

Bell, F.R. 1971. Hypothalamic control of food intake. *Proceedings of the Nutrition Society* 30:

103-108.

Bichan, A. 1990. An analysis of costs and other factors which contribute to the international competitiveness of the New Zealand dairy industry: Observation on, and comparisons with the Tasmanian and Victorian dairy industry. *Massey Dairyfarming Annual* 42: 119-121.

Bines, J.A. 1971. Metabolic and physical control of food intake in ruminants. *Proceedings of the Nutrition Society* 30: 116-122.

Binnie, R.C., Chestnut, D.M.B. and Murdoch, J.C. 1980. The effect of time of initial defoliation on the productivity of perennial ryegrass swards. *Grass and Forage Science* 35: 267-273.

Bircham, J.S. 1981. *Herbage growth and utilization under continuous stocking management.* Ph.D. Thesis, University of Edinburgh.

Bircham, J.S. and Hodgson, J. 1983a. The dynamics of herbage growth and senescence in a mixed-species temperate sward continuously grazed by sheep. *Proceedings of the XIV International Grassland Congress, Lexington, Kentucky*, pp 601-603.

Bircham, J.S. and Hodgson, J. 1983b. The influence of sward condition on rates of herbage growth and senescence in mixed swards under continuous stocking management. *Grass and Forage Science* 38: 323-331.

Bircham, J.S. and Hodgson, J. 1984. The effects of change in herbage mass on rates of senescence in mixed swards. *Grass and Forage Science* 39: 111-115.

Black, C.K. and Chu, A.C.P. 1989. Searching for an alternative way to manage prairie grass. *Proceedings of the New Zealand Grassland Association* 50: 219-223.

Black, J.L. 1990. Nutrition of the grazing ruminant. *Proceedings of the New Zealand Society of Animal Production* 50: 7-27.

Black, J.L., Colebrook, W.G., Gherardi, S.G. and Kenny, P.A. 1989. Diet selection and the effect of palatability on voluntary feed intake by sheep. *Proceedings of the Minnesota Nutrition Conference* 50: 139-151.

Black, J.L. and Kenny, P.A. 1984. Factors affecting diet selection by sheep. 2. Height and density of pasture. *Australian Journal of Agricultural Research* 35: 565-578.

Black, J.L., Kenny, P.A. and Colebrook, W.F. 1987. Diet selection by sheep. *In*: Temperate Pastures: Their Production, Use and Management; J.L. Wheeler, C.J. Pearson and G.E. Robards (eds). Australian Wool Corporation/CSIRO, pp 331-334.

Blight, G.W., Haydock, K.P., Duncalfe, F., Pepper, P.M., Meyer, R.J., Seebeck, R.M. and O'Rourke, P.K. 1984. Experimental design in cattle research when resources are limiting. *Proceedings of the Australian Society of Animal Production* 15: 52-65.

Bogdan, A.V. 1977. *Tropical Pastures and Fodder Plants.* Longman Inc., New York.

Boom, C.J. and Sheath, G.W. 1990. Effects of soil characteristics and spring management on the persistence of 'Grasslands Matua' prairie grass. *Proceedings of the New Zealand Grassland Association* 52: 241-245.

Boswell, C.C. and Cranshaw, L.J. 1978. Mixed grazing of cattle and sheep. *Proceedings of the New Zealand Society of Animal Production* 38: 116-120.

Brewer, D., Calder, F.W., MacIntyre, T.M. and Taylor, A. 1971. Ovine ill-thrift in Nova Scotia. I. The possible regulation of rumen flora in sheep by the fungal flora of permanent pasture.

Journal of Agricultural Science, Cambridge 76: 465-477.

Briseno de la Hoz, V.M. and Wilman, D. 1981. Effects of cattle grazing, sheep grazing, cutting and sward height on a grass-white clover sward. *Journal of Agricultural Science, Cambridge* 97: 699-706.

Brookes, I.M. 1982. An assessment of protein intake as a likely factor in the limitation of milk production by dairy cows grazing pasture. *In*: Dairy Production from Pasture, K.L. Macmillan and V.K. Taufa (eds). New Zealand Society of Animal Production, Hamilton, pp 211-212.

Brookes, I.M. and Holmes, C.W. 1985. The effect of a plant growth regulator (Mefluidide) on pasture growth and milk production. *Proceedings of the New Zealand Grassland Association* 46: 83-87.

Brookes, I.M. and Holmes, C.W. 1986. The effects of herbage allowance on dry matter intake and milk production of cows grazing Matua prairie grass swards. *Massey University Farm Series*, Publication No. 3, pp 11-17.

Broster, W.H. 1972. Effect on milk yield of the cow of the level of feeding during lactation. *Dairy Science Abstracts* 34: 265-288.

Broster, W.H. 1976. Plane of nutrition for the dairy cow. *In*: Principles of Cattle Production, H. Swan and W.H. Broster (eds). Butterworths, London, pp 271-285.

Broster, W.H. and Broster, V.J. 1984. Reviews of the progress of dairy science: Long term effects of the plane of nutrition on the performance of the dairy cow. *Journal of Dairy Research* 51: 149-196.

Broster, W.H. and Thomas, C. 1981. The influence of level and pattern of concentrate input on milk output. *In*: Recent Advances in Animal Nutrition, W. Haresign (ed). Butterworths, London, pp 49-69.

Brougham, R.W. 1955. A study of the rate of pasture growth. *Australian Journal of Agricultural Research* 6: 804-812.

Brougham, R.W. 1956. Effect of intensity of defoliation on regrowth of pasture. *Australian Journal of Agricultural Research* 7: 377-387.

Brougham, R.W. 1959a. The effects of season and weather on the growth rate of ryegrass and clover pasture. *New Zealand Journal of Agricultural Research* 2: 283-296.

Brougham, R.W. 1959b. The effects of frequency and intensity of grazing on the productivity of a pasture of short-rotation ryegrass and red and white clover. *New Zealand Journal of Agricultural Research* 2: 1232-1248.

Brougham, R.W. 1960. The effects of frequent grazing at different times of the year on the productivity and species yield of a grass-clover pasture. *New Zealand Journal of Agricultural Research* 3: 125-136.

Brougham, R.W. 1961. Some factors affecting the persistency of short rotation ryegrass. *New Zealand Journal of Agricultural Research* 4: 516-522.

Brougham, R.W. 1970. Frequency and intensity of grazing and their effects on pasture production. *Proceedings of the New Zealand Grassland Association* 32: 137-144.

Brougham, R.W. and Chu, A.C.P. 1987. Strategies for pastoral production. *Proceedings of the 4th Animal Science Congress, Asian-Australasian Association of Animal Production*

Societies, Hamilton, pp 1-4.

Brown, K.R. and Evans, P.S. 1973. A review of the work of the late D.B. Edmond. *New Zealand Journal of Experimental Agriculture* 1: 217-226.

Bryant, A.M. 1978. Dairy cattle management: Summer supplementary feeding. *Proceedings of the Ruakura Farmers' Conference, Hamilton* 30: 121-129.

Bryant, A.M. 1980. Effect of herbage allowance on dairy cow performance. *Proceedings of the New Zealand Society of Animal Production* 40: 50-58.

Bryant, A.M. 1981a. Maximising milk production from pastures. *Proceedings New Zealand Grassland Association* 42: 82-91.

Bryant, A.M. 1981b. The efficiency of cows differing in breeding index. *Proceedings of the Ruakura Farmers' Conference, Hamilton* 33: 145-149.

Bryant, A.M. 1982a. Autumn-winter management and dairy cow performance. *Massey Dairyfarming Annual* 34: 24-32.

Bryant, A.M. 1982b. Effects of mowing before and after grazing on milk production, *In*: Dairy Production from Pasture, K.L. Macmillan and V.K. Taufa (eds). New Zealand Society of Animal Production, Hamilton, pp 381-382.

Bryant, A.M. 1983. The effect of breeding index on the performance of non-lactating Jersey Cattle. *Proceedings of the New Zealand Society of Animal Production* 43: 63-66.

Bryant, A.M. 1984. Feed management practices at Ruakura. *Proceedings of the Ruakura Farmers' Conference, Hamilton* 36: 20-24.

Bryant, A.M. 1989. Altering the seasonality of milk production. *Proceedings of the Ruakura Farmers' Conference, Hamilton* 41: 60-65.

Bryant, A.M. 1990a. Present and future grazing systems. *Proceedings of the New Zealand Society of Animal Production* 50: 35-38.

Bryant, A.M. 1990b. Optimum stocking and feed management practices. *Proceedings of the Ruakura Farmers' Conference, Hamilton* 42: 55-59.

Bryant, A.M. and Cook, M.A.S. 1980. A comparison of three systems of wintering dairy cattle. *Proceedings of the Ruakura Farmers' Conference, Hamilton* 32: 181-187.

Bryant, A.M. and Holmes, C.W. 1985. Utilisation of pasture on dairy farms. *In*: The Challenge - Efficient Dairy Production, T.I. Phillips (ed). The Australian Society of Animal Production, Albury-Wodonga, pp 48-63.

Bryant, A.M. and L'Huillier, P.J. 1986. Better use of pasture. *Proceedings of the Ruakura Farmers' Conference, Hamilton* 38: 43-51.

Bryant, A.M. and MacDonald, K.A. 1983. Relationships between amount of feed on the farm, autumn-winter grazing management and dairy cow performance. *Proceedings of the New Zealand Society of Animal Production* 43: 93-95.

Bryant, A.M., MacDonald, R.A. and Clayton, D.G. 1982. Effects of nitrogen fertilizer on production of milk solids from grazed pasture. *Proceedings of the New Zealand Grassland Association* 73: 58-63.

Bryant, A.M., Paul, K.J. and Scott, D.W.C. 1988. The new milk payment system. *Proceedings of* *the Ruakura Farmers' Conference, Hamilton* 40: 1-7.

Bryant, A.M. and Sheath, G.W. 1987. The importance of grazing management to animal production in New Zealand. *Proceedings of the 4th Asian-Australasian Animal Science Congress, Hamilton*, pp 13-17.

Bryant, A.M. and Trigg, T.E. 1979. Immediate and longer term response of dairy cows to level of nutrition in early lactation. *Proceedings of the New Zealand Society of Animal Production* 39: 139-147.

Bryant, A.M. and Trigg, T.E. 1981. Progress report on the performance of Jersey cows differing in breeding index. *Proceedings of the New Zealand Society of Animal Production* 41: 39-47.

Bryant, A.M. and Trigg, T.E. 1982. The nutrition of the grazing dairy cow during early lactation. *In*: Dairy Production from Pasture, K.L. Macmillan and V.K. Taufa (eds). New Zealand Society of Animal Production, Hamilton, pp 185-207.

Bryant, E. and Gillings, D. 1985. Statistical analysis of longtudinal repeated measures designs. *In*: Biostatistics: Statistics in Biomedical Public Health, and Environmental Sciences, P.K. Sen (ed). Elsevier Scientific Publishers, Amsterdam.

Bryant, H.T. and Blaser, R.E. 1961. Yields and stands of orchardgrass compared under clipping and grazing intensities. *Agronomy Journal* 53: 91-11.

Burgess, R.E., Cosgrove, G., Fraser, T.J., Belgrave, B.R., Hare, M.D. and Charlton, J.F.L. 1986. Grasslands Matura Prairie Grass. Special Publication No. 5, Grasslands Division, DSIR, Palmerston North. 35 pp.

Burlison, A.J. and Hodgson, J. 1985. The influence of sward structure on the mechanics of the grazing process in sheep. *Animal Production* 40: 530-531.

Burlison, A.J., Hodgson, J. and Illius, A.W. 1991. Sward canopy structure and bite dimensions and bite weight of grazing sheep. *Grass and Forage Science* 46: 29-38.

Butler, B.M. 1986. *The effect of grazing intensity and frequency during spring and early summer on the sward characteristics of a ryegrass-white clover pasture.* M.Agric.Sc. Thesis, Massey University.

Butler, B.M., Chu, A.C.P., Matthews, P.N.P. and Korte, C.J. 1985. Effects of spring grazing management on herbage mass and sward characteristics in the ryegrass-white clover pasture. *Proceedings of the XV International Grassland Congress, Kyoto*, pp 1182-1184.

Butler, B.M., Hoogendoorn, C.J. and Richardson, M.A. 1987. The influence of leaf allowance on animal performance in late spring and summer. *Proceedings of the 4th Animal Science Congress of Asian and Australasian Association of Animal Production Societies, Hamilton*, pp 174.

Butris, G.Y. and Phillips, C.J.C. 1987. The effect of herbage surface water and the provision of supplementary forage on the intake and feeding behaviour of cattle. *Grass and Forage Science* 42: 259-264.

Caird, L. and Holmes, W. 1986. The prediction of voluntary intake of grazing cows. *Journal of Agricultural Science, Cambridge* 107: 43-54.

Campbell, A.G. 1969. Grazing interval, stocking rate and pasture production. *New Zealand Journal of Agricultural Research* 12: 67-74.

Campling, R.C. and Balch, C.C. 1961. Factors affecting the voluntary intake of food by cows. 1. Preliminary observations on the effect, on the voluntary intake of hay, of changes in the amount of reticulo-rumen contents. *British Journal of Nutrition* 15: 523-530.

Carton, O.T. and Brereton, A.J. 1982. The effects of grazing management on dry matter production and sward processes in a rotationally grazed sward. *Proceedings of the 9th General Meeting of the European Grassland Federation*, Reading. British Grassland Society Occasional Symposium No. 14, pp 149-153.

Chacon, E. and Stobbs, T.H. 1976. Influence of progressive defoliation of a grass sward on the eating behaviour of cattle. *Australian Journal of Agricultural Research* 27: 709-727.

Chamberlain, D.G., Martin, P.A. and Robertson, S. 1989. Optimizing compound feed use in dairy cows with high intakes of silage. *In*: Recent Advances in Animal Nutrition, W. Haresign and D.J.A. Cole (eds). Butterworths, London, pp 175-193.

