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NUTRITIVE VALUE OF CHICORY (*Cichorium intybus*) AS A SPECIAL PURPOSE FORAGE FOR DEER PRODUCTION

A Thesis Presented in Partial Fulfilment of
the Requirements for the Degree of Doctoral of
Philosophy in Animal Science at Massey University

KUSMARTONO

1996

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 been already 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

(Kusmartono, Department of Animal Science, Massey University, Palmerston North, NEW ZEALAND. *Nutritive value of chicory (Cichorium intybus) as a special purpose forage for deer production*)

A series of grazing and indoor experiments were conducted at Massey University Deer Research Unit and Nutrition Laboratory, Palmerston North, New Zealand, to study the effects of grazing chicory (*Cichorium intybus*) and perennial ryegrass (*Lolium perenne*)/white clover (*Trifolium repens*) upon the growth, voluntary feed intake (VFI) and venison production of red and hybrid deer, and to study rumen digestion in deer fed either diet, to define factors responsible for the difference in feeding value (FV) between the two forages. Half of the animals in each experiment (Chpater 2) were grazed on either chicory or perennial ryegrass using a rotational grazing system, whilst for the indoor experiments (Chapter 3 & 4), rumen fistulated red deer individually kept in metabolism crates were fed fresh chicory or perennial ryegrass using automatic feeders at hourly intervals. In the last grazing Experiment (Chapter 5), to investigate the effect of condensed tannin (CT) in chicory and perennial ryegrass upon protein degradation, half of the animals were supplemented with polyethylene glycol (PEG; MW 3350) to inactivate CT and effects of CT were defined by comparing unsupplemented deer (CT acting) with PEG supplemented deer (CT inactivated).

1. The effects of grazing chicory or perennial ryegrass/white clover pasture upon growth and VFI of red and hybrid calves were compared both during lactation in summer of 1993 (Experiment 1; Chapter 1) and during post-weaning growth in autumn, winter and spring of 1993 (Experiment 2; Chapter 2). Relative to pasture, chicory had a higher ratio of readily fermentable:structural carbohydrate in all seasons and had higher organic matter digestibility (OMD) in summer and autumn but not in spring. Deer grazing chicory had higher VFI, bite weight, liveweight gain (LWG), and greatly reduced ruminating time than deer grazing pasture. Carcass dressing percentage and carcass weight of deer grazing chicory were higher than those grazing pasture. Hybrid deer grew better than red deer

and there were forage x genotype interactions in Experiment 2, with LWG and carcass weight of hybrid deer (especially stags) being much greater when grazed on chicory. Carcass weight for red deer and hybrid stags was 64.9 and 73.0 kg when grazed on chicory and 56.6 and 57.0 kg when grazed on pasture. Grazing chicory advanced the date of first cut velvet antler by 28 days and increased the weight of total harvestable (first cut+regrowth) velvet antler. It was concluded that grazing chicory increased carcass weight, especially in hybrid stags with increased growth potential, and increased velvet antler production. This was achieved by increased VFI in all seasons and increased OMD of chicory in summer and autumn relative to deer grazing pasture.

2. Intra-ruminal particle size reduction in rumen fistulated castrate red deer (*Cervus elaphus*) fed fresh chicory was compared with that in deer fed fresh perennial ryegrass in a two-period each of 12 days indoor experiment, with each period being 15 days long. Measurements included the efficiency of particle breakdown during the time allowed for rumination (<C.PART>) to below the critical size required to leave the rumen (passage through a 1mm sieve) and jaw activities (ie. eating and ruminating). Total eating time and the number of eating bouts were similar for deer fed each forage, but deer fed chicory had a greater chewing rate during eating (97.4 *v.* 81.0 chews/min), and a higher number of chews/g DM eaten (36.2 *v.* 31.5). Deer fed chicory had lower total ruminating time (30 *v.* 257 min/22.5h), lower number of boli ruminated (38 *v.* 440/22.5h), lower number of rumination bouts (5.4 *v.* 16.2/22.5h) and less chews per minute ruminating (16.5 *v.* 44.3) than those fed perennial ryegrass. Of the ten deer used to measure (<C.PART>), only four ruminated when fed chicory compared with nine when fed perennial ryegrass. Deer fed chicory had a higher efficiency of particle breakdown (<C.PART>; 0.64 *v.* 0.42), higher fractional degradation of particles >1mm to <1mm (9.2 *v.* 5.1%/h) and faster fractional disappearance of total DM from the rumen (10.2 *v.* 5.3%/h). All three measurements for chicory were similar in deer that did or did not ruminate, but with perennial ryegrass all values were considerably reduced in the deer that did not ruminate. It was concluded that chicory can be broken down faster in the rumen, with less

rumination being required than perennial ryegrass, and that some deer (60%) could break down swallowed chicory to below the critical particle size without ruminating at all. The faster clearance of DM from the rumen explains the high VFI of deer grazing chicory.

3. The effects of feeding chicory and perennial ryegrass indoors on apparent digestibility, rumen fractional disappearance rate (FDPR), rumen fractional degradation rate (FDR), rumen fractional outflow rate (FOR) and mean retention time (MRT; 1/FOR) were measured in deer fed at hourly intervals. The ratio of readily fermentable carbohydrate to structural carbohydrate was *c.* three times higher in chicory than in perennial ryegrass. Apparent digestibility of DM was higher in deer fed chicory than in deer fed perennial ryegrass (0.785 *v.* 0.727), whilst apparent digestibility of neutral detergent fibre (NDF) was lower in deer fed chicory (0.679 *v.* 0.755), due only to reduced hemicellulose digestibility (0.667 *v.* 0.783). Relative to deer fed perennial ryegrass, those fed chicory had higher rumen FDPR values for DM (14.5 *v.* 8.6%/h), soluble carbohydrate (69.9 *v.* 54.7%/h), cellulose (15.5 *v.* 9.8%/h) and lignin (6.8 *v.* 3.8%/h). Rumen FDR in deer fed chicory was higher than those fed perennial ryegrass for cellulose (11.4 *v.* 7.0%/h) and lignin (2.7 *v.* 1.0%/h), but tended to be lower for hemicellulose. Rumen FOR was higher and MRT was lower for both liquid and particulate matter in deer fed chicory compared to deer fed perennial ryegrass. It was concluded that rumen FDPR and apparent digestibility were much higher in deer fed chicory than in deer fed perennial ryegrass, due to faster degradation rates of most constituents in the rumen and faster outflow rates from the rumen. An exception was hemicellulose, where reduced rumen degradation rates and shorter rumen particulate MRT contributed to reduced apparent digestibility. Faster clearance from the rumen, due to both faster degradation and outflow rates may be used to explain the greater VFI, as well as faster growth rate in deer grazing chicory compared to those grazing perennial ryegrass. Faster rates of lignin solubility (as in the rumen (as measured by FDR) probably contributed to the more rapid breakdown of chicory in the rumen.

4. A laboratory and a grazing experiment were conducted to study the effects of CT in chicory and perennial ryegrass upon protein solubility and protein degradation. Nitrogen (N) solubility was measured *in vitro* in mineral buffer, using freeze dried samples of forages cut at the vegetative stage. Rumen ammonia concentration in rumen fistulated castrate red deer stags grazing either on perennial ryegrass or chicory was used as an index of protein degradation. Samples of rumen fluid were taken every 4 h for 24 h for ammonia concentration and pH. In both experiments, the effects of CT were deduced from responses to supplementation with PEG which binds and activates CT. PEG was given three times daily (total 20 g/day) in the grazing experiment. Small concentrations of CT were measured in both forages (0.3-2.5 g/kg DM), with chicory containing slightly higher total CT concentration than perennial ryegrass. Protein solubility was lower for chicory than for perennial ryegrass but was not affected by PEG addition for either forage. Rumen ammonia concentration was consistently higher for PEG-supplemented than for unsupplemented deer grazing each forage, suggesting that the low CT concentration in both forages was slowing protein degradation to ammonia without affecting protein solubility. Rumen pH tended to be slightly higher in PEG supplemented animals than in unsupplemented animals grazing either forage and mean rumen pH over all sampling times was much lower for deer grazing chicory, either with (5.81 *v.* 6.62) or without PEG supplementation (5.63 *v.* 6.44). It was concluded that action of CT contained in perennial ryegrass and chicory reduced protein breakdown in the rumen of deer grazing both forages, and that the low rumen pH found in deer grazing chicory may explain the low fibre digestibility of this forage.

5. Overall it was concluded that chicory was of very high FV and had excellent nutritional attributes for increasing deer production. However, its adoption as a forage by the NZ deer industry is likely to depend upon agronomic aspects, in particular devising grazing systems and breeding new chicory cultivars that have increased persistency and less tendency to go into a lignified reproductive state during summer. Chicory should be either sown alone or in a mixture with a legume such as white clover and should not be grazed in winter. Chicory should

not be grazed using accepted practices for perennial ryegrass/white clover pastures (ie including a grass component and grazing it in winter); rather special grazing systems as used in this thesis should be used to prolong the life of chicory stands to 5 or 6 years.

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LIST OF ABBREVIATIONS

ADF	acid detergent fibre
cm	centimetre
Cr-EDTA	chromium ethylenediamintetra acetic acid
CT	condensed tannin
D	digestibility
DM	dry matter
DMI	dry matter intake
DOMI	digestible organic matter intake
EAA	essential amoni acids
FDR	fractional degradation rate
FDPR	fractional disappearance rate
FO	faecal output
FOR	fractional outflow rate
FV	feeding value
GR	a measurement of total soft tissue depth over the 12th rib at a point 11 cm from the carcass line
GI	gastro intestinal
GIB	game industry board
GT	grazing time
h	hours
ha	hectare
k_f	efficiency of utilization of ME for fattening
k_g	efficiency of utilization of ME for growth
k_l	efficiency of utilization of ME for lactation
k_m	efficiency of utilization of ME for maintenance
kg	kilograms
l	litres
Ltd	limited

LWG	liveweight gain
ME	metabolisable energy
min	minute
MJ	megajoule
N	nitrogen
NAN	non-ammonia nitrogen
NaOH	sodium hydroxide
ND	not determined
NDF	neutral detergent fibre
NEAA	non-essential amino acids
NH_3	ammonia
NV	nutritive value
NZ	New Zealand
OM	organic matter
OMD	organic matter digestibility
OMI	organic matter intake
PEG	polyethylene glycol
rpm	revolutions per minute
SC	structural carbohydrate
SD	standard deviation
SE	standard error
t	tonne
µg	microgram
USA	United States of America
VFA	volatile fatty acid
VFI	voluntary feed intake
v/v	volume by volume
WSC	water soluble carbohydrate

INTRODUCTION

Chicory (*Chicorium intybus* L) is a perennial herb of the family Asteraceae that has a low rosette, and broad prostate leaves. It has been used for more than 300 years in its countries origin of Central Europe as the vegetable 'witloof' (George 1985) and to make artificial coffee extracted from its taproots (Arya & Saini 1984). Chicory has pale blue ray flowers that are usually open in the early morning and closed by mid afternoon following cross pollination by honey bees (McGregor, 1976). Flowering in chicory commences in early December and is continuous over several weeks, peaking in late December-early January. Each flower contains about 15-25 seeds which are in the form of achenes.

Because of its deep root systems, chicory is able to establish and grow well under dry conditions in summer (Clapham *et al.*, 1962). The first trial using chicory as an animal forage in New Zealand (NZ) was conducted in 1950 by O'Brien (1950). This trial concluded that chicory did not persist for any length of time, had little value as a forage plant, but had a good growth potential on low fertility soil which dried out in summer. Later, it was reported that under warm weather in spring, it produced a large amount of leaf DM (Lancashire 1978), but in late spring leafy stems bearing inflorescences emerged from the crown and reached more than 1 m in height if left ungrazed (Rumball 1986).

Since 'Grasslands Puna' chicory was released in 1985 as the world's first forage chicory (Rumball 1986), it has been subjected to many studies focussing on either its agronomic properties or feeding value (FV). For example, Hare *et al.* (1987) in Manawatu and Fraser *et al.* (1988) in Canterbury reported the highest DM production of chicory (25 tonnes/ha) from early December to middle of May. This agronomic merit of chicory offers opportunity to provide feed during the dry periods of summer-autumn when DM production of perennial ryegrass/white clover pasture and its quality decrease.

Studies on FV of chicory using sheep (Matthews *et al.* 1990; Komolong 1994), and cattle (Clark *et al.* 1990) conclusively showed a higher potential of chicory in supplying nutrients for growth than grass. Information on the FV of chicory for deer is only available from the study of Niezen *et al.* (1993) using lactating red deer hinds. This study also showed a higher response in growth of deer grazing chicory than those grazing perennial ryegrass/white clover. Therefore, this thesis focussed on evaluating chicory for producing venison by one year of age, using red and hybrid (0.25 elk;0.75 red) weaner deer and studying rumen digestion in deer fed either chicory or perennial ryegrass, to define factors responsible for the difference in FV between the two forages.

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Chapter 1

Review of literature

1.1. INTRODUCTION

This chapter, based on previously published studies, describes the current status of deer farming in New Zealand (NZ). Reference will be made to the commencement of deer farming in NZ, deer species present and their population on the farm, deer products and marketing issues. The seasonal cycles of growth, voluntary feed intake (VFI) and digestion in temperate deer will also be reviewed. The concept of a deer production system using inputs of special purpose forages will be developed with emphasis being given to feeding value (FV) and its components involved such as nutritive value (NV) and VFI.

1.1.1. The commencenent of deer farming in NZ

Deer are not indigenous to NZ, but the very first deer herd in NZ was imported and established in 1861. The importation of deer was continued by private individuals, Government and Acclimatization Societies until 1917. Among other introduced ungulates, deer have generally thrived most due to a combination of favourable factors including a moist, temperate climate with mild winters and a luxuriant, varied, evergreen vegetation of NZ. Since then, the number of deer increased markedly and they then caused extensive damage to forest plants and high-country watersheds, and contributed to a serious erosion problem. Shooting was then used to control numbers and for producing a variety of deer products (Challies 1985). The commercial sale of NZ feral venison started in 1960 to West Germany. Venison produced from this source peaked at about 4300 tonnes/annum in 1972 representing 130,000 carcasses, and thereafter rapidly declined, due to depletion of the feral deer (Spiers 1987). The reduction in a very lucrative form of game meat production then stimulated the commencement of commercial deer farming in NZ, to produce a regular supply of deer products under controlled conditions (Barry and Wilson 1994). Deer farming was legalised in NZ in 1969 by the Noxious Animals in Captivity Regulations and the Deer Farming Regulations, and the first commercial deer farm was set up in 1970 (Yerex 1982).

1.1.2. Species of deer and those farmed in NZ

Species of deer currently present in NZ were liberated from 1861 to the early 1900s, and they were mainly from Europe and North America. The species included red deer (*Cervus elaphus scoticus*), fallow deer (*Dama d. dama*), North American wapiti (*Cervus elaphus canadensis*), sambar deer (*Cervus u. unicolor*), sika deer (*Cervus nippon*), white-tailed deer (*Odocoileus virginanus borealis*), rusa deer (*Cervus timorensis russa*), and moose (*Alces alces andersoni*). Most were successfully established in the wild, especially red deer and fallow deer which were subsequently domesticated and farmed (Challies 1985; Wallis 1993). However, moose failed to establish, even though convincing sign of their presence was found in 1972 (Tustin 1974). The sambar and rusa originated from the tropics, whilst the rest came from temperate climates.

Drew & Hogg (1990) and Fennessy & Pearse (1990) reported that cross-breeding between the North American wapiti and the red deer has occurred in the wild, forming a high proportion of the feral Fiordland (South west of NZ) herd, now known as the NZ wapiti.

1.2. SEASONALITY IN TEMPERATE DEER

Based on their origin, farmed deer can be classified into temperate and tropical species. Temperate deer (ie. red, fallow deer and wapiti) exhibit strong seasonality as mainifested by pronounced annual cycle in VFI, growth and rumen digestion, whilst tropical deer (ie. sambar, rusa and Axis deer) show less seasonality.

1.2.1. Seasonality in voluntary feed intake

Voluntary feed intake (VFI) by red deer shows marked seasonal variation, being high during spring-summer and being low over the autumn-winter period (Fennessy *et al.* 1981; Kay & Staines 1981; Suttie & Kay 1985; Blaxter *et al.* 1988; Suttie *et al.* 1989). Pollock (1975) reported that the seasonal cycle was most pronounced in intact adult stags and less pronounced in young stags. Calves, adult stags, castrates, and hinds all demonstrated this seasonal cycle to

a greater or a lesser extent (Kay 1979). Similar cycles of dry matter intake (DMI) have been reported in other temperate and boreal species: the reindeer (*Rangifer taradan*; Ryg & Jacobsen 1982), the moose (*Alces alces*; Gasaway & Coady 1974), the North American wapiti (*Cervus elaphus canadensis*; Watkins & Hudson 1984), and the roe deer (*Capreolus capreolus*; Drozdz *et al.* 1975).

A seasonal cycle in VFI in red deer is associated with a seasonal cycle in basal metabolic rate, ambient temperature, activity, the quantity and availability of forage under outdoor conditions (Kay 1985) and is under photoperiodic control (Suttie & Simpson 1985). The pronounced seasonal changes in metabolic rate and appetite may be regarded as a response to the sum of the nutrient demands arising from the other seasonal cycles (ie. reproductive activities), rather than a primary response to changing daylength. Thus, increased appetite can be regarded as a consequence rather than cause of growth (Kay 1985). The changing of the daylength is the environmental stimulus that entrains the physiological cycle to season of the year (Barry *et al.* 1991), with plasma melatonin concentration believed to synchronize the cycles to changes in photoperiod.

The intake pattern of stags is similar to hinds until September (in NZ), then the VFI of stags increases, reaching its peak in February and markedly reduces during March and April with the onset of the breeding season (March-May). The intake of hinds was low over the winter and high in spring from September, reaching the highest levels in the October to January period and falling during autumn (Figure 1.1). The VFI cycle thus showed greater annual fluctuation in stags than in hinds.

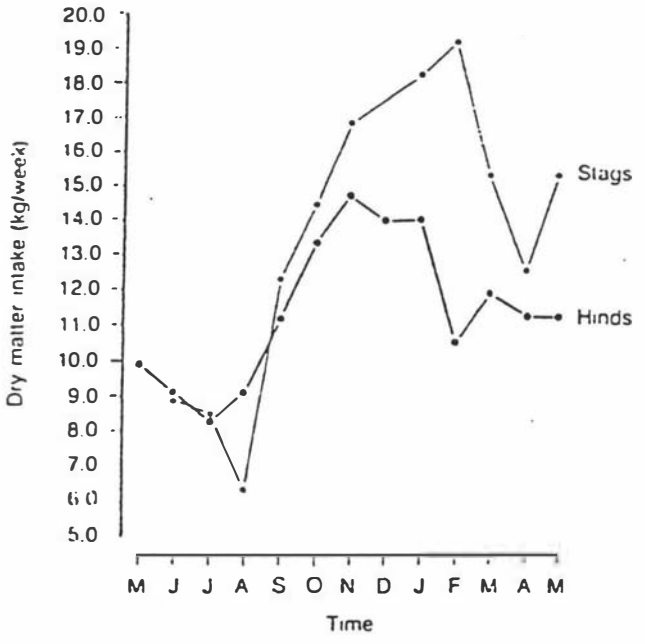

Figure 1.1. Mean monthly dry matter intake (DMI) of hinds and stags fed indoors for 1 year (From Suttie *et al*. 1987).

1.2.2. Seasonality in growth

Seasonal cycles of growth are functionally and intimately related with those of VFI, though they are not strictly identical (Freudenberger *et al*. 1994). The growth of juvenille red deer slows down greatly during their first winter, even when ample food is provided and then accelerates in spring (Fennessy 1981; Suttie *et al*. 1983). Although both the hinds and stags show seasonality in growth, a lower amplitude of seasonality was observed in hinds than in stags when they were offered the same diet (Suttie *et al*. 1987; Figure 1.2). The same evidence was also reported by Bandy *et a l*. (1970) who found that female black tailed deer (*Odocoileus hemionus*) grew faster for the first six months of life but thereafter males grew faster and for a longer period during each growth season, resulting in both a higher seasonal liveweight and a higher asymptotic body size.

As shown in Figure 1.2, the pattern of liveweight gain (LWG) of red deer stags were similar to hinds until August, but they grew more rapidly from August to March before losing weight during the breeding season between March and April. Adult deer lay down fat reserves during summer. Stags mobilize them during the

rut, whilst hinds mobilise them throughout the winter (Wood *et al.* 1962; Mitchel *et al.* 1976). Fennessy (1981) revealed that older stags experienced a considerable and unavoidable weight loss during the rut in the autumn period followed by a slight weight loss in the winter period.

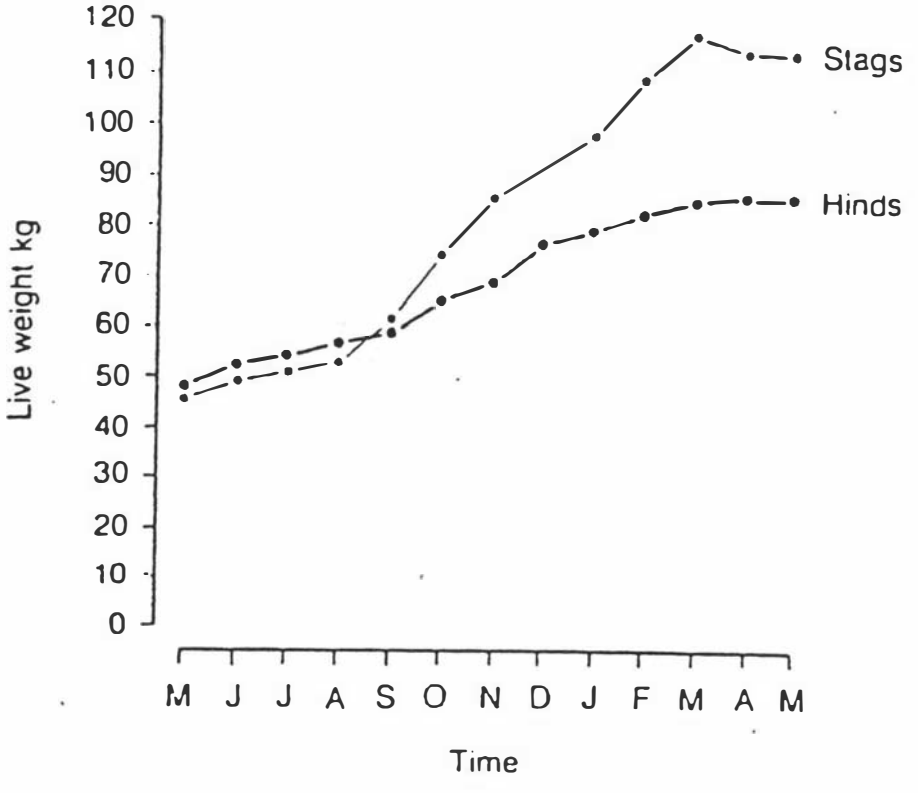

Figure 1.2. Mean monthly liveweight of stags and hinds fed indoors for 1 year (Adapted from Suttie *et al.* 1987). The deer were 5 months old at the start of the experiment and 17 months of age at the end.

1.2.3. Seasonality in digestion

As discussed earlier, red deer reach peak VFI during spring-summer and minimum VFI during autumn-winter. This evidence was not only observed in the field, but also found when deer were fed indoors with lucerne hay (Domingue *et al.* 1991; Freudenberger *et al.* 1994), low-quality grass or good-quality chopped or pelleted grass (Milne *et al.* 1978) or grass hay (Sibbald & Milne 1993). The seasonal increase in VFI of red deer during summer was not associated with any change in apparent digestibility (Barry *et al.* 1991; Domingue *et al.* 1991; see

Table 1.1). Sibbald & Milne (1993) concluded that the seasonal increase in VFI of red deer during summer is accompanied by a larger amount of rumen digesta load due to a greater extent to which the rumen wall is stretched in spring than in winter. Barry *et al.* (1991) added that a lower rumen fractional outflow rate (FOR; ie. increased mean retention time; MRT), higher rumen pool size, rumen ammonia and rumen acetate:propionate in summer compared to winter may also be contributing factors to apparent digestibility being similar between the two seasons.

Table 1.1. Seasonal changes in VFI, apparent digestibility, rumen pool size and rumen fractional outflow rate in castrated male sheep, goats and red deer fed a lucerne chaff diet

Paremeter	Season	Goats	Sheep	Red deer	S.E.
Voluntary DM intake ($g/kgW^{0.75}$/day)	S[a]	68.7	52.2	62.5	3.20
	W	57.4	54.8	46.7	4.24
DM digestibility	S	0.56	0.54	0.57	0.004
	W	0.62	0.56	0.55	0.008
Rumen pool (DM+liquid) ($g/kgW^{0.75}$)	S	340	275	289	17.5
	W	268	307	191	13.4
Fractional outflow rate (FOR)/hr					
- Cr-EDTA	S	0.108	0.104	0.158	0.0054
	W	0.096	0.103	0.163	0.0056
- Ru-P	S	0.076	0.069	0.070	0.0038
	W	0.068	0.069	0.076	0.0034
- Lignin	S	0.037	0.033	0.028	0.0016
	W	0.035	0.033	0.035	0.0014
- Cr-EDTA/Lignin	S	3.07	3.24	5.97	0.308
	W	2.82	3.12	4.77	0.110

[a]S, summer; W, winter. Adapted from Domingue *et al.* (1991)

Table 1.1 shows that rumen FOR of liquid as marked by Chromium Ethylene Diaminetetra acetic acid (Cr-EDTA), is especially fast for red deer, and the rate at which water leaves the rumen in relation to particulate matter is faster for red deer than for sheep or goats (Barry *et al.* 1991; Domingue *et al.* 1991). Total rumen volume did not change between seasons, but there were increases in total rumen pool size, rumen pool size of liquid, ammonia and volatile fatty acids (VFA) concentrations in summer (Freudenberger *et al.* 1994). The latter authors argued that this may be a digestive adaptation that deer have evolved to increase rumen MRT (1/FOR, and hence time for microbial attack) under conditions where VFI increases in summer, ensuring that apparent digestibility does not decline with the summer increase in VFI. Mean retention time of particulate matter in the rumen of red deer can be calculated to be 35.7h in summer and 28.6h in winter (Domingue *et al.* 1991). Deer have evolved a digestive system in which rate of digesta passage through the rumen is much faster than that for sheep and accomodate summer increases in VFI by stimulating digestion through necessary changes in digestive characteristics (Katoh *et al.* 1991).

1.3. DEER INDUSTRY IN NZ

1.3.1. Deer population

The NZ deer farming industry has grown dramatically since the early 1980's (Fennessy *et al.* 1991). As shown in Figure 1.3*a*, the deer population was about 1.4 million in 1992 and decreased to about 1.3 million in 1994 (Game Industry Board; GIB 1994*a*). Predicted population of farmed deer up to the year 2000 is shown in Figure 1.3*b* (GIB 1993*a*). About 85% of the recorded deer population in 1993 were pure red deer, 10% were wapiti (elk) or wapiti-red hybrids, and 5% were fallow (Guild 1993).

(a) (b)

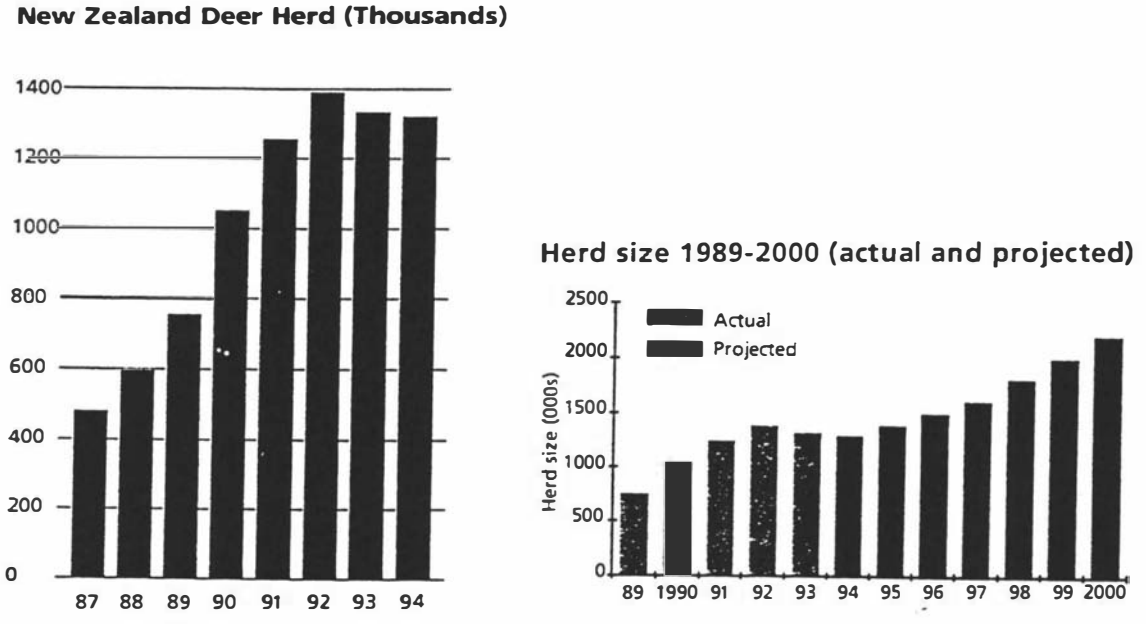

Figure 1.3. (*a*) Actual NZ deer herd 1987-1994, and (*b*) projected size of the NZ farmed deer herd for the years 1989-2000. (Adapted from GIB 1993*a*; 1994*a*).

1.3.2. Venison production and carcass quality

Venison production is a new and rapidly growing form of animal production in NZ (Ataja *et al.* 1992) and most NZ farmers specialising in venison production produce stags for slaughter at age of 12-24 months (Barry & Wilson 1994) or even longer (15-27 months; Drew 1985). The nature of the seasonal pattern of VFI and liveweight gain (LWG), which is characterised by high rates of growth in spring and summer and low gain in autumn and winter, dictates the success in achieving standard slaughter weight (92 kg LW or > 50 kg carcass). Older stags may lose 25% of their weight during the rut and winter and zero growth was observed over the 6-7 months autumn-winter period by rising two-year-old stags (Adam 1984). It is economically preferable to produce carcass weighst of 50-65 kg at one year of age or less (by August-November) coincinding with peak market demands and high sale price rather at an older age.

Options for achieving a desirable carcass weight at 10-12 months include the use of large deer species such as Canadian Wapiti x red deer sires to produce hybrids (Drew & Hogg 1990; Fennessy & Pearse 1990). Drew & Hogg (1990) reported that hybrid animals have much heavier carcass at a young age (69 kg carcass at 11 months) and they could also be used as a terminal sire over red deer.

Another option is growing pasture species that produce high dry matter (DM) during summer-autumn or during winter. Grazing weaners of Moata annual ryegrass, a highly productive grass during winter and spring, along with its grazing management and hormonal manipulation has been reported 75% of red deer stags attained 50 kg carcass weight or greater by one year of age (Ataja *et al.* 1992). Inputs of a summer-autumn growing pasture species such as red clover has led to a higher percentage (100%) of red deer stags achieving 50 kg carcass weight or greater by one year of age or less (Semiadi *et al.* 1993; Soetrisno *et al.* 1994).

