
**STUDIES ON THE NUTRITION OF
FARMED LIVESTOCK**

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BSc (University of Newcastle 1964), PhD (University of Newcastle 1967)

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of Massey University**

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DECLARATION

I declare that the material contained in this thesis has not been submitted by me to any other University for the award of any degree. The contribution of other persons is as described in the "statement of authorship" section

T N Barry. 30/11/96.

T N Barry

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I received encouragement and support over many years from the late Dr Cam Reid, formerly Director, Applied Biochemistry Division, DSIR, New Zealand. Cam's advice was instrumental in shaping my career in science in New Zealand and was always appreciated. I would also like to thank Sir Neil Waters, formerly Vice Chancellor, Massey University, for his confidence in appointing me Professor of Animal Science in March 1985, when I had no teaching experience. Sir Neil had a vision to increase the research profile of Massey University and I am proud to be part of this process.

This thesis was prepared whilst the author was on sabbatical leave at the Rowett Research Institute, Aberdeen, UK. I thank Margaret Paterson and other staff of the Skene House Business Centre, Aberdeen, for word processing, and Annette Barry and Fiona Finlayson for undertaking the huge task of all the photocopying and collating.

Finally I would like to thank my wife, Annette, for her love and support during the long period over which this work was conducted. Without her support this thesis would not have been possible. The study period for this DSc thesis has encompassed all our married life; the work reported in paper 1 was in fact in progress on 19 April 1969, the day we were married.

STATEMENT OF AUTHORSHIP

A total of 104 scientific papers are submitted in this DSc thesis. These comprise 97 original scientific papers in peer-reviewed journals and 7 review articles that have also been peer reviewed. All have been accepted for publication. All have appeared in press except papers 40, 41, 49, and 104 which have been accepted but have not appeared in press at this stage.

The papers have been grouped into nine sections. All of the papers in Sections 1 & 2, approximately half of those in Section 3 & two of the three papers in Section 6 report work that was conducted whilst the candidate (i.e. T. N. Barry) was a Research Scientist at the Invermay Agricultural Research Centre, Mosgiel, New Zealand. This comes to a total of 42 papers and was conducted over the period 1968 - 1985. In all instances I was responsible for planning and initiating the work, I supervised all aspects of the experimental work and was responsible for writing up the work. I am the senior author on most of these papers.

The work reported in the other 62 papers was undertaken after the candidate took up the position of Professor of Animal Science at Massey University, Palmerston North, New Zealand in March 1985. Most of these are papers from PhD student theses, where the candidate was Chief Supervisor. Papers 70 and 87 are from Masters theses and papers 71 and 72, 91 and 102 are from B. Agric. Sci (Hons) theses, in all cases where the candidate was Chief Supervisor. My responsibility was to attract external funding for all this work, to plan the work together with the post-graduate student and the co-supervisors, to supervise the work together with the co-supervisors and to supervise the writing up. In all cases I had principal responsibility for writing. Papers 66 and 67 are from a PhD thesis where I was a co-supervisor.

All the work has involved feeding forage diets. A feature of the work has been to collaborate with Agronomists and Soil Scientists, to ensure that the forages were well established and maintained so that good nutritional data could be obtained. Persons who provided Agronomic and/or Soil Science expertise in this manner include Drs A. G. Sinclair, W. L. Lowther and R. C. McDonald of the Invermay Research Centre, and Professor J. Hodgson and Dr P. D. Kemp of Massey University. A Prof M. J. Hedley and Dr D. J. Woolley of Massey University also provided expertise on the uptake of ^{35}S and ^{14}C into plant

tissues.

Parts of the deer research involved collaboration with Associate Prof P. R. Wilson and Dr K. J. Stafford who are Veterinarians and work in the Department Veterinary Clinical Sciences at Massey University. This was done to ensure that correct animal health procedures were used, particularly in field trials, and to gain collaboration in jaw recording procedures. In collaboration with Agronomists, Soil Scientists and Veterinarians, the candidate was the principal initiator of the work and provided the nutritional input. I appreciate this collaboration with my colleagues over many years, which has been most productive.

Since moving to Massey University I have enjoyed collaboration with the Ruminant Nutrition and Metabolism Group of Agresearch, also located at Palmerston North. Collaborating Nutritional Scientists have been Drs D.W. Dellow, G.C. Waghorn and W.C. McNabb and also Dr G.B. Douglas who provided Agronomic input. The work has involved training PhD students. I have been Chief Supervisor in all cases and Drs Dellow, Waghorn, McNabb and Douglas have been co-supervisors. In these instances the candidate and the Agresearch co-supervisors were jointly responsible for planning and supervising all aspects of the work. This applies to most papers in the second half of Section 3, to one paper in Section 6, and to five papers in Section 7.

The work on cottonseed nutritive value described in Section 4 was carried out with Prof P.J. Moughan and Dr W. C. McNabb, who were both co-supervisors of the PhD student. I was Chief Supervisor. I was the principal applicant in obtaining the cottonseed grant and Prof Moughan was a co-applicant.

The candidate had sole financial responsibility for all work carried out in Sections 7 & 8 as the Director of Massey University Deer Unit and was the initiator of the work. The sambar deer work (Section 9) was done in collaboration with Dr P.D. Muir of Agresearch, who was also a co-supervisor of the PhD candidate. Both of us contributed to the planning and supervision of the nutrition and reproduction aspects of the research, but the candidate had principal responsibility for nutrition work and Dr Muir had principal responsibility for the reproductive work.

SUMMARY

The work involves two main areas, namely advances in the feeding value of forages for ruminant animals and advances in the nutrition of alternative herbivore livestock, mainly red (temperate) deer, sambar (tropical) deer and goats. It is shown that absorption of amino acids limits protein deposition (N retention) in sheep fed fresh perennial ryegrass/white clover pasture ad libitum and that absorption of sulphur-containing amino acids (SAA) limits wool growth (a form of protein deposition) in sheep fed pasture conserved as hay or silage. Correlation analyses were used to show that extensive nitrogen (N) degradation in the silage fermentation process reduced N retention, wool growth, and voluntary feed intake (VFI) in sheep fed sole diets of silage.

Methods were developed for reducing forage protein degradation by anaerobic micro-organisms, initially using additions of the chemical formaldehyde to forages conserved as hay and silage and secondly by using fresh forages containing condensed tannins. Formaldehyde treatment dramatically reduced protein degradation in the silage fermentation process and when applied at an appropriate rate increased N retention, VFI and body growth in sheep. Formaldehyde treatment also increased wool growth in sheep fed hay or silage, but the responses were shown to be limited by forage SAA content, and increased body growth at constant feed intake.

Low dietary concentrations of condensed tannin (2-4g/kgDM) were shown to be anti-nutritional in monogastric diets, depressing absorption of some amino acids from the small intestine. High dietary concentrations of condensed tannins in Lotus pedunculatus (65-95g/kgDM) were also shown to be anti-nutritional in ruminant diets, depressing rumen fibre digestion, VFI, the apparent digestibility of protein in the small intestine and body and wool growth in grazing sheep. Medium concentrations of condensed tannin in Lotus corniculatus (35g/kgDM) were shown to be nutritionally beneficial for sheep, increasing the absorption of SAA and their use in body synthetic reactions and increasing wool growth and milk production in grazing sheep. New methodology was developed for measuring condensed tannins, and a range of feeds previously thought not to contain these compounds were shown to contain condensed tannin bound to protein and fibre. The significance of bound condensed tannins in ruminant nutrition was established using cottonseed meal.

Rumen fermentation of SMCO to dimethyl disulphide (a protein inactivating agent) was shown to be very rapid and to reduce VFI, body growth and wool growth in sheep fed forage kale (*Brassica oleracea*). Methods were developed to reduce this effect, including procedures for growing low SMCO kales and trace element supplementation to increase the animals resistance mechanisms. Products of digestion of kale diets were shown to be low in protein relative to ME.

Review articles are presented suggesting methods of improving forage feeding value, using the application of new analytical methods and the application of both conventional plant breeding techniques and Molecular Biology (ie Genetic Engineering). Use of the latter is suggested to try and break the well established negative correlation between forage feeding value and plant persistence, to try and produce new forage plants that have both high feeding value and long persistence under grazing.