Chambers, A.R.M., Hodgson, J. and Milne, J.A. 1981. The development and use of equipment for the automatic recording of ingestive behaviour in sheep and cattle. *Grass and Forage Science* 36: 97-105.

Chapman, D.F., Clark, D.A., Land, C.A. and Dymock, N. 1983. Leaf and tiller growth of *Lolium perenne* and *Agrostis* spp. and leaf appearance rates of *Trifolium repens* set-stocked and rotationally grazed pastures. *New Zealand Journal of Agricultural Research* 26: 159-168.

Charles, A.H. 1979. Treading as a factor in sward deterioration. *In*: Changes in sward composition and productivity, A.H. Charles and R.J. Haggar (eds). British Grassland Society, Occasional Symposium No. 10, pp 137-140.

Christian, K.R. 1987. Matching pasture production and animal requirements. *In*: Temperate Pastures, J.L. Wheeler, C.J. Pearson and G.E. Robards (eds). Australian Wool Corporation/CSIRO, pp 463-476.

Chu, A.C.P., McPherson, H.G. and Halligan, G. 1979. Recovery of growth following water deficits of different duration in prairie grasss. *Australian Journal of Plant Physiology* 6: 255-263.

Clark, D.A. and Brougham R.W. 1979. Feed intake of grazing Friesian bulls. *Proceedings New Zealand Society of Animal Production* 39: 265-274.

Clark, J.H. 1975. Lactational responses to postruminal administration of proteins and amino acids. *Journal of Dairy Science* 58: 1178-1197.

Clark, P. 1985. Matua prairie grass establishment. *Proceedings of the New Zealand Grassland Association* 46: 147-149.

Cochran, W.G. and Cox, G.M. 1957. *Experimental Designs*. 2nd Edition. Wiley, New York.

Collins, H.A. 1989. *Single and mixed grazing of cattle, sheep and goats*. Ph.D. Thesis, University of Canterbury, New Zealand.

Combellas, J., Baker, R.D. and Hodgson, J. 1979. Concentrate supplementation and the herbage intake and milk production of heifers grazing *Cenchrus ciliaris* . *Grass and Forage Science* 34: 303-310.

Combellas, J. and Hodgson, J. 1979. Herbage intake and milk production by grazing dairy cows. 1. The effects of variation in herbage mass and daily herbage allowance in a short-term trial. *Grass and Forage Science* 34: 209-214.

Conrad, H.R., Pratt, A.D. and Hibbs, J.W. 1964. Regulation of feed intake in dairy cows. 1. Change in importance of physical and physiological factors with increasing digestibility. *Journal of Dairy Science* 47: 54-62.

Corbett, J.L., Langlands, J.P., McDonald, I. and Pullar, J.D. 1966. Comparison by direct animal calorimetry of the net energy values of an early and late season growth of herbage. *Animal Production* 8: 13-27.

Corbett, J.L., Langlands, J.P., and Reid, G.W. 1963. Effects of season of growth and digestibility of herbage on intake by grazing dairy cows. *Animal Production* 5: 119-129.

Cosgrove, G.P. 1986. 'Grassland Matua': will it put you in clover? *Massey Dairyfarming Annual* 38: 196-198.

Cosgrove, G.P. and Brougham, R.W. 1985. Grazing management influences on seasonality and performance of ryegrass and red clover in a mixture. *Proceedings of the New Zealand Grassland Association* 46: 71-76.

Cosgrove, G.P. and Brougham, R.W. 1988. Pasture strategies for dairy beef production. *Proceedings of the New Zealand Grassland Association* 49: 57-62.

Cowie, J.D., Kear, B.S. and Orbell, G.E. 1972. Soil map of Kairanga County, North Island, New Zealand. New Zealand Soil Bureaux Map 102.

Cruickshank, G.J. 1986. *Nutritional constraints to lamb growth at pasture.* Ph.D. Thesis, University of Canterbury, New Zealand.

Cruickshank, G.P., Poppi, D.P. and Sykes, A.R. 1985. Intake and duodenal protein flow in early weaned lambs grazing white clover, luceme, ryegrass and prairie grass. *Proceedings of the New Zealand Society of Animal Production* 45: 113-116.

Crush, J.R., Evans, J.P.M. and Cosgrove, G.P. 1989. Chemical composition of ryegrass (*Lolium perenne* L.) and prairie grass (*Bromus willdenowwi* Kunth) pastures. *New Zealand Journal of Agricultural Research* 32: 761-768.

Curll, M.L. 1982. The grass and clover content of pastures grazed by sheep. *Herbage Abstracts* 52: 403-411.

Curll, M.L. and Wilkins, R.J. 1983. The comparative effects of defoliation, treading and excreta on a *Lolium perenne-Trifolium repens* pasture grazed by sheep. *Journal of Agricultural Science, Cambridge* 100: 451-460.

Curran, M.K. and Holmes, W. 1970. Prediction of the voluntary intake of food by dairy cows. 2. Lactating grazing cows. *Animal Production* 12: 213-224.

Davey, A.W.F., Grainger, C., Mackenzie, D.D.S., Flux, D.S., Wilson, G.F., Brookes, I.M. and Holmes, C.W. 1983. Nutritional and physiological studies of differences between Friesian cows of high and low genetic merit. *Proceedings of the New Zealand Society of Animal Production* 43: 67-70.

Davidson, A.I. and Robson, M.J. 1984. The effect of temperature and nitrogen supply on the physiology of grass/clover swards. *In*: Forage Legumes. British Grassland Society Occasional Symposium No. 16, pp 56-60.

Davies, A. 1974. Leaf tissue remaining after cutting and regrowth in perennial ryegrass. *Journal of Agricultural Science, Cambridge* 82: 165-172.

Davies, A. 1977. Structure of the grass sward. *Proceedings of the International Meeting on*

Animal Production from Temperate Grassland; B. Gilsenam (ed). Irish Grassland and Animal Production Association, Dublin, pp 36-44.

Davies, A. 1981. Tissue turnover in the sward. *In*: Sward measurement handbook, J. Hodgson, R.D. Baker, A Davies, A.S. Laidlaw and J.D. Leaver (eds). British Grassland Society, Hurley, pp 179-208.

Davies, A. 1988. The regrowth of grass swards. *In*: The Grass Crop, M.B. Jones and A. Lazenby (eds). Chapman and Hall Limited, London, pp 85-117.

Davies, A., Evans, M.E. and Sant, F.I. 1981. Changes in origin, type and rate of production of ryegrass tillers in the post-flowering period in relation to seasonal growth. *In*: Plant Physiology and Herbage Production, C.E. Wright (ed). British Grassland Society Occasional Publication No. 13, pp 73-76.

Davies, A. and Simons, R.G. 1979. Effect of autumn cutting regime on developmental morphology and spring growth of perennial ryegrass. *Journal of Agricultural Science, Cambridge* 92: 457-469.

Davies, I. 1969. The influence of management on tiller development and herbage growth. Welsh Plant Breeding Station, Abersywyth, Technical Bulletin No. 3.

Davies, I. 1976. Developmental characteristics of grass varieties in relation to their herbage production. 2. Spring defoliation of *Dactylis glomerata*: the fate of reproductive tillers which are cut, but whose stem apex is retained. *Journal of Agricultural Sciece, Cambridge* 87: 33-38.

Dawson, J. 1989. Winter milk: The rationale and opportunities. *Proceedings of the Ruakura Farmers' Conference, Hamilton*, 41: 66-68.

Dawson, K.P., Jewiss, O.R. and Morrison, J. 1983. The effects of strategic application of nitrogen on the improvement of seasonal ryegrass swards and its interaction with available water. *In*: Efficient Grassland Farming, A.J. Corrall (ed). British Grassland Society Occasional Publication No. 14, pp 171-174.

Deinum, B. and Dirven, J.G.P. 1975. Climate, nitrogen and grass. 6. Comparison of yield and chemical composition of some temperate and tropical grass species grown at different temperatures. *Netherlands Journal of Agricultural Science* 23: 69-82.

De Jong, A. 1986. The role of metabolites and hormones in the control of feed intake in ruminants. *In*: Control of digestion and metabolism in ruminants, L.P. Milligan, W.L. Grovum and A. Dobson (eds). Prentice-Hall, New Jersey, pp 560-578.

Della-Fera, M.A. and Baile, C.A. 1985. Central nervous system cholecystokinin and the control of feeding behaviour in sheep. *Progress in Clinical and Biological Research* 192: 115-122.

Department of Statistics, New Zealand. 1990a. Agriculture Statistics, 1989. 63 pp.

Department of Statistics, New Zealand. 1990b. New Zealand Official Yearbook, 94th Edition, Wellington. 707 pp.

Dowman, M.G. and Collins, F.C. 1982. The use of enzymes to predict the digestibility of animal feeds. *Journal of the Science of Food and Agriculture* 33: 689-696.

Dove, H., Foot, J.Z. and Freer, M. 1989. Estimation of pasture intake in grazing ewes, using the alkanes of plant cuticular waxes. *Proceedings of the XVI International Grassland Congress, Nice,* pp. 1091-1092.

Dove, H., Milne, J.A. and Mayes, R.W. 1990. Comparison of herbage intakes estimated from *in vitro* or alkane-based digestibilities. *Proceedings of the New Zealand Society of Animal Production:* 50:457-459.

Dudzinski, M.L. and Arnold, G.W. 1973. Comparisons of diet of sheep and cattle grazing together on sown pastures on the southern tablelands of New South Wales by principal component analysis. *Australian Journal of Agricultural Research* 24: 899-912.

Earle, D.F. 1976. A guide to the scoring of dairy cow condition. *Journal of Agriculture, Victoria* 74: 228-231.

Earle, D.F., McGowan, A.A. 1979. Evaluation and calibration of an automated rising plate meter for estimating dry matter yield of pasture. *Australian Journal of Experimental Agriculture and Animal Husbandry* 19: 337-343.

Eccles, W.J., Matthew, C. and Chu, A.C.P. 1990. Response of Matua prairie grass and Ellett perennial ryegrass to excess soil moisture in sand, silt and clay soils. *Proceedings of the New Zealand Grassland Association* 51: 127-129.

Edmond, D.B. 1970. Effects of treading on pasture, using different animals and soils. *Proceedings of the XI International Grassland Congress, Surfers Paradise*, pp. 604-608.

Ernst, P., Le Du, Y.L.P. and Carlier, L. 1980. *In*: The Role of Nitrogen in Intensive Grassland Production, W.J. Prins and G.H. Arnold (eds). European Grassland Association International Symposium, Wageningen, Pudoc, pp 119-126.

Evans, L.T. 1964. Reproduction. *In*: Grasses and Grasslands, C. Barnard (ed). Macmillan & Co., London, pp 126-153.

Evans, P.S. 1971. Root growth of *Lolium perenne* L. 2. Effects of defoliation and shading. *New Zealand Journal of Agricultural Research* 14: 552-562.

Falloon, R.E. 1976. The effect of infection by *Ustilago bullata* on vegetative growth of *Bromus catharticus*. *New Zealand Journal of Agricultural Research* 14: 249-254.

Falloon, R.E. and Hume, D.E. 1988. Productivity and persistence of prairie grass (*Bromus willdenowii* Kunth). 1. Effects of the head smut fungus, *Ustilago bullata* Berk. *Grass and Forage Science* 43: 179-184.

Falloon, R.E. and Rolston, M.P. 1990. Productivity of prairie grass (*Bromus willdenowii* Kunth) affected by sowing date and the head smut fungus (*Ustilago bullata* Berk). *Grass and Forage Science* 45: 357-364.

Fleming, G.A. 1973. Mineral composition of herbage. *In*: Chemistry and Biochemistry of Herbage, C.W. Butler and R.W. Bailey (eds). Academic Press, London, Volume 1, pp 529-566.

Forbes, J.M. 1971. Physiological changes affecting voluntary food intake in ruminants. *Proceedings of the Nutrition Society* 30: 135-142.

Forbes, J.M. 1980. A model of the short term control of feeding in the ruminant: effects of changing animal or feed characteristics. *Appetite* 1: 21-41.

Forbes, J.M. 1986. *The Voluntary Feed Intake of Farm Animals*. Butterworths, London.

Forbes, J.M. 1988a. Prediction of voluntary intake by the dairy cow. *In*: Nutrition and Lactation in the Dairy Cow, P.C. Gamsworthy (ed). Butterworths, London, pp 294-312.

Forbes, J.M. 1988b. Metabolic aspects of the regulation of voluntary food intake and appetite. *Nutrition Research Reviews* 1: 145-168.

Forbes, T.D.A. 1982. *Ingestive behaviour and diet selection in sheep and cattle.* Ph.D. Thesis, Edinburgh University.

Forbes, T.D.A. and Hodgson, J. 1985. Comparative studies of the influence of sward conditions on the ingestive behaviour of cows and sheep. *Grass and Forage Science* 40: 69-77.

Frame, J. 1981. Herbage mass. *In*: Sward Measurement Handbook, J. Hodgson, R.D. Baker, A. Davies, A.S. Laidlaw, J.D. Leaver (eds). British Grasslands Society, pp 36-69.

Frame, J. and Newbould, P. 1984. Herbage production from grass/white clover swards. *In*: Forage Legumes. British Grassland Society Occasional Symposium No. 16, pp 15-35.

Francis, S.M. and Smetham, M.L. 1985. Pasture utilization and its effect on herbage quality. *Proceedings of the New Zealand Grassland Association* 46: 221-225.

Fraser, T.J. 1985. Role of Matua prairie grass in an all-grass system for prime lamb production. *Proceedings of the New Zealand Grassland Association* 46: 157-161.

Garwood, E.A. 1969. Seasonal tiller populations of grass and grass/clover swards with and without irrigation. *Journal of the British Grassland Society* 24: 333-334.

Gerring, J.C. and Young, P.W. 1961. The most critical feed period for the dairy herd. *New Zealand Journal of Agriculture* 103: 2-10.