With regard to carcass quality, it has been reported that deer have a superior carcass weight to liveweight ratio compared with other ruminants, with dressing-out percentage of mature pasture-fed stags being higher (59%) than young sheep and cattle (40-50%; Drew 1985; Table 1.2). The deer has a different muscle distribution than cattle, with muscle groups in the hind leg and saddle areas being proportionately 8 and 23% heavier respectively in deer than the same muscle in cattle (Berg & Butterfield 1976). Deer carcasses comprise 52-54% of high-priced cuts, 39-42% of second class cuts, and about 6% of discarded bone (Drew 1985). From a fat composition point of view, deer is considered to have greater potential to produce lean meat than sheep or cattle, as Fennessy *et al.* (1982) reported that one kg of carcass gain in young stags comprises 0.23 kg fat compared with 0.41 kg fat/kg gain in ram lambs. Nutrient content of venison from red deer as reported by Drew & Seman (1987) is high in protein and iron, but very low in fat, energy and cholesterol (Table 1.3). Such carcass characteristics of venison may become increasingly important as consumers become

increasingly health conscious, and discriminate against fatty ruminant meats (Wright 1993).

Table 1.2. Carcass weight (CW) and fatness in lambs, bulls and stags

	CW range (kg)	Carcass fat (% CW)
Ram lambs	15-20	22-27
Bulls	200-240	18-22
Stags	55-70	8-12

Adapted from Drew (1985)

Table 1.3. Nutrient composition per 100 g of untrimmed venison meat red deer

	Loin	Leg
Protein g)	24.7	23.8
Fat (g)	3.3	3.0
Water (g)	70.8	71.2
Minerals (g)	1.4	1.9
Energy (KJ)	545	519
Cholesterol (mg)	66	74

Adapted from Drew & Seman (1987)

1.3.3. Velvet antler production

Velvet antler of the male deer is grown annually and harvested at an early stage of growth (approximately 55-60 days from casting). In NZ, the velveting season occurs from October through to early February. The procedure must be done under the supervision of veterinarian, and the use of analgesic drugs has become compulsary for pain prevention (Code of Recommendations and Minimum Standards for the Welfare of Deer During the Removal of Antlers, Ministry of Agriculture and Fisheries; MAF 1992). After removal, the velvet has to be

immediately cooled and frozen, then packaged, pending sale or drying for further processing (Seman *et al.* 1989). Most velvet exported from NZ is processed in one of about 24 velvet drying plants, producing a consistent quality with the highest standards. The shape, and weight of antler are important criteria of quality, and it is determined by the age and breed type of the stags, the stage of growth at harvest time, nutrition, and the care with which the velvet is removed and frozen (Muir & Sykes 1988).

There was an increase in velvet production in NZ as stag numbers grew rapidly from 1988, peaked in 1992 at 372,000 and it grew slower until 1994 as the stags number dropped in 1993 to a low of 345,000 (GIB 1994*b*; Figure 1.4).

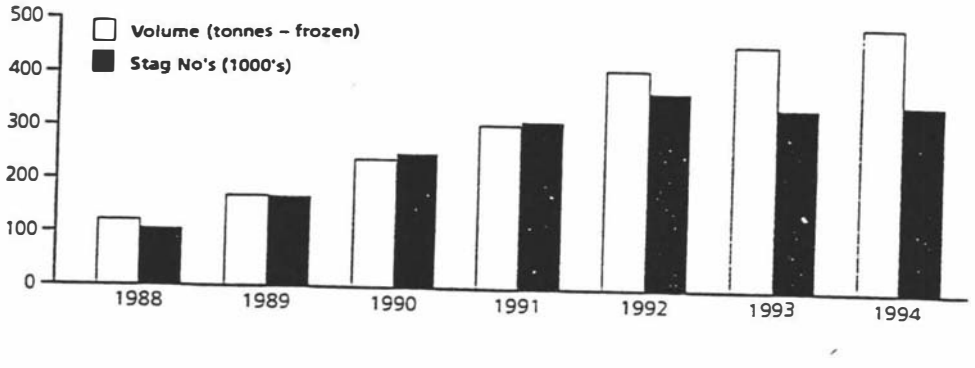

Figure 1.4. New Zealand deer velvet production (GIB 1994*b*)

1.3.4. Export market requirements and seasonal fluctuations in price schedule of venison.

The future of the NZ deer industry greatly depends on the development of markets which are able to pay acceptable prices for high quality deer products. Venison production in NZ is market driven, where the profitability is mainly based on selling the last, not the first kilogram. Therefore, the differences in

requirements for venison from market to market have been identified and the market strategy to satisfy the consumers has also been initiated.

Since 1992, the NZ marketing strategy has been adopting a two brand marketing strategy, focussing on the product's and NZ strengths, quality assurance and building market demand. ZEAL™, a trademark of ZEAL quality assurance of the NZ venison, has been used to break the traditional seasonal barrier, assure its year-round availability, and certify and warranty the quality standards of the industry products. Likewise, CERVENA™ brand launched in 1993 has been used to differentiate the quality, tenderness, consistency, cleanness and hygiene of NZ farm raised venison complying with defined age specifications from feral products (GIB 1993*b*). ZEAL is used to indentify NZ farm raised venison in traditional markets (ie. Germany); CERVENA is used in developing new markets (ie. United States of America; USA & NZ).

Chilled venison constitutes an over increasing proportion of NZ venison exported to Northern Hemisphere for winter consumption. Among the country consumers, Europe (especially Germany) is still the main market for venison, followed by USA, Asia and other emerging markets. Export earnings for the deer industry for the year to March 1995 reached NZ$ 196.4 million, and of this, venison contributed NZ$130.8 million, velvet NZ$ 53.2 million, and co-products NZ$12.4 million (Figure 1.5; GIB 1995).

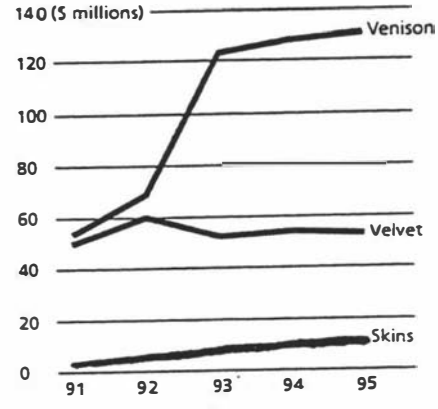

Figure 1.5. Export earnings from the deer products for the NZ deer industry (GIB 1995).

In NZ , the price of venison ($/kg carcass) varies with carcass weight and season. It is highest when carcass weight is in the range of 50-65 kg and is produced between September to November. As shown in Figure 1.6, the venison schedule is high from September to November in response to a high demand for chilled venison during the Northern Hemisphere winter. The most profitable choice for venison producers is either slaughtering rising two-year-old stags or slaughtering rising one-year-old stags at a target slaughter liveweight of 92 kg or more (>50 kg carcass weight) during September to November.

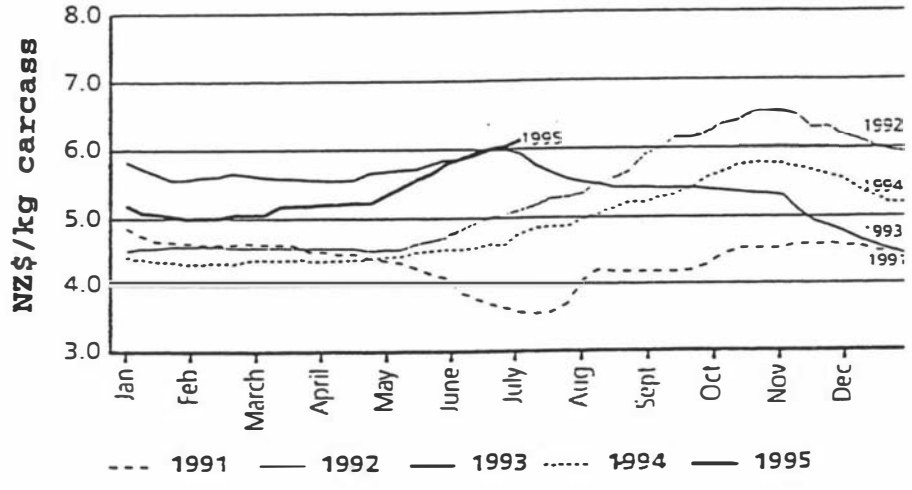

Figure 1.6. Seasonal variations in venison schedule ($/kg), prime 50-70 kg carcass during 1991 and 1994 (GIB 1995).

1.3.5. Deer feed requirements

Feed or energy requirements for red deer stags have been reported by Fennessy *et al.* (1981; Table 1.4). They estimated energy requirements for maintenance (ME_m) of red deer stags based on relationship derived indoors between LWG and metabolisable energy intake (MEI) for stags and for mixed-age deer stags fed outdoors in winter. The stags penned individually indoors were fed *ad libitum* on high quality barley-linseed pelleted diets containing approximately 11 MJ ME/kg DM and 26 g N/kg DM. They concluded that ME_m of stags fed indoors and outdoors were 0.57 and 0.85 MJ ME/$kg^{0.75}$/day respectively.

Since energy requirement of grazing deer is difficult to measure, Fennessy *et al.* (1981) estimated their ME requirements for maintenance at 30, 50, 20 and 10% above that of animals kept indoors during autumn, winter, spring and summer respectively (ie. 0.74, 0.85, 0.68 and 0.63 MJ ME/kg$^{0.75}$/day). Using the same method they estimated ME requirement for liveweight gain (ME_g) and for suckling calf being 37 and 65 MJ ME/kg LWG respectively. Meanwhile, Suttie *et al.* (1987) estimated the ME_m and ME_g of red deer hinds penned indoors being 0.52 MJ/kg$^{0.75}$/day and 53 MJ/kg LWG respectively.

Table 1.4. Seasonal ME requirement and target livewight of red deer

	Target live weight (kg)	Daily ME requirement (MJ ME/head/day) autumn 65d	winter 100d	spring 100d	summer 100d	Annual total ME requirement (MJ ME/head) 365d
Stags						
(age-years)						
0.25-1.25	48	16.0	20.9	27.0	26.5	8300
1.25-2.25	105	24.5	28.0	31.5	30.0	10500
2.25-3.25	140	23.5	33.0	38.0	36.2	12200
3.25-4.25	175	19.5	33.0	38.5	38.2	12200
4.25-5.25	190	18.5	34.5	43.5	39.0	12900
>5.25	200	19.0	26.0	42.5	38.0	12900
Hinds						
(age-years)						
0.25-1.25	44	15.0	17.5	22.0	21.0	7000
1.25-2.25	83	20.5	23.5	23.5	45.0	10500
2.25-3.25	94	22.5	24.0	47.5	47.5	11000
>3.25	100	23.5	22.5	24.5	47.5	10900

Adapted from Fennessy & Milligan (1987)

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

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

$ME = S[0.57\ LW^{0.75}] + 37\ DLWG$

where, ME is metabolisable energy requirement in MJ ME/day. S is the 'seasonal coefficient'; 1.30 for autumn (65 d), 1.50 for winter (100 d), 1.20 for spring (100 d) and 1.10 for summer (100 d); LW is liveweight in kg; DLWG is daily livweight gain in kg/day

(ii) For lactating hinds and their calves at foot

ME = S[0.57 $LW^{0.75}$ hind] + 37 DLWG hind + 65 DLWG calf

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

1.3.6. Seasonal feed supply and its relationship to deer feed requirements

Under NZ pastoral deer farming conditions utilizing conventional ryegrass/white clover pasture, a feed surplus usually occurs on a deer farm in early and mid spring, whilst a feed deficit takes place during January, February and March and in winter. Due to a high feed requirement during lactation, while feed supply decreases, P.R. Wilson (pers. comm) suggests that early weaning (late February) and slaughtering stags in late spring (one year old) could be used as a strategy to lower the feed requirement during the dry summer period (Figure 1.7).

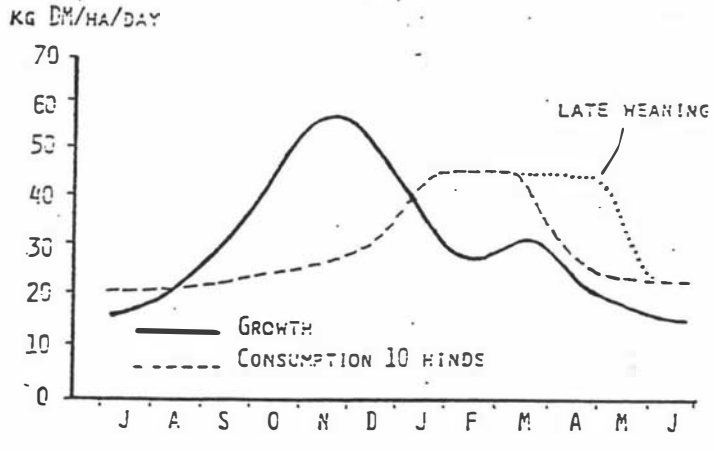

Figure 1.7. Average pasture growth rates in the Manawatu Downland. (P.R. Wilson, pers.comm).

Managing a combination between venison stags and breeding hinds is another option to match feed supply and demand (P.R. Wilson, pers.comm.; Figure 1.8). By applying such combination of stags and hinds in the Manawatu region, the feed deficits are reduced, and the surplus in spring is less.

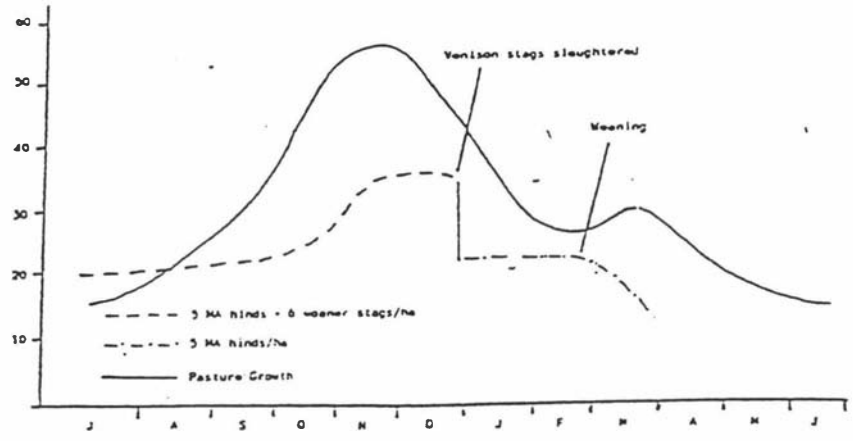

Figure 1.8. A stylised seasonal feed supply and demand pattern for the Manawatu Downland, with a venison stags and breeding hinds operation. (P.R. Wilson, pers.comm.).

Another strategy to balance feed supply and demand patterns is to use pasture species with whose patterns of growth are different from ryegrass/white clover (P.R. Wilson, pers.comm).

1.4. THE NEED FOR SPECIAL PURPOSE FORAGES IN DEER PRODUCTION.

1.4.1. Requirements of a special purpose forage crop.

It is well-known that deer in NZ calve during November-December, and that hinds are at peak lactation over summer, when the production and quality of commonly used pasture (ie. perennial ryegrass/white clover) declines due to moisture stress (Adam 1988). Since the potential for growth of young deer is slow during winter, but high during summer (lactation) and autumn (post-weaning), this potential during summer/autumn may not be realised due to reduced pasture production and quality. This reduces the ability to produce carcass weight of 50-65 kg by one year of age. Other than hormonal and grazing management manipulation (Ataja *et al.* 1991), the use of special purpose forages that have deep tap roots for water extraction and have high DM production during summer-autumn, and high nutritive value may be used to achieve the above mentioned goal. Two special purpose forages that have potential for deer production in NZ are red clover (*Trifolium pratense*) and chicory (*Cichorium intybus*).

1.4.2. Historical use of chicory in NZ farming systems.

Chicory is a perennial herb originating from Central Europe, where it has been used for more than 300 years. Chicory is also grown as the leaf vegetable 'witloof' (George 1985), and the taproot is also used to make artificial coffee (Arya & Saini 1984).

The first trial using chicory as an animal forage in NZ was conducted in 1950 by O'Brein (1955). This trial concluded that either grown as a monoculture or mixed pasture, chicory did not persist for any length of time, had little value as a forage plant, but had a good growth potential on low fertility soil which dried out in summer. Later, it was reported that chicory showed good drought resistance characteristics, with excellent DM production under rotational grazing in Palmerston North (Lancashire 1978), though large variation between plants was observed (Rumball 1986). After selection and a breeding programme in the 1970's, 'Grasslands Puna' chicory was released in 1985 as the world's first forage cultivar of chicory (Rumball 1986).

1.4.3. Agronomic merits of Puna chicory.

It has been reported that production of Grasslands Puna chicory varies depending upon factors such as sowing time, plant density and grazing management applied. When chicory was sown in spring, it established very rapidly and was strongly dominant through the late spring, summer and autumn. However, autumn sowing in mixed pastures, has resulted in chicory being less dominant because of its dormancy throughout winter (Lancashire & Brock 1983).

With regard to plant density, Hare *et al.* (1987) suggested chicory should be sown in the spring at about 2 kg seed/ha. They also reported the highest DM production of 25 tonnes/ha was recorded from early December to the middle of May when chicory was grown in a 15 cm row spacing in pure swards as compared to 8 tonnes/ha when its row spacing was increased to 30 or 60 cm. A similar DM production has also been reported by Fraser *et al.* (1988) in the Canterbury environment. The study of Lancashire (1978) showed that when

grown in mixed swards, chicory contributed 6, 22 and 40% of the total sward production during spring, summer and autumn respectively (Figure 1.9). Figure 1.9 shows that chicory is suitable as summer-autumn feed and its contribution will be significant during the time when perennial ryegrass/white clover production declines (Adam 1988).

Grazing management also affects chicory production. Figure 1.10 shows that in mixed grass swards under set stocking all year, the pasture became very strongly ryegrass/white clover dominant and chicory disappeared rapidly, but under rotational grazing, this crop persisted well and maintained almost 10% of the total yield in summer (Lancashire & Brock 1983). Under management which combined set-stocking and rotational grazing, chicory tended to decline slowly. A rotational grazing for 3-5 days, with a back fence, is recommended to achieve optimum utilisation and performance of lambs and ewes grazing chicory (Moloney & Milne 1993). Set stocking on chicory during spring by selective grazing animals (e.g. deer and yearling cattle) was able to maintain a constant herbage height (10-15 cm) and an appropriate leaf to stem ratio (3:1; Clark *et al.* 1990). In order to prevent stems becoming mature and dominant, hard grazing should be imposed on chicory (eg. every 5 weeks) during spring grazing (Matthews *et al.* 1990; Clark *et al.* 1990). The study of Li *et al.* (1994) suggested that a high proportion of leaf relative to stem of chicory can be maintained by applying hard grazing (50 mm stem height), as this could control the primary reproductive stem of chicory and maximise leaf mass.

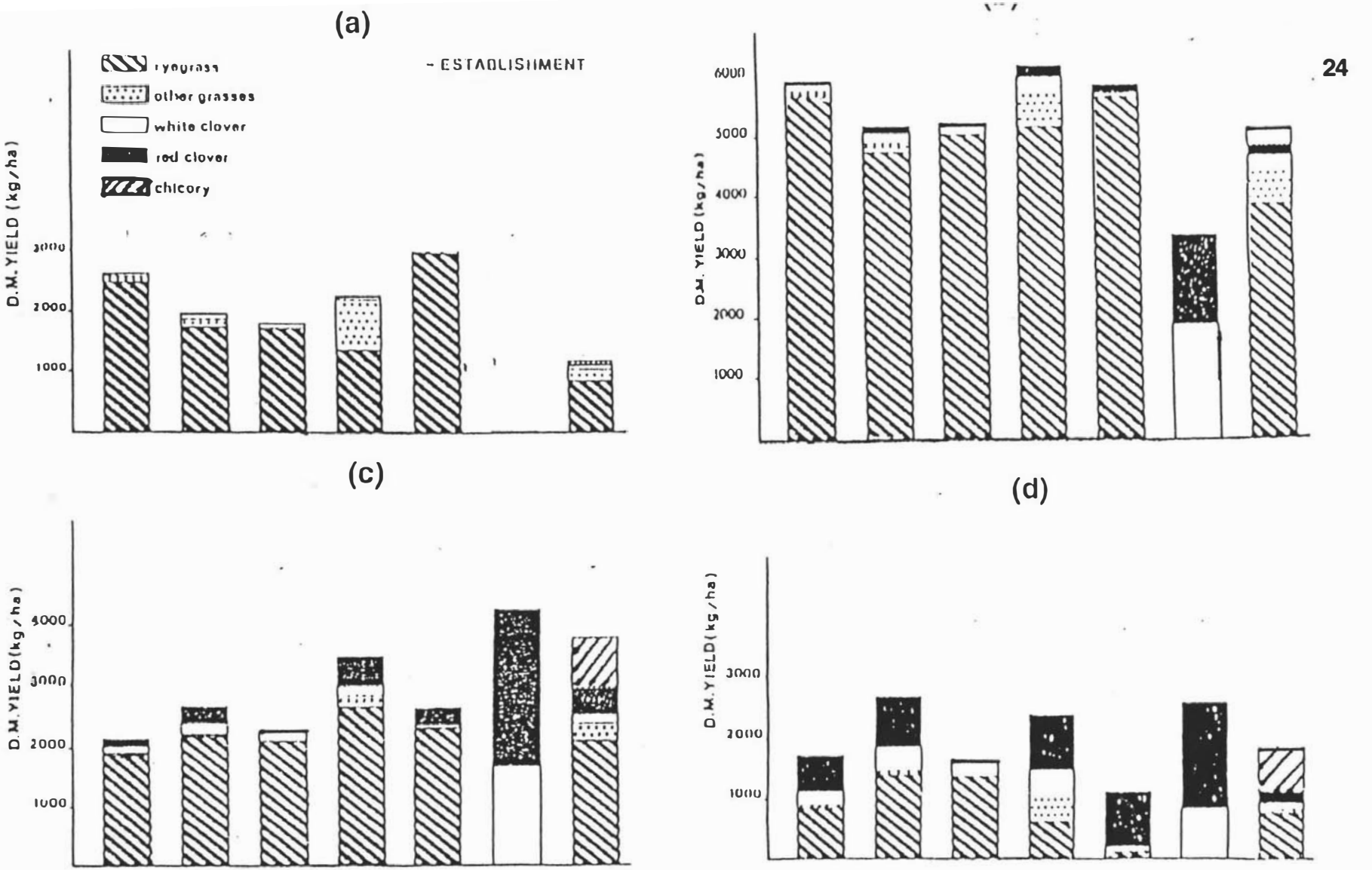

Figure 1.9. Dry matter yields of chicory in mixed pasture (Kg/ha) during: (a) autumn-winter; (b) spring; (c) summer and (d) autumn. (Adapted from Lancashire 1978).

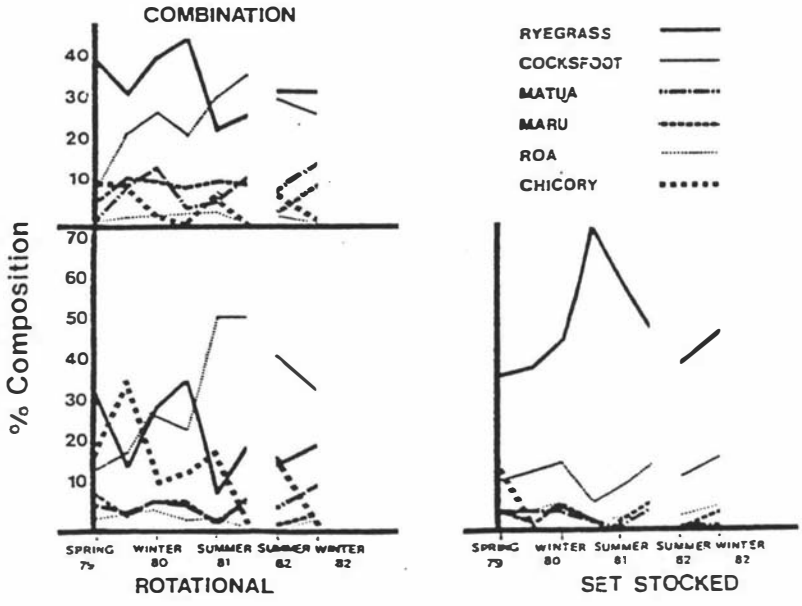

Figure 1.10. Effects of 3 grazing systems on species composition. (Adapted from Lancashire & Brock 1983).

1.4.4. The use of chicory for animal production.

'Grasslands Puna' chicory has been reported low in nitrogen (N), silicon and iron concentrations, but high in potassium, sodium, calcium, sulphur, boron, manganese, zinc and molybdenum concentrations under pot studies (Crush & Evans 1990; Rumball 1986). Low N contents of chicory have also been observed when this forage was given to calves under grazing (Fraser *et al.* 1988; Clark *et al.* 1990) or fed indoors to sheep (Komolong *et al.* 1992) and to deer (Niezen *et al.* 1993; Hoskin *et al.* 1995). Clark *et al.* (1990) reported that DM digestibility of chicory flowers were higher (81.0%) than that of leaves (77.0%) and of stems (46%). When fed to castrate fistulated deer indoors, it was reported that chicory had higher DM, organic matter (OM) and energy digestibility, but lower fibre digestibility than perennial ryegrass (Hoskin *et al.* 1995). It was argued that a high digestibility value in chicory was associated with its higher ratio of readily

fermentable:structural carbohydrate than perennial ryegrass.

A study of Fraser *et al.* (1988) evaluating the effect of herbage allowance levels on LWG showed that an allowance of 90 gDM/kg LW/day was sufficient to give a maximum LWG (880 g/hd/day) to 6-8 months old calves, since the increased pasture allowance up to 100 gDM/kg LW/day resulted in little further increase on LWG (930 g/hd/day). Calves grazing on chicory achieved similar LWG with those grazing perennial reygrass/white clover pasture both at high (630 *v.* 620 g/hd/day) and low herbage allowances (570 *v.* 600 g/hd/day; Clark *et al.* 1990). Herbage allowances used for chicory in that study were 323 and 84 gDM/kg LW/day respectively, whilst those used for perennial ryegrass were 210 and 68 gDM/kg LW/day respectively. Fraser *et al.* (1988) suggested that herbage allowance of 90 gDM/kg LW/day may be optimal, as increasing allowance up to 323 gDM/kg LW/day resulted in little further increase in LWG of the calves. Higher allowances have resulted in a high residual containing a lot of leaf and secondary stem but lower allowances may result in conditions where animals utilise most of the leaf but LWG will be close to maintenance (Clark *et al.* 1990). Therefore, it is very important to consider appropriate pasture allowances to maintain chicory quality and to achieve high animal production responses from chicory.

Komolong *et al.* (1992) reported that lamb growth over 6 weeks was higher on chicory (268 g/day) than on Wana cocksfoot (205 g/day). They argued that a higher growth response of lambs grazed on chicory was due to a higher amount of N reaching duodenum, at the same level of intake, compared to lambs grazing Wana cocksfoot. A higher duodenal non-ammonia (NAN):digestible organic matter intake (DOMI) ratio was found for chicory. None of the N consumed by lambs grazing chicory was lost as ammonia, whilst 39% of the N consumed by those grazing Wana cocksfoot was lost as ammonia from the rumen.

Chicory has also been used for deer production (see Niezen *et al.* 1992; Hunt 1993; Hoskin *et al.* 1995). Grazing lactating hinds and their fawns on chicory resulted in a 16% increase in growth of red deer fawns relative to those grazing

perennial ryegrass/white clover pasture (Niezen *et al.* 1993), whilst Hunt (1993) found grazing chicory increased weaning weight of red deer fawns by 15%. An indoor study of Hoskin *et al.* (1995) looking at rumination activity in deer fed chicory or perennial ryegrass showed that those fed chicory had a similar time spent eating (361 *v.* 379 min/24h), but markedly less time spent ruminating (33 *v.* 270 min/24h). This data indicates that chicory can be broken down faster than perennial ryegrass. Therefore, in relation to higher growth rate of deer grazing chicory than pasture, one may speculate that this may be to related higher VFI in deer grazing chicory than those grazing pasture. These aspects need to studied in future experiments.

1.5. BASIC PRINCIPLES OF FORAGE FEEDING VALUE

1.5.1. Definition of feeding value

Feeding value (FV) is defined as the animal production response to the forage consumed and is a function of intake and nutritive value per unit of intake (Ulyatt 1973).

FV = f(Intake x Nutritive Value)

Typical measures of FV are LWG with growing animals or milk production with dairy cows. Nutritive value (NV) is a function of chemical, physical composition of forages, digestibility, rate and site of digestion and the efficiency of utilisation of absorbed nutrients (Ulyatt *et al.* 1978).

1.5.2. Differences between forages in FV

In general, fresh forages commonly consumed by ruminants can be catagorised as grasses, legumes, herbs and browse (Langer 1990). Ulyatt (1973) working with temperate species reported that legumes had higher FV than grasses. A similar result has also been reported by Milford & Minson (1966) who worked with tropical species. In this regard, digestibility and VFI have been used as the main parameters, and they found that legumes were consumed and digested by sheep in higher proportion than grasses which is in agreement with other reports (eg. Minson & McLeod 1970; Weston & Hogan 1971; Minson & Wilson 1980).

When climatic conditions were considered, Minson (1990) showed that tropical grasses have lower digestibility values than tropical legumes, temperate grasses and legumes. Apart from their anatomical differences, the lower nitrogen and higher fibre contents in tropical grasses than the other counterparts might have been the main factors generating the lower digestibility value of tropical grasses. As a consequence, the production achieved (LWG or milk) is lower for animals fed grasses than legumes, both in temperate (Ulyatt 1971) and tropical regions (Margan *et al.* 1988).

1.5.3. Nutritive value of forages

Net energy supply per unit of forage consumed can be used as an indicator of NV of forage and is determined by such factors as, chemical composition and digestibility of forages and the efficiency with which the digested nutrients are utilised in the animals' tissue.

1.5.3.1. Stage of growth

Description of stage of growth in terms of plant development is a common means of describing forage quality. Plant maturity means morphological development culminating in the appearance of the reproductive cycle: tillering, flowering, pollination and seed formation (Van Soest 1994). Factors that accelerate the maturation are temperature, light and water, and those that retard it are clipping, grazing, disease etc. (Wilson 1982).

The aging of forage is frequently associated with a decrease in leafiness and an increase in the stem:leaf ratio. These coupled with the changes in each of the components, results in the characteristic pattern of decline in digestibility with increasing maturity in grass swards (Hogdson 1990). He added that the decline in digestibility of forages due to advancing maturity is associated with the decrease in leaf:stem ratio as well as readily fermentable:structural carbohydrate. The proportion of less digestible structural carbohydrate in stems increases more rapidly than in leaves as plants become mature. Laredo & Minson (1973) found that increasing the length of the regrowth period of some tropical grasses led to

a decrease in digestibility of both stem and leaf fractions at a rate of 0.25 and 0.34 units per day respectively. The rate of decrease in digestibility in tropical grasses is higher than that of temperate grasses. Akin & Chesson (1989) suggest that this difference may be associated with higher temperature under tropical climates, which promotes greater stem development than leaf as well as greater lignification compared to temperate species. Lignification of grass leaves and grass stems progresses with age and maturity whereas leaves of legumes remain at an almost constant composition (Van Soest 1994). For temperate pasture species, there is a general pattern for all plants: a high apparent digestibility associated with the vegetatve state is found in spring and this declines as the plant matures over summer.

1.5.3.2. Chemical composition

Factors influencing chemical composition of forages include species, stage of maturity and fertilizer inputs. As discussed earlier, grasses are genetically lower in N and readily fermentable carbohydrates (RFC; water soluble carbohyrate+pectin), but higher in structural carbohydrates (SC; hemicellulose+cellulose) contents than legumes, either for tropical or temperate plants (Minson 1990). Changes in herbage digestibility with increasing maturity are paralelled by changes in nitrogen content (Hodgson 1990). Typically the N content of young herbage is in the range 3-4 percent of DM, declining to as low as 1 percent in very mature herbage. Using several cool-season grasses, Morrison (1980) reported an increase in concentrations of lignin and hemicellulose more in the stems than in the leaves with advanced maturity. This fact coupled with the decrease in leaf:stem ratio as maturity advances lead to the decrease in digestiblity (Griffin & Jung 1983).

