RURAL INDUSTRIES RESEARCH
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Energy and protein requirements of fallow deer under a Mediterranean environment

A report for the
Rural Industries Research
and Development Corporation

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April 2004

RIRDC Publication No 02/110
RIRDC Project No SAR-21A

ISBN 0642 58509 1
ISSN 1440-6845

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Published in April 2004
Printed on environmentally friendly paper by Canprint

Foreword

The nutritional management of deer is a vital strategy for the deer industry to maximise its profitability. In southern Australia, the herbage availability for grazing deer fluctuates with the season, resulting in a low availability of feed in autumn and winter, a surplus of green feed in spring, and a dry feed period in summer/ autumn. The seasonal feed supply results in a significant variation in growth rate of deer. Supplementary feeding in summer and early winter is required to achieve economic production.

To develop an economic supplementary feeding strategy, research was undertaken to determine the seasonal variation in nutrient intake from pastures of grazing deer and the nutrient requirements of deer at various stages of production. The nutritive value of common feed ingredients were evaluated using sheep as a comparison and a supplementary feeding strategy investigated.

The experiments showed that deer had a similar digestibility to sheep for some feed ingredients but not others. Test tube (*in vitro*) methods (Tilley-Terry and NIR calibrations) showed reliability for predicting the nutritive value of pastures for deer, indicating the potential of developing a commercial feed assay service for the Industry. The forage intake and deer protein and energy requirements determined in this project will enable the development of least cost supplementary diets. The data obtained in this study can be immediately adopted by the deer farmers for the development of supplementary feeding and pasture management strategies during the season. This will ensure that southern Australia deer farmers are using cost effective feeding strategies to produce quality venison.

This project was funded from industry revenue which is matched by funds provided by the Federal Government and is an addition to RIRDC's diverse range of over 1000 research publications. It forms part of Deer R&D program, which aims to foster an Australian Deer Industry as a profitable, efficient mainstream agricultural enterprise.

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Simon Hearn
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Acknowledgments

The authors are grateful for the following support;

- Funding from the Rural Industries Research and Development Corporation.

- Dr Zhihong Miao and Mrs Sandy Wyatt (SARDI Livestock Systems) who trained the deer and conducted the animal house study. Mr Geoff Wyatt (SARDI-Livestock Systems) who constructed the stalls in the animal house.

- Mr Michael Fischer, Ms Kylee Swanson, Ms Sharon Falkenberg (SARDI-Livestock Systems) who conducted field trials and chemical analysis of pasture and faecal samples.

- Dr Mingan Choct and Mrs Shuyu Song from University of New England who analysed alkane concentration in pasture and faecal samples.

- Mr Jurek Kruk (SARDI-Livestock Systems) who developed NIR calibrations for predicting alkane concentration in pasture and faecal samples, *in vitro* digestibility and crude protein content in pastures.

- Mr Maurice Malycha, Mr Andrew Polkinghorne and Mr Ian Rice (Farm Services, University of Adelaide) for their assistance in deer management and maintenance of the research equipment on the Roseworthy Deer Industry Farm.

- Mr Doug Clarke (South Australian Deer Farm Association) who supplied the deer crush for the animal house research.

- Dr Shimin Liu (CSIRO, Livestock Industries) who advised on experimental design and data analysis.

- Mr Wukui Peng, visiting scholar from China, who assisted in deer husbandry and pasture evaluation for the grazing trial in 2001.

- Mr Chris Tuckwell for his valuable advice during the project.

Contents

Publications Arising from This Study

Miao, Z. H., P.C. Glatz, A. English and Y.J. Ru (2001).Managing red and fallow deer for animal house research- ANZCART December 2001.

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Ru, Y. J. and P. C. Glatz (2002). Energy requirements of 28-32 kg fallow weaner deer in southern Australia. *Asian-Australasian Journal of Animal Science* (in press).

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Executive Summary

The growth of weaner fallow deer in southern Australia is limited by the quality and quantity of pastures in autumn and low pasture availability in early winter. The understanding of nutrient requirements and seasonal feed supply is essential for the development of supplementary feeding strategies. A number of experiments were undertaken to 1) assess the nutritive value of feed ingredients commonly used by deer, 2) determine the protein and energy requirements of fallow weaner deer under southern Australian environments, 3) to estimate forage intake of grazing weaner deer during the season and 4) determine if sheep could be used as a model for predicting nutritive value of feed for deer.