Gherardi, S.G. and Black, J.L. 1989. Influence of post-rumen supply of nutrients on rumen digestion load and voluntary intake of roughage by sheep. *British Journal of Nutrition* 62: 589-599.

Gibb, M.J. and Ridout, M.S. 1986. The fitting of frequency distribution to height measurements on grazed swards. *Grass and Forage Science* 41: 247-250.

Gill, J.L. and Hafs, H.D. 1971. Analysis of repeated measurements of animals. *Journal of Animal Science* 33: 331-336.

Gill, M., Rook, A.J. and Thiago, L.R.S. 1988. Factors affecting the voluntary intake of roughages by the dairy cow. *In*: Nutrition and Lactation in the Dairy Cow, P.C. Garnsworthy (ed). Butterworths, London, pp 262-279.

Girdler, C.P., Thomas, P.C. and Chamberlain, D.G. 1988. Effect of rumen protected methionine and lysine on milk production from cows given grass silage diets. *Proceedings of the Nutrition Society* 47: 82A.

Glassey, C.B. 1980. *The effect of herbage allowance on the performance of lactating dairy cows.* M.Sc. Thesis, Massey University.

Glassey, C.B., Davey, A.W.F. and Holmes, C.W. 1980. The effect of herbage allowance on dry matter intake and milk production of dairy cows. *Proceedings of the New Zealand Society of Animal Production* 40: 59-63.

Goold, G.J. 1979. Effect of nitrogen and cutting interval on production of grass species swards in Northland, New Zealand. 1. Kikuyu-dominant swards. *New Zealand Journal of Experimental Agriculture* 7: 353-359.

Goold, G.J., Jagusch, K.T., Farquhar, P. and Maclean, K.S. 1982. The effect of mefluidide on pasture and animal performance. *Proceedings of the New Zealand Society of Animal*

Production 42: 169-171.

Goold, G.J., Thorn, E.R. and Prestidge, R.A. 1989. Pasture species for the future. *Proceedings of the Ruakura Farmers' Conference, Hamilton*, pp 57-59.

Gordon, F.J. 1974. A comparison of spring and autumn produced dried grass for milk production. *Journal of the British Grassland Society* 29: 113-119.

Grace, N.D. 1983. *The Mineral Requirements of Grazing Ruminants.* New Zealand Society of Animal Production, Occasional Publication No. 9.

Grainger, C. 1982. *Some effects of genotype on the conversion of pasture to milk by Friesian cows.* Ph.D. Thesis, Massey University.

Grainger, C., Davey, A.W.F. and Holmes, C.W. 1985. Performance of Friesian cows with high or low breeding index. *Animal Production* 40: 379-388.

Grainger, C., Holmes, C.W. and Moore, Y.F. 1985. Performance of Friesian cows with high or low breeding index. *Animal Production* 40: 389-400.

Grainger, C. and McGowan, A.A. 1982. The significance of pre-calving nutrition on the dairy cow. *In*: Dairy Production from Pasture, K.L. Macmillan and V.K. Taufa (eds). New Zealand Society of Animal Production, Hamilton, pp 134-171.

Grainger, C. and Wilhelms, G. 1979. Effect of duration and pattern of underfeeding in early lactation on milk production and reproduction of dairy cows. *Australian Journal of Experimental Agriculture and Animal Husbandry* 19: 395-401.

Grainger, C., Wilhelms, G. D. and McGowan, A.A. 1982. Effect of body condition at calving and level of feeding in early lactation on milk production of dairy cows. *Australian Journal of Experimental Agriculture and Animal Husbandry* 22: 9-17.

Grant, S.A., Barthram, G.T. and Torvell, L. 1981a. Components of regrowth in grazed and cut *Lolium perenne* swards. *Grass and Forage Science* 36: 155-168.

Grant, S.A., Barthram, G.T., Torvell, L., King, J. and Smith, H.K. 1983. Sward management, lamina turnover and tiller population density in continuously stocked *Lolium perenne*-dominated swards. *Grass and Forage Science* 39: 333-344.

Grant, S.A., Barthram, G.T., Torvell, L., King, J. and Elston, D.A. 1988. Comparison of herbage production under continuous stocking and intermittent grazing. *Grass and Forage Science* 43: 29-39.

Grant, S.A. and King, J. 1984. Grazing management and pasture production: the importance of sward morphological adaptations and canopy photosynthesis. *In*: Hill Farming Research Organisation Biennial Report 1982-1983, M.M. Alcock (ed). pp 119-129.

Grant, S.A., King, J., Barthram, G.T. and Torvell, L. 1981b. Responses of tiller populations to variation in grazing management in continuously stocked swards as affected by time of year. *In*: Plant Physiology and Herbage Production, C.E. Wright (ed). British Grassland Society Occasional Publication No. 13, pp 81-84.

Greer, G. and Chamberlain, J.E. 1986. *Economic evaluation of Matua prairie grass as a pasture species on Canterbury sheep farms.* Agricultural Economics Research Unit, Lincoln University, New Zealand, 44 pp.

Hacker, J.B. 1982. Selecting and breeding better quality grasses. *In*: Nutritional Limits to Animal Production from Pastures, J.B. Hacker (ed). Commonwealth Agricultural Bureaux, Farnham Royal, U.K., pp 305-326.

Hacker, J.B. and Minson, D.J. 1981. The digestibility of plant parts. *Herbage Abstracts* 51: 459-482.

Hancock, J. 1952. Grazing behaviour of identical twins in relation to pasture type, intake and production of dairy cattle. *Proceedings of the VI International Grassland Congress, Pennysylvania, Vol. 2* pp 1399-1407.

Hancock, J. 1954. Studies of grazing behaviour in relation to grassland management. 1. Variations in grazing habits of dairy cattle. *Journal of Agricultural Science, Cambridge* 44: 420-433.

Harris, A.J. and Chu, A.C.P. 1985. Limitations to production and choice of species in finishing pastures. *In*: Using Herbage Cultivars, R.E. Burgess and J.L. Brock (eds). Grassland Research and Practice Series No. 3, New Zealand Grassland Association, pp 53-56.

Harris, W. 1971. The effects of density, cutting height, and white clover (*Trifolium repens* L.) on the structure of a ryegrass (*Lolium* spp.) population. *Journal of Agricultural Science* 77: 385-395.

Harris, W. 1978. Defoliation as a determinant of the growth, persistence and composition of pasture. *In*: Plant Relations in Pastures, J.R. Wilson (ed). CSIRO, Melbourne, pp 67-85.

Hay, R.J.M. and Baxter, G.S. 1984. Spring management of pasture to increase summer white clover growth. *Proceedings of the Lincoln College Farmers' Conference* 34: 132-137.

Hendricksen, R. and Minson, D.J. 1980. The feed intake and grazing behaviour of cattle grazing a crop of *Lablab purpureus* cv. Rongai. *Journal of Agricultural Science, Cambridge* 95: 547-554.

Hill, M.J. and Kirby, A.C. 1985. Morphological variation in prairie grass. *Proceedings of the XV International Grassland Congress, Kyoto*, 179-181.

Hill, M.J. and Pearson, C.J. 1985. Primary growth and regrowth responses of temperate grasses to different temperatures and cutting frequencies. *Australian Journal of Agricultural Research* 36: 25-34.

Hinch, G.N., Thwaites, C.J. and Lynch, J.J.H. 1982. A note on the grazing behaviour of young bulls and steers. *Animal Production* 35: 289-291.

Hodgson, J. 1975. The influence of grazing pressure and stocking rate on herbage intake and animal performance. *In*: Pasture Utilization by the Grazing Animal, J. Hodgson and D.K. Jackson (eds). Occasional Symposium No. 8, British Grassland Society, pp 93-103.

Hodgson, J. 1977. Factors limiting herbage intake by the grazing animal. *In*: Proceedings of an International Meeting on Animal Production from Temperate Grassland, Dublin, B. Gilsenam (ed). Irish Grassland and Animal Production Association/An Foras Taluntais, pp 70-75.

Hodgson, J. 1979. Nomenclature and definitions in grazing studies. *Grass and Forage Science* 34: 11-18.

Hodgson, J. 1981. Variations in the surface characteristics of the sward and the short-term rate of herbage intake by calves and lambs. *Grass and Forage Science* 36: 49-57.

Hodgson, J. 1982. Influence of sward characteristics on diet selection and herbage intake by the grazing animal. *In*: Nutritional Limits to Animal Production from Pastures, J.B. Hacker (ed). Commonwealth Agricultural Bureaux, Farnham Royal, U.K., pp 153-166.

Hodgson, J. 1984. Sward conditions, herbage allowance and animal production: an evaluation of research results. *Proceedings of the New Zealand Society of Animal Production* 44: 99-104.

Hodgson, J. 1985a. The control of herbage intake in the grazing ruminant. *Proceedings of the Nutrition Society* 44: 339-346.

Hodgson, J. 1985b. The significance of sward characteristics in the management of temperate sown pastures. *Proceedings of the 15th International Grassland Congress, Kyoto*, pp 63-67.

Hodgson, J. 1986. Grazing behaviour and herbage intake. *In*: Grazing, J. Frame (ed). Occasional Symposium No. 19, British Grassland Society, pp 51-64.

Hodgson, J. 1989. Increases in milk production per cow and per hectare: Pasture production. *Massey Dairyfarming Annual* 41: 76-82.

Hodgson, J. 1990a. Plants for grazing. *Proceedings of the New Zealand Society of Animal Production* 50: 29-34.

Hodgson, J. 1990b. *Grazing Management: Science into Practice.* Longman Scientific and Technical, Essex. 203 pp.

Hodgson, J., Bircham, J.S., Grant, S.A. and King, J. 1981. The influence of cutting and grazing management on herbage growth and utilisation. *In*: Plant Physiology and Herbage Production, E. Wright (ed). British Grassland Society Occasional Symposium No. 13, pp 51-62.

Hodgson, J. and Jamieson, W.S. 1981. Variations in herbage mass and digestibility, and the grazing behaviour and herbage intake of adult cattle and weaned calves. *Grass and Forage Science* 36: 39-48

Hodgson, J. and Maxwell, T.J. 1981. Grazing Research and Grazing Management. *In*: Biennial Report - The Hill Farming Research Organisation, Edinburgh, 1979-81, R.G. Gunn (ed), pp 169-187.

Hodgson, J., Rodriquez Capriles, J.M. and Felon, J.S. 1977. The influence of sward characteristics on the herbage intake of grazing calves. *Journal of Agricultural Science, Cambridge* 89: 743-750.

Hodgson, J. and Wade, M.H. 1978. Grazing management and herbage production. *Proceedings of the British Grassland Society, Winter Meeting*, pp 1.1-1.12.

Hodgson, J. and Williamson, J.M. 1967. The relationship between liveweight and herbage intake in grazing cattle. *Animal Production* 9: 365-376.

Hoekestra, J.A. 1987. Design of milk production trials. *Livestock Production Science* 16: 373-384.

Hogan, J.P., Kenny, P.A. and Weston, R.H. 1987. Factors affecting the intake of feed by grazing animals. *In*: Temperate Pastures; their production, use and management, J.L. Wheeler, C.J. Pearson and G.E. Robards (eds). Australian Wool Corporation/CSIRO, pp 317-327.

Hoglund, J.H., Crush, J.R., Brock, J.D., Ball, R. and Carran, R.A. 1979. Nitrogen fixation in pasture. XII. General Discussion. *New Zealand Journal of Experimental Agriculture* 7: 45-51.

Holmes, C.W. 1974. The Massey grass meter. *Massey Dairyfarming Annual* 26: 26-30.

Holmes, C.W. 1982. The effect of fertilizer nitrogen on the production of pasture and milk on dairy farmlets. *Proceedings of the New Zealand Grassland Association* 43: 53-57.

Holmes, C.W. 1987a. Milk production from managed grasslands. *In*: Ecosystems of the World: 17B Managed Grasslands, Snaydon, R.W. (ed). Elsevier Science Publishers, Amsterdam, pp 101-112.

Holmes, C.W. 1987b. Pastures for dairy cows. *In*: Livestock Feeding on Pastures, A.M. Nicol (ed). New Zealand Society of Animal Production, Occasional Publication No. 10, Hamilton, pp 133-143.

Holmes, C.W. 1988. Genetic merit and efficiency of milk production by the dairy cow. *In*: Nutrition and Lactation in the Dairy Cow, P.C. Garnsworthy (ed). Butterworths, London, pp 195-215.

Holmes, C.W. 1990a. An analysis of costs and other factors which contribute to the international competitiveness of the New Zealand dairy industry: Introduction. *Massey Dairyfarming Annual* 42: 117-118.

Holmes, C.W. 1990b. Principles and practices of profitable dairy farming. *Proceedings of the Ruakura Farmers' Conference, Hamilton* 42: 60-67.

Holmes, C.W., Davey, A.W.F. and Grainger, C. 1981. The efficiency with which feed is utilized by the dairy cow. *Proceedings of the New Zealand Society of Animal Production* 41: 16-27.

Holmes, C.W., Grainger, C., Davey, A.W.F., Brookes, I.M., Ngarmsak, S. and Mitchell, K.D. 1987. Efficiency of milk production by Friesian cows of high or low breeding index. *Proceedings of the 4th Asian-Australasian Association of Animal Production Societies, Hamilton*, p 148.

Holmes, C.W. and Hoogendoorn, C. 1983. Some effects of grazing management in early lactation and of topping on the growth and quality of pastures. *Massey Dairyfarming Annual* 35: 36-43.

Holmes, C.W. and Hoogendoorn, C.J. 1985. Pasture quality and its effects on milk production. *Proceedings of the 16th Large Herd Conference, New Plymouth*, pp 21-23.

Holmes, C.W., Hoogendoorn, C.J., Ryan, M.P. and Chu, A.C.P. 1992. Some effects of herbage composition as influenced by previous grazing management, on milk production by cows grazing on ryegrass/white clover pastures. 1. Milk production in early spring: effects of different regrowth intervals during the preceding winter period. *Grass and Forage Science* 47: 309-315.