In comparative nutrition studies, goats were shown to utilise low quality roughage better than sheep and the mechanisms responsible were elucidated. Rumen liquid fractional outflow rate (FOR) and the ratio liquid: particulate FOR were greater for red deer than for sheep and goats, in both summer and winter. Red deer were also shown to have a longer retention time of undigested residues in the rumen in summer than in winter and greater rates of rumen ammonia production in summer. This is proposed as a seasonal cycle in digestion, for maintaining apparent digestibility constant whilst VFI increases in summer. The endogenous cycles of VFI and digestion in red deer were shown to be entrained to season by the hormone melatonin.

Grazing systems were developed for efficient venison production from red and hybrid (0.25 elk: 0.75 red) deer by 12 months of age, using both pasture and inputs of red clover and chicory. VFI and digestive characteristics of the forages were determined. It was concluded that the higher ratio of readily fermentable : structural carbohydrate in chicory than in perennial ryegrass led to faster particle breakdown, reduced rumination, and faster rates of rumen degradation and outflow. Hence VFI, apparent digestibility and rates of body growth were greater in deer fed chicory than perennial ryegrass. A similar mechanism was shown to apply for red clover. Very high fractional rates of water outflow from the rumen showed why deer could consume these forages without getting rumen frothy bloat.

Relative to red deer, sambar deer were shown to have an extended calving and to calve in all months of the year, but with a peak in autumn. They were also shown to have seasonal cycles in VFI and growth, but of much less amplitude than for red deer, and males had a much longer length of reproductive activity than red deer. Peak VFI was also in autumn. Sambar deer had a more efficient feed conversion than red deer and metabolisable energy (ME) requirements for both maintenance and gain were lower; they also conserved N more efficiently when fed low quality roughage. Because of these desirable characteristics in sambar deer, attempts were made to hybridise sambar deer and red deer, with the objective of introducing these traits into the NZ national red deer herd. An interspecies hybrid was produced for the first time, but the success rate of the artificial breeding technique was very low.

Review articles are presented on the nutrition of farmed temperate and tropical deer and procedures are outlined for improving the nutrition of farmed temperate deer and for commencing deer farming with tropical deer in tropical countries.

ABSTRACT OF THESIS

INTRODUCTION

All of the work presented in this thesis was conducted in New Zealand (NZ), except that conducted on two periods of sabbatical leave, firstly in the UK (GRI, Hurley in 1975) and secondly in Australia (CSIRO, Prospect in 1983). The work was all conducted with ruminant livestock, apart from three papers on cottonseed condensed tannins which were conducted with monogastric species. Most of the ruminant work involves sheep nutrition, but there are also large contributions on the nutrition of temperate and tropical deer and contributions on the nutrition of goats, cattle and llama. All are farmed in NZ.

As this thesis will be subjected to international examination, it is considered helpful to give some background on NZ and on its agricultural systems. New Zealand has farmed livestock populations of approximately 55 million sheep, 4.5 million beef cattle, 3 million dairy cattle (including followers), 1.5 million deer and several thousand goats. The human population is 3.5 million and most products derived from animals are exported. The NZ climate is warm temperature and is one where forage grows all year round in most environments. Perennial ryegrass (80%)/white clover (20%) pasture is grown throughout the country and is the backbone of all forms of ruminant production. Typical growth rates (Kg DM/ha/d) throughout the year are Spring 75 - 80, Summer 40 - 45, Autumn 50 - 55 and Winter 20 -25. Ruminants therefore graze fresh forages for all 12 months of the production cycle in NZ. There is no indoor feeding. Conservation as hay or silage is practised in late Spring/early Summer and fed to livestock over the 10 - 14 week winter period. Very little (and generally no) concentrate feed is given to producing ruminants. The reason for this is that prices of animal products are tied to world market prices, there is no price support (ie subsidy) for farm products and hence returns to the farmers are low. Under these circumstances inputs of concentrates have generally been shown to be uneconomic. Hence ruminant production in NZ relies on sole diets of fresh forages, or products derived from them, for the complete 12 month production cycle. It is for this reason that the nutrition of ruminants fed forage diets, and especially fresh forage, is so important in NZ. This is the reason why the work presented in this thesis is so dominated by the feeding of forage diets.

With its large sheep population, NZ also has a well developed wool industry, mainly based upon high fibre diameter wool which is used for carpet manufacture. Nutritional factors which influence wool production are therefore important in NZ.

The work presented has been divided into nine sections as shown below. Papers have been numbered from 1 to 104 and are presented in numerical order. Original scientific papers are presented as Group 1; supporting review papers are presented as Group 2.

Section No.	Title
1.	The effect of formaldehyde treatment on nitrogen utilisation by sheep fed forage conserved as hay or silage and upon voluntary feed intake, wool growth and body growth.
2.	Nutritional factors affecting the growth of lambs and cattle fed sole diets of forage kale (<u>Brassica oleracea</u>).
3.	Protein digestion and metabolism in sheep fed fresh forages and their regulation by plant condensed tannins.
4.	The effect of bound condensed tannins in cottonseed meal upon protein digestion in monogastric and ruminant animals.
5.	Selection for low leaf shear breaking load on the feeding value of perennial ryegrass for sheep.
6.	Studies on nutrient utilisation in sheep selected for high fleece weight or high fecundity.
7.	Comparative nutrition of red deer, goats, llama and sheep fed forage diets.
8.	Nutrition of farmed temperate red deer (<u>Cervus elaphus</u>) and the development of grazing systems for efficient venison production by one year of age.
9.	Biology and nutrition of tropical sambar deer (<u>Cervus unicolor</u>).

The general themes of the work are examining methods for improving the efficiency of nutrient utilisation from conserved and fresh forages (Sections 1, 3 and 5), evaluation of new crops and forages for improving nutrient supply (Sections 2, 3, and 8), the nutrition of animal genotypes selected for improved productivity and efficiency (Section 6) and the nutrition of animal species newly introduced to agriculture in NZ (Sections 7, 8 and 9).

The aim of the work was to obtain a thorough understanding of the underlying mechanisms responsible for particular results, with a view to developing future concepts aimed at further improvement.

The definition of feeding value and its components used throughout are those of Ulyatt (1973). Feeding value is defined as the animal production per head from grazing a fresh forage under conditions of unrestricted intake. Measures of feeding value are therefore rates of body growth and wool growth in growing animals and rates of milk secretion in lactating animals. Feeding value is considered to be a function of

Voluntary feed intake (normally DM consumed/day)
and
Nutritive value/DM eaten

The latter can be further divided into

1. Digestion (to include apparent digestibility, sites of digestion and mean retention times)

and

2. Efficiency of utilisation of digested nutrients

The work described in Sections 1, 2, 3, 5, and 8 encompasses all of the above, whilst other sections cover mainly one aspect. A feature of the work is studying nutritional implications from the presence of secondary compounds in the diet. Compounds studied include the effects of condensed tannins in grass and legume herbage, browse and protein concentrate meals and the effects of degradation products of SMCO and glucosinates on the nutrition of ruminants fed brassica plants. A second feature of the work is a study of the nutrition of alternative ruminant species, particularly deer.

In order for the work to advance there was a need to develop new methodologies. Papers 1, 5, 30, 31, 45, 46 are examples of the development of new laboratory methods, which were then applied in the work reported in other papers. The polyethylene glycol (PEG) concept to measure the nutritional effects of plant condensed tannins (Sections 3 & 4) and the use of intra-ruminal controlled chromium release devices (CRD) to measure food intake

in grazing deer (Section 8) are examples of methodology development for indoor and field nutritional studies. Artificial rearing of temperate (red) and tropical (sambar) deer was developed (paper 99) to overcome the nervous and temperamental nature of deer, and to produce young animals that were sufficiently quietened and suitable for generating good data in indoor experiments. Radioactive isotope procedures were developed (papers 41 & 42) to allow specialised nutritional measurements.

SECTION ONE

The effect of formaldehyde treatment on nitrogen utilisation by sheep fed forage conserved as hay or silage and upon voluntary feed intake, wool growth and body growth.

