EVALUATION OF *LOTUS CORNICULATUS* FOR INCREASING THE EFFICIENCY OF GROWTH IN YOUNG DEER

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EVALUATION OF *LOTUS CORNICULATUS* FOR INCREASING THE EFFICIENCY OF GROWTH IN YOUNG DEER

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EMMANUEL KWADWO ADU

1997

To Theresa, my wife

and to Nhyira, my son

DECLARATION

The studies presented in this thesis were completed by the author whilst a postgraduate student in the Department of Animal Science, Massey University, Palmerston North, New Zealand. This is all my own work and the views presented are mine alone. Any assistance received is acknowledged in the thesis. All references cited are included in the bibliography.

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

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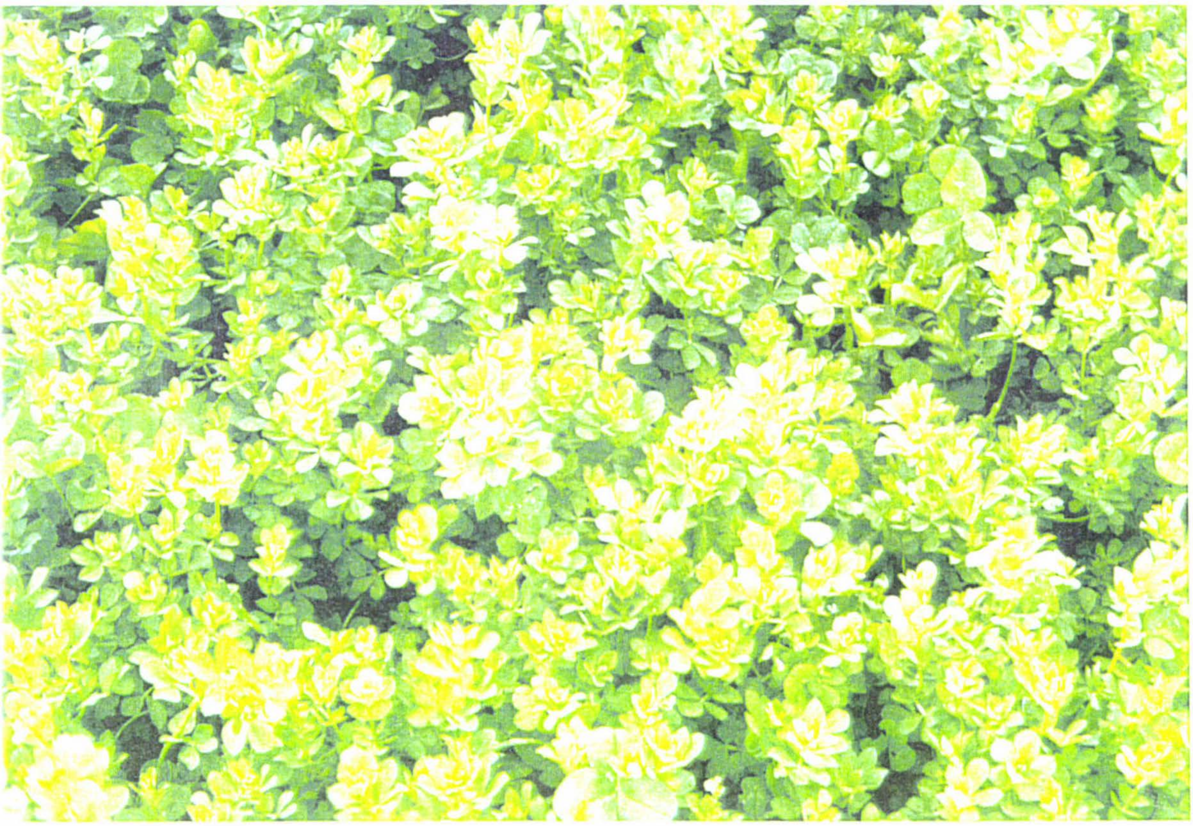

ABSTRACT

EMMANUEL KWADWO ADU, Department of Animal Science, Massey University, Palmerston North, **New Zealand.** EVALUATION OF *LOTUS CORNICULATUS* FOR INCREASING THE EFFICIENCY OF GROWTH IN YOUNG DEER.

A grazing trial with lactating red deer (*Cervus elaphus*) hinds and their calves (EXPERIMENT 1), and an indoor digestion and calorimetric study (EXPERIMENT 2) were conducted at Massey University, New Zealand during 1996, to measure the feeding value of *Lotus corniculatus* compared to perennial ryegrass (*Lolium perenne*)/white clover (*Trifolium repens*) pasture for increasing the efficiency of growth in young deer. Half of the hinds and their calves were grazed on *Lotus corniculatus* and the other half were grazed on perennial ryegrass/white clover pasture during summer (Chapter Three) in a rotational grazing system. Half of the hinds in each group suckled pure red calves with the other half suckling hybrid (0.25 elk : 0.75 red deer) calves. The indoor experiments (Chapter Four) involved feeding one animal of a pair on either freshly cut perennial ryegrass or freshly cut *Lotus corniculatus* during autumn and spring, in metabolism cages and calorimetry chambers at maintenance (1M) and twice maintenance (2M) levels of energy intake.

1. EXPERIMENT 1 (CHAPTER THREE). Liveweight gains of hinds and their calves, weaning weight of calves and voluntary feed intake of hinds were measured on *Lotus corniculatus* or perennial ryegrass/white clover pasture during lactation in summer 1996. The percentage of dead matter in both the forage on offer and diet selected was lower in *Lotus corniculatus* than in perennial ryegrass/white clover pasture. The condensed tannin (CT) levels in *Lotus corniculatus* and perennial ryegrass/white clover pasture were 21 g and 1.6 g total CT/kg DM respectively. Organic matter digestibility (OMD) was higher for *Lotus corniculatus* than for perennial ryegrass/white clover pasture. Hinds grazing *Lotus corniculatus* had higher voluntary feed intake (VFI) and liveweight change than hinds grazing perennial ryegrass/white clover pasture, and liveweight gain and weaning weight of calves were greater on lotus. Liveweight gain and weaning weight of hybrid deer were superior to pure red deer calves, with pre-weaning liveweight gain of hybrid deer calves grazed on *Lotus corniculatus* exceeding 500 g/d for the first time. CT in *Lotus corniculatus* was more tightly bound in red deer oesophageal fistula (OF) extrusa samples than in comparable studies with sheep.

2. EXPERIMENT 2 (CHAPTER FOUR) Energy losses as methane, urine and heat were consistently lower when the deer were fed *Lotus corniculatus* (21 g total CT/kg DM) than perennial ryegrass (< 1 g total CT/kg DM), but faeces energy losses were similar for the two forages. The efficiency of utilisation of ME for growth (k_g) was lower in autumn-grown than in spring-grown perennial ryegrass, and tended to be greater in autumn-grown *Lotus corniculatus* than autumn-grown perennial ryegrass. No significant differences existed in faecal N and urine N losses in deer fed the two forages, and N retention was similar in deer fed *Lotus corniculatus* and perennial ryegrass. Presence of CT-binding salivary proteins in deer but not in sheep is advanced as a reason for N retention not being greater on lotus.

3. The overall conclusion from this thesis was that as a summer feed during deer lactation, the feeding value of *Lotus corniculatus* is higher than that of perennial ryegrass/white clover pasture but essentially similar to that of other special purpose feeds developed for deer production such as chicory (*Cichorium intybus*) and red clover (*Trifolium repens*). The most cogent explanations for the higher performance in deer fed *Lotus corniculatus* is the higher VFI and the greater efficiency with which ingested energy was utilised. Because of the presence of salivary CT-binding proteins in deer, forages with higher CT concentrations are suggested for the realisation of the beneficial effects of forage CT on the efficiency of protein digestion in farmed deer. Two such forages are sulla (*Hedysarum coronarium*; 35-60 g CT/kg DM) and *Lotus pedunculatus* (50-100 g CT/kg DM). The incorporation of *Lotus corniculatus* into the pastoral agricultural system of NZ may be hindered by the slow establishment of the plant, and by the special management system required. It may be better suited agronomically to warm low to medium fertility hill country conditions, such as found in East Coast areas, where competition from other plant species is less.

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Now to him who is able to do immeasurably more than all we ask or imagine, according to his power that is at work within us, to him be glory in the church and in Christ Jesus throughout all generations, for ever and ever! Amen (Ephesians 3: 20-21, NIV).

TABLE OF CONTENTS

CHAPTER ONE

CHAPTER TWO

CHAPTER THREE

CHAPTER FOUR

CHAPTER FIVE

LISTS OF TABLES

LISTS OF FIGURES

LISTS OF APPENDIXES

LISTS OF ABBREVIATIONS

ADF	acid detergent fibre
ADIN	acid detergent insoluble nitrogen
AFRC	Agricultural and Food Research Council
ATP	energy (adenosine trinucleotide phosphate)
BEN	basal endogenous nitrogen
BF	butterfat
c.	about
CH_4	methane
cm	centimetre
Co.	company
CO_2	carbon dioxide
Cr	chromium
CRD	control release device
Cr_2O_3	chromium sesquioxide
Cr-EDTA	chromium ethylenediaminetetra acetic acid
CT	condensed tannin
CWC	cell wall component
cv.	cultivar
d	day
D	organic matter digestibility
DLWG	daily liveweight gain

DM	dry matter
DMD	dry matter digestibility
DMI	dry matter intake
E_g	energy retained for growth
EAA	essential amino acid
e.g.	for example
etc.	and so on
EUP	endogenous urinary protein
EV_l	energy value of milk
Expt.	experiment
F	faecal output
FME	fermentable metabolizable energy
FMR	fasting metabolic requirement
FOR	fractional outflow rate
FV	feeding value
g	gram
GE	gross energy
GED	apparent gross energy digestibility
GEI	gross energy intake
GH	growth hormone
GI	gastrointestinal
GR	a measure of total soft tissue depth over the 12th rib at a point 11 cm from the carcass line

GT	grazing time
h	hour
H	hybrid deer
ha	hectare
HCl	Hydrochloric acid
H_2SO_4	sulphuric acid
I	intake
IB	herbage intake per bite
i.e.	that is
IGF-1	insulin-like growth factor -1
IRL	irreversible loss rate
k	efficiency of utilisation of metabolizable energy
k_c	efficiency of utilisation of metabolizable energy for foetal growth (the conceptus)
k_f	efficiency of utilisation of metabolizable energy for fat deposition
k_g (or k_{pf})	efficiency of utilisation of metabolizable energy for growth
k_l	efficiency of utilisation of metabolizable energy for milk production (lactation)
k_m	efficiency of utilisation of metabolizable energy for maintenance
k_p	efficiency of utilisation of metabolizable

	energy for protein deposition
k_w	efficiency of utilisation of metabolizable energy for work
k_{wool}	efficiency of metabolizable energy for wool growth
kg	kilogram
$kgW^{0.75}$	kilogram metabolizable body weight
l	litres
LH	luteinizing hormone
LOT	*Lotus corniculatus*
Ltd	limited
LWG	liveweight gain
LWT	liveweight
$LWT^{0.75}$	metabolizable liveweight
M/D	energy value of a diet
ME	metabolizable energy
$ME_{lactation}$	metabolizable energy requirement for lactation
ME_m	metabolizable energy requirement for maintenance
$ME_{(m+g)}$	metabolizable energy requirement for both maintenance and growth
ME_p	metabolizable energy requirement for production
MFP	metabolic faecal protein

mg	milligram
min	minute
MJ	megajoule
ml.	millilitre
mm	millimetre
µmol	micromole
MN	microbial nitrogen
MP	Metabolizable protein
MRT	mean retention time
MW	molecular weight
n	sample size
N	nitrogen
NAN	non-ammonia nitrogen
ND	not determined (not detected)
NDF	neutral detergent fibre
NE	Net energy
NEAA	non-essential amino acid
NH_3	ammonia
NH_3-N	ammonia nitrogen
NV	nutritive value
NZ	New Zealand
NZGIB	New Zealand Game Industry Board
O_2	oxygen
OF	oesophageal fistula (ted)

OM	organic matter
OMD_A	organic matter apparently digested
OMI	organic matter intake
P	phosphorus
P:E	protein to energy ratio (the proportion of protein to energy in a diet)
PEG	polyethylene glycol
pH	a measure of acidity or alkalinity of a solution
PRG	perennial ryegrass
QDN	quickly degraded nitrogen
R	red deer
RB	bite rate
S	sulphur
S	seasonal coefficient
SDN	slowly degraded nitrogen
SEM	standard error of the mean
SNF	solid nonfat
sp (spp).	species
t	tonne
TAA	total amino acid
TAAN	truely absorbed amino nitrogen
TDN	Total digestible nutrients
UDN	undegraded nitrogen
UDP	undegradable dietary protein

UK	United Kingdom
US (USA)	United States of America
V	volume of milk at peak lactation
VFA	volatile fatty acid
VFI	voluntary feed intake
vs.	versus
v/v	volume by volume
yr	year
1M	maintenance level of food intake
2M	twice maintenance level of food intake

CHAPTER ONE

INTRODUCTION

1.1. THE NEW ZEALAND DEER INDUSTRY

Deer, like all mammals currently in New Zealand (NZ), except two species of bat and one species of seal, can be described as allochthonous to the islands (i.e. evolved in a habitat different from where they presently are). Introductions of deer, primarily for spot, begun between the late 1800s and the early 1900s from English parks and the Scottish highlands. With the absence of natural enemies, coupled with abundance of food and mild climatic conditions they quickly multiplied and soon attained the status of pest to the natural forest and competitors of livestock for available feed supplies on the lower hills (Yerex, 1982). Numbers were kept in check by a small group of private individuals interested in deerskin, and hunters employed by the NZ government. With the discovery of a large-volume high-value European market for venison, feral deer recovery was soon to attract lots of interest, leading to an eventual decline of wild populations. To keep profits from this budding industry alive individuals started ranching deer on private property. March 1970 saw the official recognition of deer farming in NZ (Yerex, 1982).

Deer farming was initially seen as a means of utilising poor quality wasteland. Introduction of modern farming techniques saw the use of high quality feeding and mating management for increased profitability. A new dimension was given to the industry when Korean importers of velvet antlers realised the superiority of the product from farmed deer compared to feral animals (Yerex, 1982). Deer farming has thus developed as a market-led industry. Numbers of farmed deer have risen to the current population of over 1.5 million, with projections of 2 million by the year 2000 (Figure 1.1). Farmed deer numbers in NZ consist mainly of fallow (*Dama*

dama), elk (*Cervus elaphus canadensis*), elk x red hybrids and pure European red deer (*Cervus elaphus elaphus*), with the latter forming about 85% of the population (Barry and Wilson, 1994).

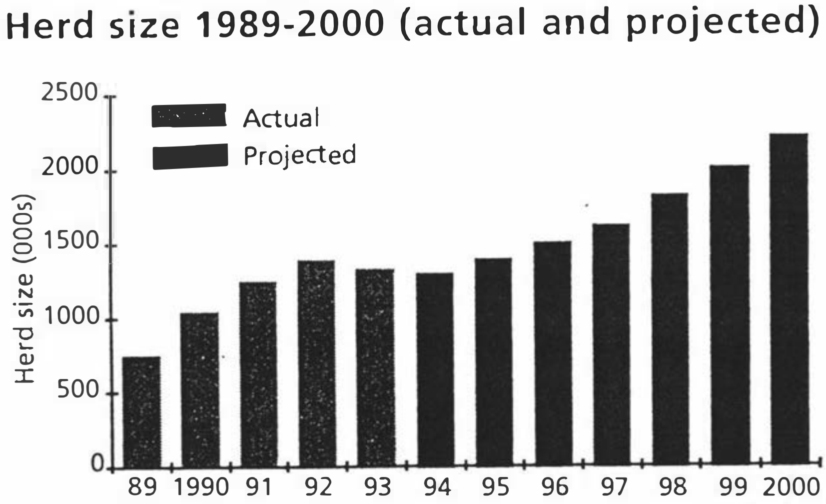

Figure 1.1. Actual and projected farmed deer numbers in NZ for the years 1989-2000 (NZGIB, 1993).

Most of the venison produced feeds the European (German, Switzerland and Austria), US and Japanese markets in that order of importance. The European markets contribute about 80% of current NZ venison sales. Products such as velvet and co-products are solely for the Oriental markets, especially Korea and Hong Kong. Total export earnings from deer reached a record high of NZ$ 221.8 million in 1996 with contributions from the various segments of the industry as depicted in Figure 1.2. With increasing numbers of farmed deer in NZ, and the current trends of consumer demand for low fat tender meat, as well as increased use of alternative medicine, projections are that export returns from deer will further increase.

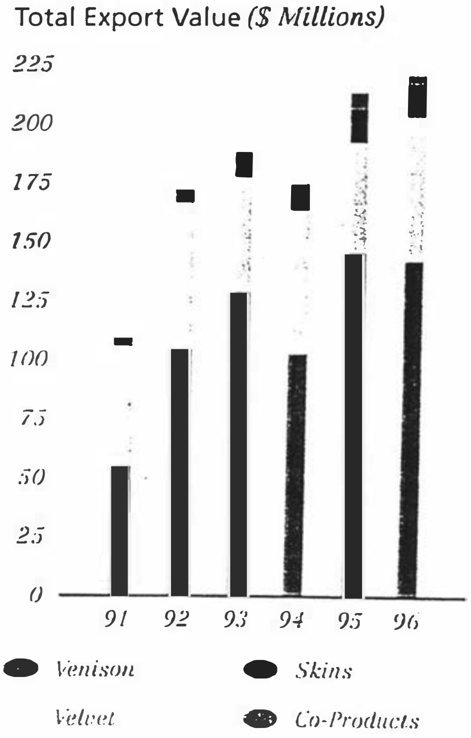

Figure 1.2. Export contributions by various segments of the NZ deer industry (NZGIB, 1996a).

Venison price schedules in the major markets are seasonal (Figure 1.3). Premium price is paid for carcasses in the range of 50-65 kg, with an additional premium for these chilled carcasses during August-November. This translates in NZ into producing carcass weights > 50 kg (92 kg liveweight (LWT) in spring (Southern Hemisphere) for maximum economic returns; i.e. when animals are a year old or younger (Ataja *et al.*, 1992; Frazer, 1993). Deer production in NZ is generally based on the slaughter of stags.

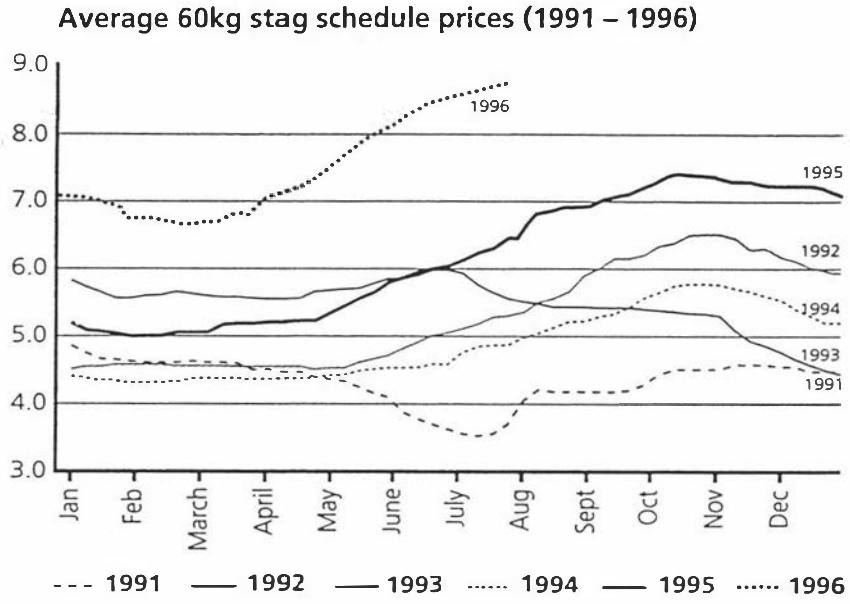

Figure 1.3. Seasonal fluctuations in venison schedule prices ($/kg carcass) for prime 50-70 kg carcass during 1991-1995 (NZGIB, 1996b).

The development and marketing of NZ deer products is under the guidance of a statutory board, the NZ Game Industry Board (NZGIB), with a mandate to strategically establish strong market leadership for NZ deer products. The NZGIB's strategy for venison involve the launching of a dual marketing strategy in April 1993 with the brand names ZEAL^{TM} and CERVENA^{TM}. ZEAL^{TM} is targeted at identifying NZ-produced venison in the established markets (Germany, Switzerland and Austria) whilst CERVENA^{TM} is targeted at developing new markets for NZ venison such as USA (with Canada as a complementary market) and Australia (with NZ as a complementary market). This strategy requires farmers to comply with acceptable standards of chemical usage to merit the export of their products under the brand names (NZGIB, 1993).

1.2. SEASONALITY IN FARMED DEER

Temperate deer have evolved in very seasonal Northern Hemisphere habitats. Plant growth and nutritive value of available herbage are higher during late summer and very low during a long autumn-winter period in these habitats. As a survival mechanism seasonal deer have therefore evolved such that activities of major nutrient demand such as parturition, lactation, early phase of calf growth and antler growth, occur during summer and early autumn when high quality food is available before winter sets in (Milne *et al.*, 1978; Barry *et al.*, 1991). Similar trends, albeit to a lesser degree, are reported in tropical and subtropical species (Sadlier, 1987; Mylea, 1991; Semiadi *et al.*, 1995). Of particular interest to this thesis are the seasonal patterns in voluntary feed intake (VFI), digestion and body growth in temperate deer.