Red weaner deer, fallow weaner deer and Merino sheep were housed in an animal house to compare the digestibility of 12 diets. The outcomes of this study showed no differences between sheep, red and fallow deer in digestibility of dry matter, organic matter and digestible energy content for all diets except for sorghum and medic hay. An *in vitro* study demonstrated that the Tilley-Terry method and near infrared spectroscopy (NIR) have potential as a rapid feed evaluation system for deer, but need further validation. The data on chemical composition and nutritive value of these feed ingredients can be used by nutritionists and deer farmers to formulate the supplementary diets based on the availability and price of these feed resources.

Quantifying the amount of nutrients deer can obtain from grazing pastures is essential so that deer farmers can determine the amount and the time that supplementary feeding is required during the season. Many methods can be used to estimate forage intake, including exclusion cages, chromium oxidate (Cr_2O_3) and differences pre and post grazing, but these methods can only be used to estimate the average intake. However, the recently developed method-the alkane technique, is used in sheep for estimating feed intake of individual animals and their diet composition. To assess the potential of using alkanes as a marker for predicting feed intake of fallow deer, the daily faecal recovery of alkanes and excretion rate of dosed artificial alkanes were measured. It was found that the while faecal recovery of natural alkanes is incomplete, the faecal concentrations of alkanes can be adjusted to provide an accurate estimation of intake. The outcomes of this experiment clearly show that the alkane technique can be used to measure feed intake under grazing conditions.

While the alkanes in plant materials can potentially be used as makers to estimate composition and digestibility of the diet of deer, the analysis of alkanes in plant materials and deer faeces is time consuming and expensive. In this study, the potential of using NIR to predict alkane content in faecal and pasture samples was assessed. NIR can be used to predict the content of most alkanes except for alkanes with chains of C_{24}, C_{26}, C_{32} and C_{36} in faecal samples and C_{24}, C_{25}, C_{26} and C_{36} in pasture samples. The use of these NIR calibrations will accelerate the estimation of diet digestibility, dietary components and botanical composition of pastures.

The determination of nutrient requirements of grazing fallow deer consisted of the measurement of forage intake of individual deer and the establishment of relationship between body weight gain and daily nutrient intake. The relationships between body weight gain and intake of metabolisable energy and crude protein were established using a general linear model. The crude protein, DE and DM intake from pastures increased from May to October and was influenced by the level of supplementation during early winter. The group with a lower supplementation had a higher forage intake. Female deer ingested less pastures than male deer, especially after August. There was a strong correlation between intake and sward height (cm). The digestible energy and crude protein requirements were strongly correlated with body weight gain. These data can be used to assist farmers to develop pasture and stock management practices under southern Australian conditions.

In practice, deer farmers need advice on the amount of supplementary feed and what type of feed should be offered to deer. An experiment was carried out to determine the feeding levels of fallow weaner deer from May to July, where nutrient supply from pasture was limiting. The results showed that the body weight was similar for low, medium and high feeding levels in April and May, although deer fed low levels had a lower live weight during July-October. Female deer grew slower than male deer, especially in September and October. Yearly variations in growth resulted from the different types of pastures used, indicating it is crucial for nutrient intake from pastures to be determined for developing supplementation strategies.

Three diets were formulated based on oats, oats-lupin and triticale. Supplementary diets were offered *ad libitum* from April to July. The predicted digestible energy and protein content were 13.5 MJ/kg, 10.8% for diet 1, 13.2 MJ/kg, 15.9% for diet 2, 13.5 MJ/kg and 10% for diet 3. The actual supplementary feed intake were 328, 423, 548 and 567 g/day in April, May, June and July, respectively. The feed intake was low, especially in April and May although feed was offered *ad libitum*, which was consistent with the previous observations. No difference in body weight was found during the season between the diets, but male deer grew faster than females, especially from August to October. The increase in protein level by including lupins in the diet based on oats did not improve the growth rate of weaner deer. Based on the cost and the final body weight in October, it is obvious that oats and triticale is more cost-effective than barley/lupin. The increase in energy concentration in the supplementary diet for the April/May period can be achieved by adding oil or tallow and will improve the growth performance of weaner.