This comprises twelve original scientific papers and two review papers. The work was stimulated by the paper of Ferguson *et al* (1967) in Australia, which showed that formaldehyde treatment of the protein casein could be used to reduce its rumen degradation, to increase post-ruminal protein absorption and to markedly increase wool growth in Merino sheep. Paper 1 showed that formaldehyde treatment of supplementary casein also increased nitrogen (N) retention and wool growth in Romney sheep in NZ. An *in vitro* screening procedure was developed which showed that formaldehyde treatment reduced protein degradation by rumen micro-organisms and increased protein subsequently digested by acid-pepsin, indicating successful protein protection.

Papers 6, 7 and 9 examined formaldehyde treatment of hay and defined procedures which successfully reduced rumen ammonia concentration from approximately 300 to 150 mg N/litre without depressing apparent energy digestibility. It also increased protein protection in *in vitro* tests. Formaldehyde treatment increased wool production in sheep fed lucerne hay by 6-15% and increased wool growth in sheep fed meadow hay in the presence but not in the absence of intraperitoneal methionine supplementation. This and the calculations presented in paper 9 showed that wool growth responses to protein protection in forages was likely to be restricted by their content of limiting sulphur-containing amino acids (SAA). Formaldehyde treatment consistently increase liveweight gain (LWG) at constant intake, thus improving feed conversion efficiency.

The remaining papers showed that forage proteins were extensively degraded during the ensilage process, that formaldehyde treatment reduced this and increased VFI, N retention and wool growth by sheep. Decarboxylation reactions in silages were shown to be important in limiting both VFI and N retention from silages, probably due to amine formation.

Intraperitoneal injections of methionine increased VFI with some silage diets, consistently increased wool growth on all diets, and improved N retention on most silage diets. This further demonstrated that N utilisation was limiting the nutritive value of silages and that SAA supply from forage diets was generally limiting wool growth.

Although formaldehyde treatment of conserved forages is no longer used in NZ, the work reported in Section 1 clearly showed that protein deposition (ie N retention) in sheep fed forage diets could be increased if rumen degradation of forage proteins to ammonia could be reduced. This concept is extended in Section 3, using condensed tannins in fresh forages to reduce protein degradation in the rumen. In the future when the normal pastures used for ensiling in NZ have been increased in condensed tannin content, using the Genetic Engineering techniques described in Section 3, it will be possible to repeat the experiments described with silage in Section 1, to establish if the action of condensed tannin also increases silage VFI, as would be expected.

SECTION TWO

Nutritional factors affecting the growth of lambs and cattle fed sole diets of forage kale (Brassica oleracea).

This section comprises twelve original scientific papers, mainly on the nutrition of sheep fed sole diets of forage kale (Brassica oleracea). This work was stimulated by the need to find alternative forages that had higher levels of digestible DM production/unit time than perennial ryegrass/white clover pasture and might lead to increases in animal production. As the highest yielding brassica for the south of NZ, forage kale was selected for evaluation.

Initially, it was shown that LWG was low in relation to the high digestibility of the crop (80-85% OMD). The principal cause was identified as the content of the recently discovered S-

methyl-L-cysteine sulphoxide (SMCO; Smith 1974), which only occurs in brassica plants. Through synthesising large amounts of SMCO and adding it to diets and through identifying soil fertility practices to grow low and high SMCO content kale, it was confirmed that rumen fermentation of SMCO to dimethyl disulphide causes haemolytic anaemia (through inactivating proteins) and then shown for the first time that it reduces VFI, LWG, and wool growth. All of the depression in LWG and wool growth could be explained by the depression in VFI. Growth improved after 6 weeks, due to the development of resistance mechanisms by the animal. Components of the resistance mechanism were identified and shown to involve the trace elements iodine and copper and to involve stimulation of replacement proteins under the influence of growth hormone and thyroid hormones. Degradation of glucosinolates yielded goitrogens which reduced iodine uptake into the thyroid gland and reduced T4 output.

SMCO was shown to be degraded extremely rapidly in the rumen and the digestion products of kale diets were shown to be low in protein in relation to ME. Oral supplementation with methionine reduced this degradation, due to its close structural similarity to SMCO, and increased wool growth.

Paper 26 identified nitrile production from glucosinolates as a further factor that could limit animal production from kale diets.

Recommendations were made for improving growth rates of ruminants grazing sole diets of forage kale, including reducing SMCO content and supplementation with iodine and copper.

Criteria can be defined for the development of successful alternative forage crops and are listed below:

1. a high ratio of readily fermentable: structural carbohydrate, to facilitate rapid rumen DM breakdown and high VFI, and as a source of energy for the incorporation of rumen ammonia into microbial protein.
2. a reasonably high protein content with low rumen degradability.

3. absence of anti-nutritional factors.
4. good plant establishment and long persistence.

Kale scores very well on criteria 1 and the research done by the candidate greatly reduced the impact of criteria 3 and identified criteria 2 as a more minor problem. However, use of forage kale has not dramatically expanded in NZ, largely because it is an annual plant and occurs a yearly replacement cost. The candidate learned this lesson well and future attempts at alternative grazed forages to perennial ryegrass-based pasture have concentrated on legumes and herbs that have much longer persistency. These are covered in Sections 3 and 8.

SECTION THREE

Protein digestion and metabolism in sheep fed fresh forages and their regulation by plant condensed tannins.

This section contains twenty eight original scientific papers and three reviews. The work was stimulated by the paper by MacRae and Ulyatt (1974), which showed that duodenal N flow in sheep fed fresh forages in NZ was only about two thirds of the N eaten. This was due to the excessive degradation of forage protein to ammonia in the rumen being faster than the rate at which ammonia could be incorporated into microbial protein, with large amounts of ammonia subsequently being absorbed from the rumen, converted to urea in the liver and excreted in the urine.

Papers 27-29 examined the hypothesis that the amount of protein absorbed from the small intestine could be restricting ruminant production in young sheep fed fresh forages ad libitum. Abomasal infusions of casein plus methionine dramatically increased protein deposition in the complete empty body, in the carcass, and in wool, confirming that fresh forages were indeed deficient in the absorption of essential amino-acids relative to energy. Paper 29 measured rates of protein synthesis in young lambs fed fresh forage ad libitum, and was amongst the first investigations to show the high rates of protein synthesised in the skin and in gut tissues, with these being numerically equal to protein synthesised in the carcass.

Subsequent papers in this section looked at forage condensed tannins as a means of manipulating the digestion of protein in ruminants fed fresh forages. Papers 30-32 examine methodology for determining plant condensed tannin content, and look at the effects of soil fertility and plant cultivar upon condensed tannin content. The two cultivars worked with are Lotus corniculatus and Lotus pedunculatus. Jones and Mangan (1977) had shown that condensed tannins in sainfoin formed stable complexes with forage proteins in the pH range 5-7, but that the complexes dissociated and released protein at pH values less than 3.5 and greater than 8. Papers 30 & 31 applied this concept to the two Lotus species, defined the concentration of condensed tannin necessary to reduce solubility and deamination of protein, and showed that bonds between condensed tannin and protein could be reversed by the addition of polyethylene glycol (PEG; MW 3,350). These papers also define the concept of free tannin and show its accumulation in plant macerates when the concentration of tannin is so high that it has exceeded the protein binding capacity of the plant. These papers discuss the probable nutritional role of bound and free condensed tannin.

Papers 33-37 were the first publications to report the effects of condensed tannin in Lotus pedunculatus upon its nutritive value for sheep. The papers show that duodenal NAN flow per unit N intake is positively and linearly related to plant condensed tannin content. However, very high concentrations of plant condensed tannin reduced the apparent digestibility of non-ammonia nitrogen (NAN) in the intestines, reduced VFI, and inhibited rumen digestion of cellulose and hemicellulose. The later were postulated as due to ruminal effects of free condensed tannin. High concentrations of condensed tannin also depressed rates of body growth and wool growth in grazing sheep.

At this point the candidate transferred from the Invermay Agricultural Research Centre near Dunedin to Massey University, which is located in a warmer climate in the North Island. The work upon forage condensed tannins continued after the change in location but with a somewhat different emphasis.