1.2.1. Seasonal patterns in voluntary feed intake

Under farming conditions where VFI is not likely to be restricted by the availability and quality of nutrients, intake in farmed deer still duplicates conditions in the wild (Suttie *et al.*, 1987; Barry *et al.*, 1991; Domingue *et al.*, 1991; Fennessy *et al.*, 1981; Semiadi *et al.*, 1993; 1995). Food intake peaks just before the rut (i.e. late summer) and plunges into a winter nadir (Figure 1.4). Voluntary dry matter intake of red deer can be 35-100% greater in summer than in winter (Barry *et al.*, 1991; Domingue *et al.*, 1991). An additional influence of food intake is the behavioural changes during the active phase of the reproductive cycle. Semiadi *et al.* (1993) reported a 57% reduction in VFI of stags during the breeding season in autumn.

There is a slight sexual dimorphism, as well as age and physiological differences in the appetite cycle of deer. Intact adult stags show a much-pronounced cycle, with animals eating about twice as much in summer as in winter. Non-pregnant hinds, immature and castrated stags show the same cycles but of reduced amplitude (Suttie and Simpson, 1985; Suttie *et al.*, 1987, 1989).

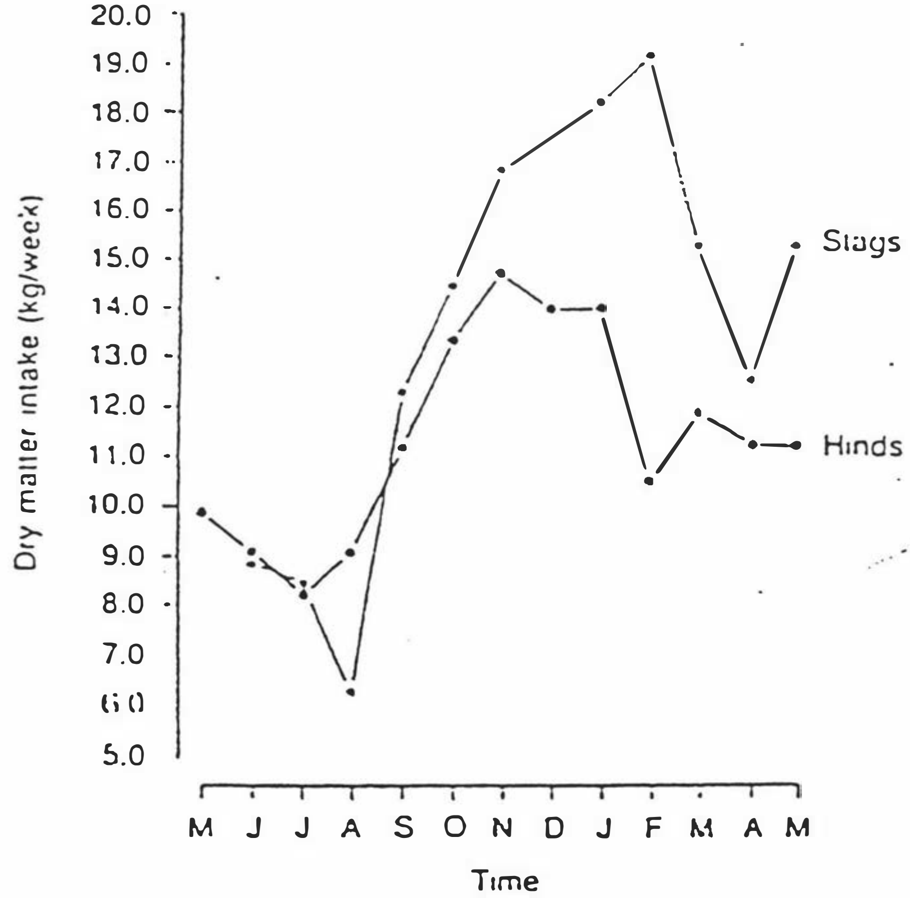

Figure 1.4. Mean monthly dry matter intake (DMI) of hinds and stags (initially 5 months of age) fed to appetite on a pelleted diet containing 46% barley, 35% lucerne, 15% soybean meal and 4% minerals and vitamins indoors for *c.* one year. The ration supplied 11 MJ ME/kg DM and 26 g N/kg DM (Suttie *et al.*, 1987).

Seasonal appetite rhythm in seasonal ruminants (including the deer and sheep) has been reported to be an endogenous circannual rhythm under the control of hormones such as growth hormone (GH), insulin-like growth factor-1 (IGF-1), prolactin, luteinising hormone (LH), and gonadal steroids (Barenton *et al.,* 1988; Suttie *et al.,* 1989). The pineal hormone melatonin entrains this physiological cycle to changing daylength (Barry *et al.,* 1991; Domingue *et al.*, 1992). Barry *et al.* (1991) indicated that animals might be responding to the sum of the nutrient demands arising from other seasonal cycles in their appetite cycle, rather than primarily responding to changing daylength. The sexual behaviour-induced appetite reduction in stags during the rut is differently driven, testosterone being the driving hormone (Bandy *et al.*, 1970).

1.2.2. Seasonal patterns in digestion

Accompanying the seasonal changes in VFI, although not influenced by it (Freudenberger *et al.,* 1994) are seasonal changes in digestive functions. Although VFI increases in summer, apparent digestibility stays relatively constant (Barry *et al.,* 1991; Domingue *et al.,* 1991; Freudenberger *et al.,* 1994). This has been made possible with the evolution of digestive processes in the deer, compared to ruminants such as sheep and goats, involving increases in rumen retention time (MRT) of particulate matter during summer (i.e. 1/lignin FOR; Table 1.1) which affords increased time for microbial attack. MRTs of 30.3 h (winter) and 36.8 h (summer) can be calculated for deer fed lucerne chaff (Domingue *et al.,* 1991; Freudenberger *et al.,* 1994). Other rumen parameters undergoing similar seasonal patterns are total pool size and rate of production (i.e. IRL) of NH_3 (Freudenberger *et al.,* 1994).

Table 1.1. Seasonal changes in voluntary organic matter and fibre intake, apparent digestibility and digestive functions in red deer (*Cervus elaphus*) stags fed chopped lucerne (*Medicago sativa*) hay (Adapted from Domingue *et al.*, 1991; Freudenberger *et al.*, 1994).

Feeding group	winter[1]	summer[1]	summer[2]
Voluntary intake			
-OM (g/kgW$^{0.75}$/d)	53.2	76.5	56.1
-Fibre (g/kgW$^{0.75}$/d)	22.9	30.7	24.3
Apparent digestibility			
-OM	0.640	0.632	0.642
-Fibre	0.436	0.394	0.421
Rumen fractional outflow rate (% h^{-1})			
-Cr.-EDTA	16.30	ND	12.40
-Lignin	3.15	2.67	2.78
Rumen retention time of particulate matter (h)	31.7	37.5	36.0
	28.8	36.1	ND
Mean	30.3	36.8	36.0
NH_3-N irreversible loss rate (mg N/g N intake)	522	ND	649

ND, not determined

[1] intake *ad libitum*

[2] summer restricted to same feed intake as winter *ad libitum*.

1.2.3. Seasonal patterns in growth

In consonance with, though not parallel to, the seasonal pattern of VFI is a seasonal cycle of body growth (Suttie *et al.*, 1987; Semiadi *et al.*, 1993). Calves are born in late spring-early summer (November-December) in NZ. Growth is faster during the early phase of life, coinciding with the long days of summer but slows down in winter (Figure 1.5). Much like the patterns in VFI, seasonal growth differences are less pronounced in hinds (Figure 1.5; Suttie *et al.*, 1987).

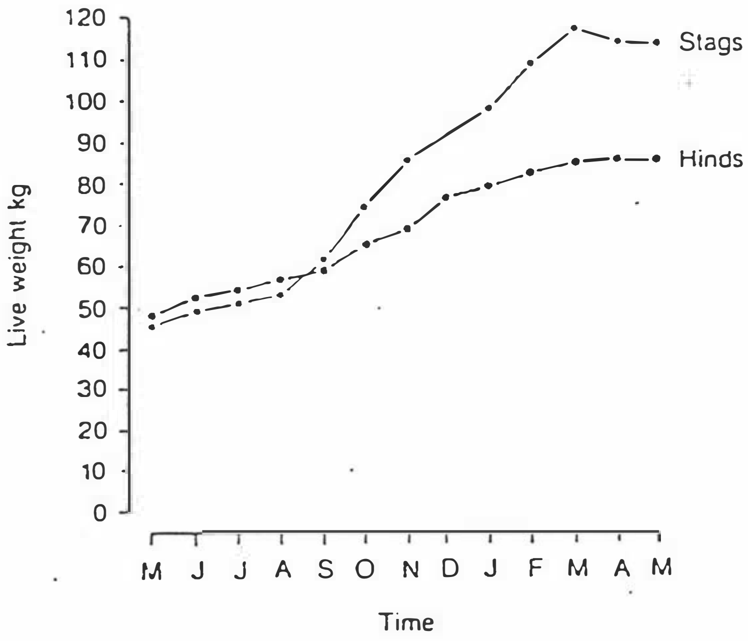

Figure 1.5. Mean monthly liveweight of stags and hinds (initially 5 months old) fed to appetite on a pelleted diet containing 46% barley, 35% lucerne, 15% soybean meal and 4% minerals and vitamins indoors for *c.* one year. The ration supplied 11 MJ ME/kg DM and 26 g N/kg DM (Suttie *et al.*, 1987).

1.3. SEASONAL PATTERNS IN PASTURE GROWTH IN RELATION TO DEER FEED REQUIREMENTS

In the warm temperate conditions of NZ, herbage yield of perennial ryegrass/white clover pastures is highest in spring and lowest in winter. Nutritive value is also highest in spring and lowest in summer (Adam, 1988). Under the conventional pastoral system therefore nutrient requirements of lactating hinds and their growing calves are poorly aligned to the cycles of pasture production, as shown in Figure 1.6.

Calving dates of red deer hinds can be advanced using hormones such as melatonin (Wilson *et al.*, 1991), to properly align the feed requirements of a breeding hind operation with pasture production patterns. However the NZGIB's marketing strategy for venison prohibits the use of hormones for deer production, due to their negative marketing image. Thus, there is a growing scientific and commercial interest in developing special purpose forages, with the ability to overcome the aforementioned constraints, for deer production in NZ.

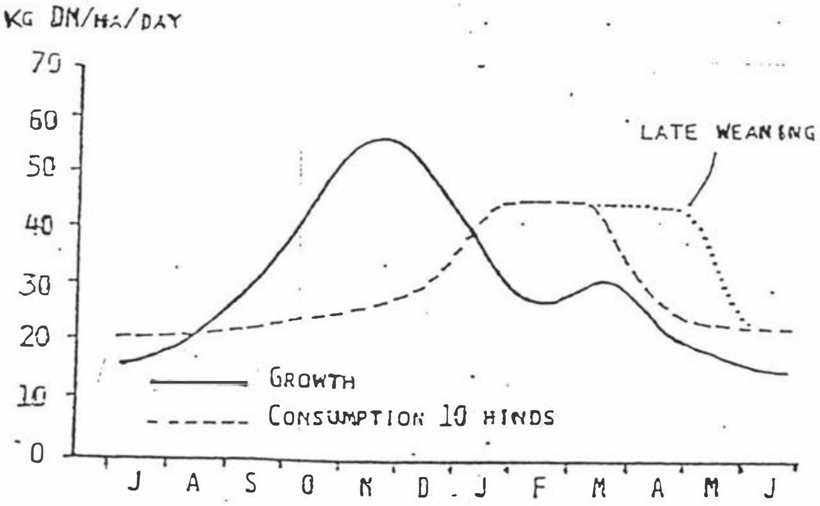

Figure 1.6. Average pasture growth rates in the Manawatu Downland and the feed requirements of a breeding hind operation (Wilson, unplublished).

1.4. THE NEED FOR SPECIAL PURPOSE FORAGES FOR DEER PRODUTION

Special purpose forages for deer production are defined in this thesis as forages with high dry matter yield, and of high nutritive value during the summer/autumn period, the period where perennial ryegrass/white clover pastures for deer production have limitations (Figure 1.6). Forages meeting these criteria in NZ are chicory (*Cichorium intybus*) and red clover (*Lolium pratense*). Red deer stags grown on both red clover and chicory have been noted to have superior liveweight gains in all seasons compared to control animals on perennial ryegrass/white clover pasture, with the greatest advantage in autumn (Kusmartono, 1996; Table 1.2). Use of these crops resulted in 100% of red deer stags attaining the target slaughter liveweight of 92 kg by one year of age, compared to only about 75% of control animals grazing perennial ryegrass-based pastures. Carcass weight and dressing out percentage were also higher on the special purpose forages without any significant difference in carcass quality as measured by the subcutaneous fat index GR. This clearly indicates that grazing animals on these special purpose forages can increase venison production from red deer stags. Other new forages being evaluated with sheep in NZ are the condensed tannin (CT)-containing forages sulla (*Hedysarum coronarium*) and birdsfoot trefoil (*Lotus corniculatus*). This thesis is aimed at evaluating *Lotus corniculatus* for increasing the efficiency of growth in young deer.

Table 1.2. Liveweight gain of red deer stags raised on different special purpose forages for deer production. Values in brackets are relative to perennial ryegrass/white clover pasture as 100, and can be regarded as indices of relative feeding value (Adapted from Kusmartono, 1996; Kusmartono *et al.*, 1996).

Author (s)	Liveweight gain		
	Perennial ryegrass/ white clover	Red clover	Chicory
		Summer[1]	
Niezen *et al.* (1993)	331 (100)	410 (124)	385 (116)
Kusmartono *et al.* (1996)	358 (100)	-	402 (112)
Mean	(100)	(124)	(114)
		Autumn[2]	
Semiadi *et al.* (1993)	192 (100)	263 (136)	-
Soetrisno *et al.* (1994)	207 (100)	237 (115)	-
Kusmartono *et al.* (1996)	178 (100)	-	246 (133)
Min (1996)	152 (100)	-	285 (181)
Mean	(100)	(126)	(157)
		Spring[2]	
Semiadi *et al.* (1993)	34 (100)	354 (104)	-
Soetrisno *et al.* (1994)	281 (100)	346 (123)	-
Kusmartono *et al.* (1996)	260 (100)	-	255 (98)
Min (1996)	253 (100)	-	335 (132)
Mean	(100)	(114)	(115)

[1] pre-weaning

[2] post-weaning

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CHAPTER TWO

LITERATURE REVIEW

2.1. INTRODUCTION

Efficient animal production requires an understanding of the nutrient requirements of an animal, particularly energy and protein, for various biological functions, and the ability of the available feed to meet these requirements. Feed evaluation systems for ruminants infers the use of appropriate techniques to predict the supply of available nutrients, whilst recognising the essential principles of ruminal and post-ruminal digestion, to meet different production targets (Ulyatt and John, 1983; Beever, 1989; Webster, 1992).

This chapter reviews the literature on the principles of forage evaluation and utilisation, and nutrient requirements of deer. Limited data from sheep and other domesticated livestock are included for comparative purposes and (or) as guidelines where information on the deer is limited or lacking.

2.2. NUTRIENT REQUIREMENTS OF DEER

Energy requirements can be expressed as one of a number of energy systems such as the Total Digestible Nutrient (TDN), Net Energy (NE) and Metabolizable Energy (ME). None of these systems is perfect. However the ME system remains the preferred method of deer nutritionists for defining the energy requirements of deer. This stems from the fact that, on pasture, ensuring that ME requirements are met generally also leads to adequate dietary levels of protein, minerals and vitamins (except where there are known deficiencies) for a given production (Geenty and Rattray, 1987; Waghorn and Barry, 1987).

Requirements for protein are generally less well defined than for energy. Protein nutrition is dependent on the amount of microbial protein and undegradable dietary protein (UDP) flux to the small intestines for absorption. However, the efficiency of rumen microbial protein synthesis is not constant. Furthermore methods for estimating the likely yield of ruminally degradable dietary nitrogen and UDP are still inaccurate (Beever, 1989). The quantity and spectrum of amino acids supplied to the metabolic processes of the animal are a result of a combination of a large number of feed, animal, and environmental factors not yet fully understood. None of the concepts and values for protein evaluation currently in use for ruminants is thus close to the metabolic situation (Beever, 1989; Asplund, 1994). Included in the factors influencing the spectrum of amino acid absorption is differences in the efficiency of utilisation of nitrogen as affected by the site of digestion (Ulyatt, 1981).

In the light of current knowledge one of the best systems for protein evaluation is the Metabolizable Protein (MP) System as proposed by the UK Agricultural and Food Research Council (AFRC) (AFRC, 1992). This system partitions dietary protein as depicted in Figure 2.1. By definition MP is 0.65 TAAN (truly absorbed amino nitrogen) (AFRC,1992; Webster, 1992).

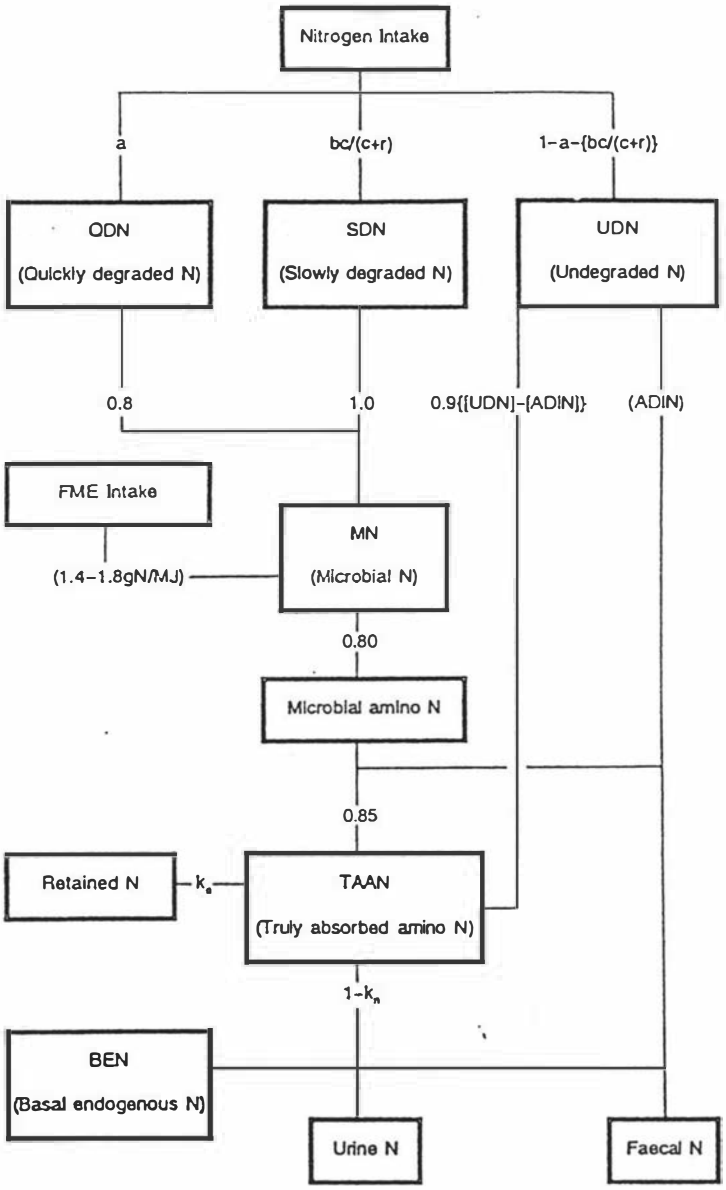

Figure 2.1. Proposed scheme for the description of protein value of diets in terms of truly absorbed amino nitrogen (AFRC, 1992).

2.2.1. Utilisation of metabolizable energy

The processes of eating and metabolism result in energy losses in various forms (Figure 2.2), such that only a fraction of ingested energy is retained for maintenance of body functions and productivity. The extent to which ME of food is utilised by the animal can be measured by either heat production or else its energy retention. Beever

(1989) has however indicated that energy retention *per se* is no longer an adequate index of animal performance or nutritive value of feed, stating that recent production objectives require a recognition of the composition of the animal products (e.g. fat and protein in milk and meat).

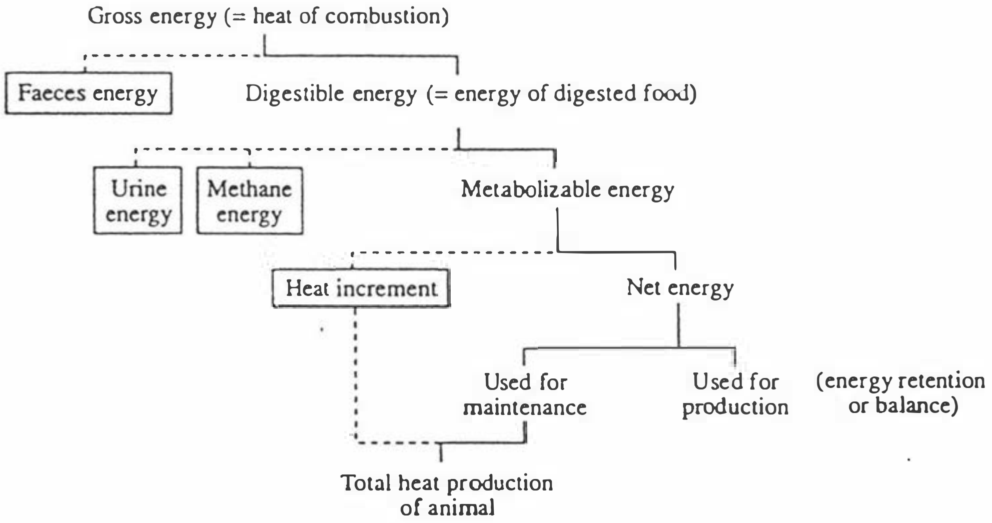

Figure 2.2. The partition of food energy in the animal. Losses of energy are shown as the boxed items on the left (McDonald *et al.,* 1995).

Figure 2.3 describes the relationship between ME intake of an animal and its energy retention for maintenance and for production. The minimum energy required to maintain vital body processes such as organ function, protein turnover, ion gradients, and substrate transport is referred to as the fasting metabolic rate (FMR). This energy leaves the animal as heat. It is measured when the animal is fasted, i.e. when ME intake is zero. A period of not less than 24-48 h is required to allow the ruminant gut to clear of any residual feed to achieve this objective (McDonald *et al.,* 1995). FMR values between 0.33 and 0.44 MJ/kgW$^{0.75}$/d have been reported for the red deer. This is noted to be similar to that of cattle but about 30% higher than that of sheep (Kay, 1985; Haigh and Hudson, 1993).