Plant cell walls comprise a complex of cellulose, hemicellulose and lignin. Waghorn & Barry (1987) stated that an increase in cell wall percentage, particularly lignin, is a major limitation to the NV of grasses, because of its low digestibility and resistance to physical breakdown in the rumen. The combined effects of increasing cell wall content and declining digestibility causes a dramatic

decline in M/D (MJ ME/kg DM) of the whole plant and lower intake by grazing animals. High concentrations of condensed tannins (CT) contained in forages have also been reported a limiting factor to their NV. Mature leaf and stem contain more CT than young ones and in species with total CT higher than 20 g/kg DM (such as *C. varia, H. coronarim* and *L. pedunculatus*), total concentration in leaf is up to five times higher than in stem (Douglas *et al*. 1993). Forage species containing CT between 20-40 g/kg DM is ideal, as CT levels higher than 40 g/kg DM in forages has been reported to decrease amino acid supply (Waghorn & Barry 1987) and depress VFI.

Input of fertilizers into soil also has significant impact on chemical composition of herbage. Under grazing conditions, the application of N fertilizers shortly after grazing is important, as it increases N content of pasture (Wheeler 1981), stimulates new tillers and allows cows to harvest larger bites than unfertilized swards (Stobbs 1975). Working with *Lotus pedunculatus*, Barry & Forss (1983) reported that when grown in low fertility acid soils concentration of CT was higher (80-110 g/kg DM) than when grown in high fertility soils (20-30 g/kg DM). Application of P and S fertilizers to the low fertility acid soils reduced CT content to 40-50 g/kg DM.

1.5.3.3. Digestibility and site of digestion

Digestibility (D) is defined as:

$$D = \frac{I - F}{I} \times 100$$

where;

I = Intake of feed DM or component such as organic matter (OM), energy, Neutral detergent fibre (NDF), etc., and

F = corresponding output in faeces.

The equation above refers to 'apparent digestibility' which relates the value of feed only to the difference between intake and undigested residue, expressed as a proportion or percent of intake and therefore cannot distinguish the proportion

of nutrients absorbed at different sections of the digestive tract. Poppi *et al.* (1987) considered rate of digestion and rate of passage as important parameters in quantifying extent of digestion at particular sites of digestion.

Rate of digestion refers to the proportion of feed digested per unit time which is influenced by rumen pH and rumen ammonia (NH_3) concentration (Van Soest 1994). A low rumen pH (<6) generally decreases rate and extent of fibre digestion (Owens & Goetsh 1986), and this occurs in diets high in starch and readily fermentable substrate (grain or concentrate feed) due to rapid release of volatile fatty acids (VFAs) and inhibition of cellulolytic bacteria. With regard to rumen NH_3 concentration, Mehrez *et al.* (1977) reported rumen NH_3-N of 194 mg/l is required for optimal fibre digestion, whilst level of rumen NH_3-N of 50 mg/l is needed for maximal microbial protein production (Satter & Slayter 1974).

Rate of passage is a measure of how long digesta is retained in the gut and is subjected to the processes of mechanical mixing (comminution), microbial fermentation, digestion and absorption (Mertens & Ely 1983). Weston (1984) revealed that major factors altering the rate of passage are chewing during both eating and ruminating, and microbial digestion. As chewing acts to break cells to release their content for digestion and reduces the size of feed particles (Waghorn & Barry 1987), the rate of particle size reduction is a dominant factor regulating fibre digestion in the rumen (Ulyatt 1983).

Due to lack of information in deer about site of digestion of particular nutrients the evidence discussed in this section will be drawn from sheep studies. The major sites of digestion in ruminants are the stomach (microbial fermentation), the small intestine (animal enzyme) and the large intestine (microbial fermantation). Ulyatt (1973) stated that rumen is the first and largest digestive organ encountered, so processes occurring within the rumen dictate to a large extent the subsequent fate of a herbage in the gastro-intestinal (GI) tract. The rumen may account for 55-65%, the small intestine accounts for 25-30% and the large intestine accounts for 5-15% of the total OM digestion (Waghorn & Barry 1987).

Ruminal digestion of cell wall contents is more likely to be rate limiting depending on the proportions and intrinsic properties of its potentially digestible and indigestible fractions (Van Soest 1994). Using white clover and short rotation perennial ryegrass, Ulyatt & MacRae (1974) found 90% of the digestible structural carbohydrate was digested in the rumen. Digestion and supply of nutrients at the small intestine is largely from microbial OM leaving the rumen and a variable proportion of the diet that escapes rumen degradation. As the undegraded dietary component is quantitatively small, nutrient supply to the small intestine is therefore dependent greatly on digestion in the rumen and the efficient capture of degraded N by microbial cell synthesis (Storm & Orskov 1984).

The particular site of OM digestion determines the form of metabolisable energy (ME) available, either as VFAs (reticulo-rumen) or microbial and undegraded dietary constituents (post-rumen). Partition of OM digestion differs with pasture species and level of intake (Ulyatt & MacRae 1974). They found that when intake of 'Ruanui' perennial ryegrass was increased from 500 g/day to 800 g/day, its digestible organic matter apparently digested in the rumen (DOMADR) was increased (0.60 to 0.80) and that in small intestine OM digestibility decreased (0.25 to 0.18). They also found a similar but non-significant effect with the 'Manawa'short rotation ryegrass and little change for white clover with intake in the partition of OM digestion in sheep. The higher DOMADR of Ruanui was associated with a lower passage rate of digesta than 'Manawa' ryegrass or white clover.

With regard to protein, Ulyatt *et al.* (1975) found that 70% of it in fresh forages of perennial and short-rotation ryegrass and white clover was degraded in the rumen of sheep and bacterial protein contribution was about 50% of the protein entering the duodenum. Cruickshank *et al.* (1992) reported that due to rumen microbial N transactions, large differences were observed in N intake between grass and legume diets were largely eliminated in the duodenal NAN supply. This evidence shows the incidence of N loss across the stomach being 33-45% for fresh diets compared to only 13% on dried diets. Most studies indicate that as

much as 30-50% of loss of ingested N on fresh herbage diets can occur whilst in passage through the ruminant stomach (MacRae & Ulyatt 1974; Ulyatt *et al.* 1975; Cruickshank *et al.* 1985), and is in the form of ammonia absorbed from the rumen. It represents a major inefficiency in N use in ruminants consuming high digestibility fresh forages.

1.5.3.4. Efficiency of utilisation of digested nutrients

The efficiency of feed utilisation can be expressed with increasing precision as a feed conversion ratio (eg. feed consumed per unit of LWG) through to true efficiency of utilisation of of ME for various functions such as, maintenance (K_m), growth (K_g), fattening (K_f) or lactation (K_l) (Ulyatt 1981). Study of Ulyatt (1970) as depicted in Table 1.5 shows a higher efficiency of feed utilisation of legume compared to grass. From the energy point of veiw, it is obvious that the amount of energy metabolized in the body was higher in sheep given white clover, as a result of higher intake level, than those fed perennial ryegrass, and hence a higher LWG was observed. Rattray & Joyce (1974) reported similar values of K_m for perennial ryegrass (62%) and white clover (62.6%), but those of K_g for white clover was higher (51%) than perennial ryegrass (32.9%).

Table 1.5. Chemical composition, *in vitro* digestibility, energy balance and LWG of sheeep fed perennial ryegrass or white clover

	Perennial ryegrass	White clover
Chemical composition (% DM):		
Crude protein	25.25	28.38
Readily fermentable carbohydrate (a)	16.68	19.89
Structural carbohydrate (b)	29.60	16.60
Ratio (a/b)	0.56	1.20
Lignin	2.86	3.10
OM digestibilty	76.70	78.90
DOMI (g/day)	833	981
VFA (mM/100 ml)	13.10	20.30
Energy balance:		
intake	14.08	15.17
Digested	10.60	11.40
Urine	0.66	0.76
Methane	1.07	1.02
Heat production	7.98	7.87
Metabolizable	8.70	9.35
Retention	1.00	1.63
LWG (g/day)	227	331

Adapted from Ulyatt (1970)

In evaluating protein metabolism in growing lambs fed on ryegrass/whiteclover pasture, Barry (1981) found that the digestion products of basal ryegrass-dominant diet were deficient in protein relative to ME. This condition has been predicted due to the loss across the rumen of one-third of total N consumed. MacRae & Ulyatt (1974) reported that the amount of N digested in the rumen of sheep fed perennial ryegrass was higher (2.12 g/100 g DOMI) than those fed white clover (0.81 g/100 g DOMI), whilst the amount of N reaching the small intestine of sheep given white clover was higher (2.80 g/100 g DOMI) than those fed perennial ryegrass (2.15 g/100 g DOMI). This also suggests that white clover can be used more efficiently than perennial ryegrass. Minson (1981) reported that lower acetic:propionic acid ratio in legumes leads to higher efficiency of their utilisation compared to grasses.

1.5.3.5. The role of CT in forages for increasing protein absorption

Extensive degradation of high quality protein by rumen micro-organisms when fresh forages are fed to ruminants causes inefficient utilisation of dietary protein. CT in forages binds to protein to form CT:protein complexes which are stable and insoluble in the pH range 3.5-7.0, but are soluble and releases protein at pH <3.0 and pH >8.0 (Jones & Mangan 1977).

Barry & Manley (1984) established a significant linear relationship between dietary CT concentration and NAN flow per unit total N intake in sheep fed fresh *L. pedunculatus* and *L. corniculatus* (Figure 1.11). Figure 1.11 shows that duodenal NAN flow out of the rumen increased as extractable CT concentration increased, and was the equivalent of total N intake at extractbale CT concentration of 40 g/kg DM. Higher CT concentrations depressed VFI and rumen fibre digestion.

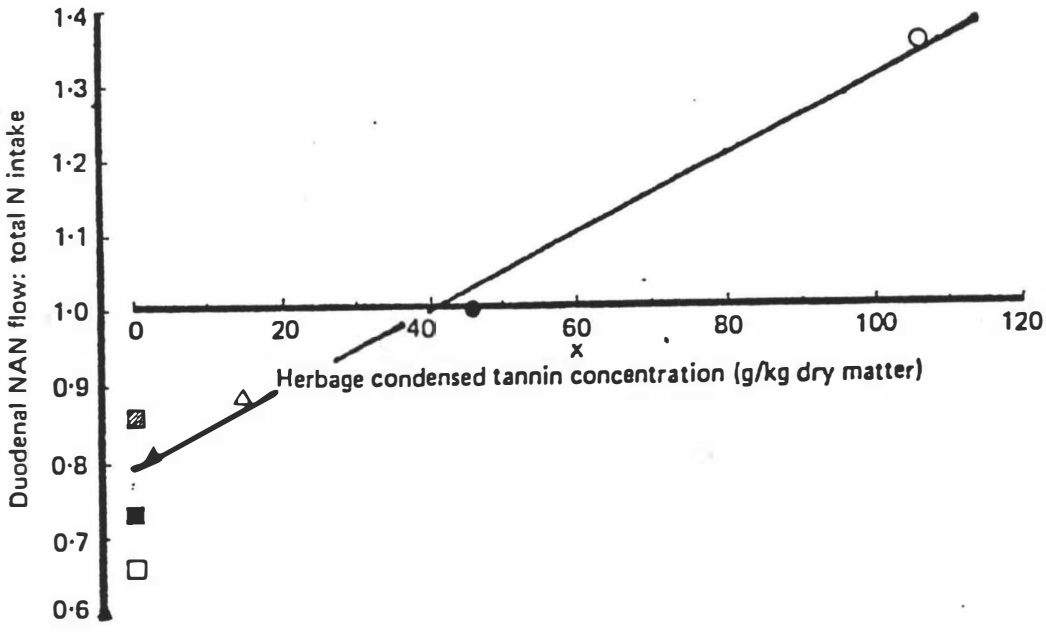

Figure 1.11. Duodenal non-ammonia (NAN) flow per unit total N intake as a function of dietary condensed tannins (CT) concentration in sheep fed on *Lotus* sp. (○) High CT (106 g extractable CT/kg DM) *Lotus pedunculatus*; (●) low CT (46 g extractable CT/kg DM) *Lotus pedunculatus*; (△) high CT (14.5 g extractable CT/kg DM) *Lotus corniculatus*; (▲) low CT (2.5 g extractable CT/kg DM) *Lotus corniculatus* (John & Lancashire 1981); (□) short rotation ryegrass; (□) perennial ryegrass; (■) white clover (MacRae & Ulyatt 1974) and (x) sainfonin (Ulyatt & Egan 1979). (Adapted from Barry & Manley 1984).

Barry (1989) suggests that the role of CT in protecting dietary protein will be significant if forage contains about 20-40 g CT/kg DM, as high concentrations of CT (50-100 g extractable/kg DM) depresses VFI of ruminants (Barry & Duncan 1984; Reed *et al.* 1982). Polyethylene glycol (PEG; MW 3,350) selectively binds to CT without affecting other aspects of the diet, and can be used to assess the nutritional affects of CT. The study of Waghorn *et al.* (1987) using *Lotus corniculatus* containing medium concentration of CT (22 g/kg DM), with and without the addition of PEG, showed that CT increased essential amino acid (EAA) apparent absorption from the small intestine by 62%, whilst that of non-

EAA (NEAA) was decreased by 10% due to CT; Table 1.6).

Table 1.6. The effect of CT (22g/kg DM) upon the digestion of amino acids in sheep fed fresh *Lotus comiculatus*

	Essential*		Non-essential**	
	Control	PEG	Control	PEG
Intake (g/day)	98.9	98.9	97.9	97.9
Abomasal flow:				
g/day	84.7	55.5	68.6	59.1
proportion intake	0.86	0.56	0.70	0.60
Apparent absorption from small intestine:				
g/d	58.8	36.2	37.4	41.3
proportion of abomasal flow	0.67	0.67	0.54	0.67
proportion intake	0.59	0.37	0.38	0.42

Adapted from Waghorn *et al.* (1987)

* Threonine, valine, isoleucine, leucine, tyrosine, phenylalanine, histidine, lysine.
** Aspargine, serine, glutamate, proline, glycine, alanine

CT content of 35 g/kg DM in *Lotus comiculatus* was reported beneficial, asthe action of CT increased wool growth in growing lambs and increased milk and milk protein yield in lactating ewes (Yuxi 1995). However, Barry (1985) failed to obtain a better animal performance in sheep given *Lotus pedunculatus* without PEG because CT content in this legume was high (76-90 g/kg DM), which indicated that a high CT content in this plant is nutritionally deleterious. Action of CT depressed both body growth and wool growth. The effect of low CT (up to 10 g/kg DM) contained in forages on animal production is still not understood and needs to be studied in the future.

1.5.4. Herbage intake by grazing animals

Ulyatt (1981) and Minson (1981) stated that experimental results under grazing have shown that up to 70% of the differences in feeding value between forages can be attributed to differences in VFI. The importance of level of herbage intake

in determining productivity of grazing animals has also been considered by some other workers who suggest that variation in intake of pasture by grazing ruminants has a major effect on animal performance (Hodgson 1981; Poppi *et al.* 1987).

1.5.4.1. Nutritional and non-nutritional components

When animals are grazing pasture, intake is determined by the opportunity for animals to harvest pasture. When pasture is offered to an animal in increasing quantities, intake increases curviliniarly (Figure 1.12). In the ascending part of the curve (non-nutritional), the ability of the animal to harvest pasture, is affected by non-nutritional factors such as pasture structure and grazing behaviour of the animal. At the plateau section of the curve (nutritional), nutritional factors such as, digestibility, feed retention time in the rumen and concentration of metabolic products are important in controlling intake.

Hodgson (1990) defined the amount of herbage eaten daily as the product of time spent grazing and the rate of herbage intake during grazing. Allden & Whittaker (1970) and Hodgson (1982) suggested the estimation of herbage intake through the following equation:

$$\mathbf{I = GT \times RB \times IB}$$

where;

I = daily intake of herbage by a grazing animal (mg OM/kg LW/day)

RB = the rate of biting during grazing period (bites/minute)

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

GT = the time spent grazing (minutes/day)

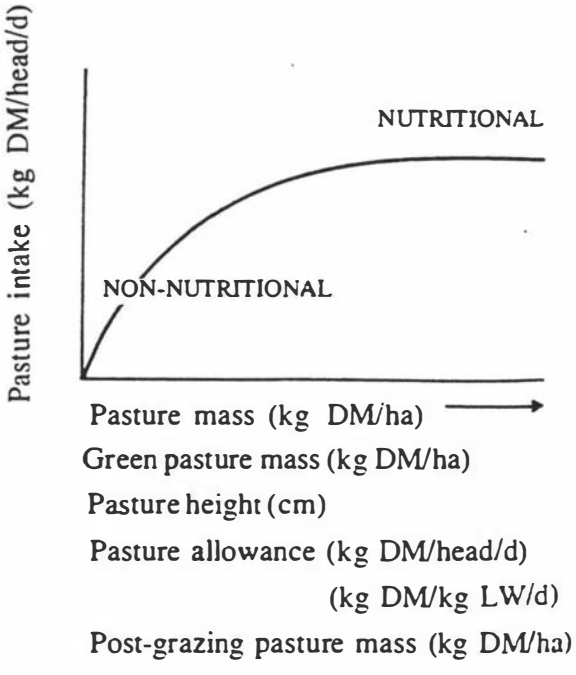

Figure 1.12. The relationship of pasture intake to various pasture characteristics and methods of pasture allocation (Poppi *et al*. 1987).

Herbage mass and sward height are two major components influencing the three components of grazing behaviour in temperate pasture (Allden & Whittaker 1970; Hodgson, 1985; Poppi *et al*. 1987), whilst in tropical pasture these are influenced by leaf:stem ratio and sward density (Stobbs 1973; Chacon & Stobbs 1976).

An increase in biting rate (RB), reflecting a decrease in sward height or herbage mass, has been found to be accompanied by a decrease in the ratio of manipulatory to harvesting bites in sheep (Penning 1986; Laca *et al*. 1992). This shows that RB is a direct response to sward conditions rather than a compensatory mechanism for a reduced bite weight (Hodgson 1985).

Intake per bite (IB) is the most sensitive animal response to variations in sward characteristics of the sward canopy. It has amply been documented with domesticated animals (mainly sheep and cattle) grazing on temperate swards that IB increases linearly with increasing sward height or herbage mass (Allden

& Whittaker 1970; Laca *et al.* 1992). The tensile strength of plant material determines IB and size of bite may be limited by the maximum force the animal is able to exert in prehending a bite. The choice by an animal of leaf or stem may be related to shearing strength in which IB decreases as tensile strength of leaves increase (Poppi *et al.* 1987). However, Inoué *et al.* (1993) working with two lines of perennial ryegrass selected for low or high leaf shear breaking load, found no significant differences between the lines in DM intakes, rumen retention times or LWG in sheep.

Grazing time (GT) usually increases when animals are grazed on very short swards, and this is done to try and prevent a decrease in VFI (Chacon & Stobbs 1976; Pennings *et al.* 1991). Any increasing in RB or GT of animals grazing short swards (below 6-8 cm and 8-10 cm) are not generally sufficient to compensate for the decline in IB and intake declines (Hodgson 1985).

Nutritional factors such as digestibility or crude protein content, the time feed stays in the rumen and concentrations of metabolic products appear to be important in controlling intake only if accessability and availability of forage are unlimited. It has been well documented that the major limitation to intake of herbage is the physical capacity of the rumen (Balch & Campling 1962; Thornton & Minson 1973). Large particles present in the rumen need to be reduced to below a certain critical particle which allows a high probability of those particles passing through the reticulo-omasal orifice. The threshold of particle size has been defined as passage through 1.0mm sieve for sheep (Troelsen & Campbell 1968; Poppi *et al.* 1980), goats (Uden & Van Soest 1982) and deer (Domingue *et al.* 1991). The amount of material that can accumulate in the rumen, and its rate of disappearance from the rumen are important factors determining VFI. Black *et al.* (1982) using computer simulation deduced that slow degradation and outflow rates from the rumen were the major factors causing long rumen MRT and reduced VFI in sheep fed perennial ryegrass, although rate of digestion might contribute approximately 5% of the difference in VFI between sheep consuming white clover and perennial ryegrass.

1.5.4.2. Grazing management

In general, grazing management is usually aimed to achieve maximum pasture and animal production, where it mostly deals with adjusting grazing frequency and grazing intensity to pasture availability. Vickery (1981) revealed that animal production may be affected by those two factors through the change of sward conditions. The proportion of green leaf declines and that of stem and dead tissue material substantially accumulates under low stocking rates (Figure 1.4a & b; Hogdson 1990). He added that although high stocking rates ensure the maintenance of a high proportion of leaf, they may result in a depression in digestibility of diet selected because they cause a short, dense sward which reduces the opportunity for selective grazing.

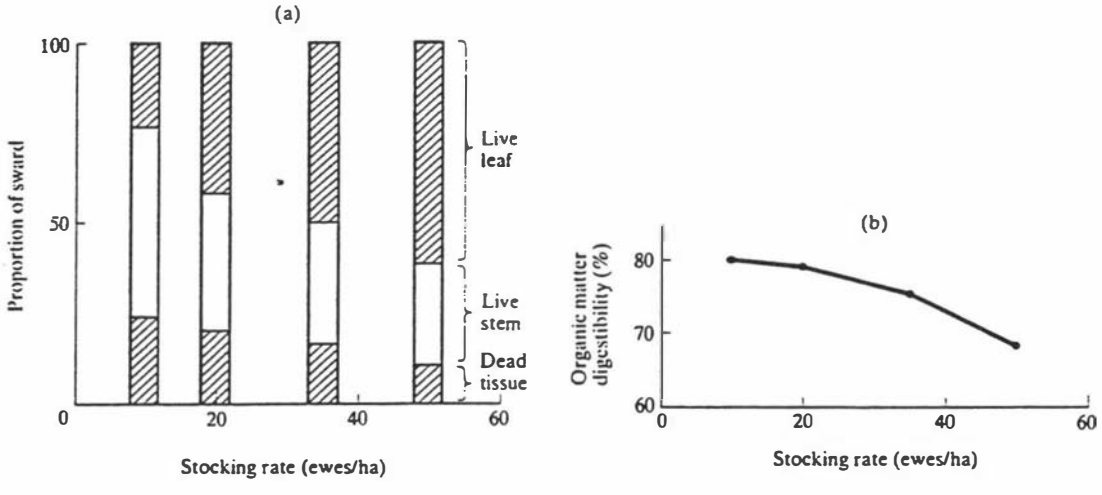

Figure 1.13. The influence of stocking rate upon (a) sward morphology and (b) digestibility of the herbage eaten (Adapted from Hodgson 1990)

1.5.5. Methods of measuring feed intake on grazing animals

The actual intake of grazing animals can be measured indirectly, either by (a) using marker technique in the individual animal, or (b) using pasture sampling in groups of animals.

1.5.5.1. Indirect method using chromium oxide

Indirect measurement of VFI using an indigestible marker such as chromium

sesquioxide (Cr_2O_3) is the most common method used nowadays. As a slow release external marker, intraruminal slow release chromium capsules are used to estimate faecal output (FO; kg OM/day) following equation described by Parker *et al.* (1989):

$$FO = \frac{X}{Y}$$

Where, $X=Cr_2O_3$ release rate from the capsule (mg/day) and $Y=Cr_2O_3$ concentration in faeces (mg/g OM).

Voluntary feed intake (kg OM/day) is then estimated involving *in vitro* OM digestibility (D) of the diet selected obtained, either by hand-plucking or via oesophageal fistula and FO using the following formula:

$$VFI = \frac{FO}{1 - D}$$

1.5.5.2. Sward technique

This measurement of VFI is based on the difference in herbage mass (kg DM/ha) between pre- and post-grazing. Since pasture may accumulate during the grazing period, a correction factor needs to be applied in estimating intake value using this method, or otherwise the grazing period should be short. Walters & Evans (1979) recorded low organic matter accumulation in the ungrazed areas during the grazing period (3-4 days) and made no correction for accumulation in estimating VFI. Ulyatt *et al.* (1974) reported a 30-40% lower value of VFI estimated using sward technique compared to that estimated using animal methods. Estimates of DM intake (DMI) are based on:

$$\text{DMI (kg/head/day)} = \frac{\text{pre-grazing DM (kg) - post-grazing DM (kg)}}{\text{number of animal grazing days}}$$

1.6. CLEARANCE OF DIGESTA FROM THE RUMEN

There is no doubt that the volume of digesta in the rumen and its rate ofremoval are very important to the nutrition of ruminants, particularly when they are fed high fibre diets or low digestibility (Weston 1982). Three processes affecting the clearance of digesta from the rumen are: (i) the disappearance of particles from rumen, (ii) the breakdown of particulate matter in the rumen, and (iii) microbial digestion (Ulyatt *et al.* (1986).

1.6.1. The efficiency of particle size breakdown

Chewing during eating and during rumination are two principal processes affecting the particle size breakdown (Ulyatt *et al.* 1986). They stated that the efficiency of chewing during eating is a function of four factors, namely: (i) frequency of chewing during eating, (ii) rate of eating, (iii) particle size breakdown during eating, and (iv) anatomy of teeth and jaws, which determine the forces applied during eating. The efficiency of chewing during rumination is a function of five factors, namely: (i) time spent ruminating, (ii) frequency of chews during ruminating, (iii) particle size breakdown during ruminating, (iv) mean bolus weight regurgitated, and (v) anatomy of the teeth and jaws (Ulyatt *et al.* 1986).

Data from McLeod *et al.* (1990) showed that large particles of legume (*Lablab purpureus*) were broken down faster than grass (*Panicum maximum*) to a critical particle size in the rumen of cattle, especially by secondary mastication (Table 1.7). However, values for proportion of large particles being broken down to critical particle size by secondary mastication obtained were overestimate as the loss of weight in digestion and detrition was not included in their calculation. A higher break down led to the total DM of legume being retained in the rumen for a shorter time than grass. A higher DMI and lower number of chews per g DMI in cattle fed legume showed a higher efficiency of its particle breakdown than when they were fed grass.

Table 1.7. Mean DMI, chewing behaviour, breakdown of large particles of cattle fed tropical grass (*Panicum maximum*) and legume (*Lablab purpureus*)

	Panicum maximum	*Lablab purpureus*
DMI (kg/day)	7.18	9.27
No.of chews ($x10^4$):		
primary mastication	1.65	1.55
secondary mastication	2.28	2.52
No.of chews/g DMI	5.46	4.38
Apparent mean retention time in the rumen:		
DM	23.90	17.30
particulate DM	25.70	22.40
large particles	16.70	12.00
Proportion of large particles broken down by:		
primary mastication	0.45	0.31
secondary mastication	0.54	0.68

Adapted from McLeod *et al.* (1990)

1.6.2. Disappearance, degradation and outflow from the rumen

Particles disappear from the rumen when they have been reduced to below a certain critical particle size which allows a high probability of passing through the reticulo-omasal orifice. Although microbial digestion in the rumen plays an important role in weakening and reducing width of feed particles by splitting plant tissue between vascular bundles (Wilson *et al.* 1989), the majority of large particles in the rumen appear to undergo comminution during ruminative mastication rather than by direct microbial action or by fracture during rumen contractions (Kennedy 1985; McLeod & Minson 1988). There is ample evidence to show that fresh forages are chewed during eating and during rumination more effectively than dried feeds (Ulyatt *et al.* 1986). Ulyatt (1983) working with fresh forages (lucerne, white clover, red clover and perennial ryegrass) and chaffed lucerne hay fed to sheep, reported 50% of feed DM was reduced in particle size to less than 1.0 mm by chewing during eating, whilst 69% of feed DM was

reduced in particle size to less than 1.0 mm by chewing during rumination. Similar value in efficiency of chewing during rumination (58-75% of feed DM) was reported by Chai *et al.* (1984) in cattle fed either chaffed alfalfa or brome grass. These evidence suggests that efficiency of chewing during rumination is a more efficient process than efficiency of chewing during eating in reducing particle size.

The length of time digesta stays in the rumen is known as MRT. The longer MRT, the more digesta is exposed to rumen microbial attack (Van Soest 1994), and this together with outflow rates from the rumen affects the amount of fibre that is digested (Faichney 1980). Since water and particulate matter of digesta behave differently in terms of outflow rate from the rumen, measurement of fluid and particulate matter FOR from the rumen is considered necessary (Faichney 1986). Variations in water FOR values occur due to effects of diet (Corbett & Pickering 1979; Corbett *et al.* 1982) and animal species (Cammell *et al.* 1983; Domingue *et al.* 1991). Water FOR values obtained for cattle were lower than those for sheep fed clover crop (Cammell *et al.* 1983). Domingue *et al.* (1991) reported a higher water FOR for red deer than goats and sheep fed lucerne hay.

1.7. METHODS OF MEASURING RUMEN OUTFLOW RATE (FOR)

There are three ways of estimating digesta FOR from the rumen, all using indigestible markers (Faichney 1975):

(i) by continuous infusion with time-sequence sampling,

(ii) by continuous infusion with total sampling, and

(iii) by single dose with time-sequence sampling

1.7.1. Attributes required for a digestion marker

The criteria of the ideal marker is as follows (Faichney 1975):

(i) It must be strictly non-absorbable

(ii) It must not affect or be affected by the grastro-intestinal (GI) tract or its microbial population

(iii) It must be physically similar to or intimately associated with the material it is to mark

(iv) Its method of estimation in digesta samples must be specific and sensitive and it must not interfere with other analyses (Faichney 1975).

Chromium-EDTA is commoly used as an external marker for determining water FOR, whilst that of particulate matter can be determined using an external marker (ruthenium-phenanthroline; Ru-P) or lignin contained in the diets as an internal marker.

1.7.2. Methods for determining rumen FOR

Rumen FOR can be determined using the following equations:

$$\text{- Water (\%/h)} = \frac{\text{Marker Cr infusion rate (mg/h) x 100}}{\text{Rumen pool size (mg Cr)}}$$

$$\text{- Particulate matter (\%/h)} = \frac{\text{Faeces lignin excretion rate (g/h) x 100}}{\text{Rumen lignin pool size (g)}}$$

It is assumed that any lignin digestion occurs in the rumen only and post-ruminal digestion of lignin is minimal.

Mean retention time can be calculated as the reciprocal of FOR:

$$\text{- Mean retention time (MRT; h)} = \frac{1}{\text{FOR}}$$

1.8. THE EFFECTS OF NUTRITION ON VELVET ANTLER GROWTH

Velvet antler are organs of bone which are cast and regrown annually by male deer. Their development is dependent upon the presence of the pedicle, which arises from the frontal bone of the skull. If pedicle initiation is delayed, then antler initiation will be delayed too. In red deer, Lincoln (1971) has shown that the

pedicle is a secondary sexual character whose development is associated with the onset of puberty. The timing of pedicle initiation has been observed as highly correlated with body weight, which depends on the level of nutrition (Fennessy & Suttie 1985; Table 1.8). Data in Table 1.8 demonstrates that stags fed on a higher plane of nutrition reached the threshold mean body weight earlier, hence had earlier pedicle initiation than those fed at a lower level of nutrition.

Table 1.8. Age and weight of red deer calves at pedicle initiation in 3 experiments

	Age (weeks)	Weight (kg)
Expt 1		
Fed to appetite (*n*=6)	19	41
Restricted (*n*=6)	31	44
s.e.m.	3.0**	1.9^{ns}
Expt 2		
Pelleted feed (*n*=5)	32.6	50
Meadow hay (*n*=5)	38.8	47
s.e.m.	1.5**	2.1^{ns}
Expt 3		
Pelleted feed (*n*=6)	36.6	55
Meadow hay (*n*=6)	39.4	51
s.e.m.	1.2*	1.7*

Adapted from Fennessy & Suttie (1985)
$^{*}P<0.05$; $^{**}P<0.01$

Suttie & Hamilton (1983) reported heavier and longer antlers in young stags fed on a high plane of nutrition (second cut meadow hay based-diet fed to appetite and a supplement of 1.1 kg/head/day of a mixture of 90% loose barley and 10% pelleted fish meal protein and vitamins) during winter compared to those fed on a low plane of nutrition (the same basal diet plus 0.23 kg/head/day of the same supplementary diet; Table 1.9). They added that for stags given a high plane of nutrition, their antler initiation was 12 weeks earlier, and their antler cleaning was 8 weeks earlier than those given a low plane of nutrition.