Papers 40-42 examine the effects of condensed tannins upon the solubilisation and degradation of ribulose -1,5- bisphosphate carboxylase (Rubisco) protein in the rumen, upon the true digestibility of plant methionine and cystine in the small intestine and study the digestion of ¹⁴C labelled condensed tannin in the small intestine. It is shown that condensed

tannin reduces the digestion of Rubisco in the rumen mainly by reducing degradation, with little effect on solubility. Whilst condensed tannins increase the flow of protein into the small intestine, paper 41 shows that they also reduce true digestibility of plant methionine and cystine in the small intestine, in sheep fed Lotus corniculatus. However, action of condensed tannin increased the amount of plant methionine and cystine absorbed from the small intestine (g/g eaten), due to its larger effect in reducing their rumen degradation and increased the absorption of total methionine. Paper 42 shows that when condensed tannins are released from forage protein during digestion in the small intestine, the carbon from the condensed tannins is not absorbed from the digestive system.

Using ³⁵S labelling techniques and HPLC analyses, papers 43 & 44 examine the fluxes and transfers between methionine, cystine and inorganic sulphate in the plasma and the effects of forage condensed tannins upon these processes. In sheep selected for high rates of wool growth, it is shown that much methionine is converted to cystine (probably in the liver), and that the effects of condensed tannins are to approximately double the amount of cystine used for body synthetic reactions whilst reducing the amount of inorganic sulphate entering and leaving the plasma pool.

Papers 46-49 report the development of an analytical method for measuring bound as well as extractable condensed tannin, and report its application to a range of forages, grains and protein-concentrate meals. With this new application, condensed tannin concentrations in Lotus corniculatus and Lotus pedunculatus were found to be higher than originally reported, and a whole range of forages previously thought not to contain condensed tannins were now identified as condensed tannin-containing. The common grasses and legumes used in temperate agriculture were now identified as containing trace amounts of condensed tannin in their leaf tissue (approximately 2g CT/kg DM). Other plants such as Glyricidia and cottonseed hulls, previously shown to contain negligible concentrations of extractable tannin, were now shown to contain substantial concentrations of bound condensed tannins. The reactivity of these new condensed tannins is reported in Paper 49, together with other procedures to confirm that condensed tannin is present.

Papers 50-53 report the results of long term field trials designed to study the effect of condensed tannins upon the productivity of sheep grazing the legumes sulla and Lotus

corniculatus. Here the authors show that both legumes are of high nutritive value to sheep and promote high levels of animal production. With Lotus corniculatus, a substantial portion of this high productivity is due to the effects of condensed tannin in increasing amino acid absorption. This is shown by effects of condensed tannin increasing wool growth in young lambs (+12%) and increasing milk secretion in lactating twin-bearing ewes (+20%), with no change in VFI, showing a similar improvement in feed conversion efficiency as found in Section 1.

Throughout this section a number of papers are presented which examine the effects of post-ruminal protein infusions and dietary condensed tannins upon the animal's endocrine system. It is shown that increasing amino acid absorption in this manner changes plasma concentrations of several hormones, that this is likely to effect the partition of absorbed nutrients and is also likely to effect gut mean retention times (and perhaps, therefore, sites of digestion). It is also shown that very high dietary concentrations of condensed tannins in Lotus pedunculatus result in elevated plasma concentrations of growth hormone, which may be involved in the lower levels of carcass fatness in sheep grazing this forage.

Paper 54 reports in vitro rumen degradation studies for a range of proteins being considered for incorporation into forage plants using Genetic Engineering techniques. There is much interest in the protein sunflower albumin 8 (SFA8) for this purpose, because of its high SAA content. Here we show that SF8 is indeed resistant to rumen degradation, but by a rather unusual and interesting mechanism.

The section concludes with three review articles. Here the authors propose for the first time (papers 55-57) that Genetic Engineering techniques (which were just becoming available at that time) should be used to transfer DNA coding for enzymes producing condensed tannins from those plants possessing this capacity (such as the Lotus species) to forage plants commonly used in agriculture that either do not possess this capacity or have it to a very low extent (such as the common grasses and legumes).

Lotus pedunculatus will successfully establish in low fertility hill country soils where the soil pH is too low for white clover (pH4.4-4.8), where the only competition is from native tussock of low nutritive value, and has therefore found a niche in this specialised

environment, notably for aerial application in hill country in the South Island and in parts of Eastern Australia. The principle problem with both sulla and Lotus corniculatus is that they are poor plant competitors in high fertility soils and hence have low persistence under grazing in these conditions. Possibilities for selecting such plants for improved persistence and for lower condensed tannin concentration are discussed in the final section of this Abstract. However, even with improved persistence it is likely that these plants will find their role in specialised niches, perhaps medium fertility, dry areas for Lotus corniculatus (soil pH 5.0-5.5) and in alluvial soils for sulla, with both sown as pure species forages. Perhaps this lack of competition is not surprising in the condensed tannin - containing forages, considering the ecological reasons for condensed tannin production are to defend the plant from attack by pathogenic micro-organisms, insects and grazing herbivores (paper 57). Such plants tend to be slow growing and put carbon into condensed tannin production instead of structural carbohydrate and protein production, as a defence against grazing herbivores. Their lack of persistence under grazing is therefore not surprising.

Section 3 has defined the nutritional benefits of low condensed tannin concentrations (35g/kgDM) in Lotus corniculatus, and to obtain these benefits in forages grown in well fertilised soils in NZ and other temperate environments, it will probably be necessary to go to Genetic Engineering, to transfer the ability to produce condensed tannins from plants such as lotus into white clover and perennial ryegrass that have widespread application as grazed forages. This aspect is also discussed in the last section of this Abstract.

SECTION FOUR

The effect of bound condensed tannins in cottonseed meal upon protein digestion in monogastric and ruminant animals.

Section 4 reports seven original scientific papers on the effects of bound condensed tannins in cottonseed meal upon protein digestion in monogastric and ruminant animals. Originally, it was thought that cottonseed did not contain any condensed tannin because it contained negligible concentrations of extractable condensed tannin. Using the methodology reported in Section 3 it is shown that cottonseed does contain substantial concentrations of condensed tannin, with most of this being in the protein-bound form and a smaller component in the

fibre-bound form. It is shown that all of the condensed tannin is present in the hulls and none in the kernels (the high protein component). In processing conditions used in Australia, a small amount of hull is left in cottonseed meal, as this gives a more firmer mixture from which the oil content can be extracted with a greater efficiency. Lint is regarded as the component of highest financial value in cotton production, followed by the oil extracted from cottonseed, with cottonseed meal (CSM) being regarded as a by-product.

Using unheated preparations, it is shown that adding low concentrations of hulls to cotton seed kernels substantially reduced the ileal digestibility of many amino acids in laboratory rats. PEG studies showed that some of this depression was due to the condensed tannin content whilst the cause of the remaining depression is unknown. Papers 61 & 62 show that whilst condensed tannin content can reduce the solubility of the protein in cottonseed meal and can reduce degradation by rumen organisms, unrealistically high concentrations of hulls are required to obtain this effect. It was concluded that bound condensed tannins, present in cottonseed hulls, are unlikely to have been mobile in the rumen and therefore to have reduced the solubility of cottonseed kernel protein. However, the effects seen with rats at low condensed tannin concentrations suggest that the bound tannin was solubilised in passage through the peptic stomach and exerted a substantial anti-nutritional effect in the small intestine of the rat.

The effects of heating and presence of condensed tannins were jointly assessed in papers 63 & 64. Whilst heating did destroy a small component of the condensed tannin (13-25%), it did not reduce the amount of reversible reactivity with protein. The apparent ileal digestibility of most amino acids in monogastric animals was markedly depressed by both heating and condensed tannins. Combinations of heat and the presence of condensed tannins were particularly damaging for the limiting essential amino acids lysine and threonine. These effects explain the generally low level of amino acid availability in CSM found with monogastric animals, and define procedures whereby the levels of amino acid availability could be substantially raised.