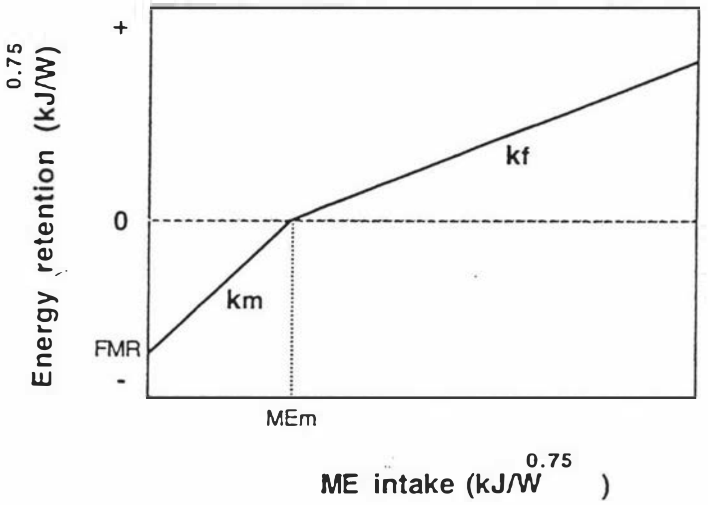

Figure 2.3. Relationship between energy retention and metabolizable energy intake for a representative feedstuff. Slopes below and above energy equilibrium represent efficiencies of energy use for maintenance (k_m) and gain (k_g or k_f) (Haigh and Hudson, 1993).

Intake of ME above FMR requirements leads first to energy equilibrium (i.e. maintenance; ME_m), followed by energy retention in body tissues or in products such as milk. The extent to which energy is retained in growing animals is largely a function of total ME intake, the estimated ME requirement of the animal for maintenance and estimated efficiency with which the ME available above maintenance is used for production (k_f or k_g). A similar situation prevails in lactating ruminants provided the energy contribution from tissue mobilisation in early lactation, or the requirements for tissue repletion in later lactation are taken into account (Beever, 1993a).

The ratio of the change in NE for maintenance, or in products obtained, for a given change in ME intake, is referred to as the efficiency of utilisation (k):

$$k = \frac{\Delta \text{ Energy retained}}{\Delta \text{ ME intake}}$$

k values are coefficients, conventionally quoted with a subscript to denote the function for which ME is used (Table 2.1)

Figure 2.3 shows that with increasing levels of feed intake energy is retained with declining efficiency, which is in the order: $k_m > k_l > k_g > k_f$. This is also dependent on the quality of the feed, going to augment the importance of feed evaluation for efficient animal production.

Table 2.1. Coefficient of metabolizable energy utilisation (McDonald *et al.,* 1995).

k factor	Efficiency of utilisation for:
k_m	Maintenance
k_p	protein deposition
k_f	fat deposition
k_g (or k_{pf})	growth in general
k_l	milk production (lactation)
k_c	foetal growth (the conceptus)
k_w	work (e.g. in draught animals)
k_{wool}	wool growth

2.3. NUTRIENT REQUIREMENTS FOR SPECIFIC FUNCTIONS

Nutrient requirement is a function of genotype, sex, physiological and ecological state of the animal (including climatic conditions under which the animal is performing, and its activity patterns) (Fennessy *et al.*, 1981; Fennessy and Milligan, 1987; Suttie *et al.*, 1987; Beever, 1989; Jiang and Hudson, 1994). The difference between feeds in the efficiency with which energy is used requires that ME intake is divided between requirements for maintenance (ME_m) and production (ME_p) in order to understand the differences between feeds in their ability to either maintain body functions or sustain production in ruminants (Waghorn and Barry, 1987).

Nutrient requirements for production comprise requirements for appropriate maintenance and productive processes (Robbins, 1983), and can be determined in one of two ways:

1. Feeding trials or
2. Factorial procedure

In the feeding trial, animals are fed at different levels. Intake is then plotted against production, and the minimum nutrient requirement that gives the maximum production is taken as the nutrient requirement for the production of the product in question. Maintenance requirement is usually determined by regressing intake (x) on nutrient retention (y). The point on the x-axis corresponding to zero retention is taken as the maintenance requirement. The interpretation of results from feed balance trials could however be confounded by the previous nutrition of the animal, particularly protein. If the animals are well supplied with reserve protein, a higher intake will be needed to maintain equilibrium than if their reserves are depleted (McDonald *et al.*, 1995).

The factorial approach involves calculating the energy (protein) content of the product in question, say milk or meat. and dividing the value by the efficiency of utilisation of the particular nutrient for the production of that product. This value is then added to the value for the maintenance requirement of the animal, in the event of calculating requirement for both maintenance and production combined. This approach however appears to underestimate requirements based on the assumption that maintenance requirement for say a lactating animal is the same as for the non-lactating animal.

2.3.1. Energy

2.3.1.1. Maintenance

ME_m is considered as the amount of energy necessary to sustain life in the nourished animal with no loss or gain in body tissue. Mathematically this can be expressed as:

$$ME_m = \frac{FMR}{k_m} \qquad [1]$$

where,

FMR = fasting metabolic requirement.

k_m = efficiency of utilisation of ME for maintenance.

Simpson *et al.* (1978) reported an ME_m value of 0.46 MJ/kgW $^{0.75}$/d for red deer stag calves 5-11 months old, penned indoors with animal calorimetry. This value was 38% higher than that in ram lambs given the same diet and housing. After making allowance for lactation, Fennessy *et al.* (1981) estimated the ME_m requirement to be 0.55 and 0.57 MJ/kgW$^{0.75}$ daily for adult red deer hinds and stags respectively in an indoor situation with feed balance studies. The value for the hinds was based on the stag data. Generally these figures have been confirmed with indoor feed balance trials (with a slightly lower figure for the hind, 0.52 MJ/kgW$^{0.75}$; Suttie *et al.*, 1987) and animal calorimetry (Semiadi *et al.*, 1997).

Jiang and Hudson (1992), in Canada, estimated the ME$_m$ requirement for wapiti hinds to be 0.57 MJ/kgW$^{0.75}$ daily in an indoor situation during winter; which is much the same as red deer stags in NZ under similar conditions (Fennessy *et al.*, 1981). The similarity between the different sexes of the two species of deer could be as a result of the similarity of body sizes between wapiti hinds and red deer stags. The tropical deer species, sambar deer (*Cervus unicolor*), was found to require a slightly lower ME$_m$ (0.47 MJ/kgW$^{0.75}$; Semiadi *et al.*, 1997) resulting in higher food conversion efficiency compared to red deer under similar conditions (Semiadi *et al.*, 1995).

2.3.1.2. Gestation

Knowledge of the gestation length and birth weight are pre-requisites for estimating energy requirements of pregnant ungulates. The gestation length and birth weight of red deer are 233 days and 8-9 kg respectively. Male calves are however slightly heavier and tend to be born several days earlier. Adam *et al.* (1988) estimated daily nutrient requirements above maintenance throughout gestation, assuming an energetic efficiency of about 13%, and taking into account the relationships between stage of gestation (days pregnant/gestation length) and the daily deposition of nutrients in the conceptus (Figure 2.5). During the final 3 months of gestation the energy requirements of red deer was noted to increase from 1.7 to 5.0 MJ/day at term (Adam *et al.,* 1988). Haigh and Hudson (1993) have however suggested that to minimise the incidence of dystocia larger hinds should be made to meet some of these needs by mobilising some body tissues in late pregnancy.

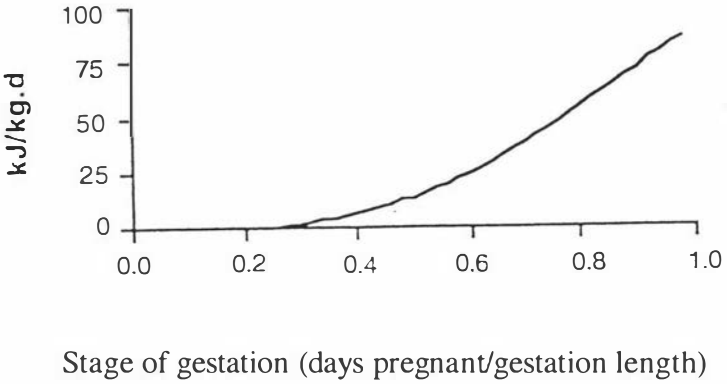

Figure 2.4. Daily deposition of energy in the conceptus (Haigh and Hudson, 1993).

2.3.1.3. Lactation

Milk yield at peak lactation in a well-nourished red deer hind (around 40 days in milk) is about 2.5 litres per day (Arman *et al.,* 1974; Loudon *et al.,* 1984). The larger wapiti produces about 4 litres (Hudson and Adamczewski, 1990; Haigh and Hudson, 1993). The proportion of fat, protein and lactose in the red deer milk during the first month of lactation are 8-13%, 7-9% and 45% respectively (Arman *et al.,* 1974). Wapiti milk is slightly more dilute at a comparable stage of lactation (Watkins *et al.,* 1985, cited by Haigh and Hudson, 1993).

The energy value of milk (EV_l) is related to milk composition as:

$$EV_l\ (MJ/kg) = 0.0386\ BF + 0.0205\ SNF - 0.236 \qquad [2]$$

where,

BF (g/kg) = butterfat and

SNF (g/kg) = solids non-fat.

Daily energetic requirements to support milk yield can also be calculated as:

$$ME_{lactation}\ (MJ/d) = k_l \times V \times EV_l \qquad [3]$$

where,

$ME_{lactation}$ = daily ME requirement for milk yield at peak lactation without any change in liveweight gain of the hind.

V = volume of milk at peak lactation.

k_l = efficiency of utilisation of ME for milk production at zero weight change = 0.64.

The energy content of cervid milk (excluding colostrum) has been noted to rise with advancing lactation as a result of variation in the fat and protein content of milk. Arman *et al.* (1974) reported the energy content of red deer milk to increase from 5.5 MJ/kg in the first month of lactation to 7.7 MJ/kg in the fourth month. Other deer species with similar relative changes are reindeer (*Rangifer tarandus*) and white-tailed deer (*Odocoileus virginianus*) (Loudon and Kay, 1984). The less concentrated wapiti milk, on the other hand, averages about 5.0 MJ/kg (Haigh and Hudson, 1993).

Despite the higher value of deer milk, the daily energy yield at peak lactation (volume x energy value) conforms closely to interspecies allometry, approaching 10 MJ in red deer and 25 MJ in wapiti. Thus hinds will need to increase ME intake by about 16-17 MJ (red deer) to 40 MJ (wapiti) (Fennessy *et al.*, 1981; Adam, 1991; Haigh and Hudson, 1993) during lactation. Lactation in deer thus results in, by far, the greatest increase in ME requirement above maintenance (see Table 2.2).

Milk yield of red deer hinds can drop by about 30-60% as a result of poor nutrition (Arman *et al.*, 1974; Loudon *et al.*, 1984). As with conventional farm livestock, it is of paramount importance to achieve and sustain a high peak yield in early lactation in order to maximise total lactation yields and consumption by suckled calves. Thus the need to adequately feed hinds to meet their nutrient requirements for lactation needs could be critical to venison production.

2.3.1.4. Growth

Fennessy *et al.* (1981) estimated an overall ME requirement for growth, based on stag data, to be 37 MJ/kg LWG in red deer. However liveweight gain in female deer is qualitatively and quantitatively different from that of males. Female black-tailed deer (*Odocoileus hemionus*) have been noted to grow faster than males in the first 6 months of life. Thereafter males grow faster and for a longer period during each growth cycle (Bandy *et al.*, 1970). Studies on the body composition of red deer also indicated that females are fatter than males (Blaxter *et al.*, 1974). Consequently Suttie *et al.* (1987) reported energetic requirement for liveweight gain in red deer hinds to be 55 MJ ME/kg. The higher energy requirement for liveweight gain in the female was attributed to the relative difference in fat deposition between the sexes.

The pattern of seasonal growth rates (especially in mature stags) implies a relatively low potential liveweight gain during the first winter, as well as during the rut (stags) in autumn even with high quality diets and abundant pasture. Thus it is of limited importance to provide any generous feeding during the period of inappetence. This emphasises the need to maximise the genetic potential for growth of the calf during the pre-weaning phase, when the animal has the greatest potential for growth, in order to increase venison production.

Calf liveweight gain is highly positively correlated with the lactation performance of the hind (Loudon *et al.*, 1984). Moreover rumen digestion only supports maintenance energy requirements of the cervid offspring while milk nutrients escaping rumen fermentation, are preferentially used for growth (Loudon and Kay, 1984). Increasing the lactation performance of hinds during summer in NZ, therefore has great potential for increased calf growth rate and consequently venison production.

2.3.1.5. Requirements for both maintenance and growth

Mathematically this can be defined as:

$$ME_{(m+g)} = \frac{FMR}{k_m} + \frac{E_g}{k_g} \qquad [4]$$

where,

$ME_{(m+g)}$ = ME requirement for both maintenance and growth.

E_g = energy retained for growth.

k_g = efficiency of utilisation of ME for growth..

and FMR and k_m are as defined in equation 1.

ME requirement for both growth and maintenance is under the influence of ecological maintenance requirements (energy required for energy equilibrium of free existence) of animals. Fennessy *et al.* (1981) and Jiang and Hudson (1994) compared the ME intake and liveweight gains of red deer stags and wapiti hinds respectively, in both indoor and outdoor situations. A regression comparison of liveweight gain in the outdoor and indoor situation on ME intake (Figure 2.5) indicates that ecological maintenance (i.e. outdoors) of deer is about 1.5-1.6 times that of physiological maintenance (i.e. indoors).

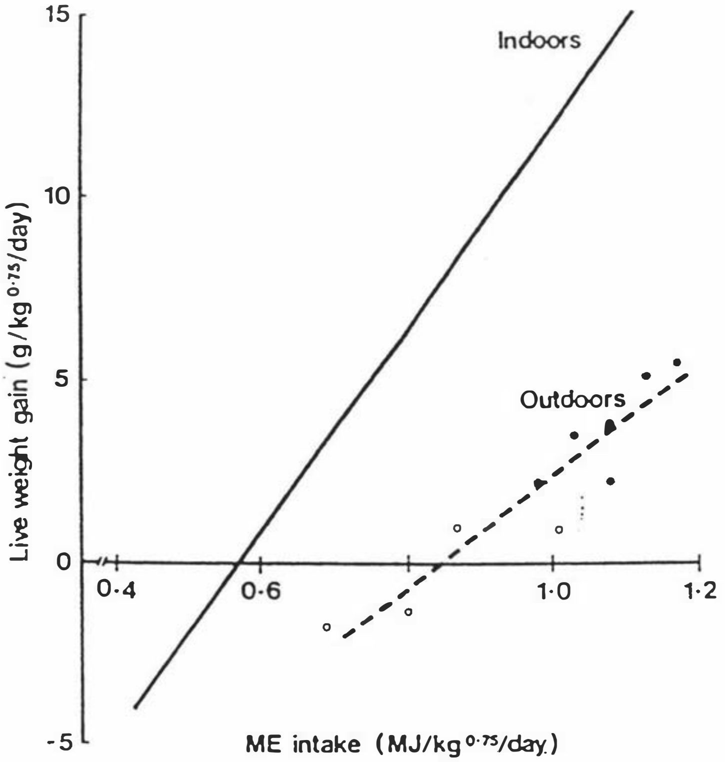

Figure 2.5. Regression relationships between metabolizable energy intake and liveweight gain for stags fed indoors and outdoors (o stags in paddocks, • stags in plantations which are more sheltered (Fennessy *et al.*, 1981).

Seasonal variation in VFI in deer is in tandem with corresponding variations in metabolic activity (Bandy *et al.,* 1970; McEwan and Whitehead, 1970; Barry *et al.*, 1991; Domingue *et al.,* 1991). Consequently, Fennessy *et al.* (1981; Table 2.2), Haigh and Hudson (1993) and Jiang and Hudson (1994), all reported seasonal differences in total ME requirement for maintenance plus growth per day. However, whilst Fennessy *et al.* (1981) cited by Suttie *et al.* (1987) reported a 30, 50, 30 and 10% higher values for outdoor animals compared to those kept indoors during autumn, winter, spring and summer respectively with red deer stags in NZ, Jiang and Hudson (1994) on the other hand, found a 5, 44 and 26% increments during winter, spring and summer respectively in wapiti hinds in Canada. Deer stags have little or no subcutaneous fat during winter (Kay, 1985). Also wapiti, as a species, have larger body size and better insulation than red deer (Haigh and Hudson, 1993). Thus the poor insulation of the red deer stags, as well as the large body size, coupled with the better insulation of wapiti may have contributed to the significant difference in the winter values.

Table 2.2. Seasonal metabolizable energy requirement and target liveweight of red deer (Adapted from Fennessy and Milligan, 1987).

		Daily ME requirement (MJ ME/h/d)			
	Target liveweight (kg)	Autumn (65 d)	Winter (100 d)	Spring (100 d)	Summer (100 d)
Stags:					
(Age-years)					
0.25-1.25	48	16.0	20.9	27.0	26.5
1.25-2.25	105	24.5	28.0	31.5	30.0
2.25-3.25	140	23.5	33.0	38.0	36.2
3.25-4.25	175	19.5	33.0	38.5	38.2
4.25-5.25	190	18.5	34.5	43.5	39.0
> 5.25	200	19.0	36.0	42.5	38.0
Hinds:					
(Age-years)					
0.25-1.25	44	15.0	17.5	22.0	21.0
1.25-2.25	83	20.5	23.5	23.5	45.0
2.25-3.25	94	22.5	24.0	24.5	47.5
> 3.25	100	23.5	22.5	24.5	47.5

Note: Metabolizable energy requirements have been calculated from the equations given below:

(i) For growing animals, adult stags and non-lactating hinds

$ME = S_* [0.57\ LWT^{0.75}] + 37\ DLWG.$

where,

ME is metabolizable energy requirement in MJ ME/day. *S* is the 'seasonal coefficient' (Fennessy *et al.,* 1981); 1.30 for autumn (65 days), 1.50 for winter (100 days), 1.20 for spring (100 days) and 1.10 for summer (100 days); LWT is liveweight in kg; DLWG is daily liveweight gain in kg/d.

(ii) For lactating hinds and their calves at foot

$\mathrm{ME} = S_{*}\,[0.57\ \mathrm{LWT}^{0.75}\ \mathrm{hind}] + 37\ \mathrm{DLWG\ hind} + 65\ \mathrm{DLWG\ calf}.$

where,

DLWG is daily liveweight gain in kg/day for the hind or calf as indicated.

The differences in ME requirements from winter to summer (see Table 2.2) may be due to an increase in the energetic costs of activity, thermoregulation and heat production associated with heat accretion (Haigh and Hudson, 1993; Jiang and Hudson, 1994). Faster growth in deer, associated with increased VFI during summer (Suttie *et al.,* 1987) may also be a contributory factor. Costs of thermoregulation are calculated as the difference between net thermal loss to the environment and the heat produced from tissue and food-related metabolism. Consequently the energetic cost of cold has been found to vary with the feeding level (Kelly *et al.,* 1993).

2.3.2. Protein

Under conditions of adequate supply of other nutrients, the amino acid requirement is defined as the quantity and quality of amino acids required to compensate for the loss of endogenous nitrogenous compounds plus requirement for production (Asplund, 1994). Protein nutrition is however a function of dietary protein quality and quantity, as well as rumen digestive functions (Ulyatt, 1981; Waghorn and Barry 1987). Haigh and Hudson (1993) indicated that protein requirements are best calculated by summing up losses of endogenous urinary and metabolic faecal protein with a margin to cover protein loss in hair and from the skin.

Haigh and Hudson (1993) reported that the daily protein needs for maintenance requirements of deer is 8 to 10 g/kgW$^{0.75}$ of digestible protein per day for a pelleted diet containing 16% protein. This amounts to between 253-316 g for a red deer hind weighing 100 kg. However Hovell *et al.* (1984) estimated that endogenous nitrogen losses contribute between 300 to 400 mg N/kgW$^{0.75}$ per day to the total N losses of a ruminant animal. This is equivalent to 6 to 8 g of N or 40 to 50 g of protein per day for a 60 kg sheep (Asplund, 1994); which translates into between 9 to 13 g/kgW$^{0.75}$/d for a red deer hind. Especially for animals on high quality forage diets, the figures by Haigh and Hudson (1993) may be underestimating N requirements of deer. This is due to the fact that rumen degradation of protein on such forages could result in non-ammonia nitrogen (NAN) flux to the small intestines for absorption being only about 0.7 of the crude protein intake (Barry, 1981; Ulyatt, 1981; Waghorn and Barry, 1987).

The paucity of information on protein requirements for the lactating deer hind has led to attempts at using estimates derived for sheep (Adam, 1991). This is based on the assumption that because nitrogen metabolism does not differ greatly in the two species (Maloiy and Scott, 1969; Maloiy *et al.,* 1970; Simpson *et al.,* 1978) dietary protein requirements per kgW$^{0.75}$ will be similar at comparable stages of development. However deer, as a species, appear to excrete slightly more protein in the urine and faeces, compared to cattle and sheep (Table 2.3) and may thus require slightly higher amounts of protein than these species.

Table 2.3. Protein losses (N x 6.25) used to calculate maintenance requirements (Adapted from Haigh and Hudson, 1993).

Species	EUP (g/kgW$^{0.75}$)	MFP (g/kgW$^{0.75}$)
	Deer species:	
Wapiti	1.00	35
Red deer	0.56	44
White-tailed deer	0.69	33
Caribou	ND	34
Mean	0.75	37
	Other species:	
Bison	ND	26
Cattle	0.58	30
Sheep	0.56	33

EUP = endogenous urinary protein

MFP = metabolic faecal protein.