Table 1.9. Influence of nutrition on antler development

	Liveweight (kg) at			Antlers	
	Pedicle initiation	Antler initiation	Antler cleaning	Weight (g)	Length (cm)
High plane	48	58	64	48	22
Low plane	47	57	62	18	10
s.e.m.	1.7^{ns}	2.1^{ns}	1.6^{ns}	8.1^{**}	2.2^{**}

Adapted from Suttie & Hamilton (1983)
$^{*}P<0.05$; $^{**}P<0.01$

1.9. CONCLUSIONS AND AREAS REQUIRING FUTURE WORK

1.9.1. The price of chilled venison ($/kg carcass) in NZ varies with carcass weight and season and the venison schedule is highest for 50-65 kg carcasses, with an additional premium during September-November in response to high export market demands from the Northern Hemisphere. Deer farmers are challenged to produce stags with targeted carcass weight (50-65 kg) at these times at 1 year of age or less, as this provides t h e appropriate carcass weight and quality at the time of peak demand.

1.9.2. Red deer in NZ calve between November and December and are at peak lactation over summer, when the production and quality of commonly used perennial ryegrass/white clover pasture decreases. This together with deer seasonal VFI being at peak in summer results in deer growth being below their maximum genetic potential.

1.9.3. The use of a good-quality annual ryegrass (Moata) for winter and spring grazing and its manipulation in surface height have been successfull to produce 75% of male red deer stags with the desired carcass weight by one year old. The challenge is to get the other 25% of male and the

female deer to grow to desired carcass weight. This success has introduced a concept of using specialist forages for venison production, which have characteristics of being able to grow and produce high DM yields during summer and autumn, and have a high digestibility. Red clover and chicory fulfil these criteria.

1.9.4. Evidence showed that grazing weaner deer on red clover increased growth rates of the deer during autumn and spring, and 100% of red deer stags grazing on this forage reached the desired carcass weights by November. Grazing red clover during lactation also increased weaning weights. Therefore, studies are needed to evaluate the nutritive value of chicory for venison production.

1.10. THE PURPOSE OF THIS STUDY

1.10.1. To evaluate the FV of chicory as a specialist forage for venison production, using both red deer and elk:red deer hybrids, during both lactation and also post-weaning growth to one year of age and to determine the contributions of VFI and NV to any changes in FV.

1.10.2. To study the rate of DM breakdown in the rumen and VFI of deer fed chicory relative to those fed perennial ryegrass. Studies on rumen FOR of liquid and particulate matter in deer fed these two diets are also major parts of NV evaluation.

1.10.3. To measure CT content in chicory and perennial ryegrass fed to deer and to observe the effects of low CT concentrations (1-10 g/kg DM) upon forage protein breakdown and its implications for deer production.

1.10.4. To device systems for the efficient grazing management of chicory, such that its persistency under grazing by deer is as long as possible. This as a key component, as deer farmers are unlikely to adopt widespread use

years and preferably longer.

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Chapter 2

The effects of grazing chicory (*Cichorium intybus*) and perennial ryegrass (*Lolium perenne*)/white clover (*Trifolium repens*) pasture upon the growth and voluntary feed intake of red and hybrid deer during lactation and post-weaning growth

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2.1. *ABSTRACT*

Two grazing trials were carried out at Palmerston North, New Zealand ((NZ) using lactating red deer hinds in the summer 1994 (Experiment 1) and using weaner deer during the autumn, winter and spring of 1993 (Experiment 2), to compare the feeding value of chicory (*Cichorium intybus*) and perennial ryegrass (*Lolium perenne*)/white clover (*Trifolium repens*) pasture for increasing the growth of deer calves. Red deer and hybrid (0.25 elk;0.75 red deer) calves were used in both experiments. Experiment 2 concluded with slaughter at the end of spring, when the deer were *c.* 12 months old. In both experiments animals were rotationally grazed on either pasture or chicory with dry matter (DM) allowances being 12 kg DM/hind per day (Experiment 1), and 6, 6 and 7 kg DM/head per day during autumn, winter and spring respectively (Experiement 2).

Perennial ryegrass comprised 62% of pasture on offer in Experiment 1 and 78-90% in Experiment 2, whilst chicory comprised 90-92% of forage on offer in both experiments. Relative to pasture, chicory had a higher ratio of readily fermentable:structural carbohydrate and had higher organic matter digestibility (OMD) in summer and autumn but not in spring.

Deer grazing chicory had higher voluntary feed intake (VFI), bite weight, liveweight gain (LWG), carcass dressing percentage and carcass weight and greatly reduced ruminating time than deer grazing pasture. Hybrid deer grew better than red deer and there were forage x genotype interactions in Experiment 2, with LWG and carcass weight of hybrid deer being much greater when grazed on chicory. Carcass weight for red deer and hybrid stags was 64.9 and 73.0 kg when grazed on chicory and 56.6 and 57.0 kg when grazed on pasture. Grazing chicory advanced the date of first cut velvet antler by 28 days and increased the weight of total harvestable (first cut+regrowth) velvet antler. It is concluded that grazing chicory increased carcass weight, especially in hybrid stags with increased growth potential, and increased velvet antler production. This was

achieved by increased VFI in all seasons and increased OMD of chicory in summer and autumn relative to deer grazing pasture. Further research is needed to determine the efficiency of rumination on particle size breakdown and to measure rumen outflow rate in deer fed chicory.

2.2. INTRODUCTION

The New Zealand (NZ) deer industry has a potential target of achieving carcass weights of 50-65 kg by one year of age or less, to meet spring export market requirements. Most deer in NZ are grazed on perennial ryegrass/white clover pasture for the complete 12 month production cycle, and initial research (Ataja *et al.* 1992) showed that deer production could be substantially increased by grazing at 10 cm surface height compared with 5 cm height. In NZ, the feed requirements of deer are not well aligned with pasture production, due to calving (Nov/Dec) occurring later than the spring increase in pasture production (September). Consequently, hinds are at peak lactation during summer (Jan/Feb) when pasture production has declined due to moisture stress and when pasture is also of lower nutritive value. Therefore, there is a need to develop special purpose forages for deer production, which have good dry matter (DM) production during summer, have deep tap roots to resist moisture stress and are of high nutritive value. Red clover (*Trifolium pratense*) and chicory (*Cichorium intybus*) fulfill these criteria, and relative to perennial ryegrass (*Lolium perenne)*/white clover (*Trifolium repens*) pasture, inputs of red clover have increased the growth of deer calves during lactation (Niezen *et al.* 1993) and during post-weaning growth to one year of age (Semiadi *et al.* 1993; Soetrisno *et al.* 1994).

Less information is available for chicory. In a series of preference experiments, chicory was one of the most preferred forages by red deer, while perennial ryegrass was the least preferred species (Hunt & Hay 1990). Chicory is also substantially higher in digestibility than perennial ryegrass (Hoskin *et al.* 1995). Niezen *et al.* (1993) reported a 16% increase in growth of red deer calves grazed with their dams on chicory during lactation relative to those grazed on perennial/white clover pasture, whilst Hunt (1993) found grazing on chicory

increased weaning weight by 15%.

The present study aimed to compare the feeding value of chicory with that of perennial ryegrass/white clover pasture for increasing the growth of red deer calves and hybrid (0.25 elk;0.75 red deer) calves both during lactation, and from weaning to slaughter at one year of age. Measurements of voluntary food intake (VFI) and of eating and ruminating times were also made.

2.3. MATERIALS AND METHODS

2.3.1. Experimental design

Two grazing experiments were conducted at Massey University Deer Research Unit (DRU), Palmerston North, NZ during 1994 (Experiment 1) and 1993 (Experiment 2). Experiment 1 involved lactating hinds and their calves and commmenced on 7 January and concluded at weaning on 28 February 1994. Experiment 2 involved growth from weaning to slaughter at one year of age, and took place between 1 March and 12 December 1993.

Both experiments were 2 x 2 x 2 factorially designed, with two types of forage (Chicory *v*. perennial ryegrass/white clover pasture), two deer genotypes (pure red deer *v*. hybrid) and two sexes (male *v*. female). The animals used in both experiments were rotationally grazed on either chicory or perennial ryegrass/white clover pasture with DM allowances that did not restrict intake and production.

2.3.2. Forages

Areas for chicory (2.4 ha;8 paddocks) were ploughed, disk harrowed and power harrowed in January 1993. Chicory seed was then sown by direct drill during the summer of 1993 at the rate of 4 kg/ha. After the chicory emerged, Gramoxone (ICI, NZ, Ltd.) at 3 litres/ha was sprayed to control grasses. The perennial ryegrass/white clover pasture was several years old. Potassic superphosphate (9% P;10%S and 7%K) was applied in late April 1994 at 250 kg/ha, corresponding to 22.5 kg P/ha, onto chicory and perennial ryegrass/white clover

pasture. Also, three applications of urea, each at 37 kg N/ha, were made in early spring (August), late spring (October) 1993 and early autumn (February) 1994, respectively. In the winter of 1993, chicory paddocks were sprayed with herbicide (Galant; DowElanco, NZ, Ltd) at 3 litres/ha to control grasses, mainly *Poa annua*.

2.3.3. Animals.

2.3.3.1. Experiment 1.

Forty lactating red deer hinds and their calves were used during the summer of 1994. Calving occurred during Nov/Dec 1993. Mean weight of hinds and calves at the start of the experiment was 113.9±1.64 kg and 28.6±0.75 kg respectively. The calves consisted of 21 red (9 stags;12 hinds) and 19 hybrid deer (6 stags;13 hinds). The hybrid calves used were produced from mating hybrid (0.5 elk;0.5 red) stags to red deer hinds. To identify new-born calves, numbered collars were used until weaning. The hinds and their calves were randomly allocated to graze either chicory or perennial ryegrass/white clover pasture.

2.3.3.2. Experiment 2.

Forty eight weaners consisting of 24 red deer (13 stags;11 hinds) and 24 hybrids (16 stags;8 hinds) were used. The animals were randomly allocated to graze either chicory or perennial ryegrass/white clover pasture on 1 March 1993. All animals were ear tagged and vaccinated against clostridial infections (Coopers, Animal Health Ltd, NZ) and yersinia infections (Yersiniavax; AgResearch, Upper Hutt, NZ) in the upper half of the neck on 1 March and 5 April 1993. Animals were drenched orally with ivermectin (IVOMEC-0.4% w/v at 200 µg/kg liveweight; Merck, Sharp and Dohme, NZ) to prevent lungworm and internal parasite infections, at 3-week intervals until the end of June and then 6-weekly until slaughter.

2.3.4. Grazing Management.

In Experiment 1 DM allowance was 12 kg DM/hind per day, whilst in Experiment 2 DM allowances were 6, 6 and 7 kg DM/head/day during autumn, winter and spring respectively. Animals were rotationally grazed in both experiments, with

rotation length being *c.*4-5 weeks. In Experiment 2, autumn was defined from the 1 March to 8 June 1993, winter from 12 June to 20 September 1993 and spring from 24 September to 12 December 1993. Because chicory is dormant during winter, animals from the two groups were joined and grazed on perennial ryegrass/white clover pasture (5.8 ha; 11 paddocks) over winter. They were separated in spring into their original pasture and chicory groups. Pasture residual mass was maintained at 1700 kg DM/ha during winter. Reproducive stem formation and flower production occurred with chicory during summer. Follow-up grazing with non-experimental deer and mechanical topping were used to cut the stems and to maximize leaf production by the chicory.

The time animals grazed each paddock was based on specified allowances calculated as follows:

$$\text{Total days} = \frac{\text{herbage mass (kg DM/ha) x total area of paddock}}{\text{(Total animals/group)x(pasture allowance/deer/day)}} \quad (1)$$

2.3.5. Pasture Measurements

Pre-grazing herbage mass (kg DM/ha) was measured before animals were introduced into each paddock, while post-grazing herbage mass was measured immediately after the animals were shifted out of the paddock. On each occasion eight quadrats per paddock, each of 0.1 m^2 size were cut to soil level using a hand-clipper. The herbage samples were then washed, oven-dried at 90°C for 18 h, and weighed.

For laboratory analysis, eight 0.1 m^2 quadrats of fresh herbage/ feed on offer were cut to soil-level from each paddock when the deer were introduced. Samples were then combined, mixed and divided into two parts. The first part was used to determine botanical composition, whilst the second part was stored at -20°C prior to measurement of nutritive value.

Hand-plucked samples were taken each day from the area where the deer were grazing by imitating the animal's selection of plants. Earlier studies showed that under these grazing conditions with young deer, hand plucked samples were of identical digestibility to extrusa samples taken with deer fistulated in the oesophagus (Semiadi *et al.* 1993). Samples collected daily were then pooled for each paddock, and stored at -20°C prior to determination of botanical composition and nutritive value.

2.3.6. Animal Measurements

All animals were weighed at 3-weekly intervals. In both experiments, 24-h studies of grazing behaviour were carried out. Numbered collars with different colours were used to identify the grazing hinds (Experiment 1) rearing calves of different genotype and sex (ie. red and hybrid; male and female), and the same system was used for weaner deer in Experiment 2. Grazing activities of the animals such as eating, ruminating, resting and biting rate were recorded by observation at 12-minute intervals (Jamieson & Hodgson 1979). During the hours of darkness two 12-V spotlights were used to aid identification. Two 24h observation periods over alternate days were used for animals grazing each forage in Experiment 1 and in autumn and spring in Experiment 2.

In order to estimate faecal organic matter output, an intra-ruminal chromium (Cr) slow-release capsule (CRD, Cr_2O_3 matrix, Captec Ltd, Auckland, NZ) was administered to each deer. Faecal samples were taken from the rectum of individual animals from Days 8-22 after CRD administration, at 2-day intervals, with the samples in Experiment 2 being taken at different times on each day. Faecal sampling on days 8, 10, 12, 14, 16, 18, 20 and 22 was done at 07.00, 09.00, 11.00, 13.00, 15.00, 17.00, 19.00 and 21.00h, respectively. Due to forage shortages during the long dry summer period of 1994, faecal samples in Experiment 1 were taken only at Days 8, 10 and 12 from the lactating hinds. The faecal samples were collected in plastic pottles, oven-dried at 90°C for 72 h, crushed and stored until required for laboratory analysis.

Three hand-reared rumen fistulate castrated red deer stags were grazed on each forage over 27 days, to measure the rate of plunger travel of chromium capsules suspended in the rumen, in order to calculate Cr release rate. The measurement was first done at Day 5 after CRD insertion and proceeded at 3-day intervals until Day 27.

2.3.7. Velvet antler removal

Velvet antler harvesting was done when the velvet antler reached *c.* 20 cm long. The animals were treated either by sedating with 10% xylazine (Rompun, Bayer Ltd, NZ) administered intramuscularly at a dosage rate of 0.5 mg/kg body, or by restraining in a pneumatic deer crush. After the animals had been mildly sedated or restrained, they were given local anaesthetic by injecting 15 ml lignocaine hydrochloride (Xylotox, A.H.Robins Co Ltd, England) in a ring block around each antler, which was then tied to form a tourniquet. About 5 min later, the velvet was cut with a sterilized saw. The sedated animals were then injected with yohimbine hydrochloride (1.5-2.0 ml; Reservyl, Aspiring Veterinary Service, NZ) intrajugularly to reverse the effect of the xylazine. Subsequently, the tourniquet was removed and the animals were released. Velvet was weighed, and date of harvesting recorded.

2.3.8. Slaughter procedure.

The post-weaning trial (Experiment 2) concluded on 12 December 1993. All stags and hinds attaining 92 kg liveweight (50 kg carcass) or greater were identified and had their antlers removed before being transported to the Deer Slaughter Premises (DSP) in Kaimai. Hot carcasses (kg) were weighed, and the carcass GR (soft tissue depth over the 12th rib 16 cm from the mid line) measured as an indirect measure of fatness (Kirton 1989). The weight and volume of rumen contents were measured after slaughter and then discarded. The emptied stomachs of all the deer were brought to Massey University, preserved with 10% formalin and kept at -20^{0}C until required. Weight of the digesta-free reticulorumen, omasum and abomasum were measured directly, whilst their volumes were measured by filling with water, except for the volume of the

omasum which was measured by water displacement. The length and width of ten papilla on samples of rumen wall taken from the roof of the dorsal sac, the floor of the atrium ruminis and the caudo ventral blindsac were measured by caliper (Stafford 1995).

2.3.9. Laboratory Analysis

Prior to laboratory analyses, all herbage samples were stored at -20°C, then freeze-dried and ground to pass a 1 mm mesh diameter sieve (Willey *mill*, USA). DM was determined by oven-heating at 100°C for 16 h. Total nitrogen (N) was determined by the Kjeldahl procedure, using a selenium catalyst and sulphuric acid digestion. Water soluble carbohydrates and pectin were determined following the procedure of Bailey (1967), whilst neutral detergent fibre (NDF), acid detergent fibre (ADF) and lignin were determined by the detergent system of Van Soest (1994). Cell wall data are presented as hemicellulose (NDF-ADF), cellulose (ADF-lignin) and lignin. In-vitro digestibility was determined using the enzymic method developed by Roughan & Holland (1977). Chromium analysis of faeces was done following the method of Costigan & Ellis (1987).

Pasture on offer and hand-plucked samples used for botanical composition were dissected into grasses, clover (white clover), chicory, dead matter and weed. Each component was separately oven-dried at 90°C for 17 h, and weighed.

2.3.10. Data calculation and statistical analysis

Faecal output (FO) was calculated as:

$$\text{FO (g OM/day)} = \frac{\text{Cr release rate (RR)(mg/day)}}{\text{Faecal Cr concentration (mg/g OM)}} \qquad (2)$$

Voluntary feed intake was then calculated using Eqn 3, using organic matter digestibilty (OMD) from estimated diet selected (hand-plucked) samples.

$$\text{Voluntary feed intake (g OM/day)} = \frac{\text{FO (g OM/day)}}{\text{1-OMD}} \quad (3)$$

The duration of grazing (h/24h) for each deer type was calculated using Eqn 4.

$$\text{Grazing time (h/24h)} = \frac{\Sigma \text{ animals observed as grazing x24}}{\Sigma \text{ animals observed}} \quad (4)$$

Total time spent ruminating/24h was calculated in a similar manner.

Bite weight (BW; gOM/bite) was calculated from eqn 5 (Hodgson 1982), using measured values for voluntary intake (I; gOM/day), grazing time (GT; min/24h) and bite rate (BR; bites/min).

$$I = GT \times BR \times BW \quad (5)$$

Liveweight gain, carcass weight, GR measurement, velvet antler weight, VFI, eating and ruminating times were analysed using the General Linear Model (GLM) Procedure (SAS 1987), as a 2 x 2 x 2 factorial design, with two types of forages (chicory and perennial ryegrass/white clover), two genotypes (red and hybrid deer) and two sexes (male and female). Age was used as a covariate for initial and final liveweights of calves in Experiment 1 and all liveweights of weaner deer in Experiment 2, whilst carcass weight was used as a covariate for carcass GR and rump fat cover. Least square means (L.S.M.) analysis was used to test the differences between treatments.

2.4. RESULTS

2.4.1. Herbage mass and botanical composition

In both experiments, pre- and post-grazing herbage masses were generally slightly higher for chicory than for pasture (Table 2.1), with the lowest post-grazing herbage masses being 1382 and 1737 kgDM/ha for pasture during summer and winter repectively. Perennial ryegrass was the principal component

of the pasture on offer, ranging from 62% in summer to 90% in winter (Tables 2.2 and 2.3). White clover ranged from a maximum of 25% in summer to a minimum of 5% in winter, whilst dead matter was at a maximum of 10-12% in summer and autumn. The chicory sward was very pure, with chicory content of feed on offer being 90-92% (Tables 2.2 and 2.4). Contents of grass, weeds and dead matter were generally each 2-3% or less, whilst white clover ranged from a low of 1.5% in summer and autumn to *c.* 5% in spring. Both the pasture and chicory swards were relatively free of weeds, and for both forages samples of estimated diet selected were of similar botanical composition to the feed on offer, except that dead matter content was lower.

Table 2.1. Pre- and post-grazing herbage mass (kgDM/ha) of perennial ryegrass/white clover pasture and chicory grazed by hinds and their calves during lactation in 1994 and by red and hybrid weaner deer during autumn, winter and spring of 1993. Mean values with their standard errors.

Season	Pasture			Chicory		
grazing	n*	Pre-grazing	Post-grazing	n*	Pre-grazing	Post-
Experiment 1						
Summer	8	2489	1382	8	3119	1641
S.E.		164.6	53.1		254.2	124.4
Experiment 2						
Autumn	11	2488	1843	12	3202	2138
S.E.		209.8	125.4		335.7	112.2
Winter[1]	21	2277	1737		0	0
S.E.		75.9	58.0			
Spring	11	2988	2082	11	4110	2634
S.E.		217.3	117.5		533.2	310.9

* Number of samples taken per season

[1] Both pasture and chicory animals were joined and grazed together on pasture during winter.

Table 2.2. Experiment 1. Botanical composition (%DM) of perennial ryegrass/white clover pasture and chicory during the summer 1994 lactation trial. Mean values with their standard errors.

Species	Forage type	
	Pasture (n=12)	Chicory (n=12)
	(Forage on offer)	
Grass	61.7±2.51	2.2±0.58
Clover	24.6±3.53	1.6±0.64
Chicory	-	92.1±0.28
Weed	2.8±0.78	0.5±0.33
Dead matter	10.8±1.98	3.3±2.05
	(Diet selected)	
Grass	72.7±1.83	3.3±0.57
Clover	16.6±1.80	2.0±0.75
Chicory	-	93.7±1.06
Weed	0.9±0.16	0.5±0.31
Dead matter	9.8±1.08	0.4±0.21

Table 2.3. Experiment 2. Botanical composition (%DM±S.E.) of perennial ryegrass/white clover pasture grazed by red and hybrid weaner deer during autumn, winter and spring in 1993.

Season	Perennial Ryegrass	White clover	Dead matter	Weed	*n**
		(Forage on offer)			
Autumn	77.5	9.3	12.0	1.2	12
S.E.	2.0	1.4	0.5	2.4	
Winter	89.5	4.8	5.6	0.1	24
S.E.	1.0	0.7	0.7	0.1	
Spring	84.5	13.0	2.0	0.5	11
SE	2.4	2.1	0.5	0.2	
		(Diet selected)			
Autumn	86.6	7.7	4.6	1.1	12
S.E.	1.0	0.6	0.7	0.2	
Winter	91.4	2.7	5.6	0.4	24
S.E.	1.2	0.6	0.3	0.5	
Spring	90.2	8.4	1.1	0.3	11
S.E.	1.2	1.1	0.3	0.1	

* Number of samples taken per season

Table 2.4. Experiment 2. Botanical composition (%DM±S.E.) of chicory grazed by red and hybrid weaner deer during autumn and spring in 1993.

Season	Chicory	Perennial Ryegrass	White clover	Dead matter	Weed	*n*[•]
			(Forage on offer)			
Autumn	89.0	6.5	1.7	1.3	1.5	12
S.E.	1.8	1.1	0.3	0.2	0.6	
Spring	90.0	2.0	5.7	2.0	0.3	11
S.E.	1.8	0.6	1.9	0.5	0.1	
			(Diet selected)			
Autumn	95.0	3.5	1.5	0	0	12
S.E.	0.6	0.4	0.4	0	0	
Spring	86.4	4.8	6.1	2.5	0.2	11
S.E.	3.7	1.7	3.0	0.8	0.2	

[•] Number of samples taken per season
Chicory was dormant during winter.

2.4.2. Nutritive value of forages

For both forages, diet selected was generally slightly higher in total N and organic matter digestibility (OMD) than the feed on offer (Tables 2.5 and 2.6). In terms of carbohydrate (CHO) composition, chicory contained higher concentrations of water soluble CHO and pectin and lower concentrations of cellulose and hemicellulose than pasture ($P<0.01$) in the diet selected. Consequently, the ratio of readily fermentable CHO (water soluble carbohydrate+pectin) to structural CHO (cellulose+hemicellulose) was higher for chicory than for pasture, in both autumn and in spring ($P<0.01$). Hence, OMD was higher for chicory than for pasture in summer and autumn, but not in spring ($P<0.01$). Relative to pasture, chicory had a much higher ash content ($P<0.01$), a slightly lower total N content in autumn and spring, but a similar lignin content.

Table 2.5. Experiment 1. Chemical composition (%DM±S.E.) of forage on offer and diet selected by red deer hinds during lactation in summer 1994.

	Pasture (*n*=6) (D.F.=10)	Chicory (*n*=6) (D.F.=10)
	(Forage on offer)	
Total N:	2.97±0.16	3.62±0.16
OMD:	74.0±0.80(10.4)[1]	84.8±0.80(15.3)
	(Diet selected)	
Total N:	3.44±0.16	3.21±0.16
Water soluble carbohydrate (a):	8.5±1.45	14.4±1.45
Pectin (a):	1.9±0.25	7.2±0.25
Cellulose (b):	20.7±0.29	10.9±0.29
Hemicellulose (b):	19.0±0.90	5.2±0.90
Ratio (a/b):	0.26±0.12	1.39±0.12
Lignin:	2.2±0.23	1.9±0.23
OMD:	76.5±0.80(11.0)	86.4±0.80(15.0)

[1] Ash content. 100-ash content = OM content

Table 2.6. Experiment 2. Chemical composition (%DM±S.E.) of forage on offer and diet selected by red and hybrid weaner deer grazing either perennial ryegrass/white clover pasture or chicory during autumn, winter and spring in 1993.

	Pasture (*n*=7) (D.F.=20)	Chicory (*n*=6) (D.F.=20)
	(Forage on offer)	
Total N:		
autumn	3.32±0.18	3.63±0.18
winter	4.08±0.12	-
spring	3.36±0.08	3.13±0.19
OMD :		
autumn	76.3±1.26(12.5)[1]	83.4±0.91(14.6)
winter	87.2±0.82(12.0)	-
spring	83.5±0.53(10.2)	86.4±0.49(13.7)
	(Diet selected)	
Total N:		
autumn	4.28±0.24	3.19±0.24
winter	4.05±0.08	-
spring	3.61±0.20	3.11±0.10
Water soluble carbohydrate (a):		
autumn	7.3±2.16	14.6±1.15
winter	8.9±1.63	-
spring	8.1+0.40	11.5±1.06
Pectin (a):		
autumn	1.4±0.42	7.0±0.50
winter	1.1±0.28	-
spring	1.9±0.26	6.0±2.13
Cellulose (b):		
autumn	20.4±1.95	11.8±1.34
winter	21.4±3.17	-
spring	20.7±0.57	12.8±2.62
Hemicellulose (b):		
autumn	20.5±5.96	4.4±2.47
winter	16.0±1.24	-
spring	16.2±3.22	5.7±1.44
Ratio (a/b):		
autumn	0.21±0.10	1.39±0.12
spring	0.27±0.12	0.95±0.13
Lignin:		
autumn	1.3±0.32	1.6±0.41
winter	1.1±0.19	-
spring	1.1±0.16	1.8±0.48
OMD:		
autumn	77.6±1.25(11.9)	85.8±0.29(15.5)
winter	85.2±0.45(17.6)	-
spring	84.8±0.53(12.6)	86.5±0.58(13.9)

[1] Ash content. 100-ash content = OM content

2.4.3. Liveweight change

The effects of genotype, sex and their interaction on age of calves at weaning in Experiment 1 were not significant. Calves used in Experiment 1 were weaned at 96.6±4.9 and 94.8±9.2 days of age (mean±standard deviation) for male and female red deer calves, respectively, whilst hybrid male and female were weaned at 94.4±5.6 and 95.8±4.0 days of age, respectively. Hybrid calves had significantly higher initial weight ($P<0.05$), liveweight gain (LWG; $P=0.08$) and weaning weight ($P<0.05$) than pure red deer calves, whilst male calves had significantly higher initial weight ($P<0.05$), LWG ($P<0.05$) and weaning weight ($P<0.01$) than female calves (Table 2.7). Liveweight gain was consistently higher for calves grazing chicory than pasture (404 v.351 g/d; $P=0.07$); there were no interactions between sex, genotype and forage type for liveweight or LWG. All hinds lost weight during lactation, with those grazing chicory losing more weight than those grazing pasture ($P<0.01$). The significant forage x genotype interaction ($P<0.05$) was due to large weight losses in hinds grazing chicory that reared pure red deer calves.

In Experiment 2, LWG of stag calves was higher than that of hind calves in all three seasons (autumn, winter and spring; $P<0.01$; Table 2.8), whilst the growth of hybrid deer was consistently greater than that of pure red deer both during autumn and spring ($P<0.01$). During autumn, LWG of weaners grazing chicory was significantly higher than that of weaners grazing perennial ryegrass/white clover pasture ($P<0.001$), and the forage x sex interaction was significant ($P<0.05$), indicating a greater LWG response to grazing chicory in stags (especially hybrids) than hinds. In spring, LWG was similar for weaners grazing chicory or pasture, but there was some indication of a forage x genotype interaction, with the growth advantage of hybrid deer over red deer being greatest on chicory.

Table 2.7. Experiment 1. Growth of red and elk:red hybrid deer calves grazing on perennial ryegrass/white clover pasture and chicory during lactation in summer 1994.

Forage	Pasture				Chicory				S.E.
Sex	Stag		Hind		Stag		Hind		(D.F.=31)
Genotype	R	H	R	H	R	H	R	H	
No.of animals Calves:	4	2	6	7	5	3	6	6	5
Initial weight (kg)	29.6	35.3	25.8	28.7	29.5	29.7	26.1	29.4	2.0
Weight change (g/day)	358	375	314	356	402	490	332	391	36.0
Weaning weight (kg)	48.3	54.8	42.1	47.2	50.4	55.2	43.3	49.8	3.0
Hinds:									
Weight change (g/day)	-17	-43	-27	-48	-139	-32	-106	-85	29.6

R = pure red deer. H = hybrid (0.25 elk;0.75 red)
DM allowance was 12 kg DM/hind/day

Table 2.8. Experiment 2. Liveweight and liveweight gain of red and hybrid weaner deer grazed on either perennial ryegrass/white clover pasture or chicory during autumn, winter and spring of 1993.

Forage	Pasture				Chicory				S.E.
Sex	Stag		Hind		Stag		Hind		(D.F.=39)
Genotype	R	H	R	H	R	H	R	H	
Number of animals	7	8	6	4	6	8	5	4	6
Mean initial age (days):									
Initial (1.3.93)	97.0	88.6	100.2	94.1	97.0	88.6	100.2	94.1	3.1
Mean liveweight (kg)[1]:									
Initial (1.3.93)	50.4	47.4	44.8	49.1	50.4	47.4	44.8	49.1	2.3
End autumn (8.6.93)	68.4	67.6	60.8	65.5	74.3	78.8	63.5	70.8	3.2
End winter (20.9.93)	87.4	83.3	71.8	77.4	88.4	99.6	75.1	81.4	4.0
End spring (12.12.93)	108.5	105.3	86.1	96.1	110.8	124.9	85.8	100.0	4.7
Liveweight gain (g/d):									
Autumn (99 days)	178	203	157	264	246	318	193	220	17.2
Winter (100 days)	171	146	98	113	127	193	103	93	13.6
Spring (79 days)	260	271	174	223	255	310	141	232	21.1

[1] Adjusted to equal age.
R = pure red deer
H = hybrid (0.25 elk;0.75 red)

The effects of sex (P=0.06) and genotype (P<0.01) on age at weaning were significant, with hybrids being on average 8 days younger than pure red deer and stags on average 4 days younger than hinds. All liveweight data in Experiment 2 was therefore adjusted to constant age (Table 2.8), and these age effects are probably due to differences in gestation length.