Holmes, C.W. and McClenaghan, R.J. 1979. The management of spring pasture: Grazing management and growth of pasture. *Massey Dairyfarming Annual* 31: 79-80.

Holmes, C.W. and McClenaghan, R.J. 1980. The effects of grazing management, including topping, on growth of pasture (1977-1979). *In*: Results of Some Studies on Dairy Production. Dairy Husbandry Department, Massey University, pp 1-10.

Holmes, C.W., McClenaghan, R.J., Auko, P. and Nottingham, R. 1979. The relation of pasture allowance to changes in body condition and weight of pregnant non-lactating cows. *Proceedings of the New Zealand Society of Animal Production* 39: 138.

Holmes, C.W. and Mcmillan, K.L. 1982. Nutritional management of the dairy herd grazing on pasture. *In*: Dairy Production from Pasture, K.L. Mcmillan and V.K. Taufa (eds). New Zealand Society of Animal Production, Ruakura, Hamilton, pp 244-274.

Holmes, C. and Parker, W. 1992. Stocking rate and its effects on dairy farm productivity. *Massey Dairyfarming Annual* 44: 4-15.

Holmes, C.W. and Wilson, G.F. 1984. *Milk Production from Pasture.* Butterworths, Wellington. 319 pp.

Holmes, J.C. and Lang, R.W. 1963. Effect of fertilizer nitrogen and herbage dry-matter content on herbage intake and digestibility in bullocks. *Animal Production* 5: 17-26.

Holmes, W. 1980. Grazing management. *In*: Grass - its Production and Utilization, W. Holmes (ed). Blackwell Scientific Publications, Oxford, pp 125-173.

Holmes, W. and Jones, J.G.W. 1964. The efficiency of utilization of fresh grass. *Proceedings of the Nutrition Society* 23: 88-89.

Hoogendoorn, C.J. 1986. *Studies on the effects of grazing regime on sward and dairy cow performance.* Ph.D. Thesis, Massey University.

Hoogendoom, C.J., Holmes, C.W. and Chu, A.C.P. 1988. Grazing management in spring and subsequent dairy cow performance. *Proceedings of the New Zealand Grassland Association* 49: 7-10.

Hoogendoom, C.J., Holmes, C.W. and Brookes, I.M. 1985. Effects of herbage quality on milk production. *In*: The Challenge - Efficient Dairy Production, T.I. Phillips (ed). Australian Society of Animal Production, Albury-Wodonga, pp 68-70.

Hoogendoom, C.J., Holmes, C.W. and Ryan, M.P. 1987. The influence of pasture regrowth in winter on sward characteristics and dairy cow performance in early spring. *Proceedings of the 4th Animal Science Congress of the Asian-Australasian Association of Animal Production Societies, Hamilton*, pp 143.

Hoogendoom, C.J., Holmes, C.W. and Chu, A.C.P. 1992. Some effects of herbage composition as influenced by previous grazing management, on milk production by cows grazing on ryegrass/white clover pastures. 2. Milk production in late spring/summer: effects of grazing intensity during the preceding spring period. *Grass and Forage Science* 47: 316-325.

Hopkins, A., Murray, P.J. and Patefield, W.M. 1989. A comparison of the herbage productivity of *Bromus willdenowii* cv. Grasslands Matua with four cultivars of *Lolium perenne* when grown in association with *Trifolium repens.* *Grass and Forage Science* 44: 31-39.

Hughes, T.P. 1983. Sward characteristics influencing intake. *In*: Lamb Growth, A.S. Familton (ed). Animal Industries Workshop, June-July 1983, Lincoln College, Canterbury, pp 65-78.

Hughes, T.P., Sykes, A.R., Poppi, D.R. and Hodgson, J. 1991. The influence of sward structure on peak bite force and bite weight in sheep. *Proceedings of the New Zealand Society of Animal Production* 51: 153-158.

Hume, D.E. 1990a. *Morphological and physiological studies of prairie grass.* Ph.D. Thesis. Agricultural University, Wageningen.

Hume, D.E. 1990b. Growth of prairie grass (*Bromus willdenowii* Kunth) and Westerwolds ryegrass (*Lolium multiflorum* Lam.) at Wageningen, The Netherlands. *Grass and Forage Science* 45: 403-411.

Hume, D.E. 1991a. Leaf and tiller production of prairie grass (*Bromus willdenowii* Kunth) and two ryegrass (*Lolium*) species. *Annals of Botany* 67: 111-121.

Hume, D.E. 1991b. Effect of cutting on production and tillering in prairie grass (*Bromus willdenowii* Kunth) compared with two ryegrass (*Lolium*) species. 1. Vegetative plants. *Annals of Botany* 67: 533-541.

Hume, D.E. 1991c. Effect of cutting on production and tillering in prairie grass (*Bromus willdenowii* Kunth) compared with two ryegrass (*Lolium*) species. 2. Reproductive plants. *Annals of Botany* 68: 1-11.

Hume, D.E. 1991d. Primary growth and quality characteristics of *Bromus willdenowii* and *Lolium multiflorum*. *Grass and Forage Science* 46: 313-324.

Hume, D.E. and Lucas, R.J. 1987. Effects of winter cutting management on growth and tiller numbers of six grass species. *New Zealand Journal of Experimental Agriculture* 15: 17-22.

Hunt, W.F. 1970. The influence of leaf death on the rate of accumulation of green herbage during pasture growth. *Journal of Applied Ecology* 7: 41-50.

Hunt, W.F. and Field, T.R.O. 1978. Growth characteristics of perennial ryegrass. *Proceedings of the New Zealand Grassland Association* 40: 104-113.

Hutton, J.B. 1961. Studies of the nutritive value of New Zealand dairy pastures. *I.* Seasonal changes in some chemical components of pasture. *New Zealand Journal of Agricultural Research* 4: 583-590.

Hutton, J.B. 1962. Studies of the nutritive value of New Zealand dairy pastures. *II.* Herbage intake and digestibility studies with dairy cattle. *New Zealand Journal of Agricultural Research* 5: 409-424.

Hutton, J.B. 1963. The effect of lactation on intake in the dairy cow. *Proceedings of the New Zealand Society of Animal Production* 23: 39-51.

Hutton, J.B., Jury, K.E. and Davies, E.B. 1965. Studies of the nutritive value of New Zealand dairy pastures. IV. The intake and utilisation of magnesium in pasture herbage by lactating dairy cattle. *New Zealand Journal of Agricultural Research* 8: 479-496.

Hutton, J.B., Jury, K.E. and Davies, E.B. 1967. Studies of the nutritive value of New Zealand dairy pastures. V. The intake and utilisation of potassium, sodium, calcium, phosphorus, and nitrogen in pasture herbage by lactating dairy cattle. *New Zealand Journal of Agricultural Research* 10: 367-288.

Jackson, D.K. 1974. Some aspects of production and persistency in relation to height of defoliation of *Lolium perenne* (Var. S23). *Proceedings of XII International Grassland Congress, Moscow*, III: 202-214.

Jagusch, K.T., Rattray, P.V., Winn, G.W. and Scott, M.E. 1979. Crops, legumes and pastures for finishing lamb. *Proceedings of the Ruakura Farmers' Conference* 31: 47-52.

Jamieson, W.S. and Hodgson, J. 1979a. The effect of daily herbage allowance and sward characteristics upon the ingestive behaviour and herbage intake of calves under strip-grazing management. *Grass and Forage Science* 34: 261-271.

Jamieson, W.S. and Hodgson, J. 1979b. The effects of variation in sward characteristics upon the ingestive behaviour and herbage intake of calves under a continuous stocking management. *Grass and Forage Science* 34: 273-282.

Jennings, P.G. and Holmes, W. 1983. The influence of the quality of concentrate supplement on the performance of high yielding dairy cows on continuously stocked pasture. *Animal Production* 36: 507.

Jennings, P.G. and Holmes, W. 1984. Supplementary feeding of dairy cows on continuously stocked pasture. *Journal of Agricultural Science, Cambridge* 103: 161-170.

Jennings, P.G. and Holmes, W. 1985. Supplementary feeding to dairy cows grazing tropical pasture: a review. *Tropical Agriculture* 62: 266-272.

Jewiss, O.R. 1966. Morphological and physiological aspects of growth of grasses during the vegetative phase. *In*: The Growth of Cereals and Grasses, F.L. Milthorpe and J.D. Ivins (eds). Butterworths, London, pp 39-55.

Jewiss, O.R. 1972. Tillering in grasses - its significance and control. *Journal of the British Grassland Society* 27: 65-82.

Jewiss, O.R. 1981. Shoot development and number. *In*: Sward Measurement Handbook, J. Hodgson, R.D. Baker, A. Davies, A.S. Laidlaw and J.D. Leaver (eds). British Grassland Society, pp 93-114.

John, A. and Ulyatt, M.J. 1987. Importance of dry matter content to voluntary intake of fresh grass forages. *Proceedings of the New Zealand Society of Animal Production* 47: 13-16.

Johnson, C.L. 1986. Plane of nutrition. *In*: Principles and Practice of Feeding Dairy Cows, W.H. Broster, R.H. Phipps and C.L. Johnson (eds). AFRC Institute of Food Research, Reading, Technical Bulletin, pp 25-43.

Johnson, I.R. and Parsons, A.J. 1985. Use of a model to analyse the effect of continuous grazing managements on seasonal patterns of grass production. *Grass and Forage Science* 40: 449-458.

Johnston, N. 1990. Winter milk production: Year-round or seasonal production? *Massey Dairyfarming Annual* 42: 56-58.

Jones, D.I.H. and Thomas, T.A. 1987. Minerals in pastures and supplements. *In*: Ecosystems of the World, 17B Managed Grasslands, R.W. Snaydon (ed). Elsevier, Amsterdam, pp 145-153.

Jones, D.I.H. and Wilson, A.D. 1987. Nutritive quality of forage. *In*: The Nutrition of Herbivores, J.B. Hacker and J.H. Ternouth (eds). Academic Press, Sydney, pp 65-89.

Judson, G.J., Caple, I.W., Langlands, J.P. and Peter, D.W. 1987. Mineral nutrition of grazing ruminants in Southern Australia. *In*: Temperate pastures; their production, use and management, J.L. Wheeler, C.J. Pearson and G.E. Robards (eds). Australian Wool Corporation/CSIRO, pp 377-385.

Kenny, P.A. and Black, J.L. 1984. Factors affecting diet selection by sheep. 1. Potential intake rate and acceptability of feed. *Australian Journal of Agricultural Research* 35: 551-563.

Kenny, P.A. and Black, J.L. 1986. Effect of simulated sward structure on the rate of intake of subterranean clover by sheep. *Proceedings of the Australian Society of Animal Production* 16: 251-254.

Kenny, P.A., Black, J.L. and Colebrook, W.F. 1984. Factors affecting diet selection by sheep. 3. Dry matter content and particle length of forage. *Australian Journal of Agricultural Research* 35: 831-838.

King, K.R. and Stockdale, C.R. 1980. The effects of stocking rate and nitrogen fertilizer on the productivity of irrigated perennial pasture grazed by dairy cows. *Australian Journal of Experimental Agriculture and Animal Husbandry* 20: 537-542.

King, K.R. and Stockdale, C.R. 1981. Hay supplements to overcome underfeeding of dairy cows. 2. Late lactation. *Australian Journal of Experimental Agriculture and Animal Husbandry* 21: 157-162.

King, K.R. and Stockdale, C.R. 1984. Effect of pasture type and grazing management in autumn on the performance of dairy cows in late lactation and on subsequent pasture productivity. *Australian Journal of Experimental Agriculture and Animal Husbandry* 24: 312-321.

Kolver, E.S. and Bryant, A.M. 1992. Changing milk composition by feeding. *Proceedings of the Ruakura Farmers' Conference* 44: 61-71.

Korte, C.J. 1981. *Studies of late spring grazing management in perennial ryegrass dominant pastures*. Ph.D. Thesis, Massey University.

Korte, C.J. 1982. Grazing management of perennial reygrass/white clover pasture in late spring. *Proceedings of the New Zealand Grassland Association* 43: 80-84.

Korte, C.J., Chu, A.C.P. and Field, T.R.O. 1987. Pasture production. *In*: Livestock Feeding on Pasture, A.M. Nicol (ed). New Zealand Society of Animal Production, Occasional Publication No. 10, pp 7-20.

Korte, C.J. and Harris, W. 1987. Effects of grazing and cutting. *In*: Ecosystems of the World; 17B Managed Grasslands, Elsevier Science Publishers, Amsterdam, pp 71-19.

Korte, C.J. and Parsons, A.J. 1984. Persistence of a large leaved white clover variety under sheep grazing. *Proceedings of the New Zealand Grassland Association* 45: 118-123.

Korte, C.J. and Sheath, G.W. 1979. Herbage dry matter production: The balance between growth and death. *Proceedings of the New Zealand Grassland Association* 40: 152-161.

Korte, C.J., Watkin, B.R. and Harris, W. 1982. Use of residual leaf area index and light interception as criteria for spring-grazing management of a ryegrass-dominant pasture. *New Zealand Journal of Agricultural Research* 27: 135-149.

Korte, C.J., Watkin, B.R. and Harris, W. 1984. Effects of the timing and intensity of spring grazings on reproductive development, tillering and herbage production of perennial ryegrass dominant pasture. *New Zealand Journal of Agricultural Research* 27: 135-149.

Kristensen, E.S. 1988. Influence of defoliation regime on herbage production and characteristics of intake by dairy cows as affected by grazing intensity. *Grass and Forage Science* 43: 239-251.

Lambert, M.G., Clark, D.A., Grant, D.A. and Costall, D.A. 1986. Influence of fertilizer and grazing management on North Island moist hill country. 2. Pasture botanical composition. *New Zealand Journal of Agricultural Research* 29: 1-10.