N D = not determined.

Adam (1991) also recognised that red deer milk contains approximately 29% more crude protein (70 g/kg vs. 50 g/kg) than that of sheep at a similar stage of lactation. This could imply a correspondingly higher dietary protein requirement for the lactating deer hind.

Compared to sheep, red deer have generally been observed to have lower rates of accretion for all nutrients during gestation (Adam *et al.* 1988), suggesting that pregnancy does not present a severe drain on maternal body reserves in this species. The authors therefore suggested that this may be of evolutionary significance for deer adapted in the wild where food supply is seasonally scarce. Adam *et al.* (1988) also speculated that this could be an indication that the red deer might be able to support a greater foetal load when nutritional status is improved on a year-round basis on the farm.

This review has clearly shown that whilst using nutrient requirements for sheep as standards for deer is an appropriate approximation, more research into the protein requirements of farmed deer for various biological functions is required.

2.4. PRINCIPLES OF FORAGE QUALITY EVALUATION AND UTILISATION

2.4.1. The concept of feeding value

Forage quality is best expressed as the feeding value (FV), defined as the animal production response to forage consumed under conditions of *ad libitum* intake. This includes liveweight gain of growing animals and milk production in lactating animals (Ulyatt, 1973; 1981). Ulyatt (1973) defined FV as a function of food intake by the animal, and the nutritive value (NV) of the ingested material. In turn, NV is a function of the chemical and physical attributes of forages, dry matter digestibility (DMD), rate and site of digestion and the efficiency of utilisation of absorbed nutrients (Ulyatt *et al.,* 1978; Ulyatt, 1981). NV measures the animal production response per unit of feed DM consumed.

Prior information on forage quality before feeding a particular diet is important for predicting the ability of the feed to meet requirements for a targeted rate of animal production. This requires the use of another forage as a standard, which also requires an understanding of factors affecting animal production from forage diets (Moore, 1994).

Moore (1994) indicated three criteria for a relative comparison of FV as:

1. Animals used to compare forages have a potential for production and are uniform among treatments
2. Forages are available in quantities adequate for maximum intake
3. No supplemental energy and protein are provided.

2.4.2. Species differences in forage feeding value

Species difference in forage quality is related to differences in chemical composition, usually due to increases in the negative effect of poorly digestible material on intake (Minson, 1981, 1990; Ulyatt, 1981). For example compared to white clover, perennial ryegrass has a higher content of poorly digested structural carbohydrate than white clover (30% vs. 15%) on a DM basis, and a lower ratio of readily:structural fermentable carbohydrate (1.7 vs. 0.8), thus resulting in lower digestibility and intake. Under NZ conditions therefore, the FV of grasses (using liveweight gain as an index) is lower than that of legumes, and in particular the FV of perennial ryegrass is lower than that of white clover (Table 2.4; Ulyatt, 1981). In this example, perennial ryegrass has been used as the standard, with the FV of all other forages being expressed relative to perennial ryegrass as 100.

Table 2.4. Comparative feeding value in terms of sheep liveweight gain of different New Zealand pasture species. All values relative to perennial ryegrass (Grasslands Ruanui) (Adapted from Ulyatt, 1981).

Grasses	n	Comparative feeding value	Legumes	n	Comparative feeding value
Perennial ryegrass (Grasslands Ruanui)	16	100	White clover (Grasslands Huia)	14	192
Perennial ryegrass (Grasslands Ariki)	2	111	Lucerne (Wairau)	10	157
Short-rotation ryegrass (Grasslands Manawa)	11	148	Red clover (Grasslands Hamua)	5	136
Italian ryegrass (Grasslands Paroa)	1	160	Red clover (Grasslands Pawera)	4	124
Timothy, common	5	129	Red clover (Red West)	2	132
Browntop, common (spring)	1	100	*Lotus pedunculatus* (Grasslands Maku)	6	162
Browntop (summer)	1	83	Sainfoin (Melrose)	2	161
Mean		119			152

Generally tropical legumes tend to be higher in crude lignin and protein and lower in cell wall content (CWC) than tropical grasses; and higher in CWC and lignin than most temperate legumes. The crude lignin value is elevated by the presence of tannins in most tropical legumes (Van Soest, 1994). The FV, VFI and apparent digestibility for tropical grasses are all lower than for temperate grasses (Minson, 1981, 1990; Figure 2.6). However at a given digestibility, for example 60% (which is relatively high for tropical grasses), the mean VFI of tropical grasses is 20% higher than for temperate grasses (Figure 2.6), due to the fact that at a digestibility of 60% tropical grasses are very young and leafy whilst temperate grasses are mature and stemmy (Minson, 1981).

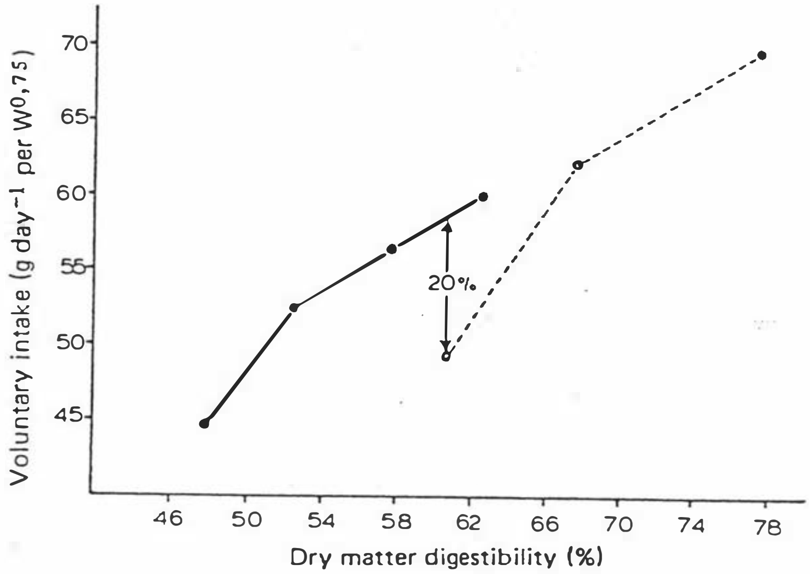

Figure 2.6. Relation between mean voluntary intake and dry matter digestibility for a wide range of tropical (——) and temperate (--------) grasses (Minson, 1981).

2.4.3. Stage of maturity

Plant maturity results in various morphological and chemical changes with consequences on forage quality. The most significant of the maturity-related chemical changes are a decline of forage FV primarily as a result of decline in leaf:stem ratio and in quality of the stem component; and a decline in the readily fermentable carbohydrate:structrual carbohydrate ratio (Hodgson, 1990; Nelson and Moser, 1994; Van Soest, 1994). The leaf:stem ratio of lucerne has been noted to decrease from 1.5 in the vegetative stage to around 0.5 at maturity (Albrecht *et al.*, 1987). Nordkvist and Aman (1986) also reported that the stem fraction of lucerne increased from 18.5 to 50.7% of the yield whilst the leaf fraction declined from 72.9 to 18.4% with increasing maturity.

The negative effect of ageing is more prominent in stem materials than leaves, more so in grasses than legumes, resulting in increases in both lignin and hemicellulose-lignin concentrations (Morrison, 1980; Hodgson, 1990; Van Soest, 1994). Advancing plant maturity also results in a decline in VFI, dry matter and OM digestibility. Kawas *et al.* (1990) reported that the dry matter intake of lucerne hay fed to sheep decreased ($P < 0.05$) as intake of neutral detergent fibre (NDF) and acid detergent fibre (ADF) increased. NDF and ADF components of cell wall have been noted to increase with advancing maturity of herbage (Doyle and McLaren, 1988; Margan *et al.*, 1988).

The age-mediated decline in FV may be due partly to a reduction in the DM intake (Merchen and Bourquin, 1994), organic matter apparently digested (OMD_A) as well as a reduction in the net rumen microbial protein synthesis (Kawas *et al.*, 1990). Kawas *et al.* (1990) observed a 48% and 30% decrease in the microbial protein entering the postruminal gut and OMD_A respectively when full-bloom lucerne hay was fed to sheep compared to pre-bloom hay. Other factors may be the fall in the crude protein content with increasing maturity (Doyle and McLaren, 1988; Kawas *et al.*, 1990) and an increase in CWC, which results in increased rumen retention time of undigested residues (Ulyatt, 1981; Kawas *et al.*, 1990). Increasing maturity may also affect the intake of both essential (EAA) and non-essential (NEAA) and total amino acids (TAA), with intake of EAA being consistently lower ($P < 0.05$) than NEAA (Kawas *et al.*, 1990). Leaf intake is also reported to be higher than stem intake (Minson, 1981; 1990). Laredo and Minson (1973) also reported that the digestibilities of stem and leaf fractions of 5 tropical grass species declined at a rate of 0.34 and 0.25 digestibility units per day respectively.

2.4.4. Chemical composition

Forage nutrients can broadly be classified into cell contents and CWC (Van Soest and Wine, 1967, cited by Beever, 1993a). In young vegetative material, the cell contents may constitute as much as 70% of the dry matter (Beever, 1993a). Consisting principally of free and water-soluble sugars (including fructosans), true- and non-protein nitrogen, and modest amounts of lipid and minerals, this fraction is considered to be extensively digested within the alimentary tract, with virtually all of this digestion occurring within the reticulo-rumen (Beever, 1993a).

Digestion of polysaccharides from intact cell walls is limited by the presence of phenolic compounds within the cell wall matrix (Akin and Chesson, 1990; Eraso and Hartley, 1990). These phenolics consist primarily of lignin and phenolic acids which are chemically bound to lignin or directly to cell wall polysaccharides (cellulose and hemicellulose). The digestibility of hemicelluloses varies with its composition. Xylose residues are generally reported to be less digestible than arabinose in forage cell walls (Buxton *et al.,* 1987). Consequently, the ratio of xylose:arabinose has often been negatively correlated with forage digestibility and has been suggested as an index of forage quality (Buxton *et al.,* 1987; Moore and Hartfield, 1994).

The chemical characteristics of forages will be influenced by forage species, prevailing environmental conditions and management factors including fertilizer application and stage of growth when the crop is grazed or harvested. The concentration of lignin is generally greater in legumes than in grasses at comparable stages of development. However for a given lignin concentration, legumes are more digestible than grasses. Buxton and Russell (1988) found that the lignin of grasses was 61% more inhibitory to cell wall digestion than the lignin of legumes in a study relating the lignin content of forages to the cell wall digestibility. Legumes also have higher N content and a higher readily fermentable:structural carbohydrate ratio than grasses.

Plant chemical constituents with consequences on forage FV and of interest to this thesis are the condensed tannins (CT). Higher levels are depressive to VFI, dry matter and organic matter digestibilities (Barry *et al.,* 1986). However moderate levels have positive effects on FV (e.g. Barry *et al.,* 1986, Waghorn, *et al.,* 1987; Barry, 1989). Concentrations can however be influenced with fertilizer application. Barry and Forss (1983) reported a reduction of CT levels of *Lotus pedunculatus* from 80-110 g CT/kg DM to 40-50 g CT/kg DM with P and S fertiliser application in a low fertility acid soil. N fertilizers also have a positive effect on the N content of forages (Blaxter *et al.,* 1971; Wheeler, 1981).

2.4.5. Herbage intake of grazing animals

Under grazing conditions between 50-70% of differences in forage FV can be attributed to differences in VFI (Minson, 1981; Ulyatt, 1981). Poppi *et al.* (1987) noted that intake by grazing animals is related to pasture allowance by a curvilinear relationship (Figure 2.7), which is a function of nutritional and non-nutritional factors influencing intake. Non-nutritional factors operate under low pasture allowance with nutritional factors operating under generous pre- and post-grazing herbage mass. For a deer operation system non-nutritional factors begin to affect intake at a post-grazing herbage mass < 1100 kg DM/ha (T. N. Barry, personal communication).

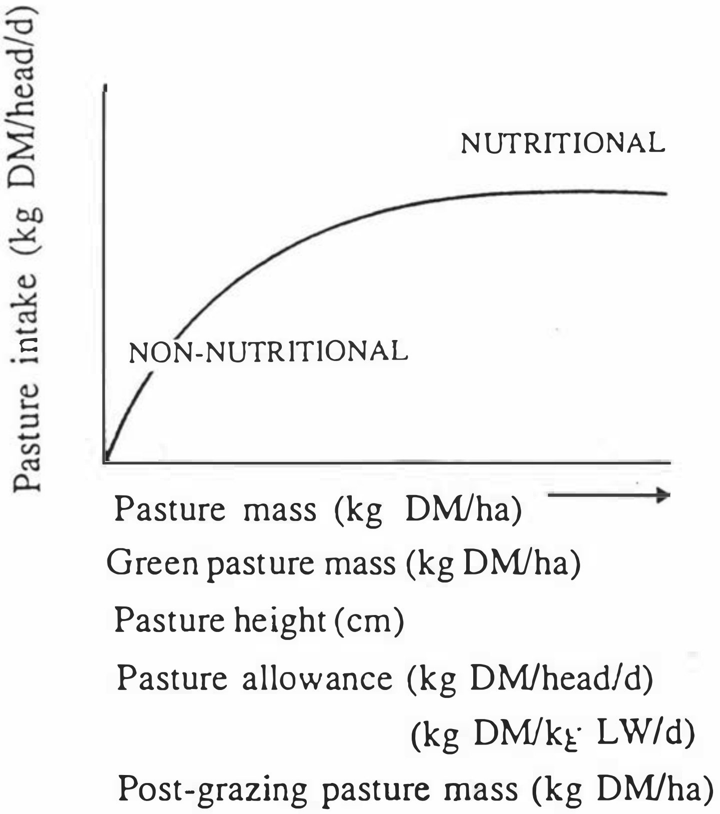

Figure 2.7. The relationship of pasture intake to various pasture characteristics and methods of pasture allocation (Poppi *et al.*, 1987).

2.4.5.1. Nutritional factors

These include factors such as digestibility, crude protein content, rumen mean retention time (MRT) and concentrations of blood metabolites. Poppi *et al.* (1987) reported the role of digestibility as the single most important nutritional factor affecting intake. Low digestibility diets increase rumen MRT and thus depress intake. Digestibility is also noted to affect intake through the M/D value (MJ ME/kg

DM) of a pasture species (Poppi *et al.,* 1987). However the relationship between intake and digestibility has been noted to be species-specific, with intake of legumes being some 40% higher than grasses at the same digestibility (Ulyatt, 1971; Laredo and Minson, 1973; Cruickshank *et al.,* 1985).

MRT is influenced by the chemical and structural composition of the forage consumed, and the adequacy of nutrients for microbial growth in the rumen. Cell contents (e.g. protein and soluble carbohydrates) are more digestible than CWC (fibrous fraction of cellulose and hemicellulose) (Poppi *et al.,* 1987). Other factors include rumen fill, which has been noted to be 25% lower for legumes than for grasses, implying that intake of legumes could be increased before a physical limit to intake was reached (Poppi *et al.,* 1987).

2.4.5.2. Non-nutritional factors

A number of studies (e.g. Poppi *et al.,* 1987; Hodgson, 1990) have shown that under grazing conditions non-nutritional factors can be related to pasture intake as:

$$I = IB \times RB \times GT \qquad [5]$$

where,

I = daily herbage intake (mg OM/kg LWT/day).

IB = herbage intake per bite (mg OM/kg LWT).

RB = rate of bite during grazing (bites/min).

GT = time spent grazing (min/day).

Laca *et al.* (1992) have reported a positive linear relationship between IB and sward height. Consequently Ataja *et al.* (1992) reported increased liveweight gain of red deer stags on perennial ryegrass during winter and spring with an increase in sward height from 5 cm to 10 cm. Low herbage mass results in increased GT due to difficulties at harvesting forage (Penning *et al.*, 1991).

2.4.6. Digestibility of ingested feed

Apparent dry matter digestibility is defined as the percentage difference between the quantity of food eaten and the quantity of faeces produced (Minson, 1981; Robbins, 1983), and is expressed as:

$$\text{Dry matter digestibility (\%)} = \frac{I - F}{I} \times 100 \qquad [6]$$

where,

I = intake of DM, OM, ME, N, etc and

F = the corresponding faecal output.

As a rule, tropical forages are less digestible compared to temperate species. Also grasses in general have been found to be less digestible compared to legumes (Wilson and Minson, 1980; Minson, 1981, 1990; Ulyatt, 1981; Wilson *et al.*, 1983; Moseley and Jones, 1984). The major cause for the differences in the digestibilities between tropical and temperate grasses is anatomically related. The anatomy of temperate grasses (C_3) as compared to the C_4 tropical grass anatomy facilitates quicker access by rumen micro-organisms to a larger surface area in the former and thus increase its digestibility (Carolin *et al.*, 1973; Hanna *et al.*, 1973; Byott, 1976). Other factors have been noted to include the higher **CWC** of tropical species. For example Wilson *et al.* (1983) reported a 50 vs. 42% CWC in tropical and temperate *Panicum* spp respectively. Margan *et al.* (1988) also noted the lower CWC levels of legumes as accounting for its increased digestibility compared to grasses. Generally the negative effect of increasing temperature, which has been noted to promote stem development, on reducing digestibility is greater for tropical species than for temperate species (Wilson and Minson, 1980; Akin and Chesson, 1990).

As discussed earlier, increasing plant maturity affects its digestibility due to lower leaf:stem ratio. Changes in digestibility with maturity can be explained in terms of changes in plant structure and chemical composition. As a plant matures, the proportions of slowly digested and indigestible chemical constituents (cellulose, hemicellulose and lignin) in the stem also increase, and as a result digestibility declines (Ulyatt, 1981; Van Soest, 1994).

The main process regulating digestion in the rumen is the rate at which long food particles can be broken down to the critical particle size for leaving the rumen: about 1 mm in sheep (Poppi *et al.*, 1980), goats (Uden and Van Soest, 1982) and deer (Domingue *et al.,* 1991). The rate of digestion (i.e. the fractional digestion rate) can be influenced by the rumen pH and the rumen ammonia (NH_3) concentration (Satter and Slayter, 1974; Van Soest, 1994). Rumen pH less than 6 generally results in decreases in the rate of fibre digestion (Owens and Goetsh, 1986), usually occurring in diets with higher starch and readily fermentable substrate content, such as grain or concentrate feeds due to a rapid release of VFA and inhibition of cellulolytic bacteria. Optimum fibre digestion occurs at rumen NH_3-N concentration $\geq$ 194 mg/l

(Mehrez *et al.*, 1977) whilst maximum microbial production is at a rumen NH_3-N concentration $\geq$ 50 mg/l (Satter and Slayter, 1974).

In a comparative study of FVs Ulyatt (1981) indicated that an important cause for the superior FV of white clover to perennial ryegrass is the lower rumen retention time of OM (i.e. faster passage rate). A faster rate of passage has been shown to increase wool growth rate of Romney (6.6 g/d compared with a control of 3.9 g/d) and Merino (4.07 kg/year vs. 3.46 kg/year) sheep (Thomson *et al.*, 1989; Smuts *et al.*, 1995). Smuts *et al.* (1995) suggested that inherent differences in gut motility may contribute to differences in wool growth rate in two ways: 1. by increasing the amount of undegradable dietary protein supplied to the small intestine for digestion, absorption and subsequent incorporation into wool protein or 2. by increasing microbial efficiency, resulting in increased flow of amino acids to the small intestines. Ulyatt (1981) concluded that the differences in rumen retention times of OM between legumes and grasses could be an indication of differences in site of digestion within the digestive tract.

2.4.7. Site of digestion

Digestion in ruminants is generally centred on the reticulo-rumen, which generally accounts for 55-65% of the total OM digestion. The small intestine accounts for 25-30% with the large intestine accounting for 5-15% of the total OM digestion (Waghorn and Barry, 1987). Digestion in the rumen and caecum is by microbial fermentation and while this process is beneficial, in that it enables ruminants to digest structural carbohydrates, it occurs with a loss of approximately 25% of digested energy as methane and heat. In addition, fermentation of protein in the rumen or caecum causes absorption and loss of nitrogen as ammonia (Moore and Hartfield, 1994). Most of the starch digested occurs within the rumen for livestock consuming forage-concentrate diets (Nocek and Tamminga, 1991). However, ruminants have the capacity for significant post-ruminal digestion of starch (Armstrong and Smithard, 1979; Owens *et al.*, 1986). Most of the starch escaping ruminal fermentation is digested within the small intestine through the activities of pancreatic amylase and intestinal maltase and isomaltase (Nocek and Tamminga, 1991). Undigested starch reaching the large intestine is readily fermented, at a degradation in the range of 70 to 100% (Hoover, 1978).

Ruminant production in NZ is based on grazing high-quality fresh forages, containing 25-35 g N/kg DM and 10.0-11.5 MJ ME/kg DM. Duodenal N flow of ruminants grazing such forages is however only 65-75% of the total N eaten (MacRae and Ulyatt, 1974), as a result of excessive rumen degradation of plant protein into ammonia being above the capacity of rumen micro-organisms to synthesise protein from ammonia. This results in inefficient utilisation of nitrogen. The amount of NAN flowing out of the rumen into the abomasum is positively related to total N intake (Waghorn and Barry, 1987) and the site of N digestion (Ulyatt, 1981). These are also functionally related to the forage and animal species. High quality NZ forages thus have a low protein to energy (P:E) ratio in absorbed nutrients (Leng 1990; Leng *et al.*, 1992) for efficient ruminant production despite the high herbage crude protein content. Support for this is the fact that Barry (1981) achieved over 25% increase in the daily growth rate of sheep fed on perennial ryegrass/white clover pasture *ad libitum* and supplemented with abomasal infusion of casein. There were also increases in wool growth and carcass protein deposition ($P < 0.001$), and a depression in fat deposition by 25 g/kg carcass ($P < 0.05$) in response to the protein infusion. Abomasal infusions of casein also resulted in increased N retention (85 vs. 110% of the requirement for wool and milk production) in lactating sheep (Barry, 1980). These results were accounted for by the increased NAN flux to the small intestines.