The data obtained during this project can be immediately adopted by deer farmers to develop supplementary feeding and pasture management strategies during the season and will ensure quality venison is produced cost-effectively.

1. Introduction

1.1 Background to the Project

Feed supply and animal production under a Mediterranean environment

The Mediterranean environment is characterised by wet cold winters and hot, dry summers. The herbage availability for grazing deer under this environment fluctuates with the season. There is a low availability of green feed in autumn and winter, a surplus of green feed in spring, and a dry feed period in summer/autumn. The quality of herbage also varies with the season. Research with subterranean clover indicates that dry matter digestibility can be as high as 80% in winter and early spring, and as low as 40-50% in summer (Ru 1996). The decline of nutritive value of subterranean clover occurs mainly after initiation of flowering (Ru 1996). It has been well documented in a Mediterranean environment that the quantity of herbage in winter, quality of herbage in summer, and both quality and quantity of herbage in autumn are the key factors limiting animal production in a number of species.

The seasonal feed supply and pasture quality under Mediterranean environment results in a significant variation in animal production. For example, body weight gain for sheep was only 100 g/day in late winter and reached 250 g/day in spring. Supplementary feeding in early winter and summer is required to achieve economic production. While deer are similar to sheep in production under grazing conditions, they have an additional high supplementary feed requirement during summer (lactation). New Zealand research indicates that seasonal growth patterns in deer is dependent on the availability and quality of feed, with voluntary feed intake closely linked to photoperiod. Characteristically, feed intake is lowest in winter and highest in spring and summer (Mulley and Falepau 1997).

Seasonal nutrient demand by deer

There are very distinct seasonal nutrient demands by deer in southern Australia. Fallow deer start fawning in November and generally weaning occurs in March. To maximise returns to producers it is essential that weaners achieve a marketable liveweight (50 kg) as soon as possible (maximum 12 months). From November to March, nutrient supply is crucial for lactating deer which have a high nutrient requirement for milk production. The nutrition of lactating deer has a significant impact on milk yield and quality and liveweight of weaners. During March to July, young fawns are being weaned, and good quality feed is needed to reduce the post weaning stress.

To meet the nutrient requirements of grazing deer, supplementary feeding is often required to ensure they achieve maximum growth rate and meet market specification in the shortest period. Weaners which do not reach market specification in twelve months will need to be fed for another twelve months. This is also compounded by the sexual maturity of males, slow growth rates during winter and increasing demand on feed reserves. This results in significant financial losses to producers and the Australian deer industry.

Questions for deer farmers to resolve

Deer producers when trying to increase profit and remain viable are often confronted with a number of critical questions associated with feeding their deer.

1. When should I feed my deer?
2. What type of supplements should I feed? and
3. How much feed should be given as supplement to deer in order to maximise growth at the minimum cost?

Currently, supplementary feeding for deer production is a hit or miss strategy. It is commenced either at the incorrect time or is not meeting the animals requirements, resulting in significant additional costs to the producer. Most Australian deer farmers are still using data from New Zealand as a guideline for their practice. It needs to be pointed out that there are significant differences in environmental conditions between New Zealand and Australia. In New Zealand, especially in the North Island where considerable research has been done, rainfall is higher than that experienced in most areas of southern Australia. The green pasture is available all year-round and the temperature is mild. However, in southern Australia, there is a long dry, hot summer and the rainfall is mainly in winter. Furthermore, there is also variation in botanical composition of pastures, resulting in different nutrient intake by grazing animals with the season. Thus New Zealand data on deer nutrition may not be valid under the Mediterranean environments experienced in Australia. Anecdotal evidence suggests that this problem has already been experienced by deer farmers. For example, they have fed weaners a significantly lower energy than the level recommended for New Zealand, but still achieved the same live weight at 12 months.