The interaction between sex and genotype was significant (P<0.05) for initial liveweight, with red deer stags and hybrid hinds being heaviest. Weaner deer that had grazed on chicory tended to have heavier liveweight than those that had grazed pasture at the end of autumn, at the end of winter and at the end of spring. Hybrid deer were heavier than pure red deer at the end of all three seasons (P<0.05). The genotype x forage interaction was significant at the end of both autumn and spring (P=0.07), explained by hybrid deer (especially stags) being heavier when grazed on chicory compared with pasture. Stags were significantly heavier than hinds at the end of all three seasons (P<0.01) and there were no interactions involving sex, genotype and forage.

2.4.4. Effects of treatments on carcass production

Most stags and at least 50% of the hinds grazing either forage attained the target slaughter liveweight of 92 kg (Table 2.9). Stags grazing chicory had significantly higher carcass weight (P<0.001) and dressing out percentage (P<0.001) than those grazing perennial ryegrass/white clover pasture, whilst hybrid stags had a significantly higher carcass weight (P<0.05) than pure red deer stags. The interaction between forage and genotype was significant (P=0.06) for carcass weight, with hybrid stags showing a much bigger response on chicory than on pasture. There was no interaction between forage and genotype for dressing out percentage. After being adjusted to equal carcass weight, carcass subcutaneous fat depth (GR) was higher (P=0.09) for stags grazing chicory than for stags grazing perennial ryegrass/white clover pasture; there was no interaction between genotype and forage. The interaction between genotype and forage for rump fat cover was significant (P<0.05), with hybrid stags grazing chicory having higher

Table 2.9. Experiment 2. Carcass production from stags and hinds grazing either perennial ryegrass/white clover pasture or chicory and attaining slaughter liveweight (92 kg) by one year of age.

Sex	Stags					Hinds		
Forage	Pasture		Chicory			Pasture	Chicory	
Genotype	R	H	R	H	S.E. (D.F.=24)	H	H	S.E. (D.F.=6)
Number of animals	7	8	6	8	7	4	4	4
No.of animals attaining target slaughter LW (%)	7 (100)	7 (88)	6 (100)	8 (100)		3 (75)	2 (50)	
Carcass weight (kg)	56.6	57.0	63.2	73.0	2.34	56.2	58.6	3.77
Dressing percentage(%)	54.1	54.1	58.4	58.6	0.45	54.4	58.6	0.25
GR tissue depth (mm)	3.2	3.1	5.7	7.1	0.70	5.7	8.3	0.83
Rump fat cover (mm)	109.1	105.9	105.7	125.7	3.95	115.7	118.8	1.94

R = pure red deer
H = hybrid (0.25 elk; 0.75 red)

rump fat cover compared to the other groups.

Hybrid hinds grazing chicory had significantly higher dressing out percentage (P<0.01) than those grazing perennial ryegrass/white clover pasture. Although hinds grazing chicory tended to have greater carcass weight, GR and rump fat cover than those grazing perennial ryegrass/white clover pasture, none of the effects attained significance.

2.4.5. Effects of treatments on stomach characteristics.

Stags grazing chicory had similar weights of digesta-free rumen and abomasal tissue, but reduced omasal weights (P<0.01) relative to stags grazing pasture; stags grazing chicory also had reduced volume (ie.capacity) of the emptied rumen (P<0.01), reduced omasal volume (P=0.07) and reduced weight and volume of rumen contents (P<0.01; Table 2.10). Similar trends were evident in the hinds, with the weights of digesta-free rumen and omasal tissue (P<0.05) and the weight and volume of rumen contents (P<0.01) being lower for deer fed chicory than those fed perennial ryegrass/white clover pasture. Rumen contents as a proportion of rumen capacity (ratio B:A; Table 2.10) was also consistently lower for stags and hinds grazing chicory than perennial ryegrass/white clover pasture.

Stags grazing chicory had significantly longer and wider rumen papillae in the roof (P<0.01), and wider (P<0.01) rumen papillae in the blindsac than those grazing perennial ryegrass/white clover pasture (Table 2.11). Similar trends were again evident in the hinds, with rumen papillae length and width in the roof and width in the atrium of hinds grazing chicory being significantly greater (P<0.01) than those grazing perennial ryegrass/white clover pasture.

Table 2.10. Experiment 2. Volume (l) and weight (kg) of the emptied rumen, omasum and abomasum organs, together with the weight and volume of rumen contents in deer grazing either perennial ryegrass/white clover pasture or chicory. All data are expressed per 100 kg liveweight.

Sex	Stags			Hinds		
Forage	Pasture	Chicory	S.E. (D.F.=22)	Pasture	Chicory	S.E. (D.F.=6)
Number of animals	14	13	14	4	4	4
Rumen:						
-volume (A)	10.38	7.26	0.760	9.13	6.78	1.812
-weight	1.96	1.98	0.063	2.27	1.93	0.085
Omasum:						
-volume	0.30	0.14	0.057	0.18	0.12	0.029
-weight	0.18	0.13	0.090	0.18	0.11	0.016
Abomasum:						
-volume	1.15	1.03	0.087	1.19	0.91	0.106
-weight	0.33	0.33	0.011	0.29	0.31	0.012
Rumen contents:						
-volume	6.13	3.57	0.254	6.48	3.53	0.608
-weight(B)	5.86	3.48	0.492	5.31	3.15	0.195
Ratio (B/A)	0.57	0.48	0.055	0.64	0.51	0.121

Table 11. Experiment 2. Mean values for the length and width of rumen papillae in stags and hinds grazing either perennial ryegrass/white clover pasture or chicory.

Sex	Stags			Hinds		
Forage	Pasture	Chicory	S.E. (D.F.=22)	Pasture	Chicory	S.E. (D.F.=6)
Number of animals	14	13	14	4	4	4
Roof (mm):						
-length	0.25	0.39	0.014	0.25	0.43	0.032
-width	0.08	0.16	0.006	0.08	0.14	0.006
Blindsac (mm):						
-length	0.82	0.85	0.048	0.85	0.81	0.013
-width	0.18	0.21	0.008	0.16	0.18	0.015
Atrium (mm):						
-length	0.84	1.06	0.025	0.93	0.86	0.225
-width	0.17	0.20	0.007	0.16	0.19	0.004

2.4.6. Voluntary feed intake (VFI) and grazing behaviour

Voluntary feed intake (VFI) of hinds grazing chicory in Experiment 1 was significantly higher than those grazing pasture ($P<0.01$;Table 2.12), whilst in Expt 2 VFI of deer weaners grazing chicory was significantly higher than those grazing pasture both in autumn ($P<0.05$) and in spring ($P<0.05$). For the deer grazing chicory, VFI tended to be higher for hinds suckling hybrid than red deer calves in Experiment 1 (6147 *v.* 4609 gOM/day) and for growing hybrid than red deer in Experiment 2, in both autumn (1562 *v.* 1396 gOM/day) and in spring (4439 *v.* 3633 gOM/day), but the effects did not attain significance.

Eating time of hinds grazing chicory or pasture was not significantly different (Table 2.12) in Experiment 1, but hinds grazing chicory had a significantly lower rumination time ($P<0.01$) and bite rate ($P<0.05$) than those grazing perennial ryegrass/white clover pasture. In Experiment 2 weaner deer grazing chicory spent significantly less time eating in autumn ($P<0.05$), and in spring ($P<0.01$) than

those grazing pasture. Deer grazing chicory in Experiment 2 spent less time ruminating in autumn ($P<0.01$) and in spring ($P<0.01$) compared to those grazing perennial ryegrass/white clover pasture. Bite rate of deer weaners grazing chicory was lower in autumn ($P<0.001$) and in spring ($P<0.001$). Calculated bite weight was significantly higher for deer grazing chicory than pasture, for lactating hinds in Expt 1 ($P<0.001$) and for weaner deer in autumn ($P<0.001$) and in spring ($P<0.05$).

Table 2.12. Experiments 1 and 2. Organic matter intake (OMI), eating and ruminating times of deer grazing either perennial ryegrass/white clover pasture or chicory during summer 1994 (lactating hinds) and during autumn and spring 1993 (weaner deer). Data are mean values for red and hybrid deer of both sexes grazing each forage.

	Pasture	Chicory	S.E. (D.F.=40)
Experiment 1 (lactating hinds):			
		Summer	
OMI (g/day)	3448	5378	428.9
Eating time (h/24h)[1]	11.2	11.2	0.04
Rate of biting (bites/min)[1]	51.7	46.7	1.40
Bite weight (mgOM/bite)[1]	101	180	16.7
Ruminating time (h/24h)[1]	6.1	2.6	0.03
Experiment 2 (weaner deer):			
		Autumn	
OMI (g/day)	1170	1479	77.6
Eating time (h/24h)[1]	10.9	8.7	0.51
Rate of biting (bites/min)[1]	52.1	34.1	2.06
Bite weight (mgOM/bite)[1]	35	86	3.0
Ruminating time (h/24h)[1]	3.5	1.6	0.41
		Spring	
OMI (g/day)	3501	4038	180.0
Eating time (h/24h)[1]	10.3	8.6	0.12
Rate of biting (bites/min)[1]	46.7	32.6	0.82
Bite weight (mgOM/bite)[1]	127	243	9.3
Ruminating time (h/24h)[1]	3.3	2.0	0.11

[1] Error d.f.= 8

2.4.7. Velvet antler production

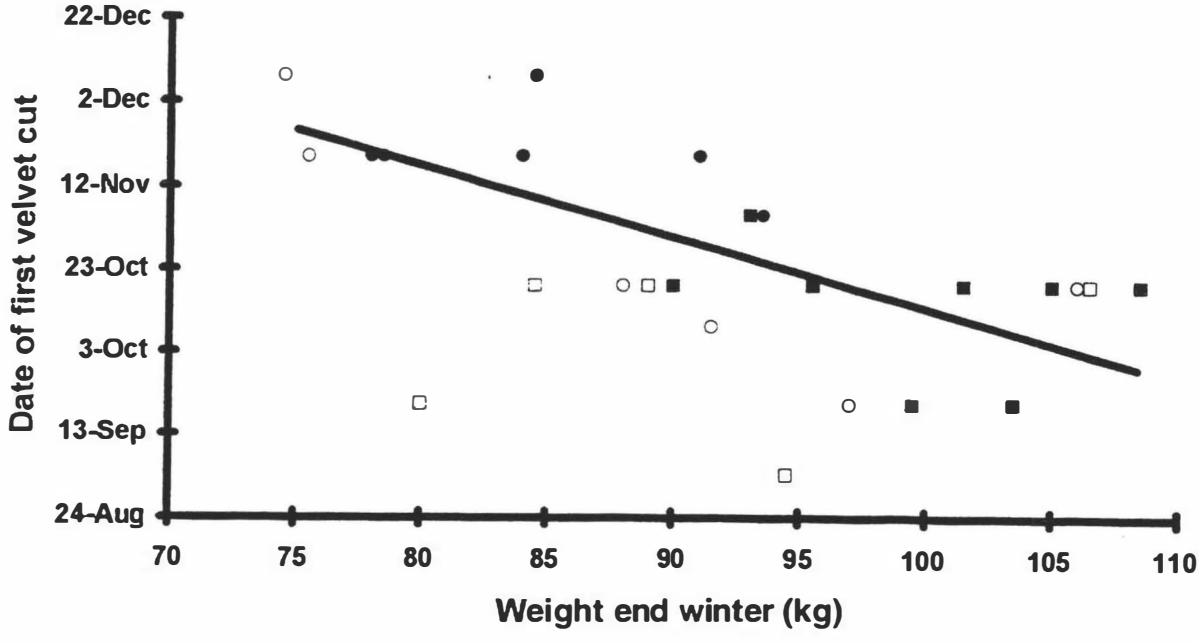
Relative to grazing on pasture, grazing on chicory tended to increase the weight of first cut velvet (P=0.12) and significantly increased the combined weight of first cut and regrowth velvet (P<0.01;Table 2.13). Grazing deer on chicory advanced the mean date of first cut velvet antler by 28 days (P<0.01). A number of liveweight (W) relationships were examined, and the date of first velvet cut (D) was found to be best correlated with liveweight at the end of winter (Fig 2.1; Eqn 6). Each 10 kg increase in liveweight (W) at the end of winter advanced date of first velvet cut by an average of 9.3 days. When liveweight at the end of winter was used as a covariate (Table 2.13), grazing on chicory still advanced date of first velvet cut (P<0.05), but the advancement was reduced to 16 days. First cut velvet was on average 14 days later for hybrid than for pure red deer stags (P=0.13); there were no forage x genotype interactions for any of the velvet measurements.

Table 2.13. Experiment 2. Velvet antler production from red and hybrid yearling stags grazing either perennial ryegrass/white clover pasture or chicory during 1993.

Feed	Pasture		Chicory		S.E.
Genotype	Red	Hybrid	Red	Hybrid	(D.F.=22)
Total No.of stags	7	8	6	8	7
Stags producing velvet (%)	100	75	83	100	
First cut (g)	280(7)*	269(6)	349(5)	399(8)	58.2
Regrowth (g)	368(3)	160(1)	379(5)	438(7)	67.2
First cut and regrowth (g)	438(7)	296(6)	727(5)	783(8)	103.7
Mean date of first cut					
- uncorrected	29 Oct	15 Nov	4 Oct	14 Oct	8.28
- corrected[1]	23 Oct	10 Nov	3 Oct	23 Oct	8.25

* Number of stags per group

[1] corrected by co-variate to equal liveweight at the end of winter.



$$D = 151 - 0.93W. \quad S.E. = \pm 0.47 \qquad (6)$$

Fig 2.1. The relationship between date of first cut velvet antler and liveweight at the end of winter. ○ red deer pasture; ● hybrid deer pasture;□ red deer chicory;■ hybrid deer chicory.

2.5. DISCUSSION

The most important results in the present study were the greater carcass weight of deer grazing chicory compared to those grazing pasture, and the greater carcass weight responses of hybrid deer on chicory than on pasture, indicating that the superior genetic potential of hybrid stags for growth can best be expressed when grazing a high nutritive value forage. Components of the superior carcass weight on chicory include a greater carcass dressing out percentage than for deer grazing pasture and superior growth rates relative to pasture-fed deer during summer and autumn. Studies with red clover (Niezen *et al.* 1993; Semiadi *et al.* 1993) have shown that inputs of this plant increased deer carcass production through increasing carcass dressing out percentage and by

increasing LWG, mainly during summer and autumn.

Relative to the perennial ryegrass-based pastures, the chicory used in Experiment 1 and Experiment 2 was of higher OMD and VFI was higher during summer, autumn and spring (Tables 2.5, 2.6 and 2.12). Hence grazing chicory promoted greater levels of deer production than grazing pasture in terms of deer calf and weaner growth, especially hybrid stags. The higher ratio of readily fermentable CHO:structural CHO must be associated with the higher OMD value of chicory compared to pasture, as total N of chicory was lower than that of pasture. The CHO composition and OMD of chicory showed little change between seasons, but pasture changed with season, being of lowest OMD in summer and highest OMD in spring. Adam (1988) stated that moisture stress during summer leads to higher contents of structural CHO in pasture, lowering its digestibility. These observations indicated that pasture is of lowest feeding value during summer and autumn, and that the nutritional advantages of chicory over pasture are likely to be greatest over these periods, thus explaining the LWG responses of chicory-fed deer over this period. As grazing time was either similar (Experiment 1) or less (Experiment 2) for deer grazing chicory than pasture and as bite rate was consistently lower for deer grazing chicory, it is evident that the principal means by which deer grazing chicory increased their VFI relative to deer grazing pasture was through increased bite weight.

Data from grazing behaviour observations showed that deer grazing chicory spent only slightly less time eating but substantially less time ruminating than those grazing pasture. This result agreed with that of Hoskin *et al.*(1995) that deer fed freshly-cut pure chicory indoors spent a similar time eating (361 *v.* 379 min/24h) but markedly less time ruminating (33 *v.* 270 min/24h) than those fed perennial ryegrass. The function of the rumination process is to reduce particle size until the critical size is reached which allows a high probability of leaving the rumen (Ulyatt *et al.* 1986) and for deer this has been defined as passage through a 1mm sieve (Domingue *et al.* 1991). The shorter ruminating time in deer fed chicory suggests that particles of this feed can be broken down to the critical

particle size and passed out the rumen faster than perennial ryegrass, and this is supported by the reduced weight and volume of rumen digesta in the deer fed chicory. This, together with the reduced volume of the emptied rumen in deer fed chicory suggests that digestion of this plant caused less distension of the rumen than digestion of perennial ryegrass/white clover pasture, offering a further reason for the increased VFI on chicory. Deer grazing chicory had longer and wider rumen papillae compared to those grazing perennial ryegrass/white clover pasture (Table 2.11). The mean length and width of rumen papillae in calves increased in response to feeding grain or intraruminally administered volatile fatty acids (VFA) solutions, with butyrate being more potent than propionate and acetate (Sanders *et al.* 1959; Tamate *et al.* 1962). The higher values of rumen papillae of deer grazing chicory compared to those grazing perennial ryegrass/white clover pasture can therefore be explained from the higher butyrate proportions found from the digestion of chicory (Hoskin *et al.* 1995).

The higher carcass subcutaneous fat depth (GR) of deer grazing chicory compared to those grazing pasture was probably related to the difference in the end products of rumen fermentation and efficiency of their utilization, as Hoskin *et al.*(1995) reported chicory produced a rumen fermentation with a higher acetate:propionate ratio and greater *n*-butyrate proportions than perennial ryegrass. This finding contrasts with the the generally accepted phenomenon that diets with a higher ratio of readily fermentable CHO:structural CHO produce rumen fermentations with a lower acetate:propionate ratio (Ulyatt 1973). Higher production of acetic and *n*-butyric acids acid in chicory compared to perennial ryegrass pasture probably contributed to GR value being higher in deer grazing chicory than those grazing pasture, as the excess of acetic acid production in the rumen can be incorporated directly into adipose tissue (Butler-Hogg & Cruickshank, 1989).

Stags grazing chicory had higher total velvet weight and earlier first velvet cut compared to those grazing pasture (Table 2.13). Fennessy & Suttie (1985) stated that pedicle initiation is highly correlated with body weight and is dependent on

the level of nutrition. Suttie & Kay (1983) reported that stags fed to appetite advanced pedicle initiation by 12 weeks compared to those under restricted feeding. P.F.Fennessy unpublished, cited by Fennessy & Suttie (1985) reported that feeding pelleted feed (barley-lucerne-linseed) *ad libitum* advanced pedicle initiation of stags by 6 weeks compared to those given meadow hay. That stags grazing chicory in this study had an earlier first velvet cut than those grazing pasture suggests that chicory is able to advance pedicle initiation, hence total velvet weight was higher. It seems that grazing chicory advanced the date of first velvet cut in the yearling stags by two mechanisms; first by increasing liveweight and second by a nutritional effect independent of liveweight. Semiadi *et al.*(1993) found that yearling stags grazing red clover had superior LWG but similar spiker velvet antler production to young stags grazing pasture. The cause of the independent nutritional effect in stags grazing chicory is unknown and warrants further investigation.

If chicory is to be included in deer production systems under grazing conditions, it is very important to maintain a high proportion of leaf relative to stem, because an increase in the proportion of reproductive stem leads to a decrease in forage quality. Li *et al.*(1994) reported that the primary reproductive stem of chicory was controlled by hard grazing (50 mm stem height), and that this maximized leaf mass. Lax grazing of chicory with sheep resulted in a lower leaf:stem ratio compared to medium, hard and very hard grazing (Li *et al.* 1994). Chicory continues to produce relatively less vigorous secondary reproductive stems once the primary stems are controlled, but these are less detrimental to leaf growth and forage quality than the primary stems.

In conclusion, carcass weights of 50-65 kg can be achieved by <1 year of age by grazing stags on chicory and hybrid stags showed greater growth and carcass weights than pure red stags when they were grazed on chicory. Higher VFI and OMD, coupled with lower ruminating times of deer grazing chicory compared to those grazing pasture suggested faster rumen particle breakdown occurring on chicory relative to pasture. Further research is needed to determine the efficiency

of rumination on particle size breakdown in deer fed chicory. Also, an experiment to investigate outflow rate of digesta needs to be done to explain the high VFI and high levels of production in deer grazing chicory.

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Chapter 3

Intra-ruminal particle size reduction in deer fed fresh perennial ryegrass (*Lolium perenne*) or chicory (*Cichorium intybus*)

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3.1. *ABSTRACT*

Pure swards of chicory (*Cichorium intybus*) and perennial ryegrass (*Lolium perenne*) were grown at Palmerston North, New Zealand. They were cut daily and fed fresh at 2 kg dry matter (DM)/day to 10 hand-reared rumen fistulated castrated red deer stags kept in metabolism crates in April and October 1994. The efficiency of particle breakdown during the time allowed for rumination (<C.PART>) to below the critical size required to leave the rumen (passage through a 1mm sieve) and jaw activities (ie. eating and ruminating) were measured. Total eating time and the number of eating bouts were similar for deer fed each forage, but deer fed chicory had a greater chewing rate during eating (97.4 *v.* 81.0 chews/min), and a higher number of chews/g DM eaten (36.2 *v*. 31.5). Deer fed chicory had lower total ruminating time (30 *v*. 257 min/22.5h), lower number of boli ruminated (38 *v.* 440/22.5h), lower number of rumination bouts (5.4 *v.* 16.2/22.5h) and less chews per minute ruminating (16.5 *v.* 44.3) than those fed perennial ryegrass. Of the ten deer used to measure (<C.PART>), only four ruminated when fed chicory compared with nine when fed perennial ryegrass.

Deer fed chicory had a higher efficiency of particle breakdown (<C.PART>; 0.64 *v.* 0.42), higher fractional degradation of particles >1mm (9.2 *v.* 5.1%/h) and faster fractional disappearance of total DM from the rumen (10.2 *v.* 5.3%/h). All three measurements for chicory were similar in deer that did or did not ruminate, but with perennial ryegrass all values were considerably reduced in the deer that did not ruminate.

It was concluded that chicory can be broken down faster in the rumen, with less rumination being required than perennial ryegrass, and that some deer (60%) could break down swallowed chicory to below the critical particle size without ruminating at all. The faster clearance of DM from the rumen explains the high voluntary feed intake (VFI) of deer grazing chicory. Future research needs to be done to partition rumen fractional disappearance rate into its components, rumen fractional degradation rate and rumen fractional outflow rate in deer fed chicory

and perennial ryegrass.

3.2. INTRODUCTION

Chewing during eating and chewing during rumination are the two principal processes which reduce ingesta particle size and therefore affect the clearance of digesta from the rumen in animals fed grass and legumes (Ulyatt *et al*. 1986). The first process appears to be very efficient in damaging surfaces, releasing soluble materials from feed and forming feed into boli (Poppi *et al*. 1981; Ulyatt 1984). The function of rumination is to further reduce the particle size of rumen contents until the critical size is reached which allows a high probability of leaving the rumen (Ulyatt *et al*. 1986). For deer, the critical particle size has been defined as a passage through a 1mm sieve (Domingue *et al*. 1991*a*). Faster particle breakdown as affected by more efficient chewing during eating and during ruminating may lead to the more rapid clearance of digesta from the rumen and hence to increases in VFI (Ulyatt *et al*. 1986).

Young deer grazing chicory (*Cichorium intybus*) have been shown to have a greater liveweight gain (LWG) and VFI compared to those grazing perennial ryegrass (*Lolium perenne*)/white clover (*Trifolium repens*) pasture (Niezen *et al*. 1993; Kusmartono *et al*. 1996). Behaviour observations, during both indoor feeding (Hoskin *et al*. 1995) and grazing (Kusmartono *et al*. 1996) showed that deer fed chicory spent a similar time eating, but considerably less time ruminating compared to those fed perennial ryegrass-based pasture. Dryden *et al*. (1995) showed that the efficiency of chewing during eating by deer in reducing particle size to <1mm (<C.EAT>) was less for chicory (0.27) than for perennial ryegrass (0.37) or the legumes *Lotus corniculatus* and lucerne (0.50). The objective of this study was to investigate the efficiency of particle breakdown (<C.PART>) during the time allowed for rumination in deer fed chicory and perennial ryegrass.

3.3. MATERIALS AND METHODS

3.3.1. Experimental design

An indoor experiment was conducted using rumen fistulated red deer (*Cervus*

elaphus) fed either perennial ryegrass (*Lolium perenne* cv. Nui) or chicory (*Cichorium intybus* cv. Puna). The experiment was conducted at Massey University Deer Research Unit in 1994 and was divided into period 1 (P1; April 1994) and period 2 (P2; October 1994). The five deer fed chicory in P1 were fed perennial ryegrass in P2, whilst those fed perennial ryegrass in P1 were fed chicory in P2. Each period was divided into an adjustment (10 days) and rumen contents baling and jaw recording (5 days) sub-periods. Parameters recorded included eating, ruminating, rumen pool size and the particle size distribution of rumen contents.

3.3.2. Forages

The chicory was sown in January 1993 and was a pure, vegetative crop. The perennial ryegrass was sown in 1991, and was from a pure sward, *c.* 10 cm in height. Potassic superphosphate (9%P;10%S and 7%K) was applied at 250 kg/ha, corresponding to 22.5 kg P/ha, onto perennial ryegrass and chicory in late autumn (April) 1993 and 1994. Also, four urea applications each of 37 kg N/ha were made to each forage in early spring (August 1993), late spring (October 1993), late summer (February 1994) and spring (August 1994), respectively. Fresh forage was cut daily at 15.00h using a mower; half was fed immediately after cutting and the remainder was spread on a concrete floor indoors overnight in a cool building to prevent deterioration.

3.3.3. Animals, housing and diets

Ten castrated, hand-reared stags each fitted with an 83mm diameter rumen cannula were used. Mean initial and final liveweights (±S.D.) of the animals were 145 (±11.6) and 135 (±10.7) kg for P1 respectively, and 129 (±12.6) and 127 (±13.2) kg for P2 respectively. The animals were individually housed in specially constructed deer metabolism crates (Milne *et al.* 1978), to which they were well accustomed. One side of the cages was movable and could be used to adjust the floor area.

The animals were randomly allocated to the two diet treatments based on

liveweight, so that each treatment group contained five animals with equal mean liveweight. Prior to being brought into cages, the animals were grazed on either perennial ryegrass or chicory for 4-5 days. In the cages, a 10-day adjustment period allowed animals to adjust to indoor conditions, to the two diets offered and to the handling procedures, including restriction of movement caused by reducing the floor area. Rumen contents baling and jaw recording was done during days 11-15. Jaw harnesses were fitted to each animal 4 days before jaw movement recording commenced, to allow the animals to become used to them. During the adjustment and rumen contents baling and jaw recording periods, all animals were fed at 08.30 and 15.30h at 2 kg DM/day. The amount of fresh material fed was based on dry matter (DM) percentage determined on the previous day. The actual dry matter intake (DMI) was calculated by taking triplicate samples of feed offered daily at 15.00 and 08.00h the following morning for DM determination (100°C; 18h). During the experiment, animals had free access to water and mineralized salt blocks (Dominion Salt, Blenheim, NZ). Duplicate 200g samples of the feed offered were taken daily, pooled and kept at -20°C, and subsamples were subsequently taken for chemical analysis.

3.3.4. Measurement of efficiency of particle breakdown

Jaw activities, such as eating, ruminating and resting were recorded using the method described by Stafford *et al.* (1993). During measurement of (<C.PART>), animals were allowed to consume feed from 08.30 to 11.30h (P1) and from 08.30 to 22.00h (P2); all feeds were then removed for 5 h (P1) and 9 h (P2) so that (<C.PART>) could be measured. The sequence was changed for P2 because some animals did not ruminate during the day in P1 (11.30-16.30h); consequently longer time was allowed for rumination in P2 and this was measured during the night, when the deer were more likely to ruminate. Baling of rumen contents was done twice a day on each animal. The first (FB) and second (SB) balings were done at 11.30 and 16.30h (P1) and at 22.00 and 07.00h (P2). Over a 5 day period, one animal fed perennial ryegrass and one animal fed chicory were baled each day in each period, with time of rumination being recorded between the two balings. At each baling, all rumen contents were removed, weighed, mixed

thoroughly and subsampled before returning the warmed rumen contents to the rumen. Subsamples of rumen digesta were taken for: (i) triplicate DM determinations, and (ii) particle size analysis for calculation of (<C.PART>) in reducing particle size of rumen contents between the two baling times. The process of baling took 20-25 min per animal. The animals remained standing and were not tranquillized during rumen baling.

Jaw activity (ie.rumination and idling) was recorded between the two baling times (*c.* 5 and 9 h in P1 and P2, respectively). A 4-channel chart recorder (Graphtec Linearecorder WR3701-4Hx1, Japan) connected to the jaw harnesses used in this study allowed simultaneous recording of jaw activity from each of two animals (one on perennial ryegrass; one on chicory).

In addition, jaw activity (ie.eating, ruminating and idling) was also recorded during the 13.5h feeding time in P2. The recording system was similar to that described by Stafford *et al.* (1992) for counting jaw activity. An individual 4-channel chart recorder (Graphtec Linear recorder WR3701-4HX1, Japan) was assigned to each animal, allowing simultaneous recording of eating, ruminating and idling from each of two animals (one perennial ryegrass; one chicory). Jaw movements were sensed as pressure changes in a partially inflated rubber bag held under the jaw by a halter. The bag was a section of bicycle inner tube, closed off at one end, the other end sealed and cemented over a flexible nylon pipe (3.5mm i.d.) joined to a 0.8m section of coiler rubber infusion tubing (CenVet, Australia) which accomodated animal movement. Nylon piping connected this rubber tubing to an electronic pressure transducer (Statham, ADCG, Hongkong) mounted outside the cage. The transducer was connected via a pre-amplifier to the open recorder. Time spent eating or ruminating was interpreted from the chart recorder output as described by Stafford *et al.* (1993) and Hoskin *et al.* (1995).

3.3.5. Laboratory methods

Prior to laboratory analysis, subsamples of the pooled feed offered were freeze-dried and ground to pass a 1mm mesh diameter sieve (Wiley *mill*, USA). Organic

matter (OM) content was measured by ashing in a furnace at 500°C for 16h and total nitrogen (N) was determined by the Kjeldahl procedure, using a selenium catalyst and sulphuric acid digestion. Hot water soluble carbohydrate (HWSC) and pectin were extracted using boiling water and ammonium oxalate respectively, and determined as described by Bailey & Ulyatt (1970). Neutral detergent fibre (NDF), acid detergent fibre (ADF) and lignin were determined by the detergent system of Van Soest (1994). The DM of rumen contents was determined by oven-drying (70°C) for 3 days, until no further loss in weight occurred.

The particle size distribution of rumen contents samples was determined by wet sieving using the apparatus (Turner & Newall Ltd, NZ) and following the procedure described by Domingue *et al.* (1991*b*). Sieve sizes (length of side of square hole) used in the present study were 2.0, 1.0, 0.5 and 0.25 mm. Materials retained on the sieves were washed onto weighed filter paper (Whatman No. 21), in a Buchner funnel, and oven-dried at 100°C for 24h to determine dry weight of each particle size fraction. The dry weight of material not retained on the sieves (<0.25 mm particles), was determined by difference from the initial sample dry weight and the sum of recovered particulate DM fractions.