Both condensed tannin and gossypol function as part of the cotton plant's resistance mechanism for defence against attack by pathogenic micro-organisms and insects. Insect

predation is a major problem in cotton growing areas, and whilst selection for low gossypol content improved the nutritive value of the meal these varieties proved impractical because of increased susceptibility to insects. For similar reasons selection for low condensed tannin content does not seem a realistic option for reducing nutritional problems in monogastric animals fed diets containing cottonseed meal; rather, the solution probably lies in developing processing technology that uses reduced heat and uses low (preferably zero) hull content.

SECTION FIVE

Selection for low leaf shear breaking load on the feeding value of perennial ryegrass for sheep.

This section reports three original scientific papers on the effects of selecting perennial ryegrass for reduced leaf shear breaking load on its feeding value for sheep. Despite its good persistency and all year round growth, perennial ryegrass is well known to be of limited feeding value. In NZ, Ulyatt (1973) classified its feeding value as about 52% of that of white clover. Computer simulation studies of Black *et al* (1982) identified slow breakdown and outflow from the rumen as the main problem, giving rise to low VFI.

Papers 65 - 67 describe the selection of perennial ryegrass for low and high leaf shear strength and test the hypothesis that reduced leaf toughness (ie low shear strength) should speed breakdown in the rumen and increase VFI. Although the selection process did reduce shear breaking load (-13% & -27%) it also changed leaf morphology, with the low selection also having shorter narrower leaves. There were no consistent differences in rate of particle breakdown, rumen outflow rate, VFI or animal production in sheep fed the two selections. An index of masticatory load (IML) was calculated as the shear load required to reduce particles to the critical size for leaving the rumen and this was shown to differ between the selections by only 3%. It is suggested that future selection be based upon IML, which includes shear strength and also leaf length: dry weight ratio.

Review paper 56 also includes a section on effects of the ryegrass endophyte fungus (*Acremonium loliae*) upon animal production and plant persistency. The compounds lolitrem

B and peramine were newly discovered at that time and were shown to cause ryegrass staggers in livestock during hot summers (lolitrem) and to confer insect resistance and increased plant persistency (peramine). A search in NZ then followed for an endophyte producing low (and preferably zero) levels of lolitrem B but substantial levels of peramine.

SECTION SIX

Studies on nutrient utilisation in sheep selected for high fleece weight or high fecundity.

This section comprises three original scientific papers, two concerning the nutrition of pregnant ewes selected for high fecundity and one concerning nutrition of sheep selected for high rates of fleece growth. All were fed forage diets.

Papers 68 and 69 report glucose and protein metabolism during late pregnancy in ewes confirmed as carrying triplet foetuses and fed fresh pasture. From abomasal infusions of casein and glucose, from glucose kinetic studies and from calculations it was deduced that glucose supply was borderline for conceptus uptake and that ewes not supplemented with casein were in negative N balance. Supplementation had no effect on lamb birth weight but clearly increased colostrum production. Supplements of casein increased wool growth and restored positive N balance, further emphasising problems of amino acid supply in ruminants fed fresh forages ad libitum.

Paper 69 reports effects of the infusions upon plasma hormone concentration in the ewes during late pregnancy and in the lambs at birth and discusses the possible effects of these hormonal changes upon maternal nutrient utilisation and upon foetal growth. This line of research had to be terminated at this point with the appointment of the candidate to the staff of Massey University.

In paper 70 it is shown that 30 years of selection of Romney sheep for increased fleece weight had no effect on urea production, even though plasma urea concentration was lower for fleece plus sheep. Rumen fractional outflow rate was shown to be increased in fleece plus sheep, which probably means microbial protein synthesis and outflow were higher for these sheep. Improved protein supply by this means could be part of the mechanism for the

selection process increasing wool growth.

SECTION SEVEN

Comparative nutrition of red deer, goats, llama and sheep fed forage diets.

This comprises ten original scientific papers on the comparative nutrition of red deer, goats, llama and sheep, in which VFI and aspects of digestion in the in the first three species are compared with those of the domestic sheep. This is followed by one review paper. Sole diets of various hays or browse were fed.

In papers 71 - 76 it is shown that VFI and fibre digestion were generally higher for goats than for sheep, with the superiority of goats increasing as the fibre content of the ration (and especially the lignin content) increased. Goats were more efficient than sheep in breaking down particles during eating, with the number of chews/DM swallowed and eating time being much higher for goats than for sheep. Goats were able to maintain a higher rumen ammonia concentration than sheep and had greater rates of rumen ammonia irreversible loss. It was calculated that endogenous N secretion into the rumen was greater for goats than sheep and this was supported by measured greater rates of apparent salivary N secretion into the rumen of goats than sheep during eating. VFI of goats increased from winter to summer and this was accompanied by a reduction in apparent digestibility. Intakes of digestible DM and OM did not change between seasons in the goat and neither did rumen fractional outflow rate of liquid and particulate markers.

Papers 75 - 79 report comparative nutrition of red deer and sheep and examine seasonal aspects of digestion in red deer. Deer had a much greater increase in VFI from winter to summer than goats, and unlike goats this was not accompanied by a decrease in the apparent digestibility of DM or OM. Rumen fractional outflow rate of water was much higher for red deer (16%/hr) than goats or sheep (10%/hr) and did not change with season. Rumen fractional outflow rate of particulate markers was consistently less in red deer during summer than winter, meaning that particulate mean retention time (1/FOR) was longer during summer. Rates of rumen ammonia irreversible loss were also shown to be greater in summer than in winter in red deer, indicating greater recycling of N to the rumen during summer.

Both the above were considered to be mechanisms evolved by red deer for maintaining digestibility whilst dramatically increasing VFI during summer. Paper 79 showed that seasonal aspects of VFI, digestion and heart rate in red deer were entrained to day length by the hormone melatonin in the same way that reproduction is entrained to season by melatonin. Subcutaneous melatonin implantation during spring caused a phase shift in the annual cycles of approximately 6 months.

In paper 80 it is shown that VFI and digestion of a low quality roughage was similar for llama x guanaco crosses and sheep. Both species were in negative N balance, but the camelids conserved N and water better than the sheep.

The section concludes with a review of the control of VFI in domesticated deer (paper 81).

SECTION EIGHT

Nutrition of farmed temperate red deer (Cervus elaphus) and the development of grazing systems for efficient venison production by one year of age.

No grazing mammals resulted during the evolution of life in NZ. Rather, grazing of plants was done by large flightless herbivorous birds such as the Moa, which has now been hunted to extinction. Herbivorous mammals were introduced to NZ with European settlement during the 19th century. These included sheep and cattle as domestic livestock and also the European red deer for recreational sport. The latter largely originated from the Scottish Highlands, quickly escaped into the wild and rapidly multiplied throughout both islands, especially in steep bush covered country. By the 1940's the deer population was causing serious damage to native forests, they were classified as noxious animals, and shooters were sent in on foot to control them. This was ineffective and aerial shooting commenced on a large scale in the 1960's, with the venison being processed and exported to Germany. This proved extremely lucrative but had to be scaled down towards 1970 by the reduced deer kill. This provided the impetus for live capture operations and the commencement of deer farming, with the deer being legalised as a farmed species in 1969. Since then the numbers of farmed deer have increased dramatically and now number 1,5 million animals; projected rate of increase is 10% per annum. The NZ farmed deer population comprises 85%

European red deer (mature hind weight 100 kg) and 10% fallow deer (mature hind weight 50 kg) and is thus based upon deer of temperate origin. Early progress in the NZ deer industry included the successful development of fencing and yarding systems, the development of animal health systems and the velvet antler industry. All female deer were kept for breeding for many years and the export venison industry did not commence until the mid 1980's. Massey University initiated research in 1987 into grazing systems for venison production and at the same time commenced studies into the digestion and metabolism of farmed deer fed fresh forage diets.