In order to address the question, posed by RIRDC, "What does it take to finish to a target weight, within what time frame and at what cost" it is essential that information on the performance of fallow deer on different supplements and under different grazing conditions be established. Feed costs make up a significant component of any deer enterprise, not only supplementary feed but also pasture management and establishment. To develop a better economic supplementary feeding strategy and maximise the use of feed resource more effectively, deer farmers need to be able to access a large amount of information on:

- Nutrient requirements of fallow deer at various production levels,
- Seasonal variation in nutrient intake of grazing deer from pastures, and
- Nutritive value of the common pasture species and feed grains used by deer.

This collective information will allow deer producers to

- Develop feeding regimes for different growth rates
- Set target finishing weights and time frames
- Develop the most cost effective feed formulation to achieve pre set growth rates
- Be more confident of meeting market demands

To date this information has been unavailable to deer producers in a Mediterranean environment. This project will set benchmarks on the performance of fallow deer and common feeds which are presently being used by deer producers.

1.2 Project Objectives

- To monitor seasonal nutrient intake by deer under grazing conditions.
- To determine energy and protein requirements of fallow deer for growth under a Mediterranean environment.
- To develop strategies for supplementary feeding during summer and winter.
- To improve liveweight gain or reduce the time taken to reach target finishing liveweight by using cost-effective diet formulations based on the nutrient requirement of deer and nutritive value of feed ingredients.
- To disseminate research outcomes to deer farmers by the ALFI database, seminars, workshop and scientific publications.
- To improve deer farmers profitability by feeding more nutritionally sound diets.

2. Nutritive Value of Feed Ingredients for Red and Fallow Deer

2.1 Introduction

The Mediterranean environment in Australia is characterised by wet, cold winters and hot, dry summers. Seasonal herbage availability for grazing deer under this environment is characterised by a low quantity of herbage in early winter, and a poor quality and quantity of herbage in summer and autumn. Variation in the feed availability limits the potential of the fallow weaner deer to reach the market body weight (45-50 kg for males; 36-38 kg for females) by 12 months of age (Mulley and Falepau, 1997). Thus supplementary feeding is a common strategy used to improve the growth of weaners during summer, autumn and early winter.

To enable deer producers to use their feed resources more efficiently, it is essential to know the nutritive value of feed ingredients so that cost diets can be formulated, especially for common feed resources used in Australia. Currently most Australian deer farmers are using nutritive value determined in sheep as guidelines. The application of nutritive values of feeds determined by sheep for red deer feeding is questionable given red deer digest fibre better than sheep in summer (Francoise Domingue et al., 1991) and *in vitro* dry matter digestibility of some feed ingredients is higher in rusa deer compared to sheep (Latupeirissa and Dryden, 1998). The interaction between animal species and pasture species in digestibility was also reported by Milne et al. (1978). More importantly, it is well known that the determination of nutritive value of feed using deer is expensive and time-consuming due to the difficulty of handling deer. The establishment and validation of a rapid *in vitro* assay for digestibility estimation is required by the industry although these *in vitro* methods are available for other ruminants (sheep and cattle). The objectives of this study were to compare the *in vivo* and *in vitro* digestibility between these three species and to explore the potential of using an *in vitro* method to evaluate nutritive value of feed for deer.

2.2 Materials and Methods

2.2.1 In vivo experiment

Animals

Six fallow and 6 red deer (castrated male weaners), 8 months of age, were obtained from a commercial deer farm in South Australia. The average body weight was 28 kg (SD=1.51) for fallow deer and 64 kg (SD=1.79) for red deer. The deer were housed as a group in a 7 m x 7 m compound constructed in the middle of an animal house, with 1900 mm ring-lock fence strained 100 mm off the floor giving a 2 m high fence (Miao et al., 2001), in the Animal Research Centre at Roseworthy Campus located 60 km north of Adelaide and 10 km east of Gawler in South Australia.

After 2 months of training the deer to hand-feed using fresh lucerne and grains, the deer were transferred into individual stalls. The dimensions of the stalls were 1200 mm long x 1950 mm high x 900 mm wide for fallow deer and 1800 mm long and 1950 mm high x 1200 mm wide for red deer. Holes with a diameter of 100 mm were cut in the stalls to allow deer to view each other in the next stall to reduce fretting and fractious behaviour. The feeder was fixed on the door next to a 5L water bucket. To reduce the stress on deer associated with fitting and using collection bags, a faecal collection net was placed underneath each individual stall, similar to the faeces collector used in metabolic cages for sheep.