By-pass protein and carbohydrate digested in the small intestine results in little loss of N and ME respectively, and the animal benefits by the absorption of amino acids. Thus any shift of digestion from the rumen to the small intestine should result in increased efficiency of utilisation of nutrients (energy and protein).

Efficiency of capture of degraded nitrogen (N) is known to vary (McAllan *et al.*, 1987), and depends upon the rate of production of N substrates (e.g. ammonia or amino acids) in the rumen and the availability of energy (ATP). Excess supply of ruminally degraded N leads to a fall in the efficiency of capture of microbial N and increases absorption of ammonia from the rumen (Beever *et al.*, 1986). Also affected is a reduction in microbial protein flux to the small intestine. This results in a significant ($P < 0.05$) reduction in the ratio of NAN flow:total N eaten in the small intestine (e.g. Waghorn *et al.*, 1987), a situation prevailing on NZ pastures (Waghorn and Barry, 1987; Waghorn *et al.*, 1987). However this situation can be alleviated by shifting the site of N and energy digestion from the rumen to the small intestine

(Ulyatt, 1981; Nocek and Tamminga, 1991), with the use of forage CT in the case of N (e.g. Barry, *et al.*, 1986; Waghorn *et al.*, 1987; Barry, 1989).

2.4.8. Efficiency of utilisation of absorbed nutrients

Efficiency of utilisation of any particular nutrient can be described as the amount of product produced per unit of nutrient utilised (Ulyatt, 1973; 1981). Efficiency of nutrient utilisation is a function of the quality of feed, on one hand and the physiological state of the animal, as well as the site of nutrient digestion on the other hand (Ulyatt 1981, Ulyatt and John 1983; Waghorn and Barry, 1987; Beever 1993a).

A significant part of the carbohydrates ingested is fermented by microbes with the production of ATP for maintenance and growth requirements of rumen microbes for energy (Isaacson *et al.*, 1975). This reaction results in the production of volatile fatty acids (VFAs) such as acetate, butyrate and propionate as the major energy sources. In general, about 75% of the energy in the fermented substrate (carbohydrate) is recovered in VFA that the host can utilise (Ulyatt, 1973). The generation of acetate is associated with an equimolar production of hydrogen, while the synthesis of propionate from pyruvate requires two moles of hydrogen per mole of propionate produced. Thus where the molar proportion of propionate is higher in relation to the total hydrogen production, which is coupled with an increased utilisation of hydrogen in the formation of propionate, there would be a reduction in the quantity of hydrogen available for methane production resulting in an improvement in the efficiency of utilisation of the pasture species (Beever, 1993b; Van Soest, 1994).

There is thus a negative correlation between propionate formation and methane production, a source of energy wastage to the animal.

The efficiency of utilisation of ME for maintenance (k_m) and for growth (k_g) is frequently used as a measure with which the absorbed energy from forages is used. The efficiency of utilisation of ME_m (k_m) has been noted to be similar for a wide range of forages. However ME has been found to be utilised at a 35% higher efficiency for gain (k_g) in legumes than for grasses (Table 2.5). ME is also utilised for growth and fattening (k_f) with a greater efficiency in temperate grasses (45.3-48.0%; Blaxter *et al.*, 1971; Ribeiro *et al.*, 1981) compared to tropical grasses (27.7%; Tudor and Minson, 1982). The lower k_f values for tropical grasses may be related to the longer MRT (Thornton and Minson, 1973), reduced OM and N flow to the small intestine (Ribeiro *et al.,* 1981) as well as a lower proportion of propionate in the rumen liquor (Tudor and Minson, 1982).

Table 2.5. Efficiency of utilisation of ME for maintenance (k_m) and gain (k_g) by young ruminants fed fresh temperate forages in New Zealand (Adapted from Waghorn and Barry, 1987).

Animal	Feed	k_m	k_g
4-8 week lambs	Lucerne, grass/white clover	0.54	0.29
16-20 week lambs	Lucerne	-	0.42
7 month lambs	White clover	0.67	0.51
	Ruanui ryegrass	0.62	0.33
	50:50 grass/white clover	0.63	0.40
5-8 month lambs	Grass/white clover	-	0.26
4-7 month lambs	Meadow hay	-	0.22
4-7 month kids	Meadow hay	-	0.28
Ruminants (not NZ)	Forage (spring and summer)		
	12 MJ ME/kg DM	0.69	0.56
	8 MJ ME/kg DM	0.66	0.28

Waghorn and Barry (1987) have also indicated seasonal differences in the efficiency with which ME is utilised for growth in both temperate legumes and temperate grasses. Whilst k_m was found to be similar between seasons, k_g was higher for spring than for autumn pastures. (Table 2.6).

Table 2.6. Efficiency of ME utilisation for maintenance (k_m) and gain (k_g) by mature sheep fed spring and autumn harvested temperate forage (Adapted from Waghorn and Barry, 1987). Values in brackets are percentage digestibilities of forages fed

Feed	k_m		k_g	
	Spring	Autumn	Spring	Autumn
Grass	0.72 (66)	0.65 (66)	0.44 (66)	0.33 (66)
Dried grass	0.70 (76)	0.71 (70)	0.45 (76)	0.34 (70)
	-	-	0.48 (-)	0.30 (-)
	0.79 (77)	0.82 (66)	0.54 (77)	0.43 (66)
Ryegrass-clover	0.63 (75)	0.52 (79)	0.40 (75)	0.25 (79)

An association between low proportions of propionic acid in the rumen liquor and grazing autumn pastures compared to spring pastures has been reported (MacRae *et al.,* 1985), and might have accounted for the seasonal differences.

Higher fibre diets produce more acetate, while increased levels of propionate generally occur on diets rich in more available carbohydrates (Ørskov and MacLeod, 1990; Beever, 1993a). However decrease efficiency of ME utilisation or otherwise cannot be blamed only on the proportion of acetic acid in rumen liquor (Van Soest, 1994). Other possible causes have been noted to include the P:E ratio (Leng, 1990) and thermogenesis associated with eating and rumination (Ørskov and MacLeod 1990; Van Soest, 1994).

2.4.9. Grazing management

Grazing management involves feed planning, in the grazing situation, to meet production targets, as well as ensuring little damage to the pasture species so that rapid re-growth is assured. This implies adjusting the frequency and intensity of grazing to pasture availability to ensure the highest efficiency of herbage utilisation. An important factor in maintaining forage quality in the grazing situation is the stocking rate. Hodgson (1990) indicated that low stocking rate results in substantial accumulation of dead matter in the forage on offer (Figure 2.8a). However high stocking rates may also result in a reduction in the OM digestibility of the diet selected despite the positive effect on the proportion of leaf in the forage on offer (Figure 2.8b). Different grazing methods have thus been developed to deal with this situation (see Hodgson, 1990).

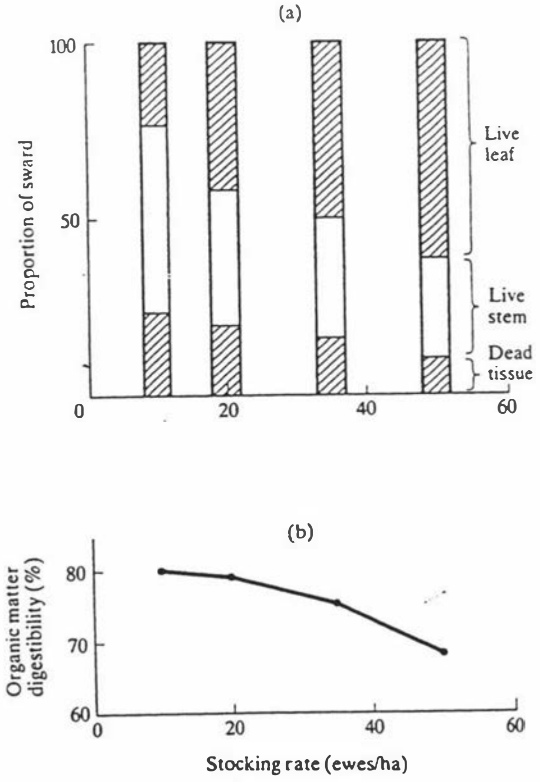

Figure 2.8. The influence of stocking rate upon (a) sward morphology and (b) digestibility of the herbage eaten (Hodgson, 1990).

2.5. THE POTENTIAL ROLE OF FORAGE CONDENSED TANNINS FOR INCREASING RUMINANT PRODUCTIVITY FROM FORAGE DIETS

Condensed tannins are polyphenolic compounds occurring widely in the leaves of trees and shrubs, but in the leaves and stems of only specialised forages such as sainfoin (*Onobrychis viciifolia*), *Lotus* spp and sulla (*Hedysarum coronarium*). Moderate levels of CT have the ability to form acid reversible complexes with dietary protein in the rumen (pH 5.5-7.0) rendering them ruminally protected. The bond is however broken under pH < 3.5 such as occur in the abomasum and small intestines making the protein available for absorption. High levels of CT (> 80 g CT/kg DM), on the other hand, depresses VFI and apparent digestibility of DM and protein (Barry and Manley, 1984; Webster, 1992; Barry, 1989).

Figure 2.7 is a regression of duodenal NAN flow to the small intestine per unit of N intake on dietary CT concentration in sheep fed fresh forages. This suggests that with *Lotus* species CT levels of between 20-40 g CT/kg DM (see Figure 2.9; Barry and Manley, 1984; Barry, 1989) will give a duodenal NAN:total N intake ratio of close to unity, so eliminating extensive absorption of ammonia from the rumen.

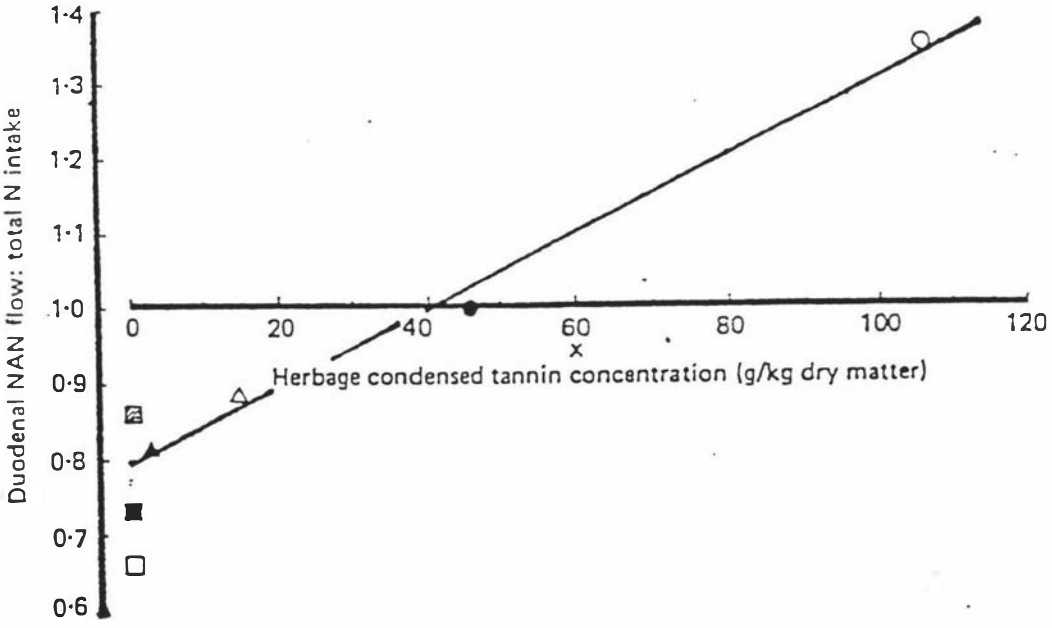

Figure 2.9. Duodenal non-ammonia nitrogen (NAN) flow per unit total N intake as a function of dietary condensed tannin concentration in sheep fed on *Lotus* spp. (o) high CT (106 g extractable CT/kg DM) *Lotus pedunculatus*; (•) low CT (46 g extractable CT/kg DM) *L. pedunculatus*; (Δ) high CT (14.5 g extractable CT/kg DM) *Lotus corniculatus*; (▲) low CT (2.5 g extractable CT/kg DM) *Lotus corniculatus*; (▨) short rotation ryegrass; (□) perennial ryegrass, (■) white clover and (x) sainfoin (Barry and Manley, 1984).

A number of studies have determined the effect of forage-CT, using polyethylene glycol (PEG; MW 3350) to neutralise the effect of CT in one group of animals (Table 2.7). The effect of CT can be calculated by comparing control sheep (CT acting) with that of PEG-supplemented sheep (CT inactivated). Table 2.7 indicates that not only does moderate levels of forage-CT concentration increase the amount of NAN flux to the small intestine (Figure 2.9), but also improves the proportion of

EAA absorbed, and increases the plasma irreversible loss (IRL) of cystine by about 44%. Production parameters such as milk production and milk protein yield of ewes (Wang *et al.*, 1996a) as well as liveweight gain and wool growth of lambs (Wang *et al.*, 1996b) were also increased by the action of forage-CT in sheep fed *Lotus corniculatus*. Asplund (1994) indicated that wool growth is perhaps the best indicator of the N status of sheep.

Table 2.7. The effect of condensed tannin on amino acids apparently absorbed from the small intestines and digestion of cystine in sheep fed fresh *Lotus* spp with and without polyethylene glycol (PEG; MW 3350) supplementation (Adapted from Waghorn *et al.*, 1987; McNabb *et al.*, 1993).

	Essential amino acids[1,a]		Non-essential Amino acids[2,a]		Cystine digestion[b]	
	Control	PEG	Control	PEG	Control	PEG
Intake (g/d)	98.9	98.9	97.9	97.9	3.33	3.52
Abomasal flux						
-g/d	84.7	55.5	68.6	59.1	3.33	2.52
-proportion intake	0.86	0.56	0.70	0.60	1.00	0.72
Apparent absorption from the small intestine:						
-g/d	58.8	36.2	37.4	41.3	1.40	1.34
-proportion of abomasal flux	0.67	0.67	0.54	0.67	0.42	0.53
-proportion intake	0.59*	0.37	0.38	0.42	0.42	0.38
Irreversible loss (µmol/min)	ND	ND	ND	ND	39.8	22.4

[1] Threonine, valine, isoleucine, tyrosine, phenylalanine, histidine and lysine.
[2] Asparagine, serine, glutamate, proline, glycine and alanine.
[a] *Lotus corniculatus* (22g CT/kg DM).
[b] *Lotus pedunculatus* (55g CT/kg DM).

Three components account for efficient venison production by one year of age in relation to the animal itself:

1. Better pre-weaning growth rates leading to better weaning weights at younger ages
2. Improved feed intake and liveweight gain during winter
3. Improved finishing weights as a result of increased weaner growth rates during autumn and spring.

Hoskin *et al.* (1995) achieved a 21 and 19% faster growth in weaner red deer stags during autumn-spring with sulla (40-60g extractable CT/kg DM) compared to chicory and perennial ryegrass/white clover pasture respectively. However, as yet, no attention has been given to the potential role of forage-CT for increasing pre-weaning growth of deer.

Another attraction to the use of CT-containing forages for venison production in NZ is the reported nematicidal properties against free-living nematodes (Taylor and Murant, 1966; Chandel and Mehta, 1990). Field trials with lambs dosed with *Trichostrongylus colubriformis* infective larvae and either grazing lucerne (with only trace amounts of CT) or sulla (50 g CT/kg DM) indicated superior liveweight gains and lower faecal egg counts in the animals grazed on sulla (Niezen *et al.,* 1995). Niezen *et al.* (1994) however suggested that the anthelmintic properties of CT may be due to a boost to the immune system as a result of the increased influx of NAN to the abomasum. Brown *et al.* (1991) and Coop *et al.* (1995), both reported improved immunity to *Trichostrongylus colubriformis* and *Ostertagia circumcinta* respectively in lambs as a result of increased flux of NAN to the abomasum by direct supplementation with undegradable dietary protein.

2.6. CONCLUSIONS

A good understanding of the principles of forage feed evaluation is essential for meeting the nutrient requirements for various production targets. For grazing animals forages are best evaluated based on the principle of FV, which incorporates VFI, dry matter digestibility and the efficiency with which nutrients are converted to specific products.

Energy requirements for deer generally follow the seasonal pattern of physiological changes such as digestion, growth and lactation. The most critical period of deer production in NZ is during summer when lactation in hinds results in nearly twice the ME requirement compared to autumn or spring. This period coincides with the period of lowest nutritive value and dry matter availability of the conventional perennial ryegrass/white clover pastures in NZ.

Though it is appropriate to use nutrient requirements for sheep as standards for deer, in the event where information on the deer is non-existent, more research on N requirements of farmed deer for various physiological functions is required.

Inputs of special purpose forages for deer production, particularly those containing medium levels of CT (20-40 g CT/kg DM) may have great potentials for alleviating the nutritional limitations for deer production on perennial ryegrass/white clover through improved N status of the lactating hind.

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CHAPTER THREE

EVALUATION OF *LOTUS CORNICULATUS* FOR INCREASING PRE-WEANING GROWTH OF RED AND HYBRID DEER

For submission to Journal of Agricultural Science, Cambridge

3.1. ABSTRACT

Lactating red deer (*Cervus elaphus*) hinds and their calves were rotationally grazed on *Lotus corniculatus* or perennial ryegrass/white clover pasture at an allowance of 12 kg DM/head/day during summer 1996 in Palmerston North, New Zealand. Half the hinds suckled pure red deer calves and half suckled hybrid (0.25 elk : 0.75 red deer) calves. Measurements were made of the diet selected, voluntary feed intake of the hinds and liveweight changes of the hinds and calves.

Lotus corniculatus and perennial ryegrass constituted about 90% of green material in the diet selected on the respective forages. Total nitrogen (N) content and organic matter digestibility (OMD) were higher for *Lotus corniculatus* than for perennial ryegrass/white clover pasture. *Lotus corniculatus* contained 21 g condensed tannin (CT)/kg dry matter (DM), whilst pasture contained only traces of CT (1.6 g/kg DM).

Hinds grazing *Lotus corniculatus* tended to have higher voluntary feed intake and calf liveweight gain (485 vs. 399 g/d; $P < 0.001$) and weaning weight (52.6 vs. 48.1 kg; $P < 0.01$) were greater than for deer grazing perennial ryegrass/white clover pasture. Hybrid calves had faster growth rate than pure red deer calves ($P < 0.01$), with hybrid calves grazing lotus having very high liveweight gain (518 g/d). Liveweight gain of hinds grazing *Lotus corniculatus* also tended to be higher (91 vs. 20 g/d; $P = 0.12$) than for hinds grazing perennial ryegrass/white clover pasture. CT was bound more strongly during chewing by red deer than found in comparable studies with sheep and the nutritional significance of this is discussed. Nutritional reasons for the superior performance of deer grazing *Lotus corniculatus* are also discussed.

3.2. INTRODUCTION

Target weaning weight in the New Zealand (NZ) deer industry is 50 kg at 110 days of age (Haigh and Hudson, 1993). This is against the backdrop that calving in red deer (*Cervus elaphus*) occurs during late spring and early summer (November-December), after the spring peak in pasture production (October). Peak lactation thus occurs during summer (January/February) by which time perennial ryegrass (*Lolium perenne*)/white clover (*Trifolium repens*) herbage, the bulwark of NZ pastoral agriculture, is maturing; and of reduced dry matter yield and digestibility due to moisture stress (Adam, 1988). Consequently calves do not realise their full genetic potential for growth from birth to weaning, the period of maximum growth potential, both in relative and absolute terms (Haigh and Hudson, 1993).

With high quality NZ fresh forages, 70% of the dietary protein is ruminally degraded, resulting in insufficient amino acid absorption for maximum productivity in grazing ruminants (Barry, 1981; Waghorn and Barry, 1987). A method of reducing this degradation is to exploit the ability of forage condensed tannins (CT) to form complexes with dietary protein. Condensed tannins occur in a restricted range of forages; and they bind plant protein in the rumen (pH 5.5-7.0) to form stable CT-protein complexes which then dissociate in environments of pH less than 3.5 such as occur in the abomasum (Jones and Mangan, 1977). This results in increases in non-ammonia nitrogen (NAN) flux to the intestines (Barry *et al.*, 1986; Waghorn *et al.*, 1987a; 1994).

The ideal CT levels in plants for ruminant animal nutrition has been suggested to be in the range of 20-40 g/kg DM (Barry, 1989; Waghorn, 1990), and concentrations in *Lotus corniculatus* fulfil this condition. Studies in sheep fed *Lotus corniculatus* showed that the action of CT increased the absorption of essential amino acids (excluding methionine and cystine) from the small intestine by 62% (Waghorn *et al*., 1987b), increased the irreversible loss rate (IRL) of cystine from blood plasma and increased cystine flux to body synthetic reactions (Wang *et al.,* 1994). Liveweight gain and wool production of lambs (Wang *et al*., 1996b) were also increased by the action of CT, as well as milk secretion in ewes rearing twin lambs (Wang *et al*., 1996a). There is however no information on the feeding value of *Lotus corniculatus* for deer. The objective of this study was to evaluate *Lotus corniculatus* for increasing pre-weaning growth and subsequent weaning weight of red and hybrid deer calves.

3.3. MATERIALS AND METHODS

3.3.1. Experimental design

A 2 x 2 x 2 factorial experiment involving lactating hinds and their calves grazing two different forages (*Lotus corniculatus* vs. perennial ryegrass/white clover pasture) over summer was conducted at the Massey University Deer Research Unit, Palmerston North, New Zealand, from 8 January to 29 February 1996. Calves of both sexes and of either pure red or elk x red hybrid (0.25 red x 0.75 elk) genotype were used in the study.