Lancashire, J.A. 1985a. Quality pasture production for the dairy industry. *In*: The Challenge: Efficient Dairy Production, T.I. Phillips (ed). Australian Society of Animal Production, Albury-Wodonga, pp 9-26.

Lancashire, J.A. 1985b. Some factors affecting the rate of adoption of new herbage cultivars. *In*: Using Herbage Cultivars, R.E. Burgess and J.L. Brock (eds). Grasslands Research and Practice Series No. 3, New Zealand Grassland Association, pp 79-87.

Lancashire, J.A. and Brock, J.L. 1983. Management of new cultivars for dryland. *Proceedings of the New Zealand Grassland Association* 44: 61-73.

Langer, R.H.M. 1963. Tillering in herbage grasses. *Herbage Abstracts* 33: 141-148.

Langer, R.H.M. 1977. Grass species and strains. *In*: Pastures and Pasture Plants, R.H.M. Langer (ed). A.H. & A.W. Reed, Wellington, pp 63-83.

Langer, R.H.M. 1990. *Pastures: Their Ecology and Management*. Oxford University Press, Auckland.

Langer, R.H.M. and Hill, G.D. 1982. *Agricultural Plants.* Cambridge University Press, U.K.

Laredo, M.A. and Minson, D.J. 1973. The voluntary intake, digestibility and retention time by sheep of leaf and stem fractions of five grasses. *Australian Journal of Agricultural Research* 24: 875-888.

Lauren, D.R., DiMenna, M.E., Greenhalgh, R., Miller, J.D., Neish, G.A. and Burgess, L.W. 1988. Toxin-producing potential of some *Fusarium* species from a New Zealand pasture. *New Zealand Journal of Agricultural Research* 31: 219-225.

Leafe, E.L., Stiles, W. and Dickinson, S.A. 1974. Physiological processes influencing the pattern of productivity of the intensively managed grass sward. *Proceedings of the XII International Grassland Congress, Moscow* 1: 442-457.

Leaver, J.D. 1975. Rearing of dairy cattle. 6. The effect of length of grazing rotation on animal and herbage production in a grazing system for calves and heifers. *Animal Production* 19: 157-164.

Leaver, J.D. 1976. Utilization of grassland by dairy cows. *In*: Principles of Cattle Production, H. Swan and W.H. Broster (eds). Butterworths, London, pp 307-327.

Leaver, J.D. 1982. *Herbage Intake Handbook.* British Grassland Society, Hurley.

Leaver, J.D. 1985. Milk production from grazed temperate grassland. *Journal of Dairy Research* 52: 313-344.

Leaver, J.D. 1986. Effects of supplements on herbage intake and performance. *In*: Grazing, J. Frame (ed). Occasional Publication No. 19, British Grassland Society, pp 79-88.

Leaver, J.D. 1987. The potential to increase production efficiency from animal-pasture systems. *Proceedings of the New Zealand Society of Animal Production* 47: 7-12.

Leaver, J.D. 1988. Levels and patterns of concentrate allocation to dairy cows. *In*: Nutrition and Lactation in the Dairy Cow, P.C. Garnsworthy (ed), Butterworths, London, pp 315-327.

Leaver, J.D. 1989. The incorporation of new techniques into cattle production systems in developed countries. *In*: New Techniques in Cattle Production, C.J.C Phillips (ed). Butterworths, London, pp 206-213.

Leaver, J.D. 1991. The role of fertilizer nitrogen in the 1990s'. *In*: Management Isssues for the Grassland Farmer in the 1990s, C.S. Mayne (ed). Occasional Symposium No. 25, British Grassland Society, Hurley, pp 140-147.

Leaver, J.D. and Fraser, D. 1989. A systems study of high and low concentrate inputs for dairy cows: grassland production and utilisation over four years. *Research and Development in Agriculture* 6: 183-189.

Le Du, Y.L.P., Baker, R.D. and Newberry, R.D. 1981. Herbage intake and milk production by grazing dairy cows. 3. The effect of grazing severity under continuous stocking. *Grass and Forage Science* 36: 307-318.

Le Du, Y.L.P., Combellas, J., Hodgson, J. and Baker, R.D. 1979. Herbage intake and milk production by grazing dairy cows. 2. The effects of level of winter feeding and daily herbage allowance. *Grass and Forage Science* 34: 249-260.

Le Du, Y.L.P. and Newberry, R.D. 1980. The milk production of grazing cows. *Grassland Research Institute Annual Report*, Hurley, pp 86-88.

L'Huillier, P.J. 1987a. Tiller appearance and death of *Lolium perenne* in mixed swards grazed by dairy cattle at two stocking rates. *New Zealand Journal of Agricultural Research* 30: 15-22.

L'Huillier, P.J. 1987b. Effect of dairy cattle stocking rate and degree of defoliation on herbage accumulation and quality in ryegrass-white clover pasture. *New Zealand Journal of Agricultural Research* 30: 149-157.

L'Huillier, P.J. 1987c. Spring grazing management: Effects on pasture composition and density and dairy cow performance. *Massey Dairyfarming Annual* 39: 63-69.

L'Huillier, P.J. 1988. Reduced input spring-summer pasture management options. *Proceedings of the 40th Ruakura Farmers' Conference, Hamilton*, pp 19-25.

L'Huillier, P.J., Poppi, D.P. and Fraser, T.J. 1986. Influence of sward structure and composition of ryegrass and prairie grass-white clover swards on the grazed horizons and diet harvested by sheep. *Grass and Forage Science* 41: 259-267.

L'Huillier, P.J. and Bryant, A.M. 1987. Influence of spring grazing management on pasture composition and density and dairy cow performance. *Proceedings of the 4th Animal Science Congress of the Asian-Australasian Association of Animal Production Societies, Hamilton*, p 141.

Ludlow, M.M., Stobbs, T.J., Davis, R. and Charles-Edwards, D.A. 1982. Effect of sward structure of two tropical grasses with contrasting canopies on light distribution, net photosynthesis and size of bite harvested by grazing cattle. *Australian Journal of Agricultural Research* 33: 187-201.

McCall, D.G., Smeaton, D.C., Gibbison, M.L., McKay, F.J. and Hockey, H.U.P. 1986. The influence of different sheep to cattle ratios on liveweight gain when grazing pastures to different levels in late spring-summer. *Proceedings of the New Zealand Society of Animal Production* 46: 121-128.

McCallum, D.A., Thomson, N.A. and Roberts, A.H.C. 1989. Grass grub tolerant pastures and fertilizer nitrogen as an alternative to white clover in pasture subject to grass grub attack. *Proceedings of the New Zealand Grasslands Association* 51: 105-108.

McCallum, R.L. 1987. Matua prairie grass under dairying. *Massey University Dairyfarming Annual* 39: 76-81.

McCaw, E. 1986. De-awning breakthrough. *Straight Furrow* 106(34): 9.

McClymont, G.L. 1967. Selectivity and intake in the grazing ruminant. *In*: Handbook of Physiology, Section 6: Alimentary Tract, Vol. 1. Control of Feed and Water Intake, C.F. Cude and H. Werner (eds). American Physiological Society, Washington DC, pp 11-36.

McCutcheon, S.N., Michel, A., Mackenzie, D.D.S. and Wilson, G.F. 1989. Improving efficiency in the dairy cow: future prospects. *Massey Dairyfarming Annual* 41: 82-95.

McDonald, P., Edwards, R.A. and Greenhalgh, J.F.D. 1988. *Animal Nutrition, 4th Edition.* Longman Scientific & Technical, Essex. 543 pp.

McDonald, R.C. 1986. Effect of topping pastures. 1. Pasture accumulation and quality. *New Zealand Journal of Experimental Agriculture* 14: 279-289.

McFeely, P.C., Browne, D. and Corty, O. 1975. Effect of grazing interval and stocking rate on milk production and pasture yield. *Irish Journal of Agricultural Research* 14: 309-319.

McGrath, D. 1986. Quality enhancement and yield suppression of Italian and perennial ryegrass with mefluidide. *Irish Journal of Agricultural Research* 25: 53-62.

McIvor, P.J. and Watkin, B.R. 1973. The pattern of defoliation of cocksfoot by grazing sheep. *Proceedings of the New Zealand Grassland Association* 34: 225-235.

McMeekan, C.P. 1956. Grazing management and animal production. *Proceedings of the VII International Grassland Congress, Palmerston North*, pp 146-155.

McMeekan, C.P. 1960. Grazing Management. *Proceedings of the VIII International Grassland Congress, Reading*, pp 21-26.

McMeekan, C.P. and Walshe, M.J. 1963. The interrelationships of grazing method and stocking rate in the efficiency of pasture utilisation by dairy cattle. *Journal of Agricultural Science* 61: 147-166.

McRae, J.C., Smith, J.S., Dewey, P.J.S., Brewer, A.C., Brown, D.S. and Walker, A. 1985. The efficiency of utilization of metabolizable energy and apparent absorption of amino acids in sheep given spring- and autumn-harvested dried grass. *British Journal of Nutrition* 54: 197-209.

McWilliam, J.R. 1978. Response of pasture plants to temperature. *In*: Plant Relations in Pastures, J.R. Wilson (ed). CSIRO, East Melbourne, pp 17-34.

Macmillan, K.J. 1979. Calving patterns and herd production in seasonal dairy herds. *Proceedings of the New Zealand Society of Animal Production* 39: 168-174.

Macmillan, K.L. and Bryant, A.M. 1980. Cow condition and its relation with production and reproduction. *Proceedings of the Ruakura Farmers' Conference* 32: 165-171.

Macmillan, K.L. 1990. Dairy herd management in 2000. *Proceedings of the Ruakura Farmers' Conference, Hamilton* 42: 77-82.

MAFF. 1975. Energy allowances and feeding systems for ruminants. Ministry of Agriculture, Food and Fisheries, Technical Bulletin 33, H.M.S.O., London.

Malechek, J.C. and Balph, D.F. 1987. Diet selection by grazing and browsing livestock. *In*: The Nutrition of Herbivores, J.B. Hacker and J.H. Ternouth (eds). Academic Press, Sydney, pp 121-132.

Mangan, J.L. 1982. The nitrogenous constituents of fresh forages. *In*: Forage Protein in Ruminant Animal Production, D.J. Thomson, D.E. Beever and R.G. Gunn (eds). British Society of Animal Production Occasional Publication No. 6, pp 25-40.

Marsh, R. 1975. A comparison between spring and autumn pasture for beef cattle at equal grazing pressure. *Journal of the British Grassland Society* 30: 165-170.

Matthew, C. 1990. Translocation from flowering to daughter tillers in perennial ryegrass (*Lolium perenne* L.). Internal Mimeograph, Department of Agronomy, Massey University. 12 pp.

Matthew, C., Xia, J.X., Chu, A.C.P., Macky, A.D. and Hodgson, J. 1991. Relationship between root production and tiller appearance rates in perennial ryegrass (*Lolium perenne* L.). *In*: Plant Root Growth: An Ecological Perspective, D. Atkinson (ed). British Ecological Society, Special Publication No. 10, pp 281-290.

Matthew, C., Black, C.K. and Buttler, B.M. Tiller dynamics of perennation in three herbage grasses. *Proceedings of the XVII International Grassland Congress, Palmerston North, 1993 (in press).*

Matthews, P.N.P. 1986. Matua prairie grass: changes in approach. Massey University Farms Series, Publication No. 3, pp 12-14.

Mayes, R.W., Lamb, C.S. and Colgrove, P.M. 1986. The use of dosed and herbage n-alkanes as markers for the determination of herbage intake. *Journal of Agricultural Science, Cambridge* 107: 161-170.

Mayne, C.S. 1991. Effects of supplementation on the performance of both growing and lactating cattle at pasture. *In*: Management Issues for the Grassland Farmer in the 1990s, C.S. Mayne (ed). Occasional Symposium No. 25, British Grassland Society, pp 55-71.

Mayne, C.S., Newberry, R.D. and Woodcock, S.C.F. 1988. The effects of a flexible management strategy and leader/follower grazing on the milk production of grazing dairy cows and on sward characteristics. *Grass and Forage Science* 43: 137-150.

Mayne, C.S., Newberry, R.D., Woodcock, S.C.F. and Wilkins, R.J. 1987. Effects of grazing severity on grass utilization and milk production of rotationally grazed dairy cows. *Grass and Forage Science* 42: 59-72.

Mayne, C.S. and Wright, I.A. 1988. Herbage intake and utilisation by the grazing dairy cow. *In*: Nutrition and Lactation in the Dairy Cow, P.C. Garnsworthy (ed). Butterworths, London, pp 280-293.

Meijs, J.A.C. 1981. *Herbage intake by grazing dairy cows.* Ph.D. Thesis, University of Wageningen, The Netherlands.

Meijs, J.A.C. 1983. Effect of herbage mass and allowance upon herbage intake by grazing dairy cows. *Proceedings of the XIV International Grassland Congress, Lexington*, pp 667-670.

Mepham, T.B. 1987. *Physiology of Lactation.* University of Nottingham, Open University Press.

Michell, P. and Fulkerson, W.J. 1985. Effect of level of utilization of pasture in spring on pasture composition in summer and on milk production in spring and summer. *In*: The Challenge: Efficient Dairy Production, T.I. Phillips (eds). Australian Society of Animal Production, Albury-Wodonga, pp 66-67.

Michell, P. and Fulkerson, W.J. 1987. Effect of grazing intensity in spring on pasture growth, composition and digestibility, and on milk production by dairy cows. *Australian Journal of Experimental Agriculture* 21: 35-40.

Milne, J.A., Hodgson, J., Thompson, R., Souter, W.G. and Barthram, G.T. 1982. The diet ingested by sheep grazing swards differing in white clover and perennial ryegrass content. *Grass and Forage Science* 37: 209-218.

Milne, J.D. 1991. Diet selection by grazing animals. *Proceedings of the Nutrition Society* 50: 77-85.

Minson, D.J. 1971. The digestibility and voluntary intake of six varieties of *Panicum*. *Australian Journal of Experimental Agriculture and Animal Husbandry* 11: 18-25.