3.3.6. Calculation of data and statistical analysis

The efficiency of particle breakdown and disappearance from the rumen during the time allowed for rumination were calculated using Eqns 1-3.

$$\text{Efficiency of particle breakdown (<C.PART>)} = \frac{\text{Wt of pool DM >1mm at FB} - \text{Wt of pool DM >1mm at SB}}{\text{Wt of pool DM >1mm at FB}} \quad (1)$$

$$\text{Fractional degradation of particles >1mm (\%/h)} = \frac{(\text{DM of pool >1mm at FB} - \text{DM of pool >1mm at SB}) \times 100}{\text{DM of pool >1mm at FB} \times \text{Hours allowed for rumination}} \quad (2)$$

$$\text{Fractional disappearance of total DM (\%/h)} = \frac{\text{(Total DM pool at FB - Total DM pool at SB) x 100}}{\text{Total DM pool at FB x Hours allowed for rumination}} \quad (3)$$

Data for eating and ruminating behaviour in P2 were tested for significant differences between treatment means by one-way analysis of variance using the General Linear Model (GLM) procedure (SAS 1987). Data for <C.PART> were analysed within each period by one-way analysis of variance, and when this showed similar results within each period further analyses were conducted using a changeover design, combining data for both periods. When the changeover design was applied to parameters measured, using the General Linear Model (GLM) procedure (SAS 1987), between animal and between feeding sequence variation were first removed, before analysing for dietary and period effects. Least Square Means (LSM) analysis was used to test the differences between treatments.

3.4. RESULTS

Chicory contained lower DM, NDF, ADF, hemicellulose, cellulose and lignin concentrations than perennial ryegrass, but higher ash and pectin concentrations (Table 3.1), with these differences being apparent in each feeding period. The ratio of readily fermentable:structural carbohydrate was consistently higher for chicory.

Table 3.1. Chemical composition (g/kgDM) of perennial ryegrass and chicory

	Period1		Period2	
	Perennial ryegrass	Chicory	Perennial ryegrass	Chicory
	(*n*=2)	(*n*=2)	(*n*=2)	(*n*=2)
Dry matter (g/kg) (*n*=7)	249	152	245	170
Ash	109	189	95	171
Total Nitrogen	33.0	28.1	27.8	25.7
Water soluble carbohyrate (*a*)	140	116	158	127
Pectin (*a*)	16	83	18	91
NDF	376	191	384	184
ADF	196	137	207	132
Hemicellulose (*b*)	179	54	178	52
Cellulose (*b*)	167	119	183	120
Ratio RFC:SC (*a/b*)*	0.38	1.29	0.40	1.45
Lignin	30	18	24	12

* Readily fermentable carbohydrate:structural carbohydrate

The eating time and the number of eating bouts were similar in period 2 for deer consuming chicory and perennial ryegrass (Table 3.2). Deer consuming chicory had a greater chewing rate during eating ($P<0.01$), less chews/g fresh feed eaten ($P<0.01$) and higher number of chews/g DM eaten ($P<0.01$) than deer fed perennial ryegrass. Relative to deer fed perennial ryegrass, deer fed chicory had lower total ruminating time, lower number of boli ruminated, lower number of rumination bouts ($P<0.05$) and less chews per minute ruminating ($P<0.01$). The number of chews per bolus ruminated by deer fed chicory tended to be lower ($P=0.14$) than those fed perennial ryegrass.

Table 3.2. Eating and ruminating times of red deer fed fresh perennial ryegrass or chicory during period 2, when feed was offered for 13.5 h per day

	Perennial ryegrass (n=5)	Chicory (n=5)	S.E. (D.F.=8)
Eating behaviour			
Eating time (min/13.5h)	221	209	49.2
Eating bouts (no./13.5h)	8.8	11.2	1.84
Chews/minute	81.0	97.4	1.73
Chews/g fresh	6.5	4.0	0.14
Chews/g DMI	31.5	36.2	0.79
Ruminating behaviour[1]			
Ruminating time (min/22.5h)	257	30	54.6
Ruminating bouts (no./22.5h)	16.2	5.4	3.11
Ruminating boluses (no./22.5h)	439.6	38.4	93.91
Chews/bolus ruminated	92.9	40.0	22.67
Chews/minute ruminating	44.3	16.5	2.38
Idling time (min/13.5h)	439	615	61.8

[1]. Including any rumination which occurred during the 13.5 h when feed was on offer

A lower number of deer ruminated when fed chicory (4/10) than when fed perennial ryegrass (9/10; Table 3.3). Considering the total deer fed each forage, deer fed chicory had a significantly lower ruminating time (P1, P=0.06; P2, P=0.10), but higher efficiency of particle breakdown (<C.PART>; P1, P<0.05; P2, P=0.11), higher fractional degradation of particles >1mm (P1, P<0.01; P2, P<0.05) and higher fractional disappearance of total DM from the rumen (P<0.01 for both periods) compared to those fed perennial ryegrass (Table 3.3). Similar results for (<C.PART>), fractional degradation rate of particles >1mm and fractional disappearance rate were recorded in the deer that ruminated, with the differences attaining significance at P<0.05 in the analysis involving both periods. Statistical tests were not possible for the deer that did not ruminate, because of the low animal numbers involved. However it is evident that efficiency of particle breakdown (<C.PART>), fractional degradation rate and fractional disappearance

rate were similar in deer fed chicory that did or did not ruminate, whereas with perennial ryegrass all three were considerably reduced in the deer that did not ruminate.

Weight of particles >1mm at FB tended to be higher in deer fed chicory in both periods than those fed perennial ryegrass, but the difference did not attain significance (Table 3.4). However, at SB the weight of particles >1mm in rumen contents was consistently less for deer fed chicory than those fed perennial ryegrass ($P<0.05$). Particle size distribution of rumen contents in deer fed each diet was similar in each period. In the samples of rumen contents taken at FB, there was a greater proportion of particles >1mm in deer fed perennial ryegrass ($P=0.09$), largely due to more particles being retained on the 2 mm sieve than in deer fed chicory ($P<0.05$; Table 3.4). These differences had disappeared in the samples taken at SB, with the proportion of particles >1mm and >2mm being similar for the deer fed each forage.

Table 3.3. Efficiency of particle breakdown (<C.PART>) by red deer fed fresh perennial ryegrass or chicory. (Mean values with standard error for 5 animals per forage in each period)

	Period1			Period2		
	Perennial ryegrass	Chicory	S.E. (D.F.=8)	Perennial ryegrass	Chicory	S.E. (D.F.=8)
Ruminating time (min):						
- all deer	44.5(5)[1]	4.9(5)	12.67	82.2(5)	14.0(5)	26.19
- ruminating*	55.6(4)[1]	8.2(3)	14.98	82.2(5)	70.0(1)	55.39
Efficiency of particle breakdown <C.PART>:						
- all deer	0.37(5)	0.63(5)	0.067	0.47(5)	0.65(5)	0.038
- ruminating*	0.38(4)	0.63(3)	0.095	0.47(5)	0.62(1)	0.050
- non-ruminating	0.24(1)[1]	0.64(2)		0	0.65(4)	
Fractional degradation of particles >1mm (%/h):						
- all deer	5.3(5)	9.3(5)	0.78	4.9(5)	9.2(5)	0.67
- ruminating*	5.7(4)	9.7(3)	0.73	4.9(5)	5.9(1)	0.71
- non-ruminating	3.6(1)	8.6(2)		0	9.9(4)	
Fractional disappearance total DM (%/h):						
- all deer	5.2(5)	10.9(5)	0.86	5.3(5)	9.6(5)	0.66
- ruminating*	5.5(4)	11.3(3)	0.71	5.3(5)	7.1(1)	0.62
- non-ruminating	3.7(1)	10.7(2)		0	10.2(4)	

[1]number of animals in each forage

*Error df=5

Table 3.4. Rumen pool size and particle size distribution (%DM retained on each sieve) at first baling and second baling in red deer fed perennial ryegrass and chicory for both periods. (Mean values with their standard error)

Sieve size (mm)	Period	Perennial ryegrass	Chicory	S.E. (D.F.=8)
First baling (FB):				
- Pool size >1mm (g DM)	1	220.1	270.0	25.32
	2	264.6	285.0	23.36
- Particle size distribution	1+2			
>2.0		29.6	17.9	4.26
1.0		3.5	4.3	0.53
0.5		4.4	6.0	0.49
0.25		10.2	12.2	0.77
<0.25		52.2	59.6	3.97
>1.0		33.2	22.2	4.30
<1.0		66.8	77.8	4.30
Second baling (SB):				
- Pool size >1mm (g DM)	1	138.3	96.5	25.32
	2	140.0	98.6	10.91
- Particle size distribution	1+2			
>2.0		24.9	17.2	4.2
1.0		3.6	5.2	0.8
0.5		4.4	8.6	0.7
0.25		10.4	11.2	1.1
<0.25		56.7	57.8	3.5
>1.0		28.6	22.4	3.9
<1.0		71.4	77.6	3.9

3.5. DISCUSSION

The most important results of this study were that the efficiency of particle breakdown (<C.PART>) in the rumen of swallowed plant material was much greater for chicory (mean 0.62) than for perennial ryegrass (mean 0.42) and that the values of (<C.PART>) for chicory were similar in deer that did or did not ruminate, whereas lower values were recorded for perennial ryegrass in the deer that did not ruminate. Ulyatt *et al.* (1986) showed that the action of the teeth during eating and rumination was essential for particle size reduction in sheep fed fresh grasses and legumes, and that rumen fermentation weakened plant material but did not reduce particle size. However, the present studies have shown that in some deer chicory disintegrates rapidly in the rumen without action of the teeth during rumination. Hence, very little and in some cases no rumination was required for swallowed chicory to break down in the rumen to below the critical particle size for passage from the rumen. The reason for these differences was that chicory contained a higher ratio of readily fermentable carbohydrate:structural carbohydrate than perennial ryegrass (1.37 *v.* 0.39; $P<0.01$; Table 3.1). Particle breakdown presumably occurred due to rumen fermentation and to the mixing action of muscular rumeno reticular contractions. This also may account for the higher DM, OM and energy digestibilities of chicory than of perennial ryegrass (Hoskin *et al.* 1995). The (<C.PART>) for perennial ryegrass found in the present study (0.42) was similar to that reported for sheep, whilst the (<C.PART>) for chicory (0.64) was similar to that found for lucerne (0.63) in sheep (Ulyatt *et al.* 1986). It is interesting to note that the (<C.PART>) of perennial ryegrass was considerably reduced when the deer did not ruminate, implying that action of the teeth during rumination was crucial to reduce particle size of this forage to <1mm as shown by Ulyatt *et al.* (1986) for sheep. Deer fed chicory had a greater chewing rate (97.4 *v.* 81.0 chews/min) and more chews/g dry matter intake (36.2 *v.* 31.5) during eating than those fed perennial ryegrass, showing that more comminutive work may be done to chicory before swallowing than to perennial ryegrass. However, despite this, the efficiency of particle breakdown during eating (<C.EAT>) was still less for deer fed chicory (0.27) than those fed perennial ryegrass (0.37; Dryden *et al.* 1995), showing that in deer fed chicory the main

functions of chewing during eating are to form a bolus for swallowing and to break down the surface of the plant.

Although the total eating time of deer fed chicory was similar to those fed perennial ryegrass (209 *v.* 221 min/13.5h), ruminating time was considerably lower in deer fed chicory compared to those fed perennial ryegrass (30 *v.* 257 min/22.5h; Table 3.2), confirming previous work by Hoskin *et al.* (1995) and Kusmartono *et al.* (1996).

Kusmartono *et al.* (1996) found that deer grazing chicory had a higher VFI than those grazing perennial ryegrass/white clover pasture. This can be explained by the fractional degradation of large particles to small particles and the fractional disappearance of DM from the rumen both being approximately twice as fast for deer fed chicory than those fed perennial ryegrass. This provides a faster clearance of DM from the rumen and hence opportunity for increased VFI, as digesta clearance from the reticulo-rumen has long been recognized as a major process determining intake and nutritive value of forages (Black *et al.* 1982).

It can be concluded that chicory can be broken down faster in the rumen, with less rumination being required than in deer fed perennial ryegrass. The rapid disintegration of chicory in the rumen led to a faster rate of DM disappearing from the rumen. Future research needs to be done to partition fractional disapperance rate into its components, rumen fractional degradation rate and rumen fractional outflow rate, to gain further knowledge of the digestion kinetics of chicory and their relationship to nutrient supply and to VFI.

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Chapter 4

Rumen digestion and rumen outflow rate in deer fed fresh chicory (*Cichorium intybus*) or perennial ryegrass (*Lolium perenne*)

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4.1. ABSTRACT

Pure swards of chicory (*Cichorium intybus*) and perennial ryegrass (*Lolium perenne*) were grown at Palmerston North, New Zealand. They were cut daily and fed hourly at 2.25 kg dry matter (DM)/day to eight hand-reared rumen fistulated castrated red deer stags kept in metabolism crates during December 1994 and January 1995 (summer). Apparent digestibility, rumen fractional disappearance rate (FDPR), rumen fractional degradation rate (FDR), rumen fractional outflow rate (FOR) and mean retention time (MRT) were measured. The ratio of readily fermentable carbohydrate to structural carbohydrate was approximately three times higher in chicory than in perennial ryegrass. Apparent digestibility of DM was higher in deer fed chicory than in deer fed perennial ryegrass (0.785 *v.* 0.727), whilst apparent digestibility of neutral detergent fibre (NDF) was lower in deer fed chicory (0.679 *v.* 0.755), due to a reduced hemicellulose digestibility (0.667 *v.* 0.783).

Relative to deer fed perennial ryegrass, those fed chicory had higher rumen FDPR values for DM (14.5 *v.* 8.6%/h), soluble carbohydrate (69.9 *v.* 54.7%/h), cellulose (15.5 *v.* 9.8%/h) and lignin (6.8 *v.* 3.8%/h). Rumen FDR in deer fed chicory was higher than those fed perennial ryegrass for cellulose (11.4 *v.* 7.0%/h) and lignin (2.7 *v.* 1.0%/h), but tended to be lower for hemicellulose. Rumen FOR was higher and MRT was lower for both liquid and particulate matter in deer fed chicory compared to deer fed perennial ryegrass.

It is concluded that rumen FDPR and apparent digestibility were much higher in deer fed chicory than in deer fed perennial ryegrass, due to faster degradation rates of most constituents in the rumen and faster outflow rates from the rumen. An exception was hemicellulose, where reduced rumen degradation rates and shorter rumen particulate MRT contributed to reduced apparent digestibility. Faster clearance from the rumen, due to both faster degradation and outflow rates may be used to explain the greater voluntary feed intake (VFI), as well as faster growth rate in deer grazing chicory compared to those grazing perennial ryegrass. Faster rates of lignin solubility in the rumen probably contributed to the

more rapid breakdown of chicory in the rumen.

4.2. INTRODUCTION

Deer grazing chicory (*Cichorium intybus*) had higher liveweight gains (LWG) and VFI, both during lactation and post-weaning, than deer grazing perennial ryegrass (*Lolium perenne*)/white clover (*Trifolium repens*)-based pasture (Kusmartono *et al*. 1996*a*). Behaviour observations, both during indoor feeding (Hoskin *et al*. 1995) and under grazing (Kusmartono *et al*. 1996*a*) showed similar time spent eating, but substantially less time spent ruminating by deer fed chicory than perennial ryegrass. In indoor studies deer fed chicory had a faster breakdown of particles to the critical particle size for leaving the rumen and faster fractional disappearance of total DM from the rumen than deer fed perennial ryegrass (Kusmartono *et al*. 1996*b*). Digesta clearance from the rumen has long been recognized as a major factor determining VFI and nutritive value of forages (Black *et al*. 1982) and explains the higher VFI on chicory.

Rumen fractional disappearance rate can be partitioned into two components; fractional degradation rate and fractional outflow rate. The objective of this study was to compare rumen digestion rate and rumen outflow rate in deer fed fresh chicory or perennial ryegrass.

4.3. MATERIALS AND METHODS

4.3.1. Experimental design

The experiment was conducted at Massey University Deer Research Unit, Palmerston North, New Zealand and was divided into two periods, each of 17 days duration. Period 1 (P1) took place from 5 to 22 December 1994, whilst period 2 (P2) took place from 10 to 27 January 1995. Red deer (*Cervus elaphus*) were fed either fresh chicory or fresh perennial ryegrass at 2.25 kg DM/day, given continuously at hourly intervals using automatic feeders. The trial was a changeover design, with the animals fed chicory in P1 being fed perennial ryegrass in P2, whilst those fed perennial ryegrass in P1 were fed chicory in P2.

Each animal grazed its assigned pasture for 6-7 days before being brought indoors and placed in a metabolism cage. Each indoor period comprised an adjustment period (10 days) and data collection period (7 days), with apparent digestibility and rumen outflow rate being measured in the data collection period. To measure rumen liquid outflow rate, Cr-EDTA marker was continuously infused into the rumen during the last 5 days of the collection period. Lignin and acid detergent fibre (ADF) were used to measure rumen outflow rate of particulate matter. Rumen fractional outflow rate of liquid and particulate matter was then determined using the continuous infusion, total sampling method (Faichney 1975), with total rumen content of the two markers determined from emptying (baling) the rumen at the end of the infusion period.

4.3.2. Forages

Chicory (*Cichorium intybus* cv. Puna) was sown in January 1992, and was a pure crop, in the vegetative stage. Perennial ryegrass (*Lolium perenne* cv. Nui) was sown in 1991, and was a pure sward, *c.* 10 cm in height. Fertilizers applied included potassic superphosphate (9%P;10%S and 7%K) dressed at 250 kg/ha, corresponding to 22.5 kg kg P/ha, to both forages in late autumn (April 1994). Urea was applied to each forage four times a year at 37 kg N/ha in late summer (February 1994), early spring (August 1994), late spring (October 1994) and summer (January 1995). Fresh forages were cut daily at 15.00h using a mower; half was fed immediately after cutting and the remainder was spread on the floor in a cool building to prevent deterioration.

4.3.3. Animals and diets

Eight hand-reared fistulated castrated stags each fitted with an 83mm diameter rumen cannula were used. Mean initial and final liveweights (±SD) of the animals were 130 (±6.8) and 129 (±8.9) kg for P1 and 136 (±7.8) and 132 (±7.3) kg for P2, respectively. The animals were kept individually in specially constructed deer metabolism crates similar to those described by Milne *et al.* (1978), to which they were well accustomed. One side of the cages was movable and could be used to adjust the floor area.

The animals were randomly allocated to two treatment groups each of four animals based on liveweight. Prior to being brought into cages, the animals were grazed on either chicory or perennial ryegrass for 6-7 days. A 10-day adjustment period allowed animals to adjust to indoor conditions, to the two diets offered and to the handling procedures, including restriction of the movement caused by reducing the floor area. During the adjustment and data collection periods, overhead feeders were set to deliver feeds at hourly intervals to achieve the steady state conditions required, and filling of the overhead feeders took place at 15.30 and 08.00 h. The daily DM offered of both feeds was kept at 2.25 kg DM/day, and the amount of fresh materials to be fed was calculated by taking triplicate samples of feed offered at 15.00 and at 08.00h the following morning. Feed refusals were collected at 08.00h for dry matter (DM) determination (100°C; 18h). During the experiment animals had free access to water and to mineralised salt blocks (Dominion Salt, Blenheim, NZ).

4.3.4. Digestibility trial

Feed offered and feed refusals were weighed and faeces were quantitatively weighed daily over the periods 16-22 December 1994 and 21-27 January 1995 in P1 and P2, respectively. The cages were designed such that there was no urine contamination of faeces, and any small amounts of faeces dropped were collected, so the total faeces was measured. Water intake was measured daily for each animal and the values were presented after being corrected for evaporative losses. Duplicate 200g samples of feed offered were taken daily, pooled per week, and kept at -20°C. Each animal's feed refusal was collected, pooled per animal per week, and kept at -20°C. At the end of each period, duplicate subsamples of pooled feed offered and feed refusals were freeze-dried and ground for chemical analysis. Faeces were collected daily and separated from any hair and residual forage; 15% of total faeces excreted was pooled per animal, and kept at -20°C. Later these were homogenized, triplicate samples were taken for DM determination (100°C; 48h) and duplicate samples were taken, freeze-dried and ground for chemical analysis.

4.3.5. Measurement of rumen outflow rate

4.3.5.1. Marker infusion

The inert liquid phase marker, Chromium Ethylene Diaminetetra Acetic acid (Cr-EDTA) was prepared following the method of Binnerts *et al.* (1968) and adjusted to a pH of 6.5-7.0. The Cr-EDTA was made up to 10 litres with a final Cr concentration of 2 mg/g of solution. Following a priming dose of 50 g into the rumen, the Cr-EDTA solution was continuously infused into the rumen for 5 days at a rate of 28-32 g/h. The exact infusion rate was determined for each animal. The infusion was done using a peristaltic pump (PLG-multipurpose pump, Desaga, Heidelberg, Germany).

4.3.5.2. Rumen contents baling

The rumens were emptied on 22 and 23 December 1994 (P1) and 27 and 28 January 1995 (P2) at the conclusion of the collection period. Rumen contents were weighed, thoroughly mixed, and subsampled before returning the warmed digesta back to the rumen. Subsamples of rumen digesta were taken for triplicate DM determination both by oven-drying and freeze-drying. Duplicate 200g subsamples of rumen digesta were taken, freeze-dried and ground for chemical analysis. The process of baling took 20-25 min per animal. The animals remained standing and were not tranquillized during rumen baling.

4.3.6. Laboratory methods

All laboratory analyses were conducted using freeze dried material, which had been ground to pass a 1mm mesh diameter sieve (Wiley *mill*, USA). Organic matter (OM) content was measured by ashing in a furnace of 500°C for 16h and total nitrogen (N) was determined by the Kjeldahl procedure, using a selenium catalyst and sulphuric acid digestion. Hot water soluble carbohydrate (HWSC) and pectin were extracted using boiling water and ammonium oxalate respectively, and determined using the method described by Bailey & Ulyatt (1970). Neutral detergent fibre (NDF), acid detergent fibre (ADF) and lignin were determined by the detergent system of Van Soest (1994). Hemicellulose was calculated as NDF-ADF and cellulose was calculated as ADF-lignin. The DM of

rumen digesta was determined by oven-drying (100°C) for 3 days, and by freeze-drying for 6 days, until no further loss in weight occurred. Chromium analysis of rumen digesta was done using the method of Costigan & Ellis (1987).

4.3.7. Calculation of data and statistical analysis

Rumen fractional outflow rate (FOR) was calculated using the continuous infusion and total sampling procedure (Faichney 1975) as shown in Eqns 1 and 2. Liquid FOR was calculated with reference to the external marker Cr-EDTA. Particulate FOR was calculated using two internal markers (lignin and ADF) and it was assumed that any lignin or ADF digestion occurred in the rumen only; Eqn 2 assumes that there was minimal post-ruminal digestion of lignin or ADF.

Rumen fractional outflow rate (FOR):

$$\text{- Water (\%/h)} = \frac{\text{Marker Cr infusion rate (mg/h)x100}}{\text{Rumen pool size (mg Cr)}} \quad (1)$$

$$\text{- Particulate matter (\%/h)} = \frac{\text{Faeces lignin or ADF excretion rate (g/h)x100}}{\text{Rumen lignin or ADF pool size (g)}} \quad (2)$$

Rumen fractional disappearance rate (FDPR) and rumen fractional degradation rate (FDR) were calculated as shown in Eqns. 3 & 4.

$$\text{Fractional disappearance rate (FDPR;\%/h)} = \frac{\text{Intake (g/h)x100}}{\text{Rumen pool size (g)}} \quad (3)$$

$$\text{Fractional degradation rate (FDR;\%/h)} = \text{FDPR - FOR (lignin)} \quad (4)$$

Rumen FDPR was calculated for dry matter, all carbohydrate constituents and lignin.

Equation 4 was applied to the fibre constituents of each feed only, on the

assumption that all fibre components left the rumen in the same particle as lignin and therefore had the same FOR. Rumen mean retention time (MRT) was calculated as the reciprocal of FOR (Faichney 1975).

Parameters measured were analysed using the General Linear Model (GLM) procedure (SAS 1987), for the changeover design; between animal and between feeding sequence variation were first removed, before analysing for dietary and period effects. Least Square Means (LSM) analysis was used to test the differences between treatments.

4.4. RESULTS

Chicory contained significantly lower concentrations of DM, NDF, ADF, hemicellulose and cellulose ($P<0.01$), but higher ash, lignin and pectin concentrations ($P<0.01$) than perennial ryegrass (Table 4.1), with these differences being apparent in each feeding period. Water soluble carbohydrate content and total N were similar for chicory and perennial ryegrass.

Table 4.1. Chemical composition (g/kgDM) of perennial ryegrass and chicory

	Period1			Period2		
	Perennial ryegrass (n=2)	Chicory (n=2)	S.E. (D.F.=2)	Perennial ryegrass (n=2)	Chicory (n=2)	S.E. (D.F.=2)
Dry matter (g/kg) (n=7)	255	180	5.6	251	200	7.8
Ash	112	180	11.1	101	136	1.8
Total nitrogen	26.0	24.0	2.81	25.3	28.4	0.50
Water soluble carbohydrate (*a*)	134	108	8.9	107	106	9.3
Pectin (*a*)	14	85	13.0	14	106	3.0
Readily fermentable carbohydrate[1]	148	193	12.5	121	212	6.5
NDF	455	229	12.0	450	228	8.0
ADF	258	173	5.6	259	165	3.1
Hemicellulose (*b*)	197	56	6.5	191	61	4.8
Cellulose (*b*)	237	140	3.2	240	133	3.3
Ratio RFC:SC (*a*/*b*)[2]	0.34	0.99	0.084	0.28	1.09	0.028
Lignin	21	33	3.5	19	34	2.6

[1] Water soluble carbohydrate + pectin
[2] Readily fermentable carbohydrate:structural carbohydrate

Dry matter intake (DMI) of deer fed chicory was slightly higher (*c.* 10%; $P<0.05$) than for deer fed perennial ryegrass (Table 4.2). Apparent digestibility of DM was greater in deer fed chicory than perennial ryegrass ($P=0.06$). Fibre apparent digestibility was lower in deer fed chicory than perennial ryegrass, with the difference approaching significance for NDF ($P=0.07$) and ADF ($P=0.06$) and attaining significance for hemicellulose ($P<0.05$).

Table 4.2. Dry matter intake, apparent digestibility, rumen fractional disappearance rate and rumen fractional degradation rate of perennial ryegrass and chicory fed to red deer

	Perennial ryegrass (n=8)	Chicory (n=8)	S.E. (D.F.=6)
Intake:			
kgDM/day	2.02	2.25	0.048
gDM/kgW$^{0.75}$/day	50.8	58.4	1.30
Apparent digestibility:			
Dry matter	0.727	0.785	0.0140
Organic matter	0.744	0.820	0.0311
NDF	0.755	0.679	0.0231
ADF	0.708	0.599	0.0349
Hemicellulose	0.783	0.667	0.0288
Cellulose	0.774	0.743	0.0331
Lignin	-0.001	0.235	0.1676
Fractional disappearance rate (%/h):			
Dry matter	8.6	14.5	1.29
Soluble carbohydrate	54.7	69.9	2.80
Pectin	40.4	58.0	10.44
Readily fermentable carbohydrate[1]	48.2	59.2	4.15
NDF	8.3	10.2	0.97
Cellulose	9.8	15.5	1.52
Hemicellulose	7.8	7.3	0.81
Lignin	3.8	6.8	0.61
Fractional degradation rate (%/h):			
NDF	5.7	6.7	0.72
Cellulose	7.0	11.4	1.11
Hemicellulose	5.0	3.2	0.67
Lignin	1.0	2.7	0.21

[1.] Water soluble carbohydrate+pectin

For both forages, readily fermentable carbohydrate disapperared from the rumen around six times faster than total fibre (NDF). Fractional disappearance rate (FDPR) of chicory from the rumen was higher than that of perennial ryegrass, with the difference attaining significance for DM ($P<0.05$), soluble carbohydrate ($P<0.01$), cellulose ($P<0.05$) and lignin ($P<0.05$). Pectin FDPR was also considerably greater for chicory than for perennial ryegrass, but due to the variability encountered, the difference did not attain significance. There was no difference in FDPR value of hemicellulose between the two diets. Fractional degradation rate (FDR) of total fibre (NDF; $P=0.06$), cellulose ($P<0.05$) and lignin ($P<0.01$) were higher in deer fed chicory than perennial ryegrass, whilst FDR of hemicellulose tended to be lower in deer fed chicory than those fed perennial ryegrass ($P=0.11$).

Total rumen pool size and rumen liquid pool size tended to be lower ($P=0.11$ and $P=0.12$ respectively) for deer fed chicory than perennial ryegrass (Table 4.3). Dry matter percentage of rumen content was similar in deer fed either diet. Rumen liquid fractional outflow rates (FOR) were high for both diets. Rumen FOR of Cr-EDTA, lignin and ADF tended to be higher in deer fed chicory than perennial ryegrass, but due to the variability encountered these approached significance at $P=0.09$ and $P=0.15$ for Cr-EDTA and attained significance at $P<0.05$ for ADF. Nevertheless, effects on Cr-EDTA FOR were repeatable, with similar results being obtained when the calculation was based on Cr-concentration in total digesta (after ashing and digestion) or Cr concentration in the supernatant after high speed centrifugation (no ashing or digestion). The ratio Cr-EDTA FOR/lignin FOR was not different in deer fed either diet. Rumen mean retention time (MRT) tended to be lower for deer fed chicory than those fed perennial ryegrass, with the difference attaining significance for ADF ($P<0.01$).

Table 4.3. Rumen pool size, rumen fractional outflow rate and rumen mean retention time for liquid and particulate matter in rumen red deer fed perennial ryegrass and chicory

	Perennial ryegrass (*n*=8)	Chicory (*n*=8)	S.E. (D.F.=6)
Rumen pool size (kg/kg DMI/day):			
Total*	5.32	3.89	0.530
Liquid	4.83	3.52	0.494
Dry matter (DM)	0.50	0.36	0.056
DM of rumen digesta (%)	9.28	9.49	0.884
Fractional outflow rate (%/h):			
Liquid			
Cr-EDTA (total digesta)	12.3	16.8	1.56
Cr-EDTA (liquid)	13.6	18.9	2.18
Particulate			
Lignin	2.78	4.08	0.551
ADF	2.02	4.30	0.506
Cr-EDTA/lignin	4.75	4.63	0.932
Mean retention time (h):			
Liquid			
Cr-EDTA	8.9	6.4	0.01
Particulate			
Lignin	49.0	37.7	9.61
ADF	52.5	27.9	4.66

* DM+liquid

Total water intake was greater for deer consuming chicory than for those consuming perennial ryegrass ($P<0.05$; Table 4.4), due to a much greater consumption of water in the forage ($P<0.001$) as the amount of water drunk was lower in deer fed chicory than those fed perennial ryegrass ($P<0.05$). Net rumen

water balance (including salivary secretion) tended to be lower in deer fed chicory than perennial ryegrass, but with the variability encountered, the difference only only approached significance at P=0.16 when expressed per kg DM intake.

Table 4.4. Total water influx, rumen outflow and net water balance of deer fed perennial ryegrass and chicory

	Perennial ryegrass (n=8)	Chicory (n=8)	S.E. (D.F.=6)
Water intake (kg/day):			
Drink	4.9	3.3	0.43
Feed	7.2	14.4	0.25
Total	12.1	16.5	1.34
Rumen outflow[1]	28.1	30.5	2.74
Net water balance:			
(kg/day)[2]	16.4	12.8	2.92
(kg/kg DMI)[2]	7.9	5.3	1.24

[1.] Liquid pool size x Cr-EDTA FOR
[2.] Rumen outflow - total water intake = salivary secretion+net water flux across the rumen wall

4.5. DISCUSSION

Fractional disappearance rate (FDPR) of DM from the rumen of deer fed chicory was significantly higher (14.5 *v.* 8.6 %/h; P<0.05) than those fed perennial ryegrass. This result agreed with the previous study of Kusmartono *et al.* (1996*b*) which reported a significantly higher FDPR value from the rumen of deer fed chicory than perennial ryegrass (10.4 *v.* 5.3%/h; P<0.01). The difference in FDPR values between the two studies was probably due to the different measurement techniques used. Fractional disappearance rate values in the present study were obtained from a continuous infusion of marker (Faichney 1975) and continuous feeding, whilst in the study of Kusmartono *et al.* (1996*a*) FDPR values were obtained based on particle size reduction of rumen contents

and twice daily feeding.