Six Merino wethers, 12 months of age, were sourced from Farm Services, Adelaide University, Roseworthy and housed in individual pens. The average body weight for sheep was 62 kg (SD=1.51). Sheep were fed lucerne chaff for 3 weeks while acclimatising to the animal house environment. Three days before the commencement of the experiment, all sheep were fitted with faecal collection bags.

Experimental diets

The *in vivo* experiment was conducted over two periods. In each period, 6 diets (Table 2.1) were tested using a 6×6 Latin Square design. Feed ingredients evaluated included grains (barley, wheat, sorghum, oats and lupin), straw (barley straw and pea straw) and hays (lucerne chaff, oaten chaff, wheaten chaff and medic hay). The experimental diets were fed *ad libitum* for two weeks, followed by a week of total faecal collection. Water was available at all times. Faeces were collected daily and 10% of the total weight were sub-sampled and dried at 60^{o}C. Hair in the faeces was removed manually. Feed residues were collected and weighed daily, and subsampled for chemical analyses.

Table 2.1. Experimental diet composition for *in vivo* study in animal house (g)

		Period 1					Period 2		
Diet No.	Ingredient	Fallow	Red	Sheep	Diet No.	Ingredient	Fallow	Red	Sheep
1	Lucerne hay	1000	1800	1600	7	Lucerne hay	1400	2200	1600
	Mineral	10	10	10		Mineral	10	10	10
2	Lucerne hay	300	540	480	8	Lucerne hay	1120	1760	1280
	Wheaten hay	700	1260	1120		Barley grain	280	440	320
	Mineral	10	10	10		Mineral	10	10	10
3	Lucerne hay	300	540	480	9	Lucerne hay	1120	1760	1280
	Oaten hay	700	1260	1120		Wheat grain	280	440	320
	Mineral	10	10	10		Mineral	10	10	10
4	Medic hay	1000	1800	1600	10	Lucerne hay	1120	1760	1280
	Mineral	10	10	10		Oat grain	280	440	320
						Mineral	10	10	10
5	Lucerne hay	400	700	600	11	Oaten hay	1120	1760	1280
	Barley straw	400	700	600		Lupin	280	440	320
	Mineral	10	10	10		Mineral	10	10	10
6	Lucerne hay	400	700	600	12	Lucerne hay	1120	1760	1280
	Pea straw	400	700	600		Sorghum grain	280	440	320
	Mineral	10	10	10		Mineral	10	10	10

Dry matter, ash and crude protein of feed and faeces were determined using standard methods (AOAC, 1980). Gross energy (GE) was measured using a Parr 1261 Adiabatic Bomb Calorimeter. Chemical composition of individual feed ingredients is listed in Table 2.2. The digestibility of individual ingredients was calculated using the following equation:

a=(v-b*p)/(1-p) (Charmley and Greenhalgh, 1987)

where a is the coefficient for the unknown feed ingredient, b is the coefficient for the ingredient with a known digestibility, v is digestibility of the diet, and p is the proportion in the diet of the ingredient with a known digestibility.

Table 2.2. Chemical composition of feed ingredients (air dry basis)

Ingredient	Dry Matter (%)	Organic matter (%)	Gross Energy (MJ/Kg)	Crude Protein (%)	Crude Fibre (%)
Barley	88.80	86.64	16.45	10.82	5.04
Sorghum	88.65	87.06	16.65	10.76	1.78
Oats	90.71	88.33	17.88	10.06	12.62
Wheat	88.94	87.38	16.49	11.79	3.46
Lupin	92.52	89.98	18.58	31.82	17.25
Lucerne hay	87.63	78.51	16.21	16.44	26.41
Medic hay	89.10	80.93	16.20	14.38	28.32
Wheaten hay	88.48	82.74	16.51	7.66	31.98
Oaten hay	88.19	83.60	16.57	6.78	24.89
Barley straw	90.22	80.15	15.58	3.79	35.91
Pea straw	89.74	84.07	16.45	6.06	45.42