This section reports thirteen original scientific papers on the nutrition of red deer fed fresh red clover or chicory and the development of 12 month grazing systems for venison production. Growth of red deer is seasonal and follows the same pattern as VFI, with high potential growth rates in spring and early summer and low growth in winter. This becomes more pronounced as stags age; in their second winter growth slows to zero for 3 months and is preceded by a 2 month rut, their first period of sexual activity, when growth is also zero. New Zealand markets for venison are dominated by Germany, which requires venison carcasses of 50-65kg in the NZ spring, for consumption in the German autumn and Christmas season. Premiums are paid for these venison carcasses produced in spring in NZ, and as deer calve in late spring/early summer in NZ (Nov/Dec) most deer farmers originally achieved these targets by slaughter of venison stags at two years of age. The candidate and his colleagues initiated research at Massey University in 1987 into the feasibility of producing venison carcasses of 50-65kg in spring by one year of age using diets of fresh forages. In the stags that did not meet this target, immunisation against GnRH and melatonin was attempted to try and reduce the 5 month growth depression in yearling stags (ie rising 2 year old) associated with the rut and with winter.

Paper 82 showed that venison production from grazed pasture was possible by 12 months of age, and defined 10cm as a suitable herbage grazing height. However only 40% of animals attained the target weight when grazed on perennial ryegrass-based pasture, compared with 60% when grazed on annual ryegrass. Subsequent papers showed that extending the period of controlled grazing on perennial ryegrass pasture (10cm) to include autumn, winter and spring increased the proportion of animals reaching the target to 75%, but most of these were

in the range of 50-55kg carcasses. Papers 85-94 showed that inputs of red clover or the herb chicory could be used to ensure 100% of stags reached 50kg and that mean carcass weights were increased to 60-65kg. These forages were selected because of their high rates of DM production during summer and autumn and their deep tap rooting system, enabling them to withstand moisture stress over these periods when the growth and OMD of perennial ryegrass/white clover pastures decline. Particularly good results were obtained with chicory, where hybrid stags (0.25 elk: 0.75 red deer) were shown to respond better than pure red deer, showing that their higher genetic potential for body growth could best be expressed when grazing a forage of high feeding value. Feeding chicory was also shown to increase velvet antler production in 12 month old stags. Management conditions were defined which resulted in red clover grazed by deer persisting for 3 years whilst chicory persisted for four years.

Detailed studies showed that red clover and chicory supported greater levels of deer production through increased VFI, greater apparent digestibility and faster rates of rumen disappearance. Rumination time was found to be extremely low in deer fed chicory, associated with extremely high rates of DM disappearance from the rumen. Fractional rate of water outflow from the rumen continued to be very high (13-17%/hr) and this is suggested as a reason why deer never develop rumen frothy bloat when grazing sole diets of these forages. Relative to deer fed perennial ryegrass, rumen fractional outflow rates of both liquid and particulate matter were much greater for deer fed chicory (hence MRT was shorter), and fractional rates of DM and fibre degradation were greater for deer fed chicory. The high ash content of chicory (160g/KgDM) probably contributes to the very fast rumen fractional outflow rate of water in deer fed this forage. Chicory has also been shown to contain 2-4g/kg DM of condensed tannin (papers 46 & 49) and this may contribute to the improved protein absorption from this forage.

Papers 82 to 84 investigated the effects of immunisation against melatonin and against GnRH (LHRH) as potential means of overcoming growth depressions associated with winter and with the rut in rising two year old stags. Procedures were developed for increasing antibody titres against both hormones. Immunisation against melatonin did increase plasma prolactin concentration during winter, but these increases were small and no increase in growth resulted. In a review Suttie & Corson (1991) showed that injections of prolactin dramatically

increased plasma prolactin concentration and the growth of young deer during winter. This suggests that refinement of the immunisation procedure to further elevate winter prolactin concentrations could potentially increase growth over this period.

Immunisation against G_nRH tended to reduce the magnitude of the autumn testosterone peak rather than to completely suppress it, and increased body growth in two of the three experiments. In the future it may be possible to improve both immunisation procedures to produce bigger levels of antibody titre over longer periods of time, which could lead to larger effects upon autumn and winter growth in rising two year old stags.

The section concludes with a short review of nutritional and animal health aspects affecting efficient venison production from farmed temperate and tropical deer (paper 95).

SECTION NINE

Biology and nutrition of tropical sambar deer (Cervus unicolor).

This section reports nine original scientific papers on the biology and nutrition of the tropical sambar deer (Cervus unicolor). Tropical deer evolved throughout the Indian sub-continent and South East Asia including Indonesia, and populations can now be found in Northern Australia, Mauritius, Taiwan and New Caledonia. Three species are being considered for deer farming, namely rusa deer (Cervus temorensis; mature hind weight 70kg), sambar deer (mature hind weight 150kg) and chital deer (Axis Axis; mature hind weight 45kg). Small numbers of sambar and rusa deer were introduced to the North Island of NZ in the 1870's. These species hybridised in the Bay of Plenty, but the sambar deer from Sri Lanka that were released in the Manawatu coastlands remained a pure species. These now number approx 500 animals. Flock House Agricultural Centre, Agresearch, is located in this area and sambar deer were captured from the wild and located there for this work. No information was available on the nutrition of tropical deer when this work commenced and only scanty information was available on their reproduction. General information suggested that all three species of tropical deer had an extended calving season relative to red deer. Sambar deer were selected because they were the largest of the tropical deer, with the long term objective of studying the merits and feasibility of producing sambar x red deer hybrids, which could have earlier calving and perhaps some other advantages compared with red deer.

The study is divided into two parts. Papers 96-98 describe the general biology, grazing patterns and diet preferences of captured sambar deer and compare them with the same measurements made with temperate red deer at the same time. Sambar deer were shown to calve over the entire year, but with a peak in autumn (April/May). Stags were in hard antler and displayed rutting behaviour over a 6 month period (May-November). Thus both male and female breeding activity occurred over a much longer period than for red deer and with a different seasonality.

Sambar deer were observed to graze for the same length of time as red deer but to have a greater proportion of night grazing. It is postulated that this evolved to reduce heat stress in tropical environments and as a defence against attack by predators. In grazing preference

experiments both sambar deer and red deer selected a mixed diet of browse, grasses and forage legumes and both were therefore classified as intermediate feeders (rather than concentrate selectors or true grazers) in the Hofman classification system. Both deer species showed a similar preference for grasses, but sambar deer showed a higher preference for browse and a lower preference for forage legumes than red deer. It was calculated that both species selected diets of similar OMD, but that sambar deer selected a diet higher in condensed tannins and lignin than red deer. This was related to higher levels of salivary condensed tannin - binding proteins in sambar deer than in red deer.

Papers 99-103 describe indoor nutritional studies which were conducted with hand reared sambar and red deer, in order to obtain quietened animals that would readily adjust to these conditions. Paper 99 showed that sambar deer calves could be removed within 24 hours of birth and successfully artificially reared using ewe milk replacer. Milk consumption declined faster in sambar than in red deer fawns and sambar fawns self weaned earlier, suggesting they become independent of hinds at an earlier age than do red deer. Paper 100 showed for the first time that sambar deer do have seasonal cycles of VFI and body growth, but that these were of much less amplitude than for red deer. Peak VFI for sambar was in autumn and minimum VFI was in spring, whilst in their second year the growth reductions associated with the rut were not as pronounced for sambar deer as for red deer. Interestingly, peak calving in both sambar deer (April/May) and red deer (Nov/Dec) are timed to correspond with the peak in VFI. Growing sambar deer had a much better efficiency of food conversion than red deer and required less ME for both maintenance and gain. This is supported by calorimetric data, where ME requirements for maintenance were found to be 474 & 567 KJ/kgW^{0.75}/day for growing sambar and red deer (Semiadi, Holmes, Barry & Muir unpublished). The period of high plasma testosterone concentration corresponding to the rut was longer for young sambar stags (May - Nov) than for young red stags (March - April), confirming the longer period of sexual activity in sambar stags.

Digestion, eating behaviour and rumination studies (papers 101 and 102) showed no difference in digestive efficiency between sambar and red deer, but that sambar deer spent more time both eating and ruminating/DM intake than red deer. Sambar deer had a different rumination cycle than red deer, with more boli/hr but less time spent per boli. It is suggested this may involve more efficient re-cycling of N into the rumen. Sambar deer

responded to a diet of low quality roughage with a lower VFI than red deer but reduced N losses in faeces and urine, indicating better N conservation (paper 102).