Minson, D.J. 1972. The digestibility and voluntary intake by sheep of six tropical grasses. *Australian Journal of Experimental Agriculture and Animal Husbandry* 12: 21-27.

Minson, D.J. 1976. Nutritional significance of protein in temperate and tropical pastures. *In*: Reviews in Rural Science. 2. From Plant to Animal Protein, T.M. Sutherland, J.R. McWilliam and R.A. Leng (eds). University of New England, Armidale, pp 27-30.

Minson, D.J. 1981a. Nutritional differences between tropical and temperate pastures. *In*: Grazing Animals, World Animal Science B, F.H.N. Morley (ed). Elsevier Scientific, Amsterdam, pp 143-157.

Minson, D.J. 1981b. Forage quality: Assessing the plant-animal complex. *Proceedings of the XIV International Grassland Congress, Lexington*, pp 23-29.

Minson, D.J. 1981c. The effects of feeding protected and unprotected casein on the milk production of cows grazing ryegrass. *Journal of Agricultural Science, Cambridge* 96: 234-241.

Minson, D.J. 1982. Effects of chemical and physical composition of herbage eaten upon intake. *In*: Nutritional Limits to Animal Production from Pastures, J.B. Hacker (ed). Commonwealth Agricultural Bureaux, Farnham Royal, UK, pp 167-182.

Minson, D.J. 1987. Plant factors affecting intake. *In*: Ecosystems of the World; 17B: Managed Grasslands. Elsevier Science Publishers, Amsterdam, pp 137-144.

Mislevy, P., Washko, J.B. and Harrington, J.D. 1977. Influence of plant stage at initial harvest and height of regrowth at cutting on forage yield and quality of timothy and orchardgrass. *Agronomy Journal* 69: 353-356.

Mitchell, K.D. 1985. *Effects of underfeeding in early lactation on the yield and composition of milk produced by high and low breeding index cows.* M.Agr.Sc. Thesis, Massey University.

Mitchell, K.J. and Glenday, A.C. 1958. The tiller population of pastures. *New Zealand Journal of Agricultural Research* 1: 305-318.

Mitchell, R.J., Hodgson, J. and Clark, D.A. 1991. The effect of varying leafy sward height and bulk density on the ingestive behaviour of young deer and sheep. *Proceedings of the New Zealand Society of Animal Production* 51: 159-165.

Monteath, M.A., Johnstone, P.D. and Boswell, C.C. 1977. Effects of animals on pasture production. *New Zealand Journal of Agricultural Research* 20: 23-30.

Morrison, J. 1987. Grassland production: fertilizer-N, water and white clover. *In*: Nitrogen and

Water Use by Grassland, R.J. Wilkins (ed). IGAP, Hurley, pp 6-23.

Mott, G.O. 1981. Potential productivity of temperate and tropical grassland systems. *Proceedings of the XIV International Grassland Congress, Lexington*, pp 35-41.

Munro, J.M.M. and Walters, R.J.K. 1986. The feeding value of grass. *In*: Grazing, J. Frame (ed). Occasional Publication No. 19, British Grassland Society, Hurley, pp 65-78.

Mursan, A., Hughes, T.P., Nicol, A.M. and Sugiura, T. 1989. The influence of sward height on the mechanics of grazing in steers and bulls. *Proceedings of the New Zealand Society of Animal Production* 49: 233-236.

Mwebaze, S. 1986. *Factors affecting the regrowth of Matua prairie grass (Bromus willdenowii)*. DipAgrSc Thesis, Massey University.

New Zealand Dairy Board. 1989, 64th Livestock Improvement Report. Livestock Improvement Corporation, Hamilton.

New Zealand Dairy Board. 1990. Annual Report, Wellington.

Ngarmsak, S. 1984. *Production characteristics and responses to feeding by Friesian cows fat and thin at calving of high or low genetic merit*. M.Agr.Sc. Thesis, Massey University.

Nichol, A.M., Clarke, D.G., Munro, J. and Smith, M.C. 1976. The influence of stubble height on digestibility, intake and liveweight gain of beef steers. *Proceedings of the New Zealand Society of Animal Production* 36: 81-86.

Norton, B.W. 1982. Differences between species in forage quality. *In*: Nutritional Limits to Animal Production from Pastures, J.B. Hacker (ed). Commonwealth Agricultural Bureaux, Farnham Royal, UK, pp 89-110.

Ong, C.K., Marshall, C. and Sagar, G.R. 1978. The physiology of tiller death in grasses. 2. Causes of tiller death in a grass sward. *Journal of the British Grassland Society* 33: 205-211.

Ørskov, E.R. 1982. *Protein Nutrition in Ruminants*. Academic Press Inc. Ltd., London. 160 pp.

Osbourn, D.F. 1980. The feeding value of grass and grass products. *In*: Grass: Its Production and Utilization, W. Holmes (ed). Blackwells, London, pp 70-124.

Parker, W.J., McCutcheon, S.N. and Garrick, D.J. 1990. The suitability of chromium controlled release capsules for estimating herbage intakes of grazing ruminants. *Proceedings, Australian Association of Animal Breeding and Genetics,* 8: 367-370.

Parker, W.J., McCutcheon, S.N. and Wickam, G.A. 1991. Effect of administration and ruminal presence of chromic oxide controlled release capsules on herbage intake of sheep. *New Zealand Journal of Agricultural Research,* 34: 193-200.

Parneix, P. 1982. Performance of new forage species *Bromus willdenowii* (cv. Bellegarde) in Western France. *Herbage Abstracts* 52: 4221.

Parsons, A.J. and Johnson, I.R. 1986. The physiology of grass growth under grazing. *In*: Grazing; J. Frame (ed). British Grassland Society Occasional Symposium No. 19., pp 3-13.

Parsons, A.J., Johnson, I.R. and Williams, J.H.H. 1988. Leaf age structure and canopy photosynthesis in rotationally and continuously grazed swards. *Grass and Forage Science*

43: 1-14.

Parsons, A.J., Leafe, E.L., Collett, B. and Stiles, W. 1983a. The physiology of grass production under grazing. 1. Characteristics of leaf and canopy photosynthesis of continuously-grazed swards. *Journal of Applied Ecology* 20: 117-126.

Parsons, A.J., Leafe, E.L., Collett, B. and Stiles, W. 1983b. The physiology of grass production under grazing. 2. Photosynthesis, crop growth and animal intake of continuously-grazed swards. *Journal of Applied Ecology* 20: 127-139.

Parsons, A.J. and Penning, P.D. 1988. The effect of the duration of regrowth on photosynthesis, leaf death and the average rate of growth in a rotationally grazed sward. *Grass and Forage Science* 43: 15-27.

Parsons, A.J. and Robson, M.J. 1980. Seasonal changes in the physiology of S24 perennial ryegrass (*Lolium perenne* L.). 1. Response of leaf extension to temperature during the transition from vegetative to reproductive growth. *Annals of Botany* 46: 435-444.

Pawlus, M., Rudnicki, F. and Sadowska, B. 1988. Effect of cutting date on chemical composition of grass. *Herbage Abstracts* 58: 1279.

Pearce, G.R., Simpson, R.J., Ballard, R. and Stephenson, D. 1987. Feeding value of dead pasture grasses. *In*: Temperate Pastures, J.L. Wheeler, C.J. Pearson and G.E. Robards (eds). Australian Wool Corporation/CSIRO, pp 429-431.

Penning, P.D. 1986. Some effects of sward conditions on grazing behaviour and intake by sheep. *In*: Grazing Research at Northern Latitudes, O. Gudmundssen, (ed). Proceedings of the NATO Workshop, Huanneyre, Iceland, pp 219-226.

Penny, D. 1987. Matua under dairying. *Massey Dairyfarming Annual* 39: 82-85.

Phillips, C.J.C. 1989. New techniques in the nutrition of grazing cattle. *In*: New Techniques in Cattle Production, C.J.C. Phillips (ed). Butterworths, London, pp 106-120.

Phillips, C.J.C. and Leaver, J.D. 1985a. Offering supplementary forage to grazing dairy cows. 1. Offering hay to dairy cows at high and low stocking rates. *Grass and Forage Science* 40: 183-192.

Phillips, C.J.C. and Leaver, J.D. 1985b. Offering supplementary forage to grazing dairy cows. 2. Offering grass silage in early and late season. *Grass and Forage Science* 40: 193-199.

Phillips, C.J.C. and Leaver, J.D. 1986a. Seasonal and diurnal variation in the grazing behaviour of dairy cows. *In*: Grazing, J. Frame (ed). Occasional Publication No. 19, British Grassland Society, pp 98-104.

Phillips, C.J.C. and Leaver, J.D. 1986b. The effect of forage supplementation on the grazing behavour of dairy cows. *Applied Animal Behavioural Science* 16: 233-247.

Pinneiro, J. and Harris, W. 1978a. Performance of mixtures of ryegrass cultivars and prairie grass with red clover cultivars under two grazing frequencies. 1. Herbage production in the establishment year. *New Zealand Journal of Agricultural Research* 21: 82-92.

Pinneiro, J. and Harris, W. 1978b. Performance of mixtures of ryegrass cultivars and prairie grass with red clover cultivars under two grazing frequencies. 2. Shoot populations and natural reseeding of prairie grass. *New Zealand Journal of Agricultural Research* 21: 665-673.

Poppi, D.P. 1983. Nutritive value of herbage. *In*: Lamb Growth, Technical Handbook, A.S. Familton (ed). Lincoln College, Canterbury, New Zealand, pp 79-92.

Poppi, D.P. 1990. Manipulation of nutrient supply to animals at pasture - opportunities and consequences. *Proceedings of the 5th Asian and Australasian Society of Animal Science Congress, Taipei*, Vol. 1, pp 40-79.

Poppi, D.P., Hughes, T.P. and L'Huillier, P.J. 1987. Intake of pasture by grazing ruminants. *In*: Livestock Feeding on Pasture, A.M. Nicol (ed). New Zealand Society of Animal Production, Occasional Publication No. 10, pp 55-63.

Poppi, D.P., Minson, D.J. and Ternouth, J.H. 1980. Studies of cattle and sheep eating leaf and stem fractions of grasses. I. The voluntary intake, digestibility and retention time in the reticulo-rumen. *Australian Journal of Agricultural Research* 32: 99-108.

Poppi, D.P., Minson, D.J. and Ternouth, J.H. 1981a. Studies of cattle and sheep eating leaf and stem fractions of grasses. 2. Factors controlling the retention of feed in the reticulo-rumen. *Australian Journal of Agricultural Research* 32: 109-121

Poppi, D.P., Minson, D.J. and Ternouth, J.H. 1981b. Studies of cattle and sheep eating leaf and stem fractions of grasses. 3. The retention time in the rumen of large feed particles. *Australian Journal of Agricultural Research* 32: 123-137.

Radcliffe, J.E. and Baars, J.A. 1987. The productivity of temperate grasslands. *In*: Ecosystems of the World; 17B Managed Grasslands, R.W. Snaydon (ed). Elsevier Science Publishers, Amsterdam, pp 7-17.

Rattray, P.V. 1978. Effect of lambing date on production from breeding ewes and on pasture allowance and intake. *Proceedings of the New Zealand Grassland Society* 39: 98-107.

Rattray, P.V. and Clark, D.A. 1984. Factors affecting the intake of pasture. *New Zealand Agricultural Science* 18: 141-146.

Rattray, P.V. and Jagusch, K.T. 1978. Pasture allowance for the breeding ewe. *Proceedings of the New Zealand Society of Animal Production* 38: 121-126.

Rattray, P.V., Jagusch, K.T., Duganach, D.M., Maclean, K.S. and Lynch, R.J. 1982a. Influence of feeding post-lambing on ewe and lamb performance at grazing. *Proceedings of the New Zealand Society of Animal Production* 42: 179-182.

Rattray, P.V., Jagusch, K.T., Duganach, D.M., Maclean, K.S. and Lynch, R.J. 1982b. Influence of pasture allowance and mass during late pregnancy on ewe and lamb performance. *Proceedings of the New Zealand Grassland Association* 4: 223-229.

Rattray, P.V. and Joyce, J.P. 1974. Nutritive value of white clover and perennial ryegrass. 4. Utilization of dietary energy. *New Zealand Journal of Agricultural Research* 17: 401-406.

Raymond, W.F. 1969. The nutritive value of forage crops. *Advances in Agronomy* 21: 1-108.

Reardon, T.F. 1977. Effect of herbage per unit area and herbage allowance on dry matter intake by steers. *Proceedings of the New Zealand Society of Animal Production* 37: 58-61.

Reed, K.F.M. 1978. The effect of season of growth on the feeding value of pasture. *Journal of the British Grassland Society* 33: 227-234.

Reid, R.L. and Horvath, D.J. 1980. Soil chemistry and mineral problems in farm livestock: A review. *Animal Feed Science and Technology* 5: 95-167.

Reid, R.L. and Jung, G.A. 1982. Problems of animal production from temperate pastures. *In*: Nutritional Limits to Animal Production from Pastures, J.B. Hacker (Ed). Commonwealth Agricultural Bureaux, Farnham Royal, UK, pp 21-43.

Reid, T.C. 1986. Comparison of autumn/winter with spring pasture for growing beef cattle. *Proceedings of the New Zealand Society of Animal Production* 46: 145-147.

Reid, T.C. and Lauren, D.R. 1989. Effects of grazing pasture with fungicide on growth rates of grazing lambs in autumn and spring. *Proceedings of the New Zealand Society of Animal Production* 49: 245-248.

Reid, T.C., Sumner, R.M.W. and Wilson, L.D. 1988. Performance parameters in an autumn lambing ewe flock. *Proceedings of the New Zealand Society of Animal Production* 48: 91-94.

Ridler, B.J. 1985. Matua worth establishment cost. *New Zealand Farmer* 106(8): 12-14.