2.2.2 In vitro experiment

Animals and feeds

Three fallow deer, 3 red deer (male, 8-10 months of age) and 3 Merino wethers were obtained from Farm Services, Adelaide University, Roseworthy Campus. All deer were held in a paddock at the Deer Farm on Roseworthy Campus, and 3 sheep were housed in the Animal House at Roseworthy Campus. Deer and sheep were fed a basic diet consisting of 50% lucerne chaff and 50% oaten chaff. During November, December and January, 1 sheep, 1 red and 1 fallow deer were slaughtered and the rumen fluid collected for *in vitro* digestibility estimation. CO_2 was passed through the rumen fluid to maintain anaerobic conditions and the container was sealed and kept in the water bath at 39 ^oC before adding to the incubation tubes. The time from collection to completion of the inoculation process was less than 2 hours as recommended by Schwartz and Nagy (1972). All feed samples tested in the *in vivo* experiment were milled through a 1 mm screen.

In vitro measurement

The *in vitro* dry matter digestibility (DMD) and digestible energy (DE) content was determined using the Tilley-Terry method (Tilley and Terry, 1963). In brief, a sample of the feed (0.5 g) was weighed into incubating tubes and 10 ml of rumen fluid and 40 ml of buffer (pH=5.8) were added. Tubes were flushed with CO_2 and capped immediately. Ten replicates of each sample were incubated in a shaking water bath at 39 ^oC for 48 hours. After the samples were centrifuged at 3000 rpm for 15 min. and washed with distilled water, 50 ml of pepsin solution was added to each tube and incubated for another 48 hours at 39 ^oC. After incubation, the samples were centrifuged (3000 rpm) and the residues dried at 60 ^oC over night. Dry matter and gross energy in the residue were determined using the standard procedure (AOAC 1980). In each batch, a quality control lucerne sample of known *in vivo* digestibility and DE content was included to correct the *in vitro* measurement.

2.2.3 Statistics

The *in vitro* experiment was a Latin square design. Main effects (diet, animal species and interaction) were analysed using a general linear model from Systat software (Wilkinson et al., 1996). Data from the *in vitro* experiment was analysed using ANOVA to compare the difference between animal species for each feed ingredient. The relationship between *in vitro* and *in vivo* measurements was tested using the regression procedure in Systat.

2.3 Results

There were no differences ($p>0.05$) between sheep, red and fallow deer in digestibility of dry matter, organic matter and DE content for all diets except for the sorghum diet and medic hay (Table 2.3). Sheep and fallow deer had a higher digestibility ($p<0.05$) for the sorghum diet than red deer. Sheep had a higher digestibility ($p<0.05$) of crude protein than deer for medic hay.

Overall, sheep had a lower *in vitro* DMD (52%) and DE (9.5 MJ/kg) than both red and fallow deer, with average values for deer being 60% and 10.5 MJ/kg, respectively. However, there was significant interaction between animal species and feed ingredient (Table 2.4). In particular, there were no differences ($p>0.05$) in *in vitro* DMD and DE of lucerne chaff and medic hay between sheep, red and fallow deer, but deer digested straws and hays better than sheep ($p<0.05$). Sheep had a lower *in vitro* DMD and DE of barley, sorghum and wheat grains. The DE content of lupin was higher ($p<0.001$) for sheep than deer.

There were significant differences ($p<0.05$) between *in vivo* and *in vitro* DMD or DE content (Table 2.5). The magnitude of the difference was higher for sheep than deer. For example, *in vitro* DMD was 10-12% units higher than *in vivo* DMD for deer and 19% units higher for sheep for all feed ingredients tested, with a similar trend for DE. The difference between *in vivo* and *in vitro* values were more obvious for grain samples than straw or hay samples (Table 2.5).

The simple regression analysis showed that *in vitro* DMD and DE content were correlated ($R^2>0.5$) with the *in vivo* DMD and DE, respectively, for both red and fallow deer when the data for all ingredients or hays/straws were pooled for analysis. However, the correlations between these parameters were poor for sheep (Table 2.6). When data for straw and hay samples were analysed, the correlation between *in vivo* and *in vitro* DMD or DE were not significant ($p>0.05$) for fallow deer, but significant ($p<0.05$) for sheep.