There are too few sambar deer in NZ to consider them for serious deer farming in their own right. Rather, hybridisation with red deer was attempted (paper 104) as a potential means of introducing some of the desirable traits in sambar deer into the NZ national deer herd, which is based on red deer. The study produced the first scientifically proven hybrid between a tropical and a temperate deer but the proportion of pregnancies that went to term was very low (1%). If the males are fertile and will mate with red deer then only low numbers are required. It remains to be seen if these reproductive techniques can be increased in efficiency so that larger numbers of these hybrids can be produced and their fertility assessed.

Part of review paper 95 concerns tropical deer. The development of deer production systems in tropical countries, including nutrition and the hybridisation of rusa and sambar deer, and the role of any sambar:red deer hybrids in the NZ deer industry are discussed.

TOWARDS PRODUCING FORAGES OF IMPROVED FEEDING VALUE

From the work presented it is possible to draw some conclusions about producing forages of improved feeding value. It is suggested this be approached as follows, with the dual objectives of producing forage plants with higher feeding value and long persistency.

1. **Selection of perennial plants for improved feeding value.** A first choice in this category would seem to be perennial ryegrass. As the selection attempted in Section 5 was not successful, other approaches should be considered. Research in progress shows that selection for higher OMD (approx 4% units) has increased feeding value, with LWG of lambs over summer being 100 and 120g/day for control and selected pasture. The inverse relationship between feeding value and persistence in rye grasses has been known for a long time (Ulyatt 1973) and it is always possible that selection in this manner may result in pasture of reduced persistence, particularly if the selection reduces endophyte levels (as may be the case).

Since review paper 56 was completed, ergovaline has been identified as a third product of Acremonium loliae and been shown to produce tremors associated with ryegrass staggers. A major advance in feeding value should come if perennial rye grass endophytes can be modified using Genetic Engineering techniques to produce little or no levels of lolitrem B and ergovaline but substantial levels of peramine. This should ensure good persistence without the summer loss of animal productivity associated with the development of ryegrass staggers.

2. **Selection of plants identified as of high feeding value for increased persistence.** Plants identified of high feeding value in Sections 3 & 8 where this approach should be tried are chicory, lotus corniculatus and sulla. All three score very well in the criteria defined for good feeding value in Section 2. Chicory and sulla have high ratios of readily fermentable: structural carbohydrate and all three forages contain condensed tannin, which will reduce ruminal protein degradation. However, all three have persistence problems under grazing and selection for different root structures may prolong persistence. In the work conducted in Section 8 it was noted that approximately 25% of the chicory plants died under deer grazing each year.

However the plants remaining after 3 years differed substantially in morphology from the initial plants; the initial plants had only one aerial shoot and one tap root per plant whereas after 3 years the surviving plants had produced 5 or 6 aerial shoots per plant and a branching root system, giving much larger plants which withstood grazing better. It is suggested that selections of chicory should be made from these plants which have successfully survived under grazing. Selections should similarly be made from lotus corniculatus and sulla for similar vegetative propagation in plants that have survived under grazing, perhaps for a more stoloniferous-type spreading root system. Selection of all three plants along these lines should produce more persistent varieties.

3. **Selection for condensed tannin content.** Work presented in Section 3 has shown the nutritional benefits of 35-40g condensed tannin/kg DM present in lotus corniculatus and other work conducted at Massey University (Montossi 1995) shows the minimum level of condensed tannin to produce wool and body growth responses in sheep grazing grasses is 5g/kg DM. We do not know the nutritional effects of condensed tannin in the range 10-25g/kg DM and there is a need to examine the possibility of selecting to try and produce such plants. Determination of condensed tannin by NIR should give the rapid analyses of large numbers of samples required for such programmes and the feasibility of selecting grasses for higher condensed tannin content and lotus corniculatus for lower content should be examined. Also, sulla needs to be selected for lower condensed tannin content.

As condensed tannin is not absorbed from the digestive system (paper 42) and exerts its beneficial effect in domestic ruminants through interacting with forage proteins, a priority is to identify the minimal concentration of condensed tannin (or range) to give beneficial nutritional effects. This could differ for each forage, depending on the molecular weight, structure and reactivity of the condensed tannin.

4. **Using Molecular Biology techniques to enhance condensed tannin and SAA content of forages.**

The candidate has long proposed that these be attempted, both for SAA (paper 9) and for condensed tannin (papers 55, 56 and 57). From Sections 1 and 3 it seems that best results for productive processes such as wool growth will be achieved if both transfers can be made simultaneously into the same plant. Initial target species for the above transformations are suggested as white clover and lucerne, followed by perennial ryegrass. In addition to increasing amino acid absorption, condensed tannin contents of 5g/kg DM or greater should confer bloat resistance (Li et al 1996). This in itself would make an enormous improvement in the extent of cattle production from the two legumes; it would eliminate bloat risk in dairy cows in NZ, where recent surveys shown the annual death rate is 1.4%.

Paper 54 shows that the protein sunflower albumin 8 (SF8) has a high SAA content and low rumen degradability and is therefore suitable for introduction into plants to increase SAA supply. The CSIRO Division of Plant Industry have calculated that it needs to comprise 5% of the total protein to produce the required increase in diet SAA content. The same Division has achieved this level of expression in lupin seeds, and the level of expression in lucerne leaves has been increased from 0.1 to 1.0% of total protein. This is not considered high enough at this stage.

The pathways of condensed tannin and lignin formation share many intermediaries in the Shikimic acid biochemical pathway (paper 57). If DNA coding for the enzymes converting p-coumaric acid to condensed tannin could be introduced into white clover, lucerne and perennial ryegrass, it would mean the diversion of some carbon from lignin to condensed tannin production. This should give a double benefit of reducing lignin concentration whilst simultaneously increasing condensed tannin content, and a key aspect of these programmes will be to regulate the amount of condensed tannin produced such that it is in the low beneficial concentration and not in the high detrimental concentration.

In systems where forages are grazed for the complete 12 month production cycle, such as NZ, experience has shown that the farming industry is unlikely to adopt new forages of high feeding value if these only persist for one or two years. The above

programmes, singly or in combination, offer ways of producing forage plants with the dual objectives of increased feeding value and longer persistence. In particular, use of Genetic Engineering techniques is suggested to try and break the well defined negative correlation between forage feeding value and plant persistence.

The work submitted in this DSC thesis was conducted over a period when supplementation of grazing ruminants with concentrate feeds was generally uneconomic in NZ, for the reasons given in the Introduction (page 10). The General Agreement on Tariffs and Trade (GATT) has since been signed and as this is gradually implemented it is likely that prices for ruminant animal products will rise in NZ, particularly for milk products. Thus supplementation of grazed forage diets could become a possibility in the future, notably for dairy cows. However, this will not lower the importance of producing grazed forages of high feeding value and long persistency, which will always be a key objective in grazing temperate environments like NZ.

TOWARDS THE FARMING OF ALTERNATIVE HERBIVORE SPECIES

Sheep and cattle are the ruminant herbivores that have been traditionally farmed by man, with goats also being used in many Asian and African countries. The work described in Section 8 has shown that efficient venison production can be obtained from the temperate red deer grazing high quality forage diets and shows that they should now be included as farmed ruminants.

Work in Section 9 shows that the tropical sambar deer have several advantages compared to temperate red deer, including a wider period of calving, less seasonal changes in growth and VFI and better efficiency of feed conversion. By introducing stags for defined short intervals, calving can be matched to patterns of forage production. Farming of pure species of tropical deer offers little prospect in NZ, because of low animal numbers, but must offer real potential for many tropical countries that have wild populations of tropical deer, such as Indonesia, Thailand, Malaysia and India. Capture operations could be initiated, as done in the 1970's in NZ, and deer farmed in systems to suit local patterns of forage production. The work described in Section 9 shows the diet preference and excellent growth of sambar deer. Similar data are now needed in the tropics, for sambar, rusa and chital deer.