Whilst the initial plan was to offer deer identical amounts of both feeds, VFI recorded was slightly higher for chicory than for perennial ryegrass, due to some feed refusal for perennial ryegrass. This is unlikely to have influenced the results, as all data are expressed either in relation to the amount eaten or in relation to rumen pool size.

An objective of the present study was to determine factors responsible for higher FDPR of DM from the rumen of deer fed chicory compared to those fed perennial ryegrass. Results showed that the higher FDPR of DM in chicory than perennial ryegrass was due to both faster rumen FDR, notably of cellulose and lignin, and also faster FOR of both liquid and particulate matter from the rumen. A major reason for greater FDPR on chicory must be higher the dietary concentration of readily fermentable carbohydrate (water soluble carbohydrate+pectin) and its faster rate of disappearance from the rumen compared to deer fed perennial ryegrass.

Although water soluble carbohydrate, pectin, cellulose and lignin were rapidly degraded in rumen of deer fed chicory, hemicellulose was degraded at a slightly lower rate relative to deer fed perennial ryegrass. This may be due to pH effects, as Church (1979) stated that degradation of hemicellulose was optimal at pH 6.0. Kusmartono *et al.* (1996*c*) reported a lower mean rumen pH observed over a period of 24 h in deer grazing chicory (5.7) than those grazing perennial ryegrass (6.5) and the low pH may have restricted hemicellulose fermentation by rumen micro-organisms.

Effects on apparent digestibility of fibre can be explained through a knowledge of rumen FDR and FOR, given that 90% of the fibre that is digested in fresh forages is digested in the rumen (Ulyatt & MacRae 1974). In the case of cellulose, it seems that faster rumen FDR on chicory is counteracted by lower particulate MRT in the rumen, allowing less time for microbial attack, resulting in

apparent digestibility of cellulose in deer fed chicory being similar to that of deer fed perennial ryegrass. However, in the case of hemicellulose, it seems lower FDR and shorter MRT in the rumen combined to produce reduced apparent digestibility of hemicellulose in deer fed chicory relative to deer fed perennial ryegrass.

A higher proportion of lignin disappeared from the rumen faster in deer fed chicory than those fed perennial ryegrass (6.8 *v.* 3.8%/h; $P<0.05$) and rumen lignin FDR was also greater for deer fed chicory (2.7 *v.* 1.0%/h; $P<0.01$). This is probably related to the difference in lignin solubility between these two diets. Akin & Benner (1988) found that neither bacteria nor fungi could degrade lignin contained in a higly lignified cordgrass after being incubated for 7 days in rumen fluid at 39°C. They argued that the loss of lignin from plant tissue was due to solubilization rather than direct fermentation (ie. degradation). This argument is supported by data of Gaillard and Richards (1975) who found that the relatively high concentrations of dissolved (ie. solubilized) lignins produced in the rumen are condensed and precipitated after passage from the rumen into the acidic conditions of the abomasum. As lignin is bonded to cellulose and hemicellulose within plant fibre (Van Soest 1994), greater rumen solubility of lignin in deer fed chicory may have made cellulose more accessible to rumen micro-organisms and contributed to the high cellulose FDR.

Rumen FOR of liquid and particulate matter were both measured using two techniques. The general agreement between the two methods for each forage further supports rumen FOR being faster for deer fed chicory than perennial ryegrass. Rumen FOR found in the present studies have been compared in Table 5.5 with other rumen FOR determined using similar techniques and at a similar time of the year. It can be seen that liquid leaves the rumen and flows into the intestines much faster than for particulate matter and that this ratio (ie. FOR Cr-EDTA/FOR lignin) is consistently greater for red deer than for sheep or goats. Rumen frothy bloat is caused by a build up of soluble protein in the rumen (Mangan 1959), and the high rumen liquid FOR of red deer probably explains

why this species never gets bloat when grazing on rapidly digested forages such as red clover or chicory. Relative to perennial ryegrass, responses in rumen FOR seem to differ between red clover and chicory. Fractional outflow rate for red clover was lower than for perennial ryegrass, whereas with chicory FOR was higher. The higher ash content of chicory may be a contributing factor, with the deer increasing liquid FOR as a means of reducing a potential build up in rumen osmotic pressure. This is supported by the greater total water intake of chicory-fed deer. Katoh *et al.* (1991) reported that deer have evolved a digestive system in which rate of digesta passage through the rumen is much faster than that for sheep and accomodated summer increases in VFI by stimulating rumen digestion through necessary changes in digestive characteristics.

Although not conclusive, the present studies have indicated that rumen net water balance (and hence salivary secretion) may be less in deer consuming chicory than perennial ryegrass. This seems feasible, as total time spent ruminating in deer fed chicory is only *c.* 10% of those fed perennial ryegrass (Kusmartono *et al.* 1996*b*), and salivary secretion rates are much greater during ruminating than during resting (Bailey & Balch 1961; Van Soest 1994). Salivary secretion rates in deer fed these forages need to be measured in the future studies. Lower salivary secretion rates in deer fed chicory could certainly explain the low rumen pH on this forage, due to reduced buffering capacity.

It can be concluded that apparent digestibility of DM and OM was higher in chicory than in perennial ryegrass, but the reverse was found for hemicellulose apparent digestibility. More rapid FDPR of total DM from the rumen of deer fed chicory was due to higher FDR and faster liquid and particulate matter FOR and was related to the higher ratio of readily fermentable carbohydrate (RFC) to structural carbohydrate (SC) in chicory than in perennial ryegrass. This evidence may be used to explain the greater VFI and higher LWG of lactating and growing deer grazing chicory than perennial ryegrass/white clover pasture under field conditions (Kusmartono *et al.* 1996*a*).

Table 4.5. Fractional outflow rate (FOR; %/h) of liquid and particulate matter in red deer, goats and sheep fed different diets during summer

Author	Diet	Ash (g/kg DM)	Animal	FOR		
				Cr-EDTA	Lignin	Cr-EDTA/Lignin
Present study	perennial ryegrass	112	red deer	12.3	2.78	4.75
	chicory	180	red deer	16.8	4.08	4.63
Freudenberger *et al.* (1994*a*)	perennial ryegrass/ white clover	108	red deer	15.1	3.92	3.84
	red clover	114	red deer	13.3	2.52	5.51
Freudenberger *et al.* (1994*b*)	lucerne hay	109	red deer	12.4	2.78	4.50
Domingue *et al.* (1991)	lucerne hay	94	red deer	15.8	2.77	5.97
			goats	10.8	3.66	3.07
			sheep	10.4	3.32	3.24

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Chapter 5

The effects of condensed tannins in chicory (*Cichorium intybus*) and perennial ryegrass (*Lolium perenne*) on protein solubility and protein degradation

This chapter has been submitted to the Journal of Agricultural Science, Cambridge

5.1. ABSTRACT

The effects of condensed tannins (CT) in chicory (*Cichorium intybus*) and perennial ryegrass (*Lolium perenne*) upon protein solubility and protein degradation were studied at Massey University, Palmerston North, New Zealand (NZ) during 1995. Nitrogen (N) solubility was measured *in vitro* in mineral buffer, using freeze dried samples of forages cut at the vegetative stage. Rumen ammonia concentration in rumen fistulated castrate red deer (*Cervus elaphus*) stags grazing either on perennial ryegrass or chicory was used as an index of protein degradation. Samples of rumen fluid were taken every 4 h for 24 h for ammonia concentration and pH. In both experiments, the effects of CT were deduced from responses to supplementation with polyethylene glycol (PEG; MW 3,350) which binds and activates CT. PEG was given three times daily (total 20 g/day) in the grazing experiment.

Small concentrations of CT were measured in both forages (0.3-2.5 g/kg DM), with chicory containing slightly higher total CT concentration than perennial ryegrass. Protein solubility was lower for chicory than for perennial ryegrass but was not affected by PEG addition for either forage. Rumen ammonia concentration was consistently higher for PEG supplemented than for unsupplemented deer grazing each forage, suggesting that the low CT concentration in both forages was slowing protein degradation to ammonia without affecting protein solubility. Rumen pH tended to be slightly higher in PEG supplemented animals than in unsupplemented animals grazing either forage and mean rumen pH over all sampling times was much lower for deer grazing chicory, either with (5.81 *v.* 6.62) or without PEG supplementation (5.63 *v.* 6.44).

It is concluded that action of CT contained in perennial ryegrass and chicory reduced protein breakdown in the rumen of deer grazing both forages, and that the low rumen pH found in deer grazing chicory may explain the low fibre digestibility of this forage. Further research is needed to study the effect of low forage CT concentrations on protein absorption and to define the minimum level of CT needed to increase production in deer and other ruminant species.

5.2. INTRODUCTION

Condensed tannins (CT) are polyphenolic secondary compounds that can react by hydrogen bonding with plant protein in the near neutral pH range to form CT:protein complexes (McLeod 1974). The CT:protein complexes are stable and insoluble at pH 3.5-7.0, but dissociate and release protein at pH <3.5 and pH>8.0 (Jones & Mangan 1977). Thus, CT should protect dietary protein from being degraded in the rumen and increase amino acid supply in the small intestine.

Barry *et al.* (1986) considered that the nutritional role of CT for ruminant animals depends on the concentration, structure and molecular weight of CT. CT concentration between 20-40 g/kg DM in *Lotus comiculatus* is considered beneficial in terms of increasing duodenal non-ammonia nitrogen (NAN) flow per unit total N intake and increasing amino acid absorption (Barry 1989; Waghorn *et al.* 1987); higher levels of CT (60-100 g/kg DM) in *Lotus pedunculatus* resulted in no increase in amino acid absorption, depressed rumen fibre digestion and depressed voluntary feed intake (VFI; Barry *et al.* 1986; Waghorn *et al.* 1994). The effects of very low CT concentrations (1-3 g/kg DM) are unknown.

Chicory (*Cichorium intybus*) and perennial ryegrass (*Lolium perenne*) have been found to contain low concentrations of CT (2.8 and 1.8 g/kg DM respectively; Hoskin *et al.* 1995; Jackson *et al.* 1996). Deer grazing chicory had higher liveweight gain (LWG) and VFI than those grazing perennial ryegrass/white clover (*Trifolium repens*) pasture (Kusmartono *et al.* 1996*a*). It is possible that action of CT may contribute to animal performance on both diets and especially to the higher level of production on chicory. The main objective of this study was to investigate the effects of CT in chicory and perennial ryegrass on protein solubility and upon rumen protein degradation. A second objective was to study 24 h profiles of rumen pH in deer fed chicory and perennial ryegrass, to see if this was affected by any changes in rumen ammonia concentration and to see if periods of low rumen pH could explain the reduced digestion of fibre in deer fed chicory (Hoskin *et al.* 1995; Kusmartono *et al.* 1996*b*).

5.3. MATERIALS AND METHODS

5.3.1. Experimental design

Two experiments were conducted. Experiment 1 was done in Massey University Nutrition Laboratory in 1995 to determine the effect of CT in chicory and perennial ryegrass upon protein solubility. Experiment 2 was done at Massey University Deer Research Unit in 1995 to determine the effect of CT in both diets on protein degradation, using rumen ammonia concentration as an index of protein degradation. In both experiments, the effects of CT were assessed by making measurements in the presence and absence of polyethylene glycol (PEG; MW 3,350), which binds and inactivates CT (Jones & Mangan 1977). Effects of CT can therefore be deduced by comparing unsupplemented animals (CT acting) with PEG animals (CT inactivated). Twenty four hour rumen pH profiles were also determined in Experiment 2.

In Experiment 2 red deer (*Cervus elaphus*) were grazed first on perennial ryegrass in winter (August) and then on chicory in spring (October) in 1995. Each forage was grazed for two periods each of 8 days duration, with and without PEG supplementation using a changeover design. The animals drenched with PEG in period 1 (P1) were not drenched in period 2 (P2), whilst those not drenched with PEG in P1 were drenched in P2.

Parameters measured were total nitrogen (N) solubility (Experiment 1), rumen pH and rumen ammonia concentration (Experiment 2) and forage CT concentration (both experiments).

5.3.2. Forages

Chicory (*Cichorium intybus* cv. Puna) was sown in January 1992, and was a pure crop, in the vegetative stage. Perennial ryegrass (*Lolium perenne* cv. Nui) was sown in 1991, and was a pure sward, approximately 10 cm in height. Fertilisers

applied included potassic superphosphate (9%P;10%S;7%K) dressed at 250 kg/ha, corresponding to 22.5 kg P/ha, to both forages in late autumn (April 1995). Urea was applied to each forage four times a year at 37 kg N/ha in late spring (October 1994), summer (January 1995), late autumn (April 1995) and early spring (September 1995).

5.3.2.1. Experiment 1

Forages were sampled in the vegetative stage. Total CT concentration was determined and the effect of different concentrations of PEG (0, 0.75, 1.5 and 3.0 mg/mg CT) upon total N solubility was then determined using buffer solution following the method described by Yu *et al.* (1995). Phosphate buffer (pH 7.0) was prepared by mixing 195 ml of 0.1 M NaH_2PO_4 with 305 ml 0.15 M Na_2HPO_4 and making up to 1 litre with distilled water. Freshly prepared phosphate buffer (50 ml, pH 7.0) maintained at 39°C, was added to groups of volumetric flasks (250 ml). Two grams of ground freeze dried sample and the required amount of PEG were added to the flasks. Flasks were fitted with Bunsen valves and incubated in a shaking water bath (90 rpm) at 39°C for 2 h. The mixture was then centrifuged at 27,000 *g* for 15 min and total N content was determined on 10 ml of the clear supernatant solution. Triplicate samples of both diets were used to measure N solubility.

5.3.2.2. Experiment 2

5.3.2.2.1. Animals and diet

Ten hand-reared rumen fistulated castrated stags each fitted with an 83mm diameter rumen cannula were used. Mean liveweights (±SD) of the animals at the start of grazing on perennial ryegrass were 132 (±7.3) kg and at the start of grazing on chicory were 127 (±8.4) kg. The animals were grazed on perennial ryegrass and chicory for two periods each of 8 days. In each period, 5 animals were drenched twice each day (08.00 and 16.00h) during the first 4 days (D1-D4), followed by three-times drenching each day (08.00, 16.00 and 24.00h) in the

last 4 days (D5-D8), with 20ml of PEG solution being given at each dose. The concentrations of PEG (Union Carbide, Danbury, CT, USA) used in D1-D4 and D5-D8 were 500 g/l and 350 g/l respectively, giving 20g PEG administered per animal per day. During the trial, hand-plucked samples were taken from each forage each day, bulked per period and kept at -20°C. On Day 1, metal probes covered in a synthetic fibre (80μ aperture, Estal-mono, Swiss Screens, Sydney, Australia) were suspended in the rumen, allowing rumen liquor to be collected by gentle suction (20ml syringe). On day 8, samples of rumen liquid were removed at 4 hour intervals for 24 hours (08.00; 12.00; 16.00; 20.00; 24.00; 04.00; 08.00h). A total of 35ml of rumen liquid was taken from each animal on each occasion; 15ml for pH measurement and 20ml was added to 5ml of deproteinising reagent (1M H_2SO_4, saturated with magnesium sulphate; Domingue *et al.*1991), and kept at -20°C for ammonia analysis.

5.3.3. Laboratory methods

All frozen samples of forage were freeze-dried and ground to pass a 1mm mesh diameter sieve (Wiley *mill*, USA). Organic matter (OM) content was measured by ashing in a fumace at 500°C for 16h. In vitro OM digestibility was determined using the enzymic method developed by Roughan & Holland (1977). Total N was determined by the Kjeldahl procedure, using a selenium catalyst and sulphuric acid digestion. CT content was determined using the 3 stage method of Terrill *et al* (1992). Extractable CT was extracted using a mixture of acetone/water/diethyl ether (4.7:20:3.3, v/v), followed by extraction of protein-bound CT using boiling sodium dodecyl sulphate containing 2-mercaptoethanol in 10 mM Tris/chloride, adjusted to pH 8.0 with HCl (SDS solution). Fibre-bound CT was determined by boiling the residue remaining from protein extraction with butanol-HCl and SDS solution. CT concentration in each fraction was then determined by the butanol-HCl procedure (Porter *et al.* 1986). The pH of rumen fluid was determined immediately after being taken using a combination electrode and a portable pH meter (EDT instruments Ltd., UK). Two buffer solutions of pH 4.0 and pH 7.0 were used as standards and adjustment was done prior to each rumen sampling.

The frozen rumen fluids were thawed and centrifuged at 2,000 *g* for 15 min. The supernatant was diluted 1 in 20 and ammonia-N was determined using the ammonia UV kit from Sigma Diagnostics (St.Louis, Mo, USA) performed on a Cobas Fara automatic analyser (Cobas Fara, F.Hoffman-La Roche Ltd, Switzerland).

5.3.4. Statistical analysis

Parameters measured in Experiment 2 were analysed at each sampling time using General Linear Model (GLM) procedure (SAS 1987), for the changeover design in each forage; between animal and between feeding sequence variation were first removed, before analysing for the the effects of PEG administration and period effects. Least Square Means (LSM) analysis was used to test the differences between treatments.

5.4. RESULTS

5.4.1 Experiment 1

Organic matter content of chicory was lower than perennial ryegrass (Table 5.1). Total N content of both diets was similar in Experiment 1 but lower for chicory in Experiment 2. Small amounts of CT were detected in both diets, with chicory being higher in total CT concentration than perennial ryegrass.

Soluble N as a percentage of total N was lower in chicory than in perennial ryegrass (Figure 5.1). Addition of PEG had no effect upon N solubility with either forage.

Table 5.1. Chemical composition (g/kg DM) of the perennial ryegrass and chicory

	Perennial ryegrass	Chicory
	(Experiment 1)	
Organic matter	873	859
Total N	33.5	36.6
Condensed tannin:		
Extractable[§]	9.55	9.18
Extractable[†]	ND	ND
Protein-bound[†]	ND	1.25
Fibre-bound[†]	1.28	1.21
Total[†]	1.28	2.46
	(Experiment 2)	
Organic matter	895	838
OMD (%)	82.5	86.8
Total N	42.7	29.4
Condensed tannin:		
Extractable[§]	1.62	3.25
Extractable[†]	ND	0.10
Protein-bound[†]	0.10	0.30
Fibre-bound[†]	0.20	0.10
Total[†]	0.30	0.50

[§] Vanillin/HCl method.
[†] Butanol/HCl method.
ND = Not detected

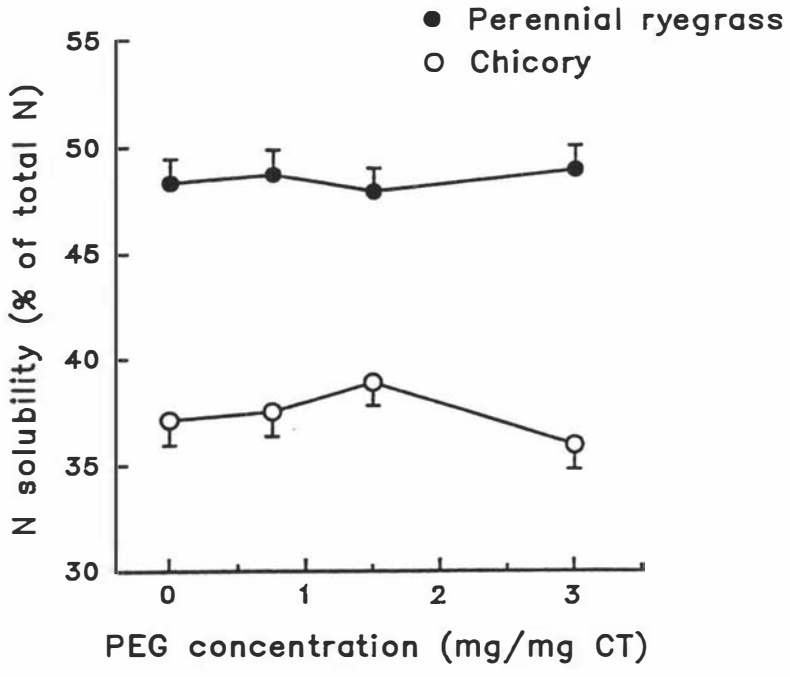

Figure 5.1. Experiment 1. The effect of PEG addition on solubility of the total nitrogen (N) in perennial ryegrass (●) and chicory (○). ⊤, S.E.

5.4.2. Experiment 2

Rumen ammonia concentration was consistently higher in deer supplemented with PEG than for unsupplemented deer, both for deer grazing perennial ryegrass (Figure 5.2*a*) or chicory (Figure 5.2*b*), with the difference attaining significance at 20.00h (P=0.06) and at 24.00h (P<0.05) for deer grazing perennial ryegras and at 08.00h (P<0.05) for deer grazing chicory. When mean values were calculated for each animal over the time period 16.00h to 24.00h for deer grazing perennial ryegrass, rumen ammonia concentration was significantly higher in PEG supplemented animals (290.4 mg N/l) than in unsupplemented animals (235.4 mg N/l; P<0.05). Similarly, when mean values were calculated for each animal over the time period 16.00h to 20.00h for deer grazing chicory, rumen ammonia concentration was significantly higher in PEG supplemented animals (320.1 g N/l) than in unsupplemented animals (241.2 g N/l; P=0.13).

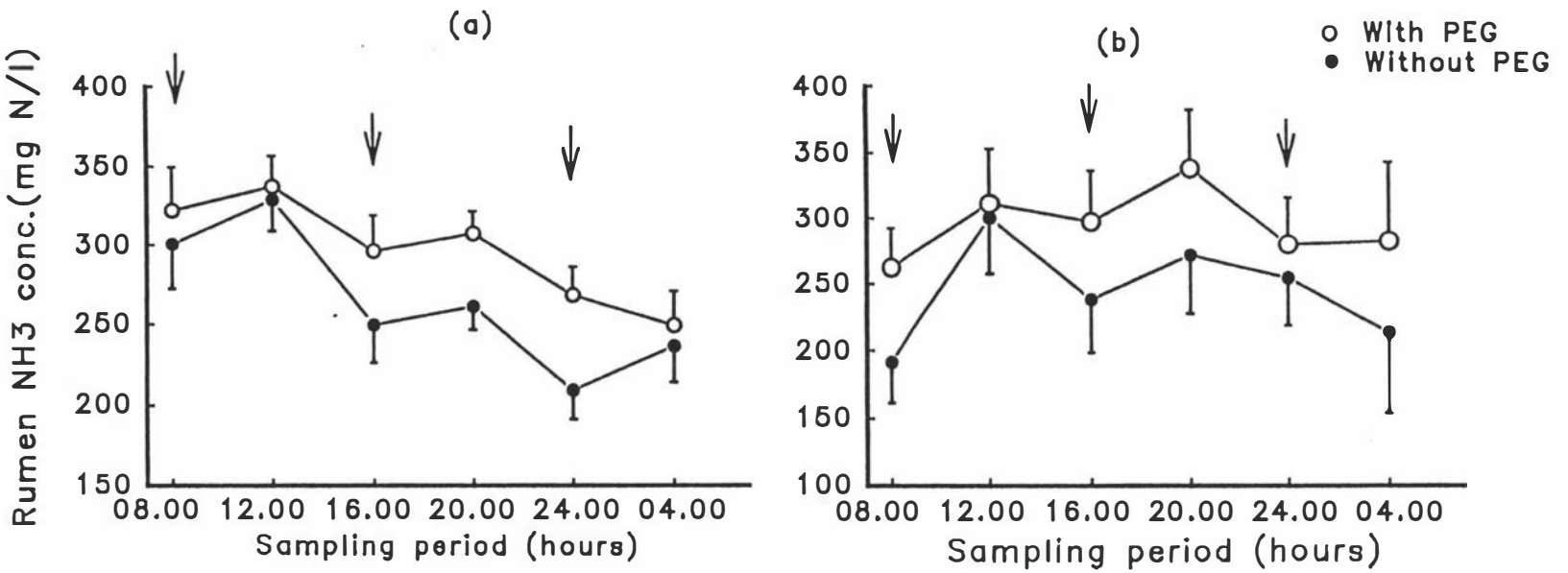

Figure 5.2. Experiment 2. Rumen ammonia concentration of deer grazing (a) perennial ryegrass and (b) chicory. With oral PEG supplementation (○); without oral PEG supplementation (●). ↓ indicates times of PEG administration. ⊤, S.E.

There was a tendency for rumen pH to be slightly higher in deer supplemented with PEG than in unsupplemented deer, for deer grazing both perennial ryegrass (Figure 5.3*a*) and chicory (Figures 5.3*b*). When mean values were calculated for each animal over the time period 20.00 to 24.00h for deer grazing perennial ryegrass, rumen pH was significantly higher in PEG supplemented animals (6.41) than in unsupplemented animals (6.26; P=0.06). Similarly, when mean values were calculated for each animal over the time period 16.00 to 24.00h for deer grazing chicory, rumen pH tended to be higher in PEG supplemented animals (5.81) than in unsupplemented animals (5.60; P=0.13). Mean rumen pH over all sampling times was much lower for deer grazing chicory, either with (5.81 *v* 6.62) or without PEG supplementation (5.63 *v.* 6.44).

5.5. DISCUSSION

Steps involved in rumen ammonia formation include initial solubility of the protein, followed by deamination of amino acids to ammonia, generally referred to as degradation (McNabb *et al.* 1996). The most important result of this study was that the action of CT in both perennial ryegrass and chicory reduced rumen ammonia concentration in deer grazing both forages (Figures 2*a* and 2*b*), but CT did not affect protein solubility, suggesting that low CT concentrations (1-3 g/kg DM) can reduce protein degradation. The study of McNabb *et al.* (1996) also found that CT contained in *Lotus pedunculatus* reduced the rate of protein degradation by rumen micro-organisms, whilst protein solubility was not affected. The action of CT in perennial ryegrass has also been reported to reduce rumen ammonia concentration in sheep grazing this forage (Montossi 1995). The effect of CT on rumen ammonia concentration in this study and that of Montossi (1995) and McNabb *et al.* (1996) was determined from responses to PEG supplementation.

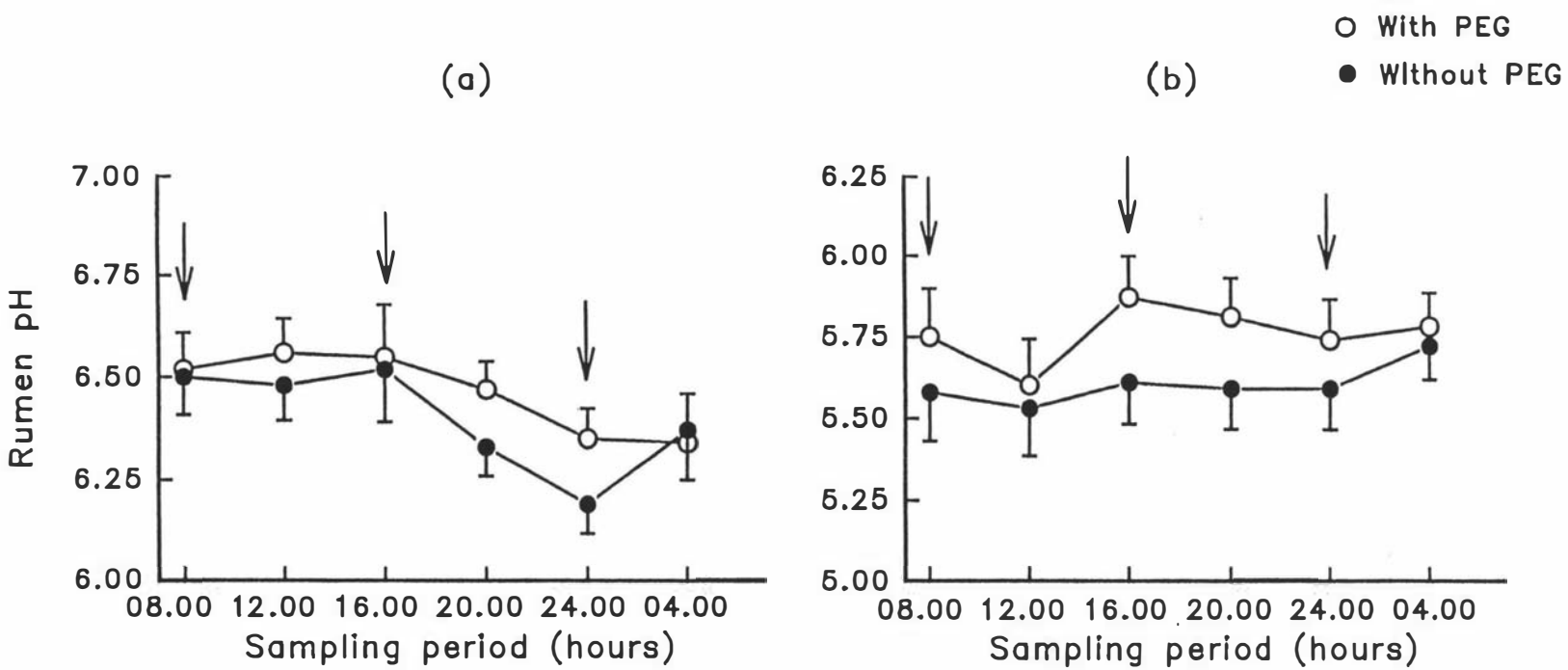

Figure 5.3. Experiment 2. Rumen pH of deer grazing (a) perennial ryegrass and (b) chicory. With oral PEG supplementation (O); without oral PEG supplementation (●). ↓ indicates times of PEG administration. ⊤, S.E.

CT contents of perennial ryegrass and chicory found in this study were low, ranging from 0.30-2.50 g total CT/kg DM and confirm the data of Hoskin *et al.* (1995). Using more sophisticated techniques, including ^{13}C-NMR, anthocyanidin formation and protein binding, Jackson *et al.* (1996) conclusively demonstrated trace levels of CT in both perennial ryegrass and chicory. The present data shows that these trace levels of CT are effective at slowing forage protein degradation in the rumen. Montossi (1995) found that 4 g total CT/kg DM was the minimum CT concentration required to increase wool production (10%) in sheep grazing grasses, with lower concentrations being ineffective even though they did cause some reduction in rumen ammonia concentration. Li *et al.* (1996) concluded that the minimum concentration of CT required to prevent rumen bloat in cattle grazing legumes was 5 g/kg DM. It may be that CT concentrations of 4-5 g/kg DM are required in chicory to increase rumen NAN outflow to a level that might increase production in deer and other ruminant species.

Data from the present study showing the tendency of higher rumen pH in deer supplemented with PEG supports the consistently higher levels of ammonia in the rumen of these animals, and offers support to the concept that CT in perennial ryegrass and chicory can slow protein degradation. Deer grazing chicory had much lower mean rumen pH over 24 h periods than those grazing perennial ryegrass (5.7 *v.* 6.5). Lower rumen pH in deer grazing chicory might be associated with reduced buffering capacity, as a previous study of Kusmartono *et al.* (1996*b*) found that deer fed chicory had lower rumen net water balance (and hence salivary secretion) than those fed perennial ryegrass. The low rumen pH of deer grazing chicory might have been the reason for the low fibre digestibility (Hoskin *et al.* 1995; Kusmartono *et al.* 1996*b*) as optimal fibre digestion occurs at pH 6.0-7.0 (Church 1979). Hungate (1966) stated that rumen pH lower than 6.0 inhibits the growth of cellulose and hemicellulose-digesting bacteria, hence decreasing the digestibility of cellulose and hemicellulose.