Ridler, B.J. 1986. Experience with Matua at No. 4 Dairy Farm. Prairie Grass. *Massey Farms Series No. 3*, Massey University, Palmerston North, pp 15-25.

Ridler, B.J., Stachurski, L.J. and Brookes, I.M. 1988. Incorporation of Matua prairie grass into grazing systems. *Proceedings of the New Zealand Grassland Association* 49: 181-184.

Roberts, A.H.C. and Thomson, N.A. 1989. Use of nitrogen fertilizer for intensive dairy production. *In:* Proceedings of a Workshop on Nitrogen in New Zealand Agriculture. Massey University Lime Research Centre, Occassional Report No. 3: 45-55.

Roberts, H.M. 1965. The effect of defoliation on the seed producing capacity of bred strains of grasses. 3. Varieties of perennial ryegrass, cocksfoot, meadow fescue and timothy. *Journal of the British Grassland Society* 20: 283-289.

Robertson, J.B. and Van Soest, P.J. 1981. The detergent system of analysis and its application to human foods. *In*: The Analysis of Dietary Fibre in Food (Basic and Clinical Nutrition, Vol. 3), W.P. James and O. Theander (eds). Mercel Dekker Inc., New York, pp 123-159.

Rogers, G.L., Bryant, A.M. and McLeay, L.M. 1979. Silage and dairy cow production. 3. Abomasal infusions of casein, methionine and glucose and milk yield and composition. *New Zealand Journal of Agricultural Research* 22: 533-541.

Rogers, G.L., Porter, R.H.D., Clarke, T. and Stewart, J.A. 1980. Effect of protected casein supplements on pasture intake, milk yield and composition in early lactation. *Australian Journal of Agricultural Research* 31: 1147-1152.

Roughan, P.G. and Holland, R. 1977. Predicting *in vivo* digestibilities of herbage by exhaustive enzymatic hydrolysis of cell walls. *Journal of the Science of Food and Agriculture* 28: 1057-1064.

Rumball, P.J. and Boyd, A.F. 1980. Comparison of ryegrass white clover pasture with and without paspalum and kikuyu grass. 2. Sheep production. *New Zealand Journal of Experimental Agriculture* 8: 21-26.

Rumball, W. 1967. Variation in prairie grass populations in New Zealand. *New Zealand Journal of Agricultural Research* 10: 357-366.

Rumball, W. 1974. 'Grasslands Matua' prairie grass (*Bromus catharticus* Vahl.). *New Zealand Journal of Experimental Agriculture* 2: 1-5.

Rumball, W., Butler, G.W. and Jackman, R.H. 1972. Variation in nitrogen and mineral composition in populations of prairie grass (*Bromus unioloides* H.B.K.). *New Zealand Journal of Agricultural Research* 15: 341-346.

Ryan, M.P. 1986. *A study of the effects of grazing management during winter on pasture quality in spring and milk production.* Dip.Agr.Sc. Thesis, Massey University.

Rys, G.T., Ritchie, I.M., Smith, R.G., Thomson, N.A., Crouchley, G. and Stiefel, W. 1978. The performance of 'Grasslands Matua' prairie grass in the Southern North Island. *Proceedings of the New Zealand Grassland Association* 40: 148-155.

SAS. 1985. SAS User's Guide: Statistics Version 5. SAS Institute Inc., Gary, North Carolina. 956 pp.

Santamaria, A. and McGowan, A.A. 1982. The effect of contrasting winter grazing management on current and consequent pasture production and quality. *In*: Dairy Production from Pasture, K.L. Macmillan and V.K. Taufa (eds). New Zealand and Australian Societies of Animal Production, pp 359-360.

Savage, G.P., Smetham, M.L. and Joe, W. 1985. Yield and nutritive quality of winter regrowth of Nui and Matua/white clover swards. *Proceedings of the Agronomy Society of New Zealand* 15: 127-130.

Schlepers, H. and Lantinga, E.A. 1985. Comparison of net pasture yield with continuous and rotational grazing at a high level of nitrogen fertilization. *Netherlands Journal of Agricultural Science* 33: 429-432.

Scott, J.D.J., Rattray, P.V. and Smeaton, D.C. 1976. Environmental factors associated with summer-autumn growth rates of cattle and sheep. *Proceedings of the New Zealand Society of Animal Production* 36: 103-119.

Sellars, M.D. 1988. Manawatu dairy farmers experiences with Matua prairie grass. *Proceedings of the New Zealand Grassland Association* 49: 185-186.

Sheath, G.W. and Bircham, J.S. 1983. Grazing management in hill country: Pasture production. *Proceedings of the Ruakura Farmers' Conference, Hamilton* 35: 41-45.

Sheath, G.W. and Boom, R.C. 1985. Effects of November-April grazing pressure on hill country pastures. 2. Pasture species composition. *New Zealand Journal of Experimental Agriculture* 13: 329-340.

Sheath, G.W. and Harris, A.J. 1985. Environmenal and management limitations of legume-based forage systems in New Zealand. *In*: Forage Legumes for Energy-Efficient Animal Production. United States Department of Agriculture, Agricultural Research Service, pp 110-115.

Sheath, G.W., Hay, R.J.M. and Giles, K.H. 1987. Managing pastures for grazing animals. *In*: Livestock Feeding on Pasture, A.M. Nicol (ed). New Zealand Society of Animal Production Occasional Publication No. 10, pp 65-74.

Simpson, R.J. and Culvenor, R.A. 1987. Photosynthesis, carbon partitioning and herbage yield. *In*: Temperate pastures: their production, use and management, J.L. Wheeler, C.J. Pearson, G.E. Robards (ed). Australia Wool Corporation/CSIRO, pp 103-118.

Smetham, M.L. 1975. The influence of herbage utilisation on pasture production and animal performance. *Proceedings of the New Zealand Grassland Association* 37: 91-103.

Smetham, M.L. 1977. Pasture legume species and strains. *In*: Pastures and Pasture Plants, R.H.M. Langer (ed). A.H. & A.W. Reed Limited, Wellington, pp 85-127.

Smith, N.E. 1988. Alteration of efficiency of milk production in dairy cows by manipulation of the diet. *In*: Nutrition and Lactation in the Dairy Cow, P.C. Garnsworthy (ed). Butterworths, London, pp 216-247.

Snaydon, R.W. 1981. The ecology of grazed pastures. *In*: Grazing Animals, Vol. 1. World Animal Science (B), F.H.W. Morley (ed). Elsevier Scientific Publishing Company, Amsterdam, pp 13-31.

Snaydon, R.W. 1987. The botanical composition of pastures. *In*: Ecosystems of the World; 17B Managed Grasslands, R.W. Snaydon (ed). Elsevier Science Publishers, Amsterdam, pp 81-87.

Sokal, R.R. and Rohlf, F.J. 1981. Biometry: The Principles and Practice of Statistics in Biological Research, 2nd Edition. W.H. Freeman and Company, San Fransisco.

Spedding, C.R.W., Large, R.V. and Kydd, D.D. 1966. Evaluation of herbage species by grazing animals. *Proceedings of the X International Grassland Congress, Helsinki*, pp 479-483.

Stakelum, G. 1986. Herbage intake of grazing dairy cows. 2. Herbage allowance, herbage mass and concentrate feeding on the intake of cows grazing primary spring grass. *Irish Journal of Agricultural Research* 25: 41-51.

Stakelum, G. and Dillon, P. 1991. Influence of sward structure and digestibility on the intake and performance of lactating and growing cattle. *In*: Management Isssues for the Grassland Farmer in the 1990s, C.S. Mayne (ed). Occasional Symposium No. 25, British Grassland Society, Hurley, pp 30-42.

Steel, R.G.D and Torrie, J.H. 1980. *Principles and Procedures of Statistics: A Biometrical Approach*. McGraw-Hill Book Company, New York.

Stehr, W. and Kirchgessner, M. 1976. The relationship between the intake of herbage grazed by dairy cows and its digestibility. *Animal Feed Science and Technology* 1: 53-60.

Stelly, M. 1972. General forward. *In*: Alfalfa Science and Technology, C.H. Hanson (ed). American Society of Agronomy, Madison, p vii.

Stevens, D.R and Hickey, M.J. 1989. Comparative performance of 'Grasslands Matua' prairie grass and 'Grasslands Nui' ryegrass under a hard, infrequent grazing management. *New Zealand Journal of Agricultural Research* 32: 17-22.

Stobbs, T.H. 1973a. The effect of plant structure on the intake of tropical pastures. 1. Variation in the bite size of grazing cattle. *Australian Journal of Agricultural Research* 24: 809-819.

Stobbs, T.H. 1973b. The effect of plant structure on the intake of tropical pastures. 2. Differences in sward structure, nutritive value and bite size of animals grazing *Setaria anceps* and *Chloris gayana* at various stages of growth. *Australian Journal of Agricultural Research* 24: 821-829.

Stobbs, T.H. 1975a. Factors limiting the nutritional value of grazed tropical pastures for beef and milk production. *Tropical Grasslands* 9: 141-150.

Stobbs, T.H. 1975b. The effect of plant structure on the intake of tropical pasture. 3. Influence of fertilizer nitrogen on the size of bite harvested by Jersey cows grazing *Setaria anceps* cv. Kazungula swards. *Australian Journal of Agricultural Research* 26: 997-1007.

Stockdale, C.R. 1985a. Influence of some sward characteristics on the consumption of irrigated pastures grazed by lactating dairy cattle. *Grass and Forage Science* 38: 31-39.

Stockdale, C.R. 1985b. Some factors affecting the consumption of irrigated pastures grazed by lactating dairy cows. *In*: The Challenge: Efficient Dairy Production, T.I. Phillips (ed). Australian Society of Animal Production, Albury-Wodonga, pp 71-72.

Stockdale, C.R. and King, K.R. 1980. The effects of stocking rate and nitrogen fertilizer on the production of irrigated pastures and grazing dairy cows. *Australian Journal of Experimental Agriculture and Animal Husbandry* 20: 529-536.

Stockdale, C.R. and King, K.R. 1982. Feeding hay to dairy cows in early lactation. *In*: Dairy Production from Pasture, K.L. Macmillan and V.K. Taufa (eds). New Zealand and Australian Societies of Animal Production, pp 215-216.

Stockdale, C.R. and King, K.R. 1983. A comparison of two techniques used to estimate the herbage intake of lactating dairy cows in a grazing experiment. *Journal of Agricultural Science* 100: 227-230.

Stockdale, C.R., King, K.R., Patterson, I.F. and Ryan, D.T. 1981. Hay supplements to overcome underfeeding in dairy cows. 1. Early Lactation. *Australian Journal of Experimental Agriculture and Animal Husbandry* 21: 148-156.

Stockdale, C.R., King, K.R. and Trigg, T.E. 1985. Nutritive value of subterranean clover for lactating dairy cows in Northern Victoria. *In*: The Challenge: Efficient Dairy Production, T.I. Phillips (ed). Australian Society of Animal Production, Albury-Wodonga, pp 75-76.

Stokoe, J. 1983. The design of experiments. *In*: Dairy Cattle Research Techniques, J.H. Ternouth (ed). Queensland Department of Primary Industries, Brisbane, pp 1-21.

Suckling, F.E.T. 1975. Pasture management trials on unploughable hill country at Te Awa. 3. Results for 1959-1969. *New Zealand Journal of Experimental Agriculture* 3: 351-435.

Sutton, J.D. and Morant, S.V. 1989. A review of the potential of nutrition to modify milk fat and protein. *Livestock Production Science* 23: 219-237.

Sykes, A.R. 1987. Endoparasites and herbivore nutrition. *In*: The Nutrition of Herbivores, J.B. Hacker and J.H. Ternouth (eds). Academic Press, Sydney, pp 211-232.

Tainton, N.M. 1974a. A comparison of different pasture rotations. *Proceedings of the New Zealand Grassland Association* 35(2): 204-210.

Tainton, N.M. 1974b. Effects of different grazing rotations on pasture production. *Journal of the British Grassland Society* 29: 191-202.

Tainton, N.M. 1981. Veld and Pasture Management in South Africa. Interprint (Pty) Ltd, Durban.

Tallowin, J.R.B. 1981. An interpretation of tiller number changes under grazing. *In*: Plant Physiology and Herbage Production, C.E. Wright (ed). British Grassland Society Occasional Publication No. 13, pp 77-80.

Tallowin, 1985. Herbage losses from tiller pulling in continuously grazed perennial ryegrass swards. *Grass and Forage Science* 40: 13-18.

Tamminga, S. 1986. Utilization of naturally occurring NPN compounds by ruminants. *Archives* *of Animal Nutrition* 36: 169-176.

Terry, R.A. and Tilley, J.M.A. 1964. The digestibility of the leaves and stems of perennial ryegrass, cocksfoot, timothy, tall fescue, lucerne and sainfoin as measured by an *in vitro* procedure. *Journal of the British Grassland Society* 19: 363-372.

Thom, E.R. and Prestidge, R.A. 1988. High performance pastures for high quality cows? *Proceedings of the Ruakura Farmers' Conference, Hamilton* 40: 13-18.

Thom, E.R., Prestidge, R.A. and van der Sijpp, S. 1989. Effects of pests and disease on prairie grass production and persistence under dairying in the Waikato Region of New Zealand. *In*: Proceedings of the 5th Australian Conference on Grassland Inverterbrate Ecology, P.P. Stahle (ed). University of Melbourne, pp 314-322.

Thom, E.R., Taylor, M.J. and Wildermoth, D.D. 1990. Effects of establishment method, seeding rate and soil fertility on the growth and persistence of a prairie grass pasture in the Waikato. *Proceedings of the New Zealand Grassland Association* 51: 79-84.

Thomas, C. and Chamberlain, D.G. 1990. Evaluation and prediction of the nutritive value of pastures and forages. *In*: Feedstuff Evaluation, J. Wiseman and D.J.A. Cole (eds). Butterworths, London, pp 319-335.