Work described in Sections 7 and 9 has shown that goats, red deer, sambar deer and llama are all able to efficiently use low quality roughage, generally better than the domestic sheep. However, the mechanism differed between species. With goats the main processes appeared to be in the rumen, including more efficient particle breakdown during eating and more efficient recycling of N into the rumen, leading to greater VFI of highly lignified diets. Red deer also responded to a low quality roughage diet with increased VFI, but the mechanism was not determined. However, sambar deer and llama responded to low quality roughage diets with low VFI, no improvement in digestibility but considerable improvement in the efficiency with which N was conserved. The mechanism of the improved N conservation needs to be studied in future work. On this basis goats, red deer, sambar deer (and probably other species of tropical deer) and South American camelids should all have the potential for animal production in areas of the world where forage quality is likely to be low for long periods of the year. Similar research to that conducted with red deer fed high quality forage

in NZ (Section 8) needs to be conducted with all the above species in their native environments, where low quality roughage is likely to be a major portion of the diet. Based upon data in Section 9, the potential for tropical deer farming in tropical countries must be good and the same can probably be said for the potential of antelope farming in Africa.

Animal production from forage diets does not have to be confined to ruminants. One of the best examples of a herbivore that is superbly adapted to its environment is the kangaroo family in Australia. Like venison, kangaroo meat is of low fat content and better meets the nutritional needs of today's human diet than do many cuts of lamb or beef (which have fat trimmed before sale). Farming of kangaroos in Australia and also tropical deer in the tropical countries is controversial with conservationists, who insist that the animals should not be moved from their native habitat. This restricts their farming potential. Changing the regulations, as was done for deer farming in NZ, to allow farming of tropical deer and kangaroos outside their normal habitat would allow new forms of livestock farming to develop and would in fact lead to a multiplication of the species, also fulfilling a conservation goal. The farming of alternative herbivores in many situations is therefore strongly linked to conservation policy; if new proposals are to succeed they will have to satisfy conservation goals as well as agricultural goals and at this time this is posing a dilemma, both for some developing and developed countries. It may be that this can only be solved by initially cropping animals such as tropical deer and antelopes in their native habitats, using a controlled killing policy that will ensure their sustainability. Once this has been shown to be both profitable and sustainable, then perhaps full scale farming will be considered, using higher animal densities/hectare and better nutrition than can be provided in the wild, thus giving much higher levels of meat output. The pathway of development could therefore have some similarities with the development of the NZ deer industry.

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LIST OF SUBMITTED PUBLISHED PAPERS

SECTION ONE

The effect of formaldehyde treatment on nitrogen utilisation by sheep fed forage conserved as hay or silage and upon voluntary feed intake, wool growth and body growth.

(Group 1)

Paper
No.

- 1 Barry, T.N. (1972). Effect of feeding formaldehyde treated casein to sheep on nitrogen retention and wool growth. New Zealand Journal of Agricultural Research 15: 107-116.
- 2 Barry, T.N. & Fennessy, P.F. (1972). Effect of formaldehyde treatment on the chemical composition and nutritive value of silage. I. Chemical composition. New Zealand Journal of Agricultural Research 15: 712-722.
- 3 Barry, T.N. & Fennessy, P.F. (1973). Effect of formaldehyde treatment on the chemical composition and nutritive value of silage. II. Digestibility of the silages and the chemical composition of rumen fluid in sheep supplemented or not supplemented with D-L-methionine. New Zealand Journal of Agricultural Research 16: 59-63.
- 4 Barry, T.N., Fennessy, P.F. & Duncan, S.J. (1973). Effect of formaldehyde treatment on the chemical composition and nutritive value of silage. III. Voluntary intake, live-weight gain and wool growth in sheep fed the silages with and without intraperitoneal supplementation with D-L-methionine. New Zealand Journal of Agricultural Research 16: 64-68.
- 5 Fennessy, P.F. & Barry, T.N. (1973). Identification and measurement of 2,3-Butanediol in silage. Journal of the Science and of Food of Agriculture 24: 643-648.
- 6 Barry, T.N. (1973). Effect of treatment with formaldehyde and intraperitoneal supplementation with D-L-methionine on the digestion and utilisation of a hay diet by sheep. I. Digestion of energy and nitrogen. New Zealand Journal of Agricultural Research 16: 185-189.
- 7 Barry, T.N. (1973). Effect of treatment with formaldehyde and intraperitoneal supplementation with D-L-methionine on the digestion and utilisation of a hay diet by sheep. II. Live-weight change and wool growth. New Zealand Journal of Agricultural Research 16: 191-196.

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- 11 Barry, T.N., Mundell, D.C., Wilkins, R.J. & Beaver, D.E. (1978). The influence of formic acid and formaldehyde additives and type of harvesting machine on the utilization of nitrogen in lucerne silages. II. Changes in amino-acid composition during ensiling and their influence on nutritive value. Journal of Agricultural Science, Cambridge 91: 717-725.
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(Group 2)

- 13 Barry, T.N. (1976). Effectiveness of formaldehyde treatment in protecting dietary protein from rumen microbial degradation. Proceedings of the Nutrition Society 35: 221-229.
- 14 Wilkinson, J.M., Wilson, R.F. & Barry, T.N. (1976). Factors affecting the nutritive value of silage. Outlook on Agriculture 9: 3-8.

SECTION TWO

Nutritional factors affecting the growth of lambs and cattle fed sole diets of forage kale (Brassica oleracea).

(Group 1)

- 15 Barry, T.N., McDonald, R.C. & Reid, T.C. (1981). Nutritional evaluation of kale (Brassica oleracea) diets. I. Growth of grazing lambs as affected by time after introduction to the crop, feed allowance and intraperitoneal amino acid supplementation. Journal of Agricultural Science, Cambridge 96: 257-267.

- 16 Barry, T.N., Reid, T.C., Millar, K.R. & Sadler, W.A. (1981). Nutritional evaluation of kale (*Brassica oleracea*) diets. II. Copper deficiency, thyroid function, and selenium status in young cattle and sheep fed kale for prolonged periods. Journal of Agricultural Science, Cambridge 96: 269-282.
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- 25 Barry, T.N., Manley, T.R., Redekopp, C. & Allsop, T.F. (1985). Endocrine regulation of metabolism in sheep given kale (*Brassica oleracea*) and ryegrass (*Lolium perenne*)-clover (*Trifolium repens*) fresh-forage diets. British Journal of Nutrition 54: 165-173.
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SECTION THREE

Protein digestion and metabolism in sheep fed fresh forages and their regulation by plant condensed tannins.

(Group 1)

27. Barry, T.N. (1981) Protein Metabolism in growing lambs fed on fresh ryegrass [Lolium perenne]-clover [Trifolium repens] pasture ad lib. 1. Protein and energy deposition in response to abomasal infusion of casein and methionine. British Journal of Nutrition 46: 521-532.
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SECTION FOUR

The effect of bound condensed tannins in cottonseed meal upon protein digestion in monogastric and ruminant animals.

(Group 1)

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SECTION FIVE

Selection for low leaf shear breaking load on the feeding value of perennial ryegrass for sheep.

(Group 1)

65. MacKinnon, B.W., Easton, H.S., Barry, T.N. and Sedcole, J.R. (1988) The effect of reduced leaf shear strength on the nutritive value of perennial ryegrass. Journal of Agricultural Science, Cambridge 111: 469-474.
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SECTION SIX

Studies in nutrient utilisation in sheep selected for high fleece weight or high fecundity.

(Group 1)

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SECTION SEVEN

Comparative nutrition of red deer, goats, llama and sheep fed forage diets.

(Group 1)

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81. Barry, T.N., Suttie, J.M., Milne, J.A. and Kay, R.N.B. (1991) Control of food intake in domesticated deer. In: Physiological Aspects of Digestion and Metabolism in Ruminants. Proceedings VII International Symposium of Ruminant Physiology. Ed. T. Tsuda, Y. Sasaki, and R. Kawashima pp. 385-401. Academic Press, San Diego.

SECTION EIGHT

Nutrition of farmed temperate red deer (Cervus elaphus) and the development of grazing systems for efficient venison production by one year of age.

(Group 1)

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SECTION NINE

Biology and nutrition of tropical sambar deer (Cervus unicolor)

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