3.3.2. Forages

The perennial ryegrass/white clover pasture (2.68 ha; 7 paddocks) was several years old, whilst the *Lotus corniculatus* (birdsfoot trefoil; cv Grassland Goldie) was either one or two years old (1.65 ha; 4 paddocks). The paddocks sown to *Lotus corniculatus* were ploughed, disk-harrowed, power harrowed and sown at 15 kg seed/ha. After plant emergence the lotus paddocks were sprayed with MCPB (Shell Chemicals Ltd.) at 4 litres /ha to control weeds, and lightly irrigated to help plant establishment during early summer.

3.3.3. Animals

Thirty-six lactating red deer hinds and their calves were used. Hinds had been mated to either hybrid (0.5 red x 0.5 elk) stags to produce the hybrid deer calves; or mated to pure red deer stags to produce the pure red deer calves. Calving occurred during November and December 1995. Newly born calves were identified with numbered collars until two weeks before weaning and then ear-tagged. Hinds were grouped on calving date, sex and genotype of calf and randomly assigned to graze either perennial ryegrass/white clover pasture or *Lotus corniculatus* from 8 January to 29 February 1996. All calves were weaned on 29 February 1996. Twenty hinds and their calves were assigned to graze perennial ryegrass/white clover pasture, and 16 hinds and their calves were assigned to graze *Lotus corniculatus*. At the start of the trial mean liveweights (± SEM) of the animals grazing perennial ryegrass/white clover pasture were 110.4 ± 2.26 kg (hinds) and 28.2 ± 0.98 kg (calves); and 109.0 ± 2.65 kg (hinds) and 28.3 ± 1.15 kg (calves) on *Lotus corniculatus*. Both hinds and calves on each treatment were drenched with Cydectin anthelmintic (Cyanamid of NZ Ltd) twice

(30.1.96 and 24.2.96) during the period of the trial to control internal parasites. On each occasion hinds received 13 ml and calves 5 ml of Cydectin thus receiving 0.59 and 0.88 mg per kg liveweight of moxidectin per drench respectively.

3.3.4. Grazing management

Animals were rotationally grazed on both forages at a pasture allowance of 12 kg DM/hind/day. Time spent in each paddock was calculated as:

$$\text{Length of grazing period (days)} = \frac{\text{Herbage mass (kg DM/ha)} \times \text{Total area of paddock}}{\text{Total no. animals/group} \times \text{Pasture allowance/hind/day}} \qquad [1]$$

The rotational length was between 2.0-3.0 weeks on perennial ryegrass/white clover pasture and 2.5-4.0 weeks on *Lotus corniculatus*. A follow-up grazing with sheep was done to maximise leaf production of *Lotus corniculatus*.

3.3.5. Pasture measurements

Pre-grazing herbage mass (kg DM/ha) was measured before animals were introduced into each paddock. Immediately after being shifted out of each paddock the post-grazing herbage mass was also measured. Measurements were done by the quadrat method (8 quadrats of 0.1 m^2 each per sampling period). Plants in each quadrat were cut to soil level using a hand-clipper, and were then washed, oven-dried at 100°C for 18-24 h and weighed to estimate the available dry matter (DM) in each paddock. Areas surrounding each quadrat were also cut to soil level, bulked per paddock, mixed and divided into two halves. These were referred to as diet on offer. One part was used to estimate botanical composition, and the other half stored at -20°C to determine nutritive value of the diet on offer.

Hand-plucked samples of each forage were taken daily from each paddock by simulating the grazing activity of the animals. These were referred to as diet selected (hand plucked). Samples were stored at -20°C. At the end of each grazing period these were bulked per paddock, thoroughly mixed and divided into two halves. One part was used to estimate botanical composition, with the other part used to determine the nutritive value. Samples were also taken with two oesophageal-fistulated (OF) deer grazed on each forage on 6 occasions. On each occasion they were fasted for 3 h and then grazed for 20 minutes to collect extrusa. The extrusa was also used to determine the nutritive value of the diet selected. OF deer were changed over between forages after the third sampling as a means of eliminating any animal differences.

3.3.6. Animal measurements

Hinds and their calves were weighed at two-weekly intervals to determine liveweight changes. Weighing was also done at weaning (29 February 1996). Hinds were dosed with an intra-ruminal slow release chromium (Cr) capsule (CRD, Cr_2O_3 matrix, Captec Ltd, NZ) on 30 January 1996 to estimate faecal output. Eight days thereafter, rectal faecal samples were taken from each hind every other day for 16 days. Each succeeding sampling was done 2 h later than the preceding sampling time to account for any differences in Cr excretion rates. Five and three rumen-fistulated deer were grazed along-side animals on perennial ryegrass/white clover pasture and *Lotus corniculatus* respectively to measure Cr release rate from the capsules. Cr capsules were suspended in the rumen on 31 January 1996, and plunger travel monitored by measurement with vernier callipers at three-day intervals from 5 February 1996 to 29 February 1996.

3.3.7. Laboratory analysis

The frozen hand plucked herbage and OF extrusa samples were freeze-dried and ground to pass through a 1 mm diameter mesh sieve (Willey mill, USA) prior to laboratory analysis. Total nitrogen (N) content of each forage was determined using the Kjedahl method, with selenium catalyst and H_2SO_4 digestion. Organic matter (OM) was determined by ashing samples at 550°C for 16 h. *In vitro* digestibility was determined by the enzymatic method (Roughan and Holland, 1977). Extractable and bound condensed tannins were determined using the method of Terrill *et al.* (1992b). Faecal Cr concentrations were determined by atomic adsorption spectrometry (Costigan and Ellis, 1987). Botanical composition of both diet on offer and diet selected (hand plucked samples only) were done by dissecting each sample into grass, lotus, clover, dead matter and weed. Samples were separately oven-dried at 100°C for 18-24 h and weighed.

3.3.8. Data calculations and statistical analysis

Factorial analysis of variance was used to examine treatment effects in all liveweight data, with the factors being forage (*Lotus corniculatus* vs. perennial ryegrass/white clover pasture), genotype (pure red vs. hybrid deer) and sex (male vs. female) using the General Linear Model (GLM) procedure (SAS, 1996). Age was used as a covariate for calf-liveweight data. Mean values and standard errors of the mean (± SEM) are presented.

Voluntary feed intake (VFI) was calculated as:

$$\mathrm{VFI} = \frac{\mathrm{F\ (g\ OM/d)}}{1-\mathrm{D}} \qquad [2]$$

where,

F is faecal OM output and D is the *in vitro* OM digestibility (OMD) of the diet selected. F was calculated from equation 3.

$$\text{F (g OM/day)} = \frac{\text{Cr release rate (RR) (mg/day)}}{\text{Faecal Cr. concentration (mg/g OM)}} \quad [3]$$

3.4. RESULTS

3.4.1. Herbage mass and botanical composition

Pre-grazing herbage mass was higher for *Lotus corniculatus* than for perennial ryegrass/white clover pasture (3796 ± 522.8 vs. 2910 ± 103.6 kg DM/ha), but post-grazing herbage mass was similar for both forages (Table 3.1) and not likely to be limiting animal production. Perennial ryegrass and *Lotus corniculatus* formed the major components in both forage on offer and diet selected in their respective treatments, being just over 90% of green material in the diet selected (Table 3.2). In both forages diet selected was higher in the major constituents and in clover contents but lower in weed and dead material compared to the forage on offer. There was a very high dead matter content (46.9 ± 4.68 vs. 30.5 ± 3.86%) for the forage on offer and diet selected in the perennial ryegrass/white clover pasture, reflecting hot dry summer growing conditions; whilst *Lotus corniculatus* contained only 6.2 ± 5.24 vs. 1.4 ± 1.05% dead matter for forage on offer and diet selected respectively, showing that it was almost a pure sward. Generally there was a very low clover content in both pasture species (Table 3.2).

Table 3.1. Mean (± SEM) pre- and post-grazing herbage mass (kg DM/ha) of perennial ryegrass/white clover pasture and *Lotus corniculatus* grazed by red deer hinds and their calves during lactation.

	Perennial ryegrass/white clover (n=14)	*Lotus corniculatus* (n=7)
Pre-grazing	2910 ± 103.6	3796 ± 522.8
Post-grazing	2503 ± 77.5	2305 ± 371.9

Table 3.2. Botanical composition (% DM ± SEM) of perennial ryegrass/white clover pasture and *Lotus corniculatus* grazed by red deer hinds and their calves during summer 1996.

	Forage			
Species	Perennial ryegrass/ white clover (n=14)		*Lotus corniculatus* (n=7)	
	Forage on offer	Diet selected[1]	Forage on offer	Diet selected[1]
Grass	45.7 ± 4.31	61.2 ± 3.20	0.7 ± 0.53	0.4 ± 0.19
Clover	4.6 ± 1.27	5.1 ± 1.18	0.3 ± 0.22	1.6 ± 1.09
Lotus	-	-	76.6 ± 6.87	91.2 ± 2.35
Weed	2.9 ± 0.59	1.3 ± 0.55	15.9 ± 7.07	5.4 ± 2.87
Dead matter	46.9 ± 4.68	30.5 ± 5.24	6.2 ± 5.24	1.4 ± 1.05

[1] Hand plucked samples.

3.4.2. Nutritive value of forages

Lotus corniculatus on offer was of higher OMD compared to perennial ryegrass/white clover pasture ($P < 0.05$). For both forages the diet selected was higher in both total N and OMD than forage on offer, as determined by both hand plucked and OF ($P < 0.01$) sampling (Table 3.3). Organic matter (OM) content was consistently lower for OF extrusa than for hand plucked samples of diet selected ($P < 0.001$), due to salivary contamination. Consequently total N values were expressed as a percentage of OM. When expressed in this manner, there was no difference in total N content in the two methods used to measure diet selected. There was however a significant interaction between forage and sampling method for the diet selected ($P < 0.05$). OMD of perennial ryegrass/white clover selected was similar for hand plucked and OF extrusa samples, but OF extrusa samples for *Lotus corniculatus* gave lower values than hand plucked samples ($P = 0.057$). Only trace amounts of CT were detected in perennial ryegrass/white clover pasture using both the vanillin-HCl and buthanol-HCl methods. Similar values were found for hand plucked samples and OF extrusa (Table 3.3). Total CT concentration in *Lotus corniculatus* selected was much lower for OF extrusa than for hand plucked samples ($P < 0.01$), due to an almost total disappearance of CT from the extractable fraction and a major reduction in protein-bound CT.

Table 3.3. Organic matter (OM; % DM), organic matter digestibility (OMD), total nitrogen (N; % OM) and condensed tannin content (g CT/kg DM) of forage on offer and diet selected by red deer hinds grazing either perennial ryegrass/white clover pasture or *Lotus corniculatus* during lactation in summer 1996.

	Perennial ryegrass/white clover		*Lotus corniculatus*	
	Forage on offer:			
n	7		7	
OM	83.9 ± 2.24		89.4 ± 2.24	
OMD	49.1 ± 1.97		57.8 ± 2.32	
Total N	2.10 ± 0.21		2.68 ± 0.21	
	Diet selected:			
	Hand plucked	OF extrusa	Hand plucked	OF extrusa
n	7	6	7	6
OM	87.7 ± 2.24	75.6 ± 2.41	91.2 ± 2.24	77.0 ± 4.30
OMD	57.2 ± 2.32	60.5 ± 2.32	68.5 ± 2.32	60.8 ± 3.34
Total N	2.69 ± 0.21	2.63 ± 0.21	3.51 ± 0.20	3.10 ± 0.31
Condensed tannins (n = 3):				
-Extractable[1]	1.8 ± 0.84	0.03 ± 0.03	8.0 ± 0.82	1.0 ± 0.08
-Extractable[2]	ND	ND	10.0 ± 0.26	0.2 ± 0.14
-Protein-bound[2]	0.8 ± 0.03	0.2 ± 0.12	10.3 ± 0.75	3.8 ± 0.53
-Fibre-bound[2]	0.7 ± 0.07	0.8 ± 0.06	0.8 ± 0.03	1.3 ± 0.20
-Total[2]	1.6 ± 0.07	1.1 ± 0.06	21.2 ± 0.51	5.2 ± 0.63

[1] Vanillin-HCl method, [2] Buthanol-HCl method, ND = not detected.

3.4.3. Voluntary intake and liveweight gains

Voluntary organic matter intake (OMI) was higher for hinds grazing *Lotus corniculatus* than for hinds grazing perennial ryegrass/white clover pasture, with the difference attaining significance when OMI was estimated using OMD of hand plucked samples ($P < 0.001$; Table 3.4), however OMI, as estimated by OF extrusa samples was not significantly different between forages (Table 3.4).

Table 3.4. Voluntary organic matter intake (OMI, g/d) as determined by two methods of estimating diet selection by grazing red deer hinds on either perennial ryegrass/white clover pasture or *Lotus corniculatus* during lactation in summer 1996.

	Perennial ryegrass/white clover	*Lotus corniculatus*	SEM
Hand plucked	1921	2757	115.4
OF extrusa[1]	2081	2216	99.9

[1] Obtained by using oesophageal fistulated (OF) deer.

Initial liveweight was significantly higher (30.1 ± 0.61 vs. 26.3 ± 0.61 kg; $P < 0.001$) for hybrid deer than pure red deer calves, but there was no significant sex effect on calf initial liveweight (Table 3.5). Liveweight gain was significantly higher for hybrid than pure red calves (468 ± 12.8 vs. 416 ± 12.8 g/d; $P < 0.01$), and for calves grazing *Lotus corniculatus* than for calves grazing perennial ryegrass/white clover pasture (485 ± 13.2 vs. 399 ± 11.8 g/d; $P < 0.001$). Male calves also significantly gained weight at a faster rate than female calves ($P = 0.10$). There were no significant interactions between sex, genotype and forage for liveweight gain.

Genotype, sex, forage and their interactions had no significant effect on weaning age of calves. Average weaning ages were 92 days on both forages, 90 and 94 days for pure red and hybrid calves, and 91 and 93 days for female and male calves respectively (Table 3.5). However weaning weight was significantly higher for hybrid deer than pure red deer calves ($P < 0.01$). Significantly higher weaning weights were also achieved on *Lotus corniculatus* (52.6 kg) compared with perennial ryegrass/white clover pasture (48.1 kg; $P < 0.01$) (Table 3.5). No significant effect was found for the interactions between sex, genotype and forage on calf weaning weight.

Hinds (i.e. dams) grazing *Lotus corniculatus* tended to gain more weight than the hinds grazing perennial ryegrass/white clover ($P = 0.12$).

Table 3.5. Growth of red and elk x red hybrid deer calves raised by hinds grazing either perennial ryegrass/white clover pasture or *Lotus corniculatus* during lactation in summer 1996.

Forage	Perennial ryegrass/white clover				*Lotus corniculatus*				SEM
Sex	Stag		Hind		Stag		Hind		
Genotype	R	H	R	H	R	H	R	H	
Calves:									
No. animals	5	5	5	5	4	4	4	4	
Initial weight (kg)[1]	26.1	31.5	25.9	28.8	25.7	30.0	28.2	29.9	0.73
Weight change (g/day)[1]	239	450	371	386	456	534	450	502	12.13
Weaning weight (kg)[1]	45.6	54.1	44.5	48.1	48.5	56.7	50.3	55.0	1.13
Age at weaning (days)	91	91	89	97	92	97	88	91	1.00
Hinds:									
Weight change (g/day)	2	68	3	7	103	60	123	78	11.9

R = red deer, H = hybrid deer (0.25 elk x 0.75 red); DM allowance = 12 kg DM/hind/d; [1] Corrected for age of calf.

3.5. DISCUSSION

The most important results obtained in this study were the significant increases in daily liveweight gain ($P < 0.001$) and weaning weight ($P < 0.01$) of calves raised by hinds grazing *Lotus corniculatus* compared to those grazing perennial ryegrass/white clover pasture and the greater liveweight gains obtained in hybrid calves compared to pure red deer calves. Liveweight gains in hybrid calves grazing lotus in this study exceeded 500 g/d, this being the first time we have achieved this in a grazing study with suckling calves. This is a major increase on earlier studies, which established growth of red deer calves suckling hinds grazing summer pasture at 331 g/d (Niezen *et al.*, 1993). Kusmartono *et al.* (1996) similarly reported greater liveweight gains in hybrid deer compared to pure red deer calves when their dams were grazed on chicory (*Cichorium intybus*), indicating the importance of improved nutrition for the realisation of the greater genetic potential for growth of elk x red hybrid deer.

Ulyatt (1973) defined feeding value as the animal production response to grazing a forage under conditions where intake was not restricted by plant availability. He further proposed feeding value as a function of voluntary feed intake, digestive efficiency and the efficiency of utilisation of digested nutrients. As a summer feed during deer lactation, it is therefore evident that the feeding value of *Lotus corniculatus* was higher than that of perennial ryegrass/white clover pasture, with one of the reasons being the higher VFI found for the hinds grazing lotus. This may have resulted in greater levels of milk production, and this needs to be measured in future studies. Organic matter digestibility was also higher for deer grazing lotus, when this was based upon hand plucked samples of the diet selected, but not when based upon samples of OF extrusa.

The extractability of CT was greatly reduced in the latter, and this may have lowered the OMD value.

Adu *et al.* (1997) found lower methane, urine and heat energy losses in young deer fed fresh *Lotus corniculatus* than perennial ryegrass; the efficiency of utilisation of ME for growth (k_g) during autumn being higher for deer fed *Lotus corniculatus* than perennial ryegrass (0.45 vs. 0.32). Similarly, Rattray and Joyce (1974) found higher k_g values for young sheep fed fresh white clover than fresh perennial ryegrass (0.51 vs. 0.33). Improved efficiency of energy utilisation in young deer fed lotus than perennial ryegrass is a further reason for the increased growth rates obtained with lotus in the present experiment.

Moderate levels of CT (20-35 g/kg DM) in forages fed to sheep have been reported to increase non-ammonia nitrogen (NAN) flux to the small intestine and to increase the absorption of essential amino acids (EAA) (Barry *et al.,* 1986; Waghorn *et al.,* 1987a,b, 1994) and cystine irreversible loss rate (IRL) (McNabb *et al.,* 1993; Wang *et al.,* 1994). However, binding of CT during eating differs between sheep and deer.

A comparison of the action of chewing during eating in the sheep and red deer eating *Lotus corniculatus* and sulla (*Hedysarum coronarium*) on the extractability and recovery of forage CT is shown in Table 3.6. The extractable CT fraction was greatly reduced during chewing by both sheep and red deer, but this was almost completely recovered in the protein-bound and fibre-bound fractions in the sheep, with the overall recovery of the total CT being close to 90%. However, recovery of total CT in the OF extrusa of red deer was less than 30%, illustrating stronger binding of CT. Mule deer saliva contains a proline-rich protein fraction not found in the saliva of sheep (Austin *et al.,* 1989), which has a high affinity for forage tannins (Austin *et al.,* 1989; Robbins *et al.,* 1991). Initial studies suggest that red deer saliva can also bind CT (A. E. Hagerman, unpublished) and this may be binding a large component of the CT in the current studies. The nutritional significance of this tighter CT binding with red deer saliva during eating lotus remains to be established; it could however be significant as in a related study Adu *et al.* (1997) found that N retention was similar in weaner deer fed fresh *Lotus corniculatus* or perennial ryegrass, whereas in sheep the CT-containing forage species promote greater N retention (Reid *et al.,* 1974; Egan and Ulyatt, 1980; Nuñez-Hernandez *et al.,* 1991; Wiegand *et al.,* 1995).

Table 3.6. Extractability of forage condensed tannins (CT) from oesophageal fistula (OF) extrusa samples of sheep and red deer fed *Lotus corniculatus* and sulla (*Hedysarum coronarium*), compared with the original plant material. CT content were estimated by the buthanol-HCl method.

	Sample		Author (s)
	Manually harvested plant material	OF extrusa	
	Sheep:		
Extractable CT	31.3	10.0	Terrill *et al.* (1992a)[1,a]
Protein-bound CT	13.1	25.5	
Fibre-bound CT	1.7	5.0	
Total CT	46.1	40.3 (87%)[3]	
Extractable CT	17.0	2.8	Min *et al.* (1997a)[2]
Protein-bound CT	12.3	22.8	
Fibre-bound CT	0.5	1.2	
Total CT	29.8	26.8 (90%)[3]	
	Red deer:		
Extractable CT	36.1	ND	Min *et al.* (1997b)[2]
Protein-bound CT	10.9	10.6	
Fibre-bound CT	1.2	2.5	
Total CT	48.2	13.1 (27%)[3]	
Extractable CT	10.0	0.2	Present study[2]
Protein-bound CT	10.3	3.8	
Fibre-bound CT	0.3	1.3	
Total CT	21.2	5.2 (25%)	

[1] Sulla (*Hedysarum coronarium*).

[2] *Lotus corniculatus.*

[3] Percentage of total CT in corresponding manually harvested sample.

[a] Values represent means of two experiments.

ND = not detected.

The results presented in this paper have clearly established *Lotus corniculatus* as a superior feed for lactating deer hinds and their calves. Further studies are required with *Lotus corniculatus* fed to young deer from weaning to slaughter for venison production at one year of age, and also to study the effect of forage CT on EAA absorption in the red deer.

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CHAPTER FOUR

DIGESTION AND EFFICIENCY OF UTILISATION OF ENERGY AND NITROGEN IN WEANER RED DEER FED *LOTUS CORNICULATUS* AND PERENNIAL RYEGRASS

For submission to Journal of Agricultural Science, Cambridge

4.1. ABSTRACT

Digestion and efficiency of utilisation of energy and nitrogen (N) were measured in growing weaner red deer (*Cervus elaphus*) at Massey University, Palmerston North, New Zealand, during autumn and spring 1996. Four artificially reared weaner red deer were fed fresh *Lotus corniculatus* or fresh perennial ryegrass when kept under constant lighting indoors at maintenance (1M) and twice maintenance (2M) levels of energy intake. Digestibility and N balance were measured in metabolism cages, whilst oxygen (O_2) consumption, carbon dioxide (CO_2) production and methane (CH_4) production were measured in open-circuit calorimetry chambers. Heat production was calculated from gaseous exchange and urine N measurements. *Lotus corniculatus* and perennial ryegrass contained approximately 21 g and < 1 g condensed tannin (CT)/kg DM.