It can be concluded that action of CT contained in perennial ryegrass and chicory reduced protein breakdown in the rumen of deer grazing both forages, without

affecting protein solubility. Rumen pH of deer grazing chicory was low (5.7) and this may explain the low fibre digestibility of this forage. Considering the potential of chicory as a special forage for deer production (Niezen *et al*. 1993; Kusmartono *et al*. 1996*a*), further research is needed to study the effect of low CT contained in chicory on protein absorption and to define the minimum level of forage CT needed to increase production in deer and other ruminant species.

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Chapter 6

General Discussion

6.1. INTRODUCTION

Grasslands Puna chicory is a perennial herb that produces high amounts of DM during summer (25 t/ha; Hare *et al.* 1987) because its deep root system enables it to extract water during dry summer conditions. A high DM production of chicory during summer is in good alignment with high feed requirements of lactating hinds. Previous studies using chicory fed to hinds during lactation resulted in an increase in growth rates and weaning weight of red deer calves (Hunt 1993; Niezen *et al.* 1993).

Although chicory has been reported to have higher apparent OM and energy digestibility than perennial ryegrass (Hoskin *et al.* 1995), its nutritive value as a specialist forage for venison production has not been examined in detail.

This thesis specifically evaluated chicory for producing venison by one year of age, using pure red and hybrid (0.25 elk; 0.75 red) weaner deer, and studied rumen digestion in deer fed chicory or perennial ryegrass, to define factors responsible for the superior deer production on chicory. Perennial ryegrass/white clover pasture, as commonly used in the NZ pastoral system, was used as the control.

6.2. VENISON PRODUCTION FROM CHICORY

It has been shown in Chapter 2 that grazing deer on chicory resulted in higher growth rates of fawns during lactation and weaners during both autumn and spring than those grazing perennial ryegrass/white clover pasture. In Table 6.1 growth rates of red deer stags grazing perennial ryegrass/white clover pasture have been compared with those grazing on different specialist forages. Grazing red deer stags on either red clover or chicory resulted in higher growth rates. This evidence suggests that red clover and chicory had higher feeding value (FV) for deer than perennial ryegrass/white clover pasture, which is in agreement with with the results of Ulyatt (1981) for sheep grazing red clover. Overall, Table 6.1 shows that the feeding falue (FV) of chicory was higher than that of red clover in

autumn (157 *v.* 126), similar in spring (115 *v.* 114), but lower in summer (114 *v.* 124), when all data were expressed relative to LWG on perennial ryegrass/white clover pasture as 100. On average, animal production responses to inputs of specialist forages (red clover and chicory) were greatest in autumn, least in spring and intermediate in summer.

Table 6.1. Liveweight gain (g/day) of red deer stags grazing perennial ryegrass/white clover pasture, red clover and chicory during lactation and during post-weaning growth. Values in brackets are relative to perennial ryegrass/white clover pasture as 100 and can be regarded as indices of relative FV. The data are compared with that of grazing sheep.

Author(s)	Liveweight gain		
	Perennial ryegrass/ white clover	Red clover	Chicory
		Summer	
Niezen *et al.* (1993)	331(100)	410(124)	385(116)
Present study	358(100)	-	402(112)
Mean	(100)	(124)	(114)
		Autumn	
Semiadi *et al.* (1993)	192(100)	263(136)	-
Soetrisno *et al.* (1994)	207(100)	237(115)	-
Present study	178(100)	-	246(133)
Min (1996)	152(100)		285(181)
Mean	(100)	(126)	(157)
		Spring	
Semiadi *et al.* (1993)	341(100)	354(104)	-
Soetrisno *et al.* (1994)	281(100)	346(123)	-
Present study	260(100)	-	255(98)
Min (1996)	253(100)		335(132)
Mean	(100)	(114)	(115)
		Sheep data: Spring	
Ulyatt (1981)	(100)	(133)	

In Table 6.2 the effect of deer genotype on carcass weight and dressing percentage of stags found in this study has been compared with the results of Min (1996). Data in Chapter 2 showed that hybrid deer (especially male) had highest LWG on chicory, indicating that the superior genetic potential of hybrid stags for growth can best be expressed when grazing a forage with high FV such as chicory. Consequently, all deer grazing chicory attained target carcass weight by one year of age or less. The data in Table 6.2 show highest carcass weight at one year of age was consistently obtained from hybrid stags grazing chicory.

Table 6.2. Carcass production and dressing percentage of red and hybrid deer stags grazing either perennial ryegrass/white clover pasture or chicory.

Author	Perennial ryegrass/ white clover pasture		Chicory	
	R	H	R	H
Present study:				
-Carcass weight (kg)	56.6	57.0	63.2	73.0
-Dressing percentage (%)	54.1	54.1	58.4	58.4
Min (1996):				
-Carcass weight (kg)	48.6	53.3	56.0	59.3
-Dressing percentage (%)	52.6	53.7	57.6	56.2

R = Pure red deer
H = Hybrid (0.25 elk;0.75 red)

6.3. VELVET PRODUCTION IN SPIKER STAGS GRAZING CHICORY

Data in Chapter 2 showed that grazing deer on chicory advanced the mean date of first cut velvet antler by 28 days, increasing the length of time for total velvet growth and hence total velvet antler weight was higher. Semiadi *et al.* (1993) found no difference in velvet antler weight of young stags grazing red clover, even though LWG responses were higher than those obtained in deer grazing perennial ryegrass/white clover pasture. This indicated that a high FV of chicory

increased not only the body growth rates of deer, but also increased antler production in a one year venison operation. As the effect was still present after correcting for the higher liveweight of deer grazing chicory, it seems that a component(s) of chicory specifically increased velvet antler production in these young stags. Grazing chicory may have advanced pedicle initiation, as the study of Fennessy (unpublised cited by Fennessy & Suttie (1985) showed that feeding red deer calf stags with a high quality pelleted feed (barley-lucerne-linseed) *ad libitum* advanced pedicle initiation of stags by 6 weeks compared to those fed meadow hay.

However, in another study, Suttie & Corson (1991) using 2 and 3-year red deer stags fed on the same basal diet (meadow hay) *ad libitum* supplemented with 1.5 kg/head/day of diets containing high and low proportion of protected protein during winter, concluded that there was no diference in casting date or velvet antler weight of both the two age groups. Similarly, Cosgrove *et al.* (1995) found no difference in velvet weight of 4-year red deer stags grazing either perennial ryegrass/white clover pasture or chicory, though date of button drop for those grazing chicory was 5 days earlier than those grazing perennial ryegrass/white clover pasture. Thus, whilst feeding a high FV forage such as chicory increased velvet antler production in yearling stags, it appears to be without effect in adult stags. It may be that *ad libitum* feeding on chicory during autumn stimulates the earlier development (and perhaps size) of the pedicle, so giving greater velvet production in spiker stags over a longer time period. The data of Min (1996) offers support for this hypothesis.

Some indication of the compound(s) that could be responsible for the earlier antler growth in young stags grazing chicory can be gained from comparing the chemical composition of chicory with that for perennial ryegrass and red clover (Table 6.3). Nitrogen solubility was lower and total condensed tannin (CT) content was slightly higher for chicory, suggesting that amino acid absorption may be higher for chicory than for perennial ryegrass, and this aspect will be covered in more detail later in this General Discussion. Total ash (ie mineral content) was

consistently higher for chicory, and content of each mineral in chicory as listed in Table 6.3 has been reported to exceed the range of values reported for ryegrass.

Table 6.3. Chemical composition of perennial ryegrass, red clover and chicory

Author(s)	Season	Perennial ryegrass	Red clover	Chicory
Total N (g/kg DM)				
Semiadi *et al.* (1993)	autumn	31.0	34.0	-
	spring	31.0	38.0	-
Soetrisno *et al.*(1994)	autumn	34.2	34.4	-
	spring	26.0	41.2	-
This study				
-Chapter 2	summer	34.4		32.1
	autumn	42.8		31.9
	spring	36.1		31.1
-Chapter 3	autumn	33.0	-	28.1
	spring	27.8	-	25.7
-Chapter 4	summer	26.0	-	26.2
Total CT (g/kg DM)				
Hoskin *et al.*(1995)	autumn	1.82	-	2.80
Jackson *et al.*(1996)	summer	0.90	1.70	1.70
This study (Chapter 5)	autumn	1.28	-	2.46
	summer	0.30	-	0.50
Soluble N (% total N)				
Barry & Forss (1983)		-	55.3	-
This study (Chapter 5)	autumn	37.1	-	48.3
Ash (g/kg DM)				
This study				
-Chapter 2	summer	104	-	153
	autumn	125	-	146
	spring	102	-	137
-Chapter 3	autumn	109	-	189
	spring	95	-	171
-Chapter 4	summer	107	-	158
-Chapter 5	autumn	127	-	141
	summer	105	-	162
Mineral composition (g/kg DM)				
Thomas *et al.* (1952):				
- Phosphorus	autumn	5.7	-	12.0(3.8)[1]
- Potassium	autumn	23.2	-	44.0(76.0)
- Sodium	autumn	2.0	-	3.1(2.5)
- Calcium	autumn	5.0	-	22.2(13.2)
- Magnesium	autumn	0.4	-	1.1(2.1)
- Manganese	autumn	0.2	-	0.6(ND)
- Zinc	autumn	ND	-	ND (4.4)

[1] Values in brackets are from Crush & Evans (1990) for Puna chicory

Kay *et al.* (1982) using two-year old red deer stags reported that tip section of the antler, a rapidly growing point, experienced slower mineralisation than the zone 2-4 cm below the tip. Similarly, Muir *et al.* (1985) fed adult red deer stags with diets differing in protein content found no difference in hard antler weight. They found slow mineralisation of the whole antler from time of first harvest at 4 weeks until 13 weeks after casting, but rapid mineralisation occurred from week 13 until the time of hard antler removal (week 23). This evidence suggests that mineral supply from the high total ash concentration in chicory is unlikely to have affected velvet antler growth in young stags. Therefore, it would be more reasonable to argue that the higher velvet production found in this study with spiker stags was due to a higher protein supply in stags grazing chicory than those grazing perennial ryegrass/white clover pasture. Effects of protein supply on initiation of pedicle development needs to be studied in weaner stags grazing fresh forages.

As chicory is dormant during winter, all the deer then have to be grazed on pasture during this time and then be returned to chicory during the first week of September (spring). The question then needs to be raised is whether the pedicle initiation that has occurred earlier by grazing young stags on chicory during the first autumn, (and led to an increase in velvet production) has any subsequent effect on lifetime productivity of velvet. This is unknown at this time, but needs to be tested experimentally. In order to be able to answer this question, a future grazing study needs to be carried out using the experimental design shown in Diagram 6.1 below.

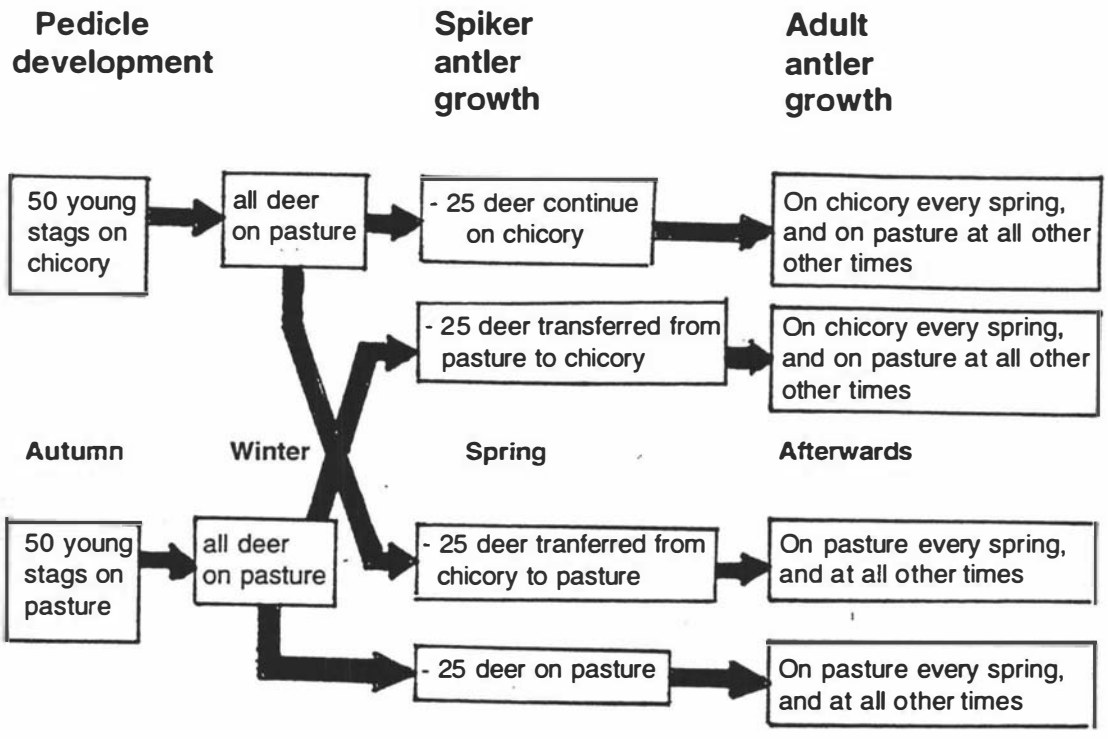

Diagram 6.1. An experimental design to investigate the effect of feeding chicory on velvet antler production of 2 to 3-year old and adult stags.

This design will show if grazing *ad libitum* on chicory during pedicle development as a weaner can affect lifetime velvet production in adult stags grazing either pasture or chicory during the period of spring velvet growth.

6.4. DEER PRODUCTION RESPONSES IN RELATION TO FEEDING VALUE

It has been defined earlier that feeding value (FV) is the animal production response to the total forage consumed, and is a function of intake and nutritive value (NV).

FV = f(Intake x Nutritive value)

In the context of this thesis, liveweight gain, carcass weight and antler weight can be considered to be indices of FV.

Voluntary feed intake is determined by chemical and physical properties of the

forage. NV is a function of:

(i) Apparent digestibility, site of digestion, rumen particle size breakdown and rumen outflow rate.

(ii) The efficiency with which digested nutrients are converted into products within the animals' tissues.

6.4.1. Voluntary feed intake (VFI)

It has been shown in Chapter 2 that deer grazing chicory had consistently higher VFI than those grazing perennial ryegrass/white clover pasture. Behaviour data either under grazing (Chapter 2) or fed indoors in the study of Hoskin *et al.* (1995) or Chapter 3 showed that deer fed chicory spent similar time eating, but much less time ruminating than deer fed perennial ryegrass. This suggests faster breakdown of swallowed plant material in the case of chicory; this can be established from a study of the dynamics of rumen digestion and will be covered in subsequent sections.

6.4.2. Apparent digestibility and concentration of metabolisable energy (ME)

Apparent digestibility and dietary ME concentration (MJ/kg DM) are measures of the total nutrients supplied to ruminants per unit of feed eaten, but give no information on site of digestion.

Data in Chapter 4 showing that chicory had higher DM and OM, but lower fibre apparent digestibility values than perennial ryegrass confirms the finding of Hoskin et al. (1995). Ulyatt & MacRae (1974) concluded that a higher apparent digestibility value of white clover relative to perennial ryegrass was due to higher RFC:SC ratio in white clover (1.17:1.00). As results from the present study showed that chicory had higher RFC:SC ratio than perennial ryegrass (Chapters 2, 3 & 4), this could then be used to explain the reason of higher DM and OM digestibility in chicory than perennial ryegrass.

Metabolisable energy (ME) concentration in chicory has been compared with that

of other forages in Table 6.4. As the OM content of chicory was generally slightly lower than that of the other forages, all data have been expressed as MJ ME/kg OM. Metabolisable energy content of chicory and red clover did not change with season, whilst that of perennial ryegrass and white clover changed with season, being high in spring and low in summer and autumn. Consequently, the greatest advantage of chicory over perennial ryegrass in terms of ME concentration occurred in summer and autumn. At these times, chicory consistently had a higher relative ME concentration than either red or white clover.

Table 6.4. Metabolisable energy concentrations (MJ ME/kg OM) of different forages calculated as OMD x 16.3. Values in brackets are relative to perennial ryegrass/white clover pasture as 100.

Author(s)	Species	Season	ME (MJ ME/kg OM)	RFC/SC ratio
Ulyatt (1971)	-Perennial ryegrass	spring	12.8(100)	0.47
		summer	12.5(100)	0.55
	-White clover	spring	13.8(110)	1.49
		summer	12.2(98)	1.16
Ulyatt & MacRae (1974)	-Perennial ryegrass	autumn	11.1(100)	0.42
	-White clover	autumn	10.7(96)	1.17
Semiadi *et al.* (1993)	-Perennial ryegrass	autumn	12.5(100)	ND
		winter	13.5(100)	ND
		spring	13.1(100)	ND
	-Red clover	autumn	13.1(105)	ND
		spring	13.3(102)	ND
Niezen *et al.* (1993)	-Perennial ryegrass	summer	12.8(100)	ND
	-Red clover	summer	13.1(102)	ND
	-Chicory	summer	13.8(108)	ND
Present study[1] (Chapter 2)	-Perennial ryegrass	summer	12.1(100)	0.26
		autumn	12.6(100)	0.26
		spring	13.8(100)	0.27
	-Chicory	summer	13.8(114)	1.39
		autumn	13.9(110)	1.39
		spring	14.1(102)	0.95
Chapter 4	-Perennial ryegrass	summer	12.1(100)	0.31
	-Chicory	summer	13.4(111)	1.04

[1] Diet selected
ND = not determined

6.4.3. Particle breakdown, rumen degradation and rumen outflow rates

Data in Chapter 3 showed that chicory can be broken down to particles < 1.0 mm, the critical particle size with a high probability of leaving the rumen, faster than perennial ryegrass and this might have been the reason for the lower time spent ruminating by deer fed chicory than those fed perennial ryegrass. The evidence that some deer fed chicory indoors did not ruminate indicated that chicory disintegrates in the rumen very rapidly without the action of the teeth, in this study for 60% of the deer.

Chapter 4 showed that FDR of NDF, cellulose and lignin in red deer fed chicory were higher than in deer fed perennial ryegrass. This combined with higher FOR values of water and particulate matter led to faster FDPR or clearance of DM from the rumen of red deer fed chicory than those fed perennial ryegrass. Digesta clearance from the rumen has long been recognised as a determinant of both VFI and NV of forages (Black *et al.* 1982). This mechanism explains the higher VFI observed in deer grazing chicory than those grazing perennial ryegrass/white clover pasture.

Hemicellulose was degraded in the rumen slower in red deer fed chicory than in red deer fed perennial ryegrass. A lower FDR value of hemicellulose was associated with lower rumen pH value in red deer fed chicory than in red deer fed perennial ryegrass (5.7 *v.* 6.5) which may have restricted the growth of hemicellulose-digesting bacteria. Consequently, FDPR of hemicellulose was similar in red deer fed either forage.

Ulyatt & MacRae (1974) found that 93% of the digestible RFC in fresh forages was digested in the stomach region. Chapter 5 showed higher fractional disappearance rate of RFC (water soluble CHO+pectin) from the rumen of deer fed chicory than those fed perennial ryegrass. This together with a higher RFC content in chicory, especially pectin, could lead to a larger amount of energy being absorbed from the rumen. Thus, the greater clearance of DM from the rumen of deer fed chicory can be traced to a higher content of RFC and its faster

disappearance from the rumen, faster FDR of cellulose, greater lignin solubility and faster rates of outflow from the rumen of both liquid and particulate matter.

6.4.4. Rumen protein degradation

Komolong (1994) found in sheep that none of the plant protein was lost as ammonia absorbed from the rumen in lambs fed chicory, whilst 39% of the protein was lost as ammonia in those fed Wana cocksfoot. Consequently, the amount of protein reaching the duodenum per kilo gram digestible organic matter intake (DOMI) in lambs fed chicory was higher (44 g/kg DOMI) than those fed Wana cocksfoot (32 g/kg DOMI).

There are several reasons for this. Firstly, the higher CT found for chicory than for perennial ryegrass in this study may have reduced rumen degradation of chicory protein and increased the flow of undegraded dietary protein (UDP) at the duodenum; the reduced rumen ammonia concentration in groups not drenched with PEG (Chapter 5) offers evidence for this with chicory and also perennial ryegrass.

Secondly, rumen microbial protein synthesis is known to increase with increasing rumen liquid FOR (ie. dilution rate; Harrison *et al.* 1975; Isaacson *et al.* 1975). The higher liquid FOR for chicory than for perennial ryegrass suggests that the rate of microbial protein synthesis could be higher for deer fed chicory than perennial ryegrass and this needs to be measured in future studies.

Thirdly, it is well accepted that the availability of readily fermentable energy limits rumen microbial protein synthesis on forage diets. The higher readily fermentable carbohydrate content of chicory than perennial ryegrass suggests a further reason why rumen microbial protein synthesis might be higher on the chicory diet.

MacRae *et al.* (1985) showed that increasing protein absorption from the small intestine of sheep increased the efficiency with which ME absorbed from grass diets was used for growth. It may be that the greater duodenal protein flow in

animals fed chicory than grass (Komolong 1994) is associated with improved conversion of ME above maintenance for growth, and this needs to be measured in future experiments using calorimetry.

6.5. PERSISTENCY OF CHICORY

The use of chicory by NZ farmers is relatively low because when sown in a pasture mixture this forage generally persists only for 2 years. Potential crown damage due to grazing in wet weather and infection of the taproot by rots caused by *Sclerotinia* fungal spp. are contributing factors to the low persistence of chicory.

Previous studies by Clark *et al.* (1990) & Matthews *et al.* (1990) suggested that the key grazing management should be to aim for maximum leaf yield and minimum stem development, as in mature stands left ungrazed the stems became thickened and hardened substantially from a height of *c.* 60 cm and continue to grow over 2 m tall.

The study of Li *et al.* (1994) reported that plant density (number of plants/m^2) of chicory reduced substantially during spring-summer grazing by deer, but it was compensated by increases in shoot numbers/plant (Figure 6.1; Li *et al.* 1994), which led to less dense or more open swards of chicory. When expressed in terms of percentage of plants surviving, there was a tremendous decline in plant survival during November-January. In order to maintain the quality of chicory stands, hard grazing during spring and mechanical topping should be imposed to control the growth of primary reproductive stems. Lax grazing has been reported to result in a greater accumulation of reproductive stem, hence decreasing the quality of chicory stands (Li *et al.* 1994). However, the spring grazing should not be too severe (lower than 100-150 mm), as it otherwise could hasten plant death.

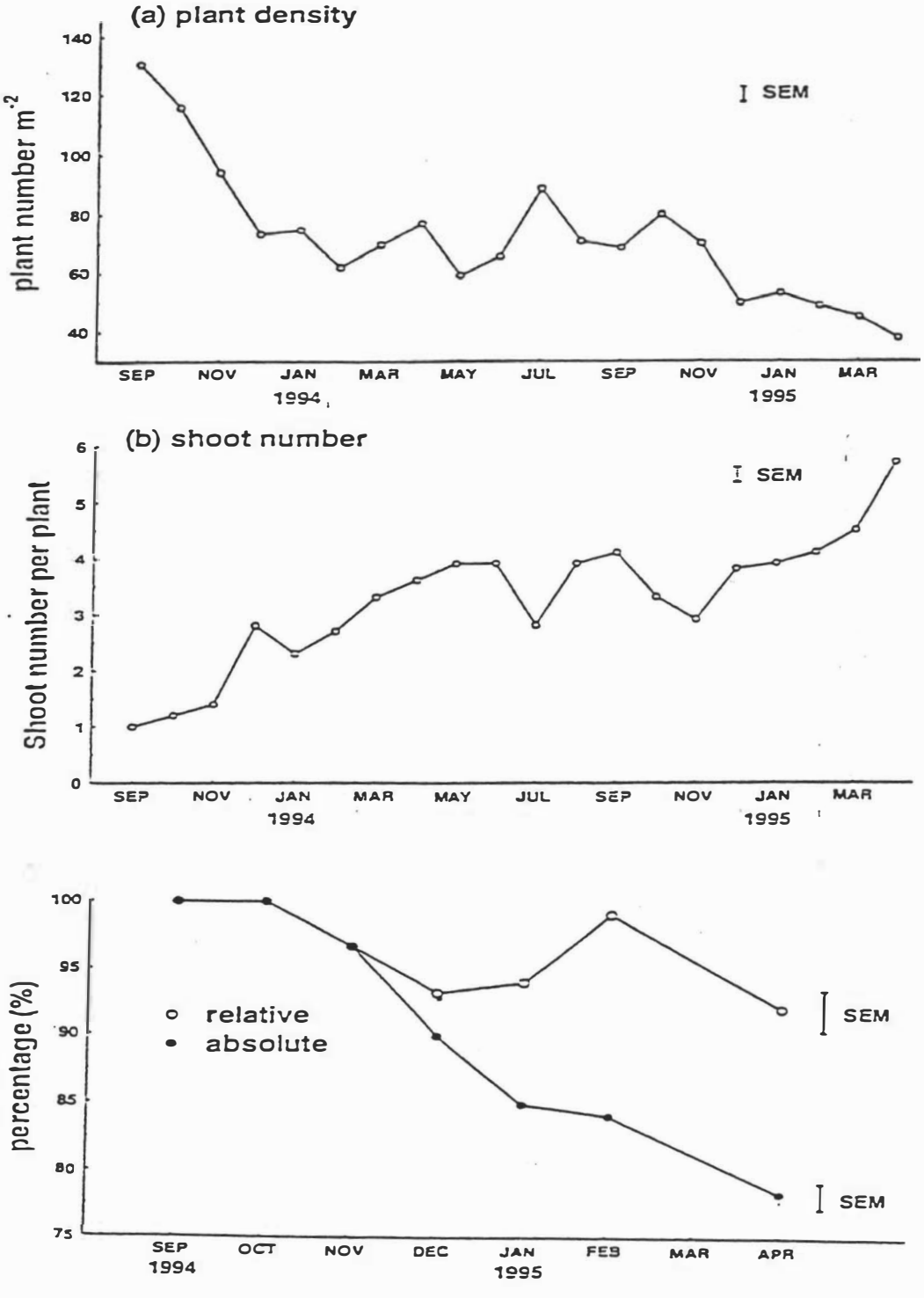

Figure 6.1. Plant density of chicory on Massey University Deer Research Unit over two seasons (Adapted from Li *et al.* 1994). Greatest reductions in plant density occured in October/November (ie spring). Absolute percentage of plant survived were based on the counting on September 1994, whilst relative percentage of survived were based on the previous counting.

6.6. FUTURE RESEARCH

Data obtained from indoor trials using limited numbers of animals showed a higher than usual variability within animals fed chicory. Therefore, future digestion and rumen metabolism research with chicory should use a larger number of animals per group, perhaps n= 6 or 8.

Since the persistence of chicory is still a major limiting factor for farmers in using this forage, highest priority should be given to research aiming for selecting more persistent chicory plants that have less reproductive stem formation during summer and have high resistence to *Sclerotinia* spp.

Low CT content (1.48 g/kg DM) in chicory was able to slow protein degradation (Chapter 5), but its effect was not strong enough. Data from various studies showed a small variation in CT content of chicory (see Hoskin *et al.* 1995; Jackson *et al.* 1996; Chapter 5 of the present study). This may indicate that CT content in chicory is a heritable trait, as chicory in those studies was grown in a similar environment. Therefore, there is a chance to breed new varities of chicory that have higher CT content (up to 10 g/kg DM), and are less lignified in summer. The reason for producing chicory with CT content higher than required for grasses (5 g/kg DM; Montossi 1995) is to protect further the amount of N being degraded in the rumen, as N content in chicory was slightly lower than that in perennial ryegrass species (Chapters 2, 3 & 4). However, the effect higher CT content in chicory on protein absorption and on fibre digestibility needs to be studied in more detail.

Future research is needed with other animal species to see the effects of feeding chicory on animal production. The use of chicory for dairy cows has big possibilities, because milking in NZ occurs in summer dry conditions when the DM production and FV of chicory is high. However, since chicory contains sesquiterpine lactone compounds (ie. oxylactosin, deoxylactosin, lactosin and

lactocopirin) that taint the milk of lactating dairy cows (F. Viser; NZ Dairy Research Institute, pers. comm.), breeding programes with chicory should be aimed to select out the milk taint factors. F. Viser (Pers.comm.) recommends that grazing dairy cows on chicory should be done for 2 hours after each of the two daily milking times, to minimise the contamination of milk by lactone compounds, and that pure swards of chicory should be sown on dairy farms. If low lactone forms of chicory could be developed, it would be possible to feed dairy cows on chicory for more than 4 h/day and thus take more advantage of the high FV of chicory.

Feeding chicory has resulted in low rumen pH, which led to the low values of FDR and FDPR of hemicellulose from the rumen. The use of some buffer compounds such as potassium carbonate, sodium bicarbonate, magnesium oxide in the diet has successfully maintained rumen pH of lactating cows fed cereal concentrate diets within the normal range (Strokes *et al*. 1986; West *et al*. 1987). Cows fed buffered diets in these studies had greater dry matter intake and greater digestibility of DM, ADF and NDF than control animals. Therefore, in practice, the use of these compounds should be investigated when deer or other ruminant animals are to be grazed on chicory. They could be administered in the forms of licks in a grazing situation.

Woolford (1984) reported a range of forage crops that had different buffering capacities against acidity. Legumes (red clover and alfalfa) were reported to have higher buffering capacities (560 and 480 milliequivalent NaOH/kg DM respectively) than grasses (Italian ryegrass, perennial ryegrass and cocksfoot; 430, 350 and 300 milliequivalent NaOH/kg DM respectively), and forage maize (200 milliequivalent NaOH/kg DM). Values for chicory were not determined. It may therefore be possible to increase rumen pH by growing chicory in a mixture with a legume, using the higher buffering capacity of the legume to keep the pH above 6.0 units. Initially, in vitro studies need to be conducted where chicory, legumes (white or red clover) and chicory:legume mixtures are fermented with

rumen fluid for up to 24h and pH taken at 3h intervals. If including a legume with chicory did reduce the extent of pH fall, and kept the pH above 6.0 units, then this could readily be integrated into a system for growing and managing chicory.

Future research is also needed to examine the effect of grazing stags on chicory on velvet production along the lines indicated in Diagram 6.1.

6.7. CONCLUSION

Based on the results obtained in this study using deer and on those from previous reports using deer, sheep or cattle (Clark *et al.* 1990; Matthews *et al.* 1990; Niezen *et al.* 1993), it can be concluded that chicory has a much higher FV than perennial ryegrass. In this study, it was expressed by higher VFI, carcass and velvet antler production in deer grazing chicory than those grazing perennial ryegrass/white clover pasture. From a view of sustainability, it has been found that deer grazing chicory had less parasite burden (and hence required less use of anthelmintic chemical for drenching) than those grazing perennial ryegrass/white clover pasture (Hoskin, unpublished). However, since its persistence is still a major problem, a special grazing management needs to be developed for commercial use of chicory, which is primarily directed towards maximising leaf yield and minimising stem development.

In practice, it is preferable that chicory is grown as pure swards to maintain its persistence. However, white clover may appear voluntarily from buried seed and grows well in a mixture with chicory. As the presence of clover species can be considered useful as a nitrogen supplying legume, sowing a broad leaved perennial white clover (*Trifolium repens* cv. Kopu) in a mixture with chicory may have benefits in both supplying nitrogen and covering open areas in chicory stands caused by decreasing plant density. This would mean that fertiliser would no longer be needed as a source of nitrogen for the chicory. It is strongly suggested that chicory should not be sown in a mixture with perennial grasses; this would need to be grazed in winter and such grazing would damage the

crowns of the chicory, so reducing its persistency. Other than grazing management, breeding programmes directed towards producing new varieties of chicory with slow seed head development, longer persistency, low lactone content and higher CT content are needed.

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