Assuming that the nutritive value of ingredients is additive, the digestibility of dry matter, organic matter and the content of digestible energy of individual feed ingredients was calculated. The chemical composition and nutritive value of these ingredients are listed in Table 2.7. Among the grains, it is obvious that oats and sorghum are good energy sources for deer, but the observation in the animal house indicates that the palatability of sorghum is not as good as oats. Of the straws, pea straw has a relatively high protein content compared with barley straw, but both straws are poor nutrient sources. Medic hay is as good as lucerne hay in terms of the content of digestible energy and crude protein. This is important information for southern Australian deer farmers where lucerne hay is extremely expensive.

Table 2.3. Nutrient digestibility of the diets by sheep (12 months old wether), red and fallow deer (8 months old weaners) measured using total faecal collection

	Dry matter (%)					Crude protein (%)					Digestible energy (MJ/kg)				
Diet No.	Fallow	Red	Sheep	s.e.m.	P value	Fallow	Red	Sheep	s.e.m.	P value	Fallow	Red	Sheep	s.e.m.	P value
						Period 1									
1	64.3	65.8	64.0	1.09	0.470	74.7	74.7	76.1	0.88	0.429	10.2	10.3	10.1	0.18	0.610
2	58.2	59.5	59.8	0.89	0.516	67.7	67.4	68.4	0.83	0.666	9.4	9.6	9.5	0.15	0.777
3	60.7	62.1	63.3	1.22	0.355	64.4	64.6	67.5	1.52	0.298	9.9	10.0	10.2	0.20	0.663
4	60.1	61.3	62.9	1.07	0.221	67.9b	68.7b	71.4a	0.76	0.012	9.4	9.6	9.8	0.17	0.230
5	58.8	60.7	58.8	1.08	0.355	69.5	67.2	68.5	0.92	0.230	9.1	9.3	9.0	0.19	0.439
6	55.6	60.1	57.5	1.22	0.065	66.0	67.5	68.9	1.11	0.216	8.8	9.4	9.2	0.18	0.073
						Period 2									
7	66.4	63.9	62.8	1.89	0.399	77.1	73.9	74.2	1.39	0.217	10.5	10.0	9.9	0.32	0.391
8	65.0	68.2	68.8	1.79	0.335	73.8	74.1	75.9	2.03	0.739	10.3	10.8	11.0	0.32	0.325
9	69.3	70.9	69.7	1.28	0.688	77.7	76.1	76.4	1.35	0.687	11.0	11.3	11.1	0.23	0.698
10	68.1	69.5	70.2	1.64	0.689	79.3	76.4	79.3	1.52	0.332	11.2	11.3	11.5	0.30	0.752
11	57.7	62.5	55.2	2.64	0.175	52.8	64.7	60.0	3.23	0.050	10.1	10.6	9.4	0.47	0.225
12	74.2a	70.8b	76.0a	1.16	0.018	79.9a	74.5b	80.5a	1.08	0.002	11.9a	11.2b	12.3a	0.21	0.009

Values followed with different letters within each chemical component are different between animal species at P=0.05; s.e.m.= standard error of means

Table 2.4. Dry matter digestibility and digestible energy content in feed ingredients for sheep, red and fallow deer measured using an *in vitro* method (data were corrected using the *in vivo* data for lucerne chaff)