Energy losses as methane, urine and heat were consistently lower when deer were fed *Lotus corniculatus* than when fed perennial ryegrass, but faeces energy losses were similar for the two forages. The efficiency with which ME was used above maintenance (k_g) was low for perennial ryegrass grown during autumn and tended to be greater for *Lotus corniculatus* grown during this time. However the difference was not significant due to between animal variability.

No differences in faeces N and urine N losses were found when deer were fed *Lotus corniculatus* compared to perennial ryegrass. Consequently nitrogen retention (% N intake) was not significantly different when the deer were fed either *Lotus corniculatus* or perennial ryegrass.

Presence of CT-binding salivary proteins in deer but not in sheep is advanced as a reason for N retention not being greater on *Lotus corniculatus;* and forages containing higher levels of CT are therefore suggested for farmed deer. However the reduced energy losses in deer fed *Lotus corniculatus* contributed to the greater growth rates found in deer grazing *Lotus corniculatus* than perennial ryegrass/white clover pasture. A PEG supplementation trial is needed to establish if action of CT contributed to the improved energy utilisation in deer fed *Lotus corniculatus.*

4.2. INTRODUCTION

Lotus corniculatus has been shown to be of higher feeding value for very young deer than perennial ryegrass/white clover pasture, producing higher rates of pre-weaning calf growth (Adu *et al.*, 1997). A component of this is undoubtedly the higher voluntary feed intake (VFI) found for the deer grazing *Lotus corniculatus*, but other components of feeding value deserving attention are apparent digestibility and the efficiency of utilisation of digested nutrients.

Under grazing conditions forage condensed tannins (CT; 20-55 g CT/kg DM) have been exploited to shift the site of digestion of nitrogen (N) from the reticulo-rumen to the small intestine through the formation of stable CT-forage protein complexes in the rumen (pH 5.5-7.0) which dissociate in the abomasum ($pH < 3.5$). In sheep grazed on *Lotus* species this has been reported to increase the ratio of duodenal non-ammonia nitrogen (NAN) flow:total N intake, to increase the absorption of essential amino acid (EAA) by 60% (Waghorn *et al.*, 1987b) and to increase plasma cystine irreversible loss (IRL) rate from blood plasma (McNabb *et al.*, 1993; Wang *et al.*, 1994). Milk production and milk protein yield of ewes rearing twin lambs (Wang *et al.*, 1996a) and wool growth and liveweight gain of lambs grazing *Lotus corniculatus* (Wang *et al.*, 1996b) were also increased by the action of CT. However the role of forage-CT on the efficiency of utilisation of digested nutrients has yet to be studied.

This study investigated the apparent digestibility and the efficiency of utilisation of energy and N for growth in weaner red deer (*Cervus elaphus*) fed *Lotus corniculatus* or perennial ryegrass, containing medium and trace amounts of CT respectively, using a combination of nutrient balance and calorimetric techniques.

4.3. MATERIALS AND METHODS

4.3.1. Experimental design

Four artificially reared young red deer of mixed sex were used in two experiments during autumn (late March-May; Expt. 1) and spring (October-December; Expt. 2) 1996 at the Deer Research Unit and Animal Physiology Unit, Massey University, Palmerston North, New Zealand. Animals were either fed fresh perennial ryegrass or fresh *Lotus corniculatus* (birdsfoot trefoil cv. Grasslands Goldie) at two levels of intake (Maintenance or twice maintenance) when kept under constant lighting in both metabolism cages and open circuit calorimetry chambers indoors.

Both experiments involved feeding two animals (a hind and a stag) on perennial ryegrass and two animals (a hind and a stag) on *Lotus corniculatus* in a pair-wise manner. In both instances the experiment begun with one animal each on perennial ryegrass or *Lotus corniculatus* at a maintenance (1M) level of intake followed by twice maintenance (2M) level of intake; the second pair starting with 2M levels of intake followed by 1M intake levels.

Nitrogen balance and energy digestibility were measured in metabolism cages whilst methane and heat production were measured in open circuit calorimeter chambers, after an adjustment period of seven days in both situations. Data collection lasted for seven days during each period of measurement.

4.3.2. Animals

Two male and two female red deer calves artificially reared from birth, were used for both trials. The deer were either assigned to graze perennial ryegrass or *Lotus corniculatus* to adapt animals to their respective experimental diet prior to the start of the experiment. At the end of Expt. 1 all animals were grazed on perennial ryegrass during winter. One hind died of pneumonia when the animals were grazed outdoors. and was thus replaced by another one during Expt. 2. Animals were weighed at the beginning and end of each measurement period. Average liveweights of animals at the start and finish of each trial are presented in Table 4.1, showing that the animals maintained their weight when on 1M level of intake whilst they gained weight on 2M level of intake. All animals were drenched with Cydectin anthelmintic (Cyanamid of NZ Ltd.) on two occasions each during Expt. 1 (18.3.96 and 20.5.96) and during Expt. 2 (7.10.96 and 10.11.96). In-between the two experiments, two drenches were also given on 14.6.96 and 1.7.96. Each animal received 5 ml of Cydectin (0.88 mg moxidectin/kg LWT) per drench. All animals were given 2 ml of both Yersiniavax (Agvax Developments Ltd, NZ) and Ultravax 5 in 1 (GSL Ltd, Victoria, Australia) vaccines on 22.3.96 with a second dose of both vaccines given six weeks thereafter (14.6.96), to protect the deer against Yersiniosis and clostridial diseases respectively.

Table 4.1. Mean liveweight (± SEM) of weaner red deer (*Cervus elaphus*) used in digestion and calorimetry trials during autumn-winter (late March-May; Expt. 1) and spring (October-December; Expt. 2) 1996.

Forage intake	Perennial ryegrass		*Lotus corniculatus*	
	1M	2M	1M	2M
		Digestion trial:		
Expt. 1:				
Initial liveweight	37.5 ± 2.12	34.5 ± 1.41	33.9 ± 5.52	32.5 ± 4.95
Final liveweight	35.0 ± 3.54	35.7 ± 0.99	33.5 ± 2.83	34.2 ± 1.20
Expt. 2:				
Initial liveweight	51.0 ± 2.00	52.3 ± 4.25	58.0 ± 3.50	57.8 ± 0.25
Final liveweight	49.5 ± 2.00	54.5 ± 5.50	57.0 ± 3.00	61.0 ± 1.50
		Calorimetry:		
Expt. 1:				
Initial liveweight	35.0 ± 3.54	35.7 ± 0.99	33.5 ± 2.83	34.2 ± 1.20
Final liveweight	32.3 ± 4.60	37.5 ± 2.12	32.5 ± 4.95	36.9 ± 1.27
Expt. 2:				
Initial liveweight	51.0 ± 2.00	52.3 ± 4.25	58.0 ± 3.50	59.0 ± 1.00
Final liveweight	49.5 ± 2.00	55.5 ± 4.50	57.0 ± 3.00	61.8 ± 0.75

4.3.3. Forages

Perennial ryegrass was cut from paddocks established with this forage several years ago, whilst the *Lotus corniculatus* were pure swards either two or three years old (Adu *et al.,* 1997). Prior to the experiment commencing, the perennial ryegrass paddocks were sprayed with Versatill^{TM} (DowElan Co. (NZ) Ltd.) at 1.5 l/ha to kill any clovers present. Urea was applied to the perennial ryegrass as a top-dressing at 37 kg N/ha in late summer (March) and in spring (October) 1996. Forages fed were cut daily at 15.00 h and any contaminating species removed. One half was fed immediately and the other portion spread on a concrete floor in a cool building overnight to prevent deterioration. This was fed at 09.30 h the next day. Samples of each forage were oven-dried at 100°C for 24 h and used to estimate the next days' requirement for fresh feed.

4.3.4. Digestibility and nitrogen balance

Apparent digestibility and N balance were measured over a seven-day period in metabolism cages similar to those described by Milne *et al.* (1978). Feed on offer, feed refusals, and total faeces and urine output were measured on a daily basis. Urine was collected over sufficient H_2SO_4 (25% v/v) to maintain the pH at about 1 (*c.* 100 ml vs. 200 ml and 200 ml vs. 600 ml in autumn and spring for perennial ryegrass vs. *Lotus corniculatus* respectively). Faeces were cleaned of both contaminating plant material and hair on a daily basis and weighed. Duplicate 200 g samples of the feed on offer were taken daily, pooled and stored at -20°C and used to measure the chemical composition of the feed on offer. Approximately 10% of the feed refusals, total faeces and urine output were collected on a daily basis and pooled per animal during the digestion period and stored at -20°C. At the end of the trial, faecal and urine samples were thawed and pooled per animal, mixed thoroughly and sub-sampled for laboratory analysis.

4.3.5. Calorimetry

Measurements of oxygen (O_2) consumption, carbon dioxide (CO_2) and methane (CH_4) production per animal were carried out each day in two open circuit calorimetry chambers as described by Holmes (1973). Air temperature at the maintenance level was 15-17°C and 13-16°C at the twice maintenance level of intake, and were higher than the lower critical temperature for young red deer (Semiadi *et al.,* 1996). The composition of air samples drawn from the in-going and exhaust air-streams were measured by paramagnetic (Servomex, UK) and infrared (Beckman, USA) gas analysers on aliquot representative samples (approximately 7.000 ml) collected at a constant rate during each 24 h period.

4.3.6. Laboratory analysis

Freeze-dried samples of feed on offer, feed refusals and faeces were ground to pass through a 1 mm sieve mesh (Willey Mill, USA). About 40 g of each duplicate samples of the feed on offer were bulked and all feed on offer, feed refusals and faeces samples were analysed for organic matter (OM), total N and energy content. Organic matter was determined by ashing samples at 550°C for 16 h. Total N content of all samples taken was determined by the Kjeldhal method whilst gross energy was determined by adiabatic bomb calorimeter (Gallenkamp Autobomb, Loughborough, Leics, UK) by pelleting samples of feed and faeces (0.5-0.8 g DM; 12 mm diameter) prior to combustion. A technique similar to that described by Fuller and Cadenhead (1969) was used to prepare 20 g samples of urine for combustion. All samples were pooled into 3 batches per forage and analysed for extractable and bound CT using the method of Terrill *et al.* (1992).

4.3.7. Data calculation and statistical analysis

Apparent digestibility of dry matter (DM), organic matter (OM), nitrogen (N) and energy were calculated as:

$$\text{Apparent digestibility} = \frac{\text{Intake (g)} - \text{faeces (g)}}{\text{Intake (g)}} \qquad [1]$$

and N and energy retentions were calculated as:

$$\text{N (energy) retention} = \text{N (energy) intake} - \text{faeces N (energy)} - \text{urine N (energy)} \qquad [2]$$

Heat production was calculated from measurements of O_2 consumption, CO_2 production and CH_4 production and urinary N excretion using the equation of Brouwer (1965).

The efficiency of utilisation of metabolizable energy for growth (k_g) was calculated as the increment in energy retained divided by the increment in ME intake. Effects of forage species, level of feeding, season and their interactions on apparent digestibility, N excretion and N retention were analysed in a 2 x 2 x 2 factorial design. Differences in k_g between forages and season were analysed as a 2 x 2 factorial design using the General Linear Model (GLM) procedure (SAS, 1996).

4.4. RESULTS

4.4.1. Nutritive value of forages

Organic matter content was significantly higher for *Lotus corniculatus* than for perennial ryegrass, ranging from 89.8-90.9% DM and 87.5-89.6% DM respectively ($P < 0.05$), and was higher for spring-cut forages than for autumn-cut forages (90.3 vs. 88.7% DM) ($P < 0.01$), with no significant interaction between forage and season (Table 4.2). Total N content of *Lotus corniculatus* tended to be higher than perennial ryegrass in Expt. 2 but not in Expt. 1; and was significantly lower in spring than during autumn (2.71 ± 0.141 vs. 3.53 ± 0.141% DM; $P < 0.001$). Gross energy content of *Lotus corniculatus* was significantly higher than for perennial ryegrass ($P < 0.01$), with there being no effect of season and no forage x season interaction. Only trace amounts of CT were detected in perennial ryegrass, ranging from a total CT level of 0.2-0.8 g CT/kg DM as determined by the buthanol-HCl method. On the other hand, the total CT levels of *Lotus corniculatus*, using the same method, ranged from 17.8-23.6 g CT/kg DM (Table 4.2), with the higher values in spring.

Table 4.2. Organic matter (OM; % DM), total nitrogen (N; % DM), gross energy (GE) content (MJ/kg DM) and condensed tannin content (g CT/kg DM) of fresh perennial ryegrass (PRG) or fresh *Lotus corniculatus* (LOT) fed to weaner red deer during autumn (late March-May; Experiment 1) and spring (October-December; Experiment 2) 1996.

	Experiment 1		SEM	Experiment 2		SEM
	PRG	LOT		PRG	LOT	
n	4	4		4	4	
Organic matter	87.5	89.8	0.58	89.6	90.6	0.58
Total N	3.72	3.21	0.199	2.21	3.21	0.199
GE content	18.4	18.8	0.17	17.4	18.5	0.17
Condensed tannins:						
-n	3	3		3	3	
-Extractable[1]	3.6	6.3	0.70	0.4	11.8	0.86
-Extractable[2]	0.0	7.8	1.58	0.1	15.6	1.94
-Protein-bound[2]	0.2	8.3	0.55	0.0	6.7	0.68
-Fibre-bound[2]	0.6	1.6	0.10	0.1	1.3	0.12
-Total[2]	0.8	17.8	1.76	0.2	23.6	2.16

[1] Vanillin-HCl method; [2] Buthanol-HCl method

4.4.2. Digestibility and metabolizability

Intake of DM, OM and gross energy recorded in the two experiments are shown in Table 4.3. Intakes of the two forages were similar at maintenance level of feeding, but at the higher level of feeding the deer consumed more *Lotus corniculatus* than perennial ryegrass.

No significant differences were found for apparent digestibility of DM, OM and energy in the two experiments; neither were there any significant interactions between forage, level of feeding and season for these parameters.

Table 4.3. Dry matter (DM) intake, organic matter (OM) intake, gross energy (GE) intake and apparent digestibilities of fresh perennial ryegrass or fresh *Lotus corniculatus* fed to weaner red deer during autumn (late March-May; Expt.1) and spring (October-December; Expt. 2) 1996 at maintenance (1M) and twice maintenance (2M) levels of intake.

	Perennial ryegrass		*Lotus corniculatus*		SEM
	1M	2M	1M	2M	
Expt. 1:					
DM intake					
-g/d	715.0	915.0	655.0	1075.0	106.54
-g/kgW$^{0.75}$/d	48.4	63.4	46.7	78.1	6.10
OM intake					
-g/d	626.5	802.7	585.7	974.7	95.09
-g/kgW$^{0.75}$/d	42.4	55.6	41.8	70.8	5.50
GE intake					
-MJ/d	13.1	17.2	12.3	20.4	1.90
-MJ/kgW$^{0.75}$/d	0.89	1.19	0.88	1.48	0.107
Apparent digestibility					
-DM	0.753	0.705	0.712	0.742	0.0359
-OM	0.786	0.773	0.728	0.761	0.0280
-Energy	0.750	0.712	0.681	0.721	0.0292
Expt. 2:					
DM intake					
-g/d	910.0	1390.0	950.0	1550.0	106.54
-g/kgW$^{0.75}$/d	48.0	72.6	46.7	74.5	6.10
OM intake					
-g/d	805.6	1268.6	863.4	1413.4	96.09
-g/kgW$^{0.75}$/d	42.5	66.3	42.4	67.9	5.50
GE intake					
-MJ/d	15.7	24.6	17.7	28.6	1.90
-MJ/kgW$^{0.75}$/d	0.83	1.23	0.87	1.32	0.107
Apparent digestibility					
-DM	0.707	0.736	0.727	0.760	0.0359
-OM	0.746	0.773	0.749	0.788	0.0280
-Energy	0.733	0.725	0.700	0.717	0.0292

Table 4.4 shows significantly lower methane energy losses, as a percentage of gross energy intake, on *Lotus corniculatus* than on perennial ryegrass (9.2 ± 0.48 vs. 10.9 ± 0.48%; $P < 0.05$), and on 2M than 1M level of intake (8.8 ± 0.48 vs. 11.3 ± 0.48%; $P < 0.01$). There were no significant interactions between forage, level of feeding and season. Faecal energy losses, as a percentage of gross energy intake, were not significantly affected by any of the treatments imposed (Table 4.4). Urine energy losses (% GEI) tended to be lower on *Lotus corniculatus* than on perennial ryegrass (5.6 ± 0.52 vs. 6.4 ± 0.52) and were significantly lower in spring than in autumn (4.5 ± 0.52 vs. 7.4 ± 0.52; $P < 0.05$). Metabolizability of both diets was not affected by forage, level of feeding or season, and the mean (± SEM) values for *Lotus corniculatus* and perennial ryegrass were 0.59 ± 0.015 and 0.60 ± 0.015 respectively.

Table 4.4. Methane, urine and faecal energy losses (% GEI), and metabolizability in weaner red deer fed either fresh perennial ryegrass or fresh *Lotus corniculatus* during autumn (late March-May; Expt. 1) and spring (October-December; Expt. 2) 1996 at maintenance (1M) and twice maintenance (2M) level of intake.

	Perennial ryegrass		*Lotus corniculatus*		SEM
	1M	2M	1M	2M	
Expt. 1:					
Energy losses:					
-Methane	10.9	9.2	10.6	8.4	0.96
-Faeces	25.0	28.8	31.9	27.9	3.12
-Urine	7.4	7.4	7.0	7.1	1.01
Metabolizability	0.61	0.57	0.55	0.60	0.031
Expt. 2:					
Energy losses:					
-Methane	13.2	10.0	10.0	7.6	0.96
-Faeces	26.7	26.0	30.0	28.3	3.12
-Urine	5.1	4.3	3.9	3.5	1.01
Metabolizability	0.60	0.63	0.60	0.63	0.031

4.4.3. Nitrogen balance

Table 4.5 shows the N balance for the deer fed *Lotus corniculatus* and perennial ryegrass. Apparent N digestibility was not significantly different between forages, but was significantly lower in spring than during autumn (0.740 ± 0.0192 vs. 0.680 ± 0.0192; $P = 0.06$) (Table 4.5). There was significantly higher urine N loss (g/d) when the deer were fed *Lotus corniculatus* compared to when fed perennial ryegrass (21.6 ± 1.60 vs. 16.3 ± 1.60; $P < 0.05$). However, this was not significantly different when expressed as a percentage of N intake. The interaction between forage and season was significant for urine N loss as g/d ($P < 0.05$) and as a percentage of intake ($P = 0.10$). Nitrogen retention either as g/d or percentage of N intake was not significantly different between forages (Table 4.5).

Table 4.5. Nitrogen balance in weaner red deer fed either fresh perennial ryegrass or fresh *Lotus corniculatus* during autumn (late March-May; Expt. 1) and spring (October-December; Expt. 2) 1996 at maintenance (1M) and twice maintenance (2M) level of intake.

	Perennial ryegrass		*Lotus corniculatus*		SEM
	1M	2M	1M	2M	
Expt. 1:					
N intake (g/d)	25.5	34.1	23.6	33.7	2.65
Faeces N loss					
-g/d	6.0	8.9	6.3	8.9	1.27
-% intake	24.1	26.9	26.5	26.5	3.83
Urine N loss					
-g/d	15.9	21.6	14.1	21.2	3.19
-% intake	62.2	61.8	59.8	62.8	8.74
N retention					
-g/d	3.6	3.6	3.2	3.6	2.22
-% intake	15.9	12.6	12.9	13.8	8.51
Digestibility	0.759	0.731	0.735	0.735	0.0383
Expt. 2:					
N intake (g/d)	20.0	32.7	31.2	49.1	2.65
Faeces N loss					
-g/d	7.0	11.6	9.5	13.6	1.27
-% intake	34.9	34.9	30.6	27.7	3.83
Urine N loss					
-g/d	14.3	13.3	22.4	28.8	3.19
% intake	71.4	40.4	72.0	59.0	8.42
N retention					
-g/d	-1.2	7.8	-0.6	6.7	2.22
-% intake	-6.2	24.7	-2.6	13.3	8.42
Digestibility	0.651	0.651	0.694	0.723	0.0383

4.4.4. Metabolizable energy intake, heat production and energy retention

Mean (± SEM) heat production, as a percentage of ME intake, was significantly lower for deer fed *Lotus corniculatus* than perennial ryegrass (0.61 ± 0.018 vs. 0.66 ± 0.018; $P = 0.07$), but was not significantly different between seasons (Table 4.6). Energy retention was close to zero at the maintenance feeding level in both experiments, indicating that the treatment objective of zero energy retention at maintenance level of intake was achieved (Table 4.6).

Table 4.6 Energy balance (MJ ME/$kgW^{0.75}$/d) in weaner red deer fed either fresh perennial ryegrass or fresh *Lotus corniculatus* during autumn (late March-May; Expt. 1) and spring (October-December; Expt. 2) 1996 at maintenance (1M) and twice maintenance (2M) level of intake; and the respective efficiency of utilisation of ME for growth (k_g).

	Perennial ryegrass		*Lotus corniculatus*		SEM
	1M	2M	1M	2M	
Expt 1:					
ME intake	0.54	0.85	0.48	0.92	0.072
Heat production	0.54	0.75	0.46	0.71	0.036
Energy retained	0.00	0.10	0.02	0.22	0.049
k_g	0.32		0.45		0.070
Expt. 2:					
ME intake	0.48	0.85	0.51	0.86	0.072
Heat production	0.59	0.75	0.54	0.71	0.036
Energy retained	-0.10	0.10	-0.03	0.14	0.049
k_g	0.54		0.45		0.070

The efficiency of utilisation of ME for growth (k_g) with deer fed *Lotus corniculatus* or perennial ryegrass during autumn and spring are presented in Table 4.6. No significant difference was found for k_g values between the two forages in the two experiments. However k_g values during autumn appeared to be higher when animals were fed *Lotus corniculatus* than when fed perennial ryegrass (0.45 ± 0.070 vs. 0.32 ± 0.070), and the k_g values for perennial ryegrass appeared to be higher in spring than in autumn whereas it showed no change between seasons in the young deer fed *Lotus corniculatus* (Table 4.6).