Thomas, C. and Rae, R.C. 1988. Concentrate supplementation of silage for dairy cows. *In*: Nutrition and Lactation in the Dairy Cow, P.C. Garnsworthy (ed). Butterworths, London, pp 327-354.

Thomas, H. 1980. Terminology and definitions in studies of grassland plants. *Grass and Forage Science* 35: 13-23.

Thomas, P.C. and Martin, P.A. 1988. The influence of nutrient balance on milk yield and composition. *In*: Nutrition and Lactation in the Dairy Cow, P.C. Garnsworthy (ed). Butterworths, London, pp 97-118.

Thomson, B.C., Cruickshank, G.J., Poppi, D.P. and Sykes, A.R. 1985. Diurnal patterns of rumen fill in grazing sheep. *Proceedings of the New Zealand Society of Animal Production* 45: 117-120.

Thomson, D.J. 1982. The nitrogen supplied by and the supplementation of fresh or grazed forage. *In*: Forage Protein in Ruminant Animal Production, D.J. Thomson, D.E. Beever and R.G. Gunn (eds). British Society of Animal Production Occasional Publication No. 6, pp 53-66.

Thomson, D.J. 1984. The nutritive value of white clover. *In*: Forage Legumes. British Grassland Society Occasional Symposium No. 16, pp 78-92.

Thomson, D.J., Beever, D.E., Haines, M.J., Cammell, S.B., Evans, R.T., Dhanoa, M.S. and Austin, A.R. 1984. Yield and composition of milk from Friesian cows grazing either perennial ryegrass or white clover in early lactation. *Journal of Dairy Research* 52: 17-31.

Thomson, N.A. 1988. Management for milkfat or protein, does it differ? *Proceedings of the New Zealand Society of Animal Production* 48: 225-229.

Thomson, N.A., Barnes, M.L. and Prestidge, R. 1991. The effect of cow age and management of winter liveweight gain, liveweight at calving and subsequent effects on dairy production in a seasonal supply herd. *Proceedings of the New Zealand Society of Animal Production* 51: 277-282.

Thomson, N.A., Lagan, J.F. and McCallum, D.A. 1984. Herbage allowance, pasture quality and milkfat production as affected by stocking rate and conservation policy. *Proceedings of the New Zealand Society of Animal Production* 44: 67-70.

Thomson, N.A., McCallum, R.W. and Prestidge, R.W. 1989. Is making hay or silage worth the effort? *Proceedings of the Ruakura Farmers' Conference, Hamilton* 41: 50-56.

Thornton, R.F. and Minson, D.J. 1973. The relationship between apparent retention time in the rumen, voluntary intake, and apparent digestibility of legume and grass diets in sheep. *Australian Joumal of Agricultural Research* 24: 889-898.

t'Mannetje, L. 1978. *Measurement of grassland vegetation and animal production.* Bulletin No. 54, Commonwealth Bureaux of Pastures and Field Crops, Farnham Royal.

Trigg, T.E., Jury, K.E., Bryant, A.M. and Parr, C.R. 1980. The energy metabolism of dairy cows underfed in early lacation. *In*: Energy Metabolism, L.E. Mount (ed). Butterworths, London, pp 345-349.

Troughton, A. 1957. The underground organs of herbage grasses. Bulletin No. 44, Commonwealth Bureau of Pastures and Field Crops, Hurley, Berkshire.

Ulyatt, M.J. 1970. Evaluation of pasture quality under New Zealand conditions. *Proceedings of the New Zealand Grassland Association* 32: 61-67.

Ulyatt, M.J. 1971. Studies on the causes of the differences in pasture quality between perennial ryegrass, short rotation ryegrass, and white clover. *New Zealand Journal of Agricultural Research* 14: 352-367.

Ulyatt, M.J. 1973. The feeding value of herbage. *In*: Chemistry and Biochemistry of Herbage Vol. 3., G.W. Butler and R.W. Bailey (eds). Academic Press, London, pp 131-178.

Ulyatt, M.J. 1981. The feeding value of temperate pastures. *In*: Grazing Animals, World Animal Science B, F.H.W. Morley (ed). Elsevier Scientific, Amsterdam, pp 125-141.

Ulyatt, M.J., Fennessy, P.F., Rattray, P.V. and Jagusch, K.T. 1984. The nutritive value of supplements. *In*: Supplementary Feeding, K.R. Drew and P.F. Fennessy (eds). New Zealand Society of Animal Production, Occasional Publication No. 7, 2nd edition, pp 157-184.

Ulyatt, M.J., Lancashire, J.A. and Jones, W.T. 1976. The nutritive value of legumes. *Proceedings of the New Zealand Grassland Association* 38: 107-118.

Underwood, E.J. 1981. The Mineral Nutrition of Livestock, 2nd Edition. Commonwealth Agricultural Bureaux, Farnham Royal. 180 pp.

Vadiveloo, J. and Holmes, W. 1979. Supplementary feeding of grazing beef cattle. *Grass and Forage Science* 34: 173-179.

Van Soest, P.J. 1967. Development of a comprehensive system of feed analysis and its application to forages. *Journal of Animal Science* 26: 119-128.

Van Soest, P.J. 1983. *Nutritional Ecology of the Ruminant.* O. & B. Books Inc., Corvallis, Oregon. 374 pp.

Vérité, R. and Journet, M. 1970. Influence de la teneur en ean et du la deshydratation de l'herbe sur sa valeur alimentaire pour less vaches laitieres. *Annales de Zootechnie* 19: 255-268.

Vickery, P.J. 1981. Pasture growth under grazing. *In*: Grazing Animals, World Animal Science B, F.H.W. Morley (ed). Elsevier Scientific, Amsterdam, pp 55-77.

Vine, D.A. 1983. Sward structure changes within a perennial ryegrass sward: leaf appearance and death. *Grass and Forage Science* 38: 231-242.

Wade, M.H. 1979. *The effect of severity of grazing by dairy cows given three levels of herbage allowance on the dynamics of leaves and tillers in swards of Lolium perenne.* M.Phil. Thesis, University of Reading.

Wade, M.H. and Le Du, Y.L.P. 1981. Influence of sward structure upon herbage intake of cattle grazing a perennial ryegrass sward. *Proceedings of the XIV International Grassland Congress*, Lexington, Kentucky, pp 525-528.

Waghorn, G.C. and Barry, T.N. 1987. Pasture as a nutrient source. *In*: Feeding Livestock on Pasture, A.M. Nicol (ed). Occasional Publication No. 10, New Zealand Society of Animal Production, pp 21-37.

Waghorn, G.C., John, A., Jones, W.T. and Shelton, I.D. 1987. Nutritive value of *Lotus corniculatus* L. containing low and medium concentrations of condensed tannins for sheep. *Proceedings of the New Zealand Society of Animal Production* 47: 25-30.

Wallace, L.R. 1959. Grazing management and dairy production. *Proceedings of the New Zealand Institute of Agricultural Science*, Wellington, pp 131-138

Walton, P.D. 1983. *Production and management of cultivated forages.* Reston Publishing Co., Reston, Virginia. 336 pp.

Ward, C.Y. and Blaser, R.E. 1961. Carbohydrate food reserves and leaf area in regrowth of orchardgrass. *Crop Science* 1: 366-370.

Watkin, B.R. and Clements, R.J. 1978. The effects of grazing animals on pastures. *In*: Plant Relations in Pastures, J.R. Wilson (ed). Proceedings of an International Symposium, CSIRO, Melbourne, pp 273-289.

Watson, D.J. 1947. Comparative physiological studies on the growth of field crops. 1. Variation in net assimilation rate and leaf area betwen species and varieties and within and between years. *Annals of Botany (London)* 11: 47-76.

Webby, R.W., Sheath, G.W. and Boom, C.J. 1990. Performance of new pasture cultivars in a hill country finishing system. *Proceedings of the New Zealand Grassland Association* 51: 151-156.

Weinmann, H. 1961. Total available carbohydrates in grasses and legumes. *Herbage Abstracts* 31: 255-261.

Weston, R.H. 1985. The regulation of feed intake in herbage-fed ruminants. *Proceedings of the Nutrition Society of Australia* 10: 55-62.

Weston, R.H. and Poppi, D.P. 1987. Comparative aspects of food intake. *In*: The Nutrition of Herbivores, J.B. Hacker and J.H. Ternouth (eds). Academic Press, Sydney, pp 133-161.

Wheeler, J.L. 1981. The role of forage in animal production in Australia. *In*: Forage Evaluation: Concepts and Techniques, J.L. Wheeler and R.D. Mochrie (eds). CSIRO, Melbourne, Australia, pp 21-36.

Wiepkema, P.R. 1971. Behavioural factors in the regulation of food intake. *Proceedings of the*

Nutrition Society 30: 142-149.

Wilkins, R.J. and Garwood, E.A. 1986. Effects of treading, poaching and fouling on grassland production and utilisation. *In*: Grazing, J. Frame (ed). British Grassland Society Occasional Symposium No. 19, pp 19-31.

Wilkins, R.J., Hutchinson, K.J., Wilson, R.F. and Harris, C.E. 1971. The voluntary intake of silage by sheep. 1. Interrelationships between silage composition and intake. *Journal of Agricultural Science, Cambridge* 77: 531-537.

Williams, O.B. 1981. Evolution of grazing systems. *In*: World Animal Science: Grazing Animals, F.H.W. Morley (ed). Elsevier Scientific Publishing Co., pp 1-12.

Williams, T.E. 1980. Herbage production: grasses and leguminous crops. *In*: Grass: Its Production and Utilization, W. Holmes (ed). Blackwell Scientific Publications, Oxford, pp 6-69.

Wilman, D., Droushiotis, D., Koocheki, A., Lwoga, A.B. and Shim, J.S. 1976a. The effect of interval between harvests and nitrogen application on the proportion and yield of crop fractions in four ryegrass varieties in the first harvest year. *Journal of Agricultural Science, Cambridge* 86: 189-203.

Wilman, D., Koocheki, A. and Lwoga, A.B. 1976b. The effect of interval between harvest and nitrogen application on the proportion and yield of crop fractions and on the digestibility and digestible yield and nitrogen content and yield of two perennial ryegrass varieties in the second harvest year. *Journal of Agricultural Science, Cambridge* 87: 59-74.

Wilman, D., Koocheki, A., Lwoga, A.B., Droushiotis, D. and Shim, J.S. 1976c. The effect of interval between harvests and nitrogen application on the numbers and weights of tillers and leaves in four ryegrass varieties. *Journal of Agricultural Science, Cambridge* 87: 45-57.

Wilman, D., Ojuederie, B.M. and Asare, E.D. 1976d. Italian ryegrass: 3. Growth up to 14 weeks; yields, proportions, digestibilities and nitrogen contents of crop fractions, and tiller populations. *Journal of the British Grassland Society* 31: 73-79.

Wilman, D. and Shrestha, S.K. 1985. Some effects of canopy height on perennial ryegrass and white clover in a field sward. *Journal of Agricultural Science, Cambridge* 105: 79-84.

Wilson, G.F. 1977. 'Grassland Matua' prairie ryegrass. *New Zealand Agricultural Science* 11: 47-48.

Wilson, G.F. 1978. Effect of water content of Tama ryegrass on voluntary intake of sheep. *New Zealand Journal of Experimental Agriculture* 6: 53-54.

Wilson, G.F. and Davey, A.W.F. 1982. The nutrition of the grazing cow: Mid and late lactation. *In*: Dairy Production from Pasture, K.L. Macmillan and V.K. Taufa (eds). New Zealand and Australian Societies of Animal Production, pp 219-235.

Wilson, G.F. and Dolby, R.M. 1967. Ryegrass varieties in relation to dairy cattle performance. 3. A comparison of the milk yield and composition from tetraploid and two diploid ryegrass varieties. *New Zealand Journal of Agricultural Research* 10: 415-424.

Wilson, G.F. and Grace, N. 1978. Pasture magnesium levels and milk production in dairy cows. *New Zealand Journal of Experimental Agriculture* 6: 267-269.

Wilson, G.F. and McDowall, I.H. 1966. Ryegrass varieties in relation to dairy cattle performance.

1. The influence of ryegrass varieties on milk yield and composition. *New Zealand Journal of Agricultural Research* 9: 1042-1052.

Woledge, J. 1977. The effects of shading and cutting treatments on the photosynthetic rate of ryegrass leaves. *Annals of Botany* 41: 1279-1286.

Woledge, J. 1978. The effects of shading during vegetative and reproductive growth on the photosynthetic capacity of leaves in a grass sward. *Annals of Botany* 42: 1085-1089.

Wolton, K.M. 1979. Dung and urine as agents of sward change. *In*: Changes in Sward Composition and Productivity, A.H. Charles and R.J. Haggar (eds). British Grassland Society Occasional Symposium No. 10, pp 131-135.

Wright, D.F. and Pringle, R.M. 1983. Stocking rate effects in dairying. *Proceedings of the New Zealand Society of Animal Production* 43: 97-100.

Wright, I.A. and Whyte, T.K. 1989. Effects of sward surface height on the performance of continuously stocked spring calving beef cows and their calves. *Grass and Forage Science* 44: 259-266.

Xia, J.X. 1991. *The effects of defoliation on tissue turnover and pasture production in perennial ryegrass, prairie grass and smooth bromegrass pasture.* Ph.D. Thesis, Massey University.

Xia, J.X., Hodgson, J., Matthew, C. and Chu, A.C.P. 1990. Tiller population and tissue turnover in perennial ryegrass pasture under hard and lax spring and summer grazing. *Proceedings of the New Zealand Grassland Association* 51: 119-122.

Yoda, K., Kira, T., Ogawa, H. and Hozumi, H. 1963. Self-thinning in overcrowded pure stands under cultivated and natural conditions. *Journal of the Institute of Polytechnics*, Osaka City University, Series D, 14: 107-129.

Young, B.A. 1987. The effect of climate upon intake. *In*: The Nutrition of Herbivores, J.B. Hacker and J.H. Ternouth (eds). Academic Press, Sydney, pp 163-190.