4.5. DISCUSSION

The most important findings of this study were the consistently lower energy losses as methane, urine and heat when the deer were fed *Lotus corniculatus* relative to feeding perennial ryegrass. Faeces energy losses were however similar on both forages. The efficiency with which ME was used above maintenance (k_g) was very low for autumn-grown ryegrass; and many sheep studies have found similar lower k_g for ryegrass grown in autumn than in spring (e.g. Corbett *et al.*, 1966; Blaxter *et al.*, 1971; Ribeiro *et al.*, 1981; MacRae *et al.*, 1985). The efficiency with which ME was used above maintenance (k_g) tended to be greater on *Lotus corniculatus* during autumn than on perennial ryegrass. Rattray and Joyce (1974) also found higher k_g values for white clover than perennial ryegrass fed to sheep. The sheep and deer data both therefore indicate that the relative ratios of the end products absorbed from legumes better match animal requirements for growth than the end products from grasses, especially during autumn.

In a comparative study on protein digestibility of sheep and deer fed added oak CT (*Quercus wislizenii*; Bissell and Weir, 1957) or quebracho CT (*Schinopsis* sp.; 3% or 6% of the diet; Robbins *et al.,* 1991), the deer was found to be more efficient at protein digestion on the CT-containing diets than the sheep. The inclusion of quebracho offering 3% CT resulted in only slight changes in protein digestibility in deer (64.0 ± 2.7 vs. 68.2 ± 2.3%) compared to the basal diet (an alfalfa-grain pellet) which contained no tannins. However the same diet resulted in 10 units decline in protein digestibility in the sheep (59.9 ± 2.8 vs. 70.0 ± 2.7%). Only at the higher inclusion levels (6% CT) did CT result in significant reductions in protein digestibility in both deer and sheep (Robbins *et al.*, 1991).

Austin *et al.* (1989) reported the presence of a CT-binding proline-rich protein fraction in the saliva of mule deer, which has a high affinity for binding CT in forages (Austin *et al.,* 1989; Robbins *et al.,* 1991). This protein was absent from sheep saliva. In a preliminary study, including saliva samples sent from New Zealand, A. E Hagerman (unpublished) noted the ability of the red deer saliva to also bind CT in forages. Robbins *et al.* (1991) reported greater recovery of the CT in the faeces of mule deer compared to sheep, and noted that tannin in the faeces was strongly bound by noncovalent bonds to some component presumed to be protein. Adu *et al.* (1997) also found a tighter binding of CT in the oesophageal fistulated (OF) extrusa samples of red deer compared to sheep fed the CT-containing forages *Lotus corniculatus* and sulla (*Hedysarum coronarium*). Because of the presence of CT binding proteins in the saliva of deer, CT concentrations in *Lotus corniculatus* might therefore be too low to have any significant impact on improving the

Van Soest (1994) indicated that the efficiency of utilisation of ME can be increased by feeding ionophores due, partly, to an inhibitory effect on rumen methanogenesis and the same may be true for forage CT. Consequently Molan *et al.* (1997) reported a depression in rumen bacteria activity with CT extracts, which might explain the increased tendency with which ME is utilised for growth when the deer were fed *Lotus corniculatus*. The faster growth of young deer grazing *Lotus corniculatus* than perennial ryegrass (Adu *et al.,* 1997) may therefore be partially explained by better utilisation of dietary energy in the deer fed lotus.

A further important result was that contrary to the role of forage CT in enhancing N retention in the sheep (Reid *et al.,* 1974; Egan and Ulyatt, 1980; Nuñez-Hernandez *et al.,* 1991; Wiegand *et al.,* 1995), N retention in deer fed the CT-containing *Lotus corniculatus* was not different to that of deer fed perennial ryegrass containing only traces of CT. The beneficial effect of moderate CT levels in forages in ruminant nutrition have been via a reduction in protein degradability in the rumen. CT in forages complex with forage protein during the process of chewing during eating, reducing protein degradation in the rumen. In the small intestines, the process is however reversed making the protein available for absorption. In sheep this reaction has been reported to result in increased non-ammonia nitrogen (NAN) flux to the small intestines (Waghorn *et al.,* 1987a), increased absorption of essential amino acids (EAA) (Waghorn *et al.*, 1987b), increased blood plasma cystine irreversible loss rate (Wang *et al.,* 1994) and increased milk yield, liveweight gain and wool growth (Wang *et al.,* 1996a,b).

efficiency of protein digestion in farmed red deer, but be ideal to increase the efficiency of protein digestion in the domestic sheep. As a species therefore deer may require a higher concentration of forage CT to show any beneficial effect on protein digestion and N retention. The use of such species as sulla (*Hedysarum coronarium;* 35-60 g CT/kg DM) and *Lotus pedunculatus* (50-100 g CT/kg DM) is therefore suggested. This is supported by the work of Hoskin *et al.* (1997) with trickle-infected weaner deer, who found increased liveweight gains, reduced nematode worm burdens in the gastrointestinal (GI) tract, and reduced faecal larval counts of *Dictyocaulus* sp. lungworm in calves fed sulla compared to calves fed lucerne (zero CT) and *Lotus corniculatus*.

However, relative to perennial ryegrass, *Lotus corniculatus* appears to have beneficial effects on the efficiency with which energy is utilised, and this could be due to effects of CT. The role of CT in the efficiency of utilisation of ME can however be better elucidated by administering polyethylene glycol (PEG; MW 3350), which selectively binds to forage CT and thus inactivates CT, to half the animals (Jones and Mangan, 1977). This would show if the improved energy utilisation on lotus was specifically due to CT.

In conclusion this study suggests that *Lotus corniculatus* has merit as a forage for weaner deer during autumn, due to better energy utilisation relative to deer fed perennial ryegrass. Grazing trials during this time are therefore recommended. It is however suggested that further calorimetry studies with larger animal numbers be undertaken to account for the high between animal variation observed in this study.

These should be undertaken with and without supplementation with PEG, to establish if any effects found are specifically due to action of CT.

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CHAPTER FIVE

GENERAL DISCUSSION

5.1. INTRODUCTION

New Zealand pastoral agriculture is based on grazing perennial ryegrass/white clover pasture. However the benefits of this forage is limited by summer shortages of dry matter and declining nutritive value during the long dry summers in NZ (Adam, 1988). Coupled with these limitations are the seasonal pattern of deer, such as the VFI, lactation performance and growth patterns, which are poorly aligned to the pasture production patterns in NZ (Barry *et al.,* 1991; Domingue *et al.,* 1991; Barry and Wilson, 1994). *Lotus corniculatus* is a summer legume with drought resistant qualities (Charlton *et al.* 1978) and dry matter yields in hot dry places of NZ between 10-12 t/ha/yr. (G. B. Douglas, personal communication). Besides, *Lotus corniculatus* is a moderate condensed tannin-containing forage with reduced rumen protein degradability, and improved overall efficiency of protein digestion and nitrogen (N) retention in sheep (Reid *et al.,* 1974, Barry and Manley, 1984; Barry *et al.,* 1986; Waghorn *et al.,* 1987a,b).

Improvements in nutritive value due to moderate concentrations of CT in forages fed to ruminants, particularly sheep, include increased NAN flux to the small intestine and increased absorption of EAA (Barry *et al.,* 1986; Waghorn *et al.,* 1987a,b, 1994); and increased blood plasma cystine irreversible loss rate (IRL) (McNabb *et al.,* 1993; Wang *et al.,* 1994).

One agronomic drawback of *Lotus corniculatus* is the difficulty at establishment due to a poorer competitive edge (Scott and Charlton, 1983). However once established the plant has been noted to rival lucerne and cooksfoot in persistency under lax grazing conditions in the South Island (Scott and Charlton, 1983). Initial results in the Manawatu region of the North Island also indicated over 66% persistency after 3 years (Charlton *et al.*, 1978).

However, most of the works on its nutritive value have concentrated on sheep, with only a few (Min, 1996; Min *et al.*, 1997; Hoskin *et al.*, 1997) involving deer. The aim of this thesis was to evaluate *Lotus corniculatus* for increasing the efficiency of growth in young deer in NZ using a mixture of grazing trials, indoor digestion experiments and indirect animal calorimetry.

5.2. EFFECT OF LOTUS CORNICULATUS ON PRE-WEANING GROWTH OF YOUNG DEER

Chapter Three revealed a higher feeding value (FV) of *Lotus corniculatus* for growing deer during summer than perennial ryegrass/white clover pasture. Liveweight gain and weaning weight were higher on *Lotus corniculatus* than on perennial ryegrass/white clover pasture. Other special purpose forages for deer production in NZ include chicory (Niezen *et al.*, 1993; Kusmartono, 1996; Kusmartono *et al.*, 1996) and red clover (Niezen *et al.*, 1993; Soetrisno *et al.*, 1994).

Table 5.1 is a comparison of liveweight gains of red deer hinds and their calves on different special purpose forages during lactation. Table 5.1 shows that the FV of *Lotus corniculatus* for pre-weaning growth of deer is essentially similar to that of chicory and red clover.

Table 5.1. Liveweight changes of red deer hinds and their calves during lactation grazing either perennial ryegrass/white clover pasture or one of three special purpose forages developed for deer production in New Zealand. Values in brackets are percentages relative to perennial ryegrass/white clover pasture fed in the same Experiment as 100, and may be used as an index of relative feeding value (FV).

Forage	Growth parameter			Reference
	Calf liveweight gain (g/d)	Weaning weight (kg)[1]	Hind liveweight change (g/d)	
Perennial ryegrass/white clover pasture:				
	331 (100)	46.7	27.2	Niezen *et al.* (1993)
	336 (100)	45.2[2]	-22.0	Kusmartono *et al.* (1996)
	380 (100)	46.6	2.5	Present study
Mean:	(100)	46.2	2.6	
Red clover:				
	410 (124)	50.5	69.9	Niezen *et al.* (1993)
Chicory:				
	385 (116)	49.3	6.7	Niezen *et al.* (1993)
	367 (109)	46.9[2]	-112.5	Kusmartono *et al.* (1996)
Mean:	(113)	48.1	-52.9	
Lotus corniculatus:				
	453 (119)	51.2	113.0	Present study

[1] Corrected to equal age.

[2] Age at weaning not given.

5.3. DIGESTION AND EFFICIENCY OF UTILISATION OF NUTRIENTS IN *LOTUS CORNICULATUS*

5.3.1. Energy

Feeding *Lotus corniculatus* in this study tended to increase the efficiency with which energy was used above maintenance in autumn (Chapter Four), due probably to the presence of CT in this forage. Energy losses as methane, urine and heat, were consistently lower with the feeding of lotus. Faecal energy loss was however similar to feeding perennial ryegrass. Forage CT inhibits the activity of rumen bacteria (Molan *et al.*, 1997) much as ionophores inhibits rumen methanogens (Van Soest, 1994) thus lowering energy losses. The tendency of increased efficiency of energy utilisation above maintenance might be partially responsible for the superior performance of deer fed lotus (Chapter Three). However the difference was not significant as a result of between animal variability. Further studies with larger animal numbers are therefore suggested.

5.3.2. Nitrogen

The N balance data (Chapter Four) indicate no significant advantage in *Lotus corniculatus* over perennial ryegrass in terms of N retention in deer. This is contrary to the action of CT in *Lotus corniculatus* in improving the protein status of sheep (Waghorn *et al.*, 1987a; Wang *et al.*, 1996a,b). The presence of CT-binding proteins in the saliva of deer and not in sheep (Austin *et al.*, 1989; Robbins *et al.*, 1991) might have inactivated a component of CT in *Lotus corniculatus* such that the level of CT in this plant was inadequate to have any effect on rumen protein degradation.

The results in Chapter Four indicate that the poorer performance of deer grazed on perennial ryegrass/white clover pasture might not be due only to limitations in duodenal N supply on summer pastures. Increased VFI might have led to increased milk production of hinds grazed on *Lotus corniculatus* compared to hinds grazed on perennial ryegrass/white clover pasture.

5.4. AREAS FOR FURTHER RESEARCH

The efficiency of utilisation of energy data (see Appendices 2 & 3) indicate the need for further studies with larger animal numbers as against the present number (n = 2), due to high variability between animals. Between 4 to 6 animals per forage are suggested. A PEG supplementation trial to study the effect of tannins on methane and heat energy losses may also help to elucidate the effect of CT on the efficiency of energy utilisation above maintenance.

Data from sheep experiments have established that grazing lactating ewes on *Lotus corniculatus* result in improved milk yield and milk quality (Wang *et al.*, 1996a,b). Increased milk production and improved milk characteristics may thus have been a factor in the better performance of deer grazed on *Lotus corniculatus* (Chapter Three). Further studies with *Lotus corniculatus* in deer could therefore include milk yield and milk quality measurements.

The potential benefit of CT in forages on reducing internal parasite burdens have been established in grazing sheep (Niezen *et al.*, 1994, 1995) and in indoor trials with deer (Hoskin *et al.*, 1997). A grazing trial on these aspects with deer is therefore required.

5.5. CONCLUSIONS

This study has revealed that as a summer feed for lactating deer hinds and their calves, *Lotus corniculatus* is superior to perennial ryegrass/white clover pasture and similar to other special purpose forages for deer production such as chicory (Niezen *et al.*, 1993; Kusmartono, 1996; Kusmartono *et al.*, 1996) and red clover (Niezen *et al.*, 1993). However CT levels in *Lotus corniculatus* do not seem to have any beneficial effect on the efficiency of protein digestion and N retention in farmed red deer as in the sheep, due probably to the presence of CT-binding proteins in the saliva of the deer and their absence in the sheep (see Chapter Three). Forages with higher CT levels such as sulla (*Hedysarum coronarium*) and *Lotus pedunculatus* are therefore suggested for farmed deer.

The slow establishment of *Lotus corniculatus,* and the special management practices required for its increased persistency may be a hindrance to its incorporation into the NZ pastoral agricultural system.

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APPENDIXES

APPENDIX 1. Apparent digestibility of dry matter (DMD), organic matter (OMD) and gross energy (GED) in weaner red deer calves fed either perennial ryegrass (PRG) or *Lotus corniculatus* (LOT) at maintenance (1M) and twice maintenance (2M) level of intake during autumn (Experiment 1; late March-May) and spring (October-December) 1996.

ID	Forage	Level	DM intake (kg/d)[1]	OM intake (kg/d)	GE intake (MJ/d)	Faeces DM (kg/d)	Faeces OM (kg/d)	Faeces GE (MJ/d)	DMD	OMD	GED
Experiment 1:											
1	LOT	1M	0.60 (0.60)	0.53	11.29	0.17	0.14	3.53	0.433	0.731	0.690
2	PRG	1M	0.71 (0.71)	0.62	13.08	0.21	0.17	4.06	0.499	0.730	0.690
3	PRG	1M	0.72 (0.65)	0.66	13.07	0.14	0.10	2.47	0.579	0.852	0.811
8	LOT	1M	0.71 (0.67)	0.65	13.19	0.21	0.18	4.31	0.499	0.731	0.673
1	LOT	2M	1.16 (1.26)	1.06	21.80	0.20	0.23	5.69	0.884	0.782	0.739
2	PRG	2M	0.84 (1.17)	0.76	16.14	0.14	0.15	3.94	0.643	0.799	0.756
3	PRG	2M	0.99 (1.21)	0.85	18.31	0.35	0.26	6.08	0.637	0.694	0.668
8	LOT	2M	0.99 (1.14)	0.91	19.03	0.27	0.23	5.64	0.716	0.750	0.708
Experiment 2:											
1	LOT	1M	0.90 (0.91)	0.83	16.33	0.26	0.21	5.10	0.641	0.751	0.688
3	PRG	1M	0.91 (0.89)	0.85	15.31	0.31	0.17	4.14	0.603	0.799	0.730
8	LOT	1M	1.00 (1.00)	0.92	19.01	0.26	0.23	5.46	0.742	0.755	0.713
17	PRG	1M	0.91 (0.84)	0.84	16.04	0.23	0.17	4.22	0.684	0.793	0.737
1	LOT	2M	1.73 (1.88)	1.59	31.84	0.45	0.38	9.17	1.283	0.760	0.712
3	PRG	2M	1.59 (1.81)	1.48	28.14	0.47	0.36	8.44	1.119	0.755	0.700
8	LOT	2M	1.37 (1.27)	1.26	25.30	0.34	0.29	7.03	1.027	0.768	0.722
17	PRG	2M	1.35 (1.26)	1.26	24.02	0.28	0.22	5.27	1.077	0.824	0.780

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[1] Dry matter intake in calorimeters shown in brackets.

APPENDIX 2. Energy losses in weaner red deer fed either perennial ryegrass (PRG) or *Lotus corniculatus* (LOT) at maintenance (1M) and twice maintenance (2M) level of intake in digestion trials and calorimetry studies during autumn (Experiment 1; late March-May) and spring (Experiment 2; October-December) 1996.

ID	Forage	Level	Faeces energy loss (% GEI)[1]	Urine energy loss (% GEI)	Methane energy loss (% GEI)
Experiment 1:					
1	LOT	1M	31.01 (0.559)	7.29	10.13
2	PRG	1M	31.04 (0.554)	6.78	11.87
3	PRG	1M	18.90 (0.659)	8.69	10.05
8	LOT	1M	32.75 (0.549)	6.59	11.00
1	LOT	2M	26.13 (0.622)	6.72	7.91
2	PRG	2M	24.45 (0.594)	9.37	8.70
3	PRG	2M	33.20 (0.549)	5.65	9.67
8	LOT	2M	29.66 (0.565)	8.28	8.94
Experiment 2:					
1	LOT	1M	31.24 (0.598)	3.24	9.46
3	PRG	1M	27.04 (0.575)	6.84	15.11
8	LOT	1M	28.72 (0.602)	4.80	11.06
17	PRG	1M	26.29 (0.626)	4.24	11.51
1	LOT	2M	28.80 (0.635)	2.78	7.50
3	PRG	2M	30.01 (0.582)	4.69	11.42
8	LOT	2M	27.79 (0.626)	5.02	7.80
17	PRG	2M	21.95 (0.680)	4.58	8.70

[1] Diet metabolizability shown in brackets.

APPENDIX 3. Energy balance in weaner red deer calves fed either perennial ryegrass (PRG) or *Lotus corniculatus* (LOT) at maintenance (1M) and twice maintenance (2M) level of intake in calorimetry studies during autumn (Experiment 1; late March-May) and spring (Experiment 2; October-December) 1996.

ID	Forage	Level	ME intake	Heat production	Energy retention	k_g
Experiment 1:						
1	LOT	1M	0.49	0.48	0.01	
2	PRG	1M	0.49	0.47	0.02	
3	PRG	1M	0.59	0.60	-0.01	
8	LOT	1M	0.47	0.45	0.02	
1	LOT	2M	1.03	0.75	0.28	0.49
2	PRG	2M	0.86	0.75	0.11	0.27
3	PRG	2M	0.84	0.75	0.08	0.39
8	LOT	2M	0.82	0.66	0.16	0.41
Experiment 2:						
1	LOT	1M	0.49	0.53	-0.04	
3	PRG	1M	0.44	0.60	-0.16	
8	LOT	1M	0.52	0.55	-0.03	
17	PRG	1M	0.52	0.57	-0.05	
1	LOT	2M	1.02	0.76	0.26	0.56
3	PRG	2M	0.88	0.78	0.10	0.59
8	LOT	2M	0.70	0.67	0.03	0.34
17	PRG	2M	0.83	0.73	0.10	0.49

APPENDIX 4. Nitrogen (N) balance in weaner red deer calves fed either perennial ryegrass (PRG) or *Lotus corniculatus* (LOT) at maintenance (1M) and twice maintenance (2M) level of intake in digestibility trials during autumn (Experiment 1; late March-May) and spring (October-December) 1996.

ID	Forage	Level	N intake	Urine N		Faeces N		N retention		Digestibility
			g/d	g/d	% intake	g/d	% intake	g/d	% intake	
Experiment 1:										
1	LOT	1M	21.85	13.59	62.17	5.38	24.64	2.88	13.19	0.754
2	PRG	1M	23.04	13.73	59.58	7.11	30.87	2.20	9.56	0.691
3	PRG	1M	27.86	18.04	64.74	4.84	17.38	4.98	17.88	0.826
8	LOT	1M	25.36	14.58	57.48	7.18	28.33	3.60	14.19	0.717
1	LOT	2M	27.18	21.93	63.83	9.33	27.18	3.09	8.99	0.728
2	PRG	2M	20.17	28.55	75.89	7.59	20.17	1.48	3.94	0.798
3	PRG	2M	30.67	14.64	47.74	10.29	33.55	5.74	18.71	0.664
8	LOT	2M	33.13	20.49	61.85	8.56	25.84	4.08	12.31	0.742
Experiment 2:										
1	LOT	1M	28.37	21.34	75.21	9.55	33.64	-2.51	-8.85	0.664
3	PRG	1M	19.90	17.74	89.15	7.29	36.63	-5.13	-25.78	0.634
8	LOT	1M	34.11	23.44	68.72	9.43	27.65	1.24	3.63	0.723
17	PRG	1M	20.09	10.77	53.63	6.65	33.08	2.67	13.29	0.699
1	LOT	2M	51.25	25.97	50.67	14.91	29.09	10.37	20.24	0.709
3	PRG	2M	37.40	15.82	42.29	14.21	37.98	7.38	19.73	0.620
8	LOT	2M	47.02	31.69	67.40	12.34	26.24	2.99	6.36	0.738
17	PRG	2M	27.97	10.78	38.54	8.91	31.86	8.28	29.60	0.681