Ingredient	Dry matter digestibility (%)					Digestible energy content (MJ/kg)				
	Fallow	Red	Sheep	s.e.m.	P-value	Fallow	Red	Sheep	s.e.m.	P-value
Forages										
Barley straw	40.0a	35.2b	31.3c	0.56	0.001	6.6a	5.6b	4.7c	0.12	0.001
Lucerne	64.5	65.4	64.0	0.64	0.278	10.3	10.2	10.1	0.13	0.486
Medic hay	58.7	58.5	59.6	0.79	0.549	9.4	9.2	9.6	0.16	0.099
Oaten hay	47.5ab	50.0b	45.2a	1.07	0.005	8.2a	8.5a	7.7b	0.18	0.017
Pea straw	44.0a	48.6a	37.7b	1.59	0.001	7.3a	8.2a	5.9b	0.19	0.001
Wheaten hay	42.8a	42.4a	38.1b	0.96	0.001	7.7a	7.5a	6.5b	0.18	0.000
Grains										
Barley	72.0a	71.5a	55.6b	0.77	0.000	12.2a	12.4a	10.0b	0.16	0.000
Lupins	74.2a	76.3b	75.4ab	0.64	0.107	14.0a	14.4b	15.5c	0.11	0.000
Oats	65.3a	56.6b	50.3c	0.86	0.000	11.8a	10.2b	10.0b	0.20	0.001
Sorghum	60.1a	61.6a	46.7b	1.00	0.003	10.8a	11.2a	8.7b	0.21	0.001
Wheat	70.3a	67.2b	54.5c	0.91	0.001	12.0a	11.7a	10.0b	0.18	0.001

Values followed with different letters for each ingredient are different between animal species at P=0.05 for dry matter digestibility or digestible energy content;
s.e.m.= standard error of means

Table 2.5. Comparison of *in vivo* and *in vitro* dry matter digestibility (DMD) and digestible energy (DE) content of grains, hays and straws for sheep, red and fallow deer

Method	DMD (%)			DE (MJ/kg)		
	Fallow	Red	Sheep	Fallow	Red	Sheep
			All ingredients			
In vivo	68.4	70.4	70.2	11.3	11.6	11.6
In vitro	58.1	57.6	50.8	10.0	9.9	9.0
T test	3.335	4.038	3.845	2.873	3.634	3.229
P value	0.008	0.002	0.003	0.017	0.005	0.009
			Hays/straws			
In vivo	56.0	58.0	58.1	9.0	9.3	9.3
In vitro	49.6	50.0	46.0	8.2	8.2	7.4
T test	2.561	2.571	3.335	2.103	2.668	3.287
P value	0.050	0.050	0.021	0.089	0.044	0.022
			Grains			
In vivo	83.3	85.2	84.7	14.1	14.3	14.4
In vitro	68.4	66.6	56.5	12.2	12.0	10.8
T test	2.596	3.667	3.058	2.237	2.824	2.127
P value	0.060	0.021	0.038	0.089	0.048	0.101

Table 2.6. Correlations for *in vitro* and *in vivo* dry matter digestibility (DMD) and digestible energy (DE) content of feed ingredients for red and fallow deer

Method	DMD			DE		
	Fallow	Red	Sheep	Fallow	Red	Sheep
			All ingredients			
Constant	12.990	20.953	49.843	1.251	2.569	6.590
Coefficient	0.953	0.859	0.401	1.004	0.910	0.557
R^2	0.579	0.521	0.107	0.725	0.690	0.316
T test	3.515	3.126	1.034	4.866	4.473	2.039
P value	0.007	0.012	0.326	0.001	0.002	0.072
n	11	11	11	11	11	11
			Hays/straws			
Constant	30.250	38.811	40.876	3.909	5.786	6.230
Coefficient	0.519	0.381	0.374	0.619	0.428	0.411
R^2	0.625	0.555	0.670	0.587	0.675	0.698
T test	2.582	2.233	2.849	2.386	2.884	3.038
P value	0.061	0.089	0.046	0.076	0.045	0.038
n	6	6	6	6	6	6

Table 2.7. Nutritive value of feed ingredients for red and fallow deer

	DMD (%)		OMD (%)		DE (MJ/kg)	
	Fallow	Red	Fallow	Red	Fallow	Red
Grains						
Barley	80.9	85.0	82.1	85.6	12.9	13.6
Lupin	71.8	77.9	75.2	80.1	13.6	14.4
Oats	84.9	86.6	85.5	87.0	14.9	15.1
Sorghum	92.4	88.2	93.2	88.5	15.1	14.3
Wheat	86.3	88.4	87.3	89.1	13.8	14.2
Hays						
Lucerne	64.3	65.8	64.9	66.1	10.2	10.3
Lucerne-A	66.4	63.9	66.7	64.1	10.5	10.0
Medics	59.8	61.1	60.3	61.3	9.4	9.6
Oaten hay	58.5	60.3	60.0	61.2	9.9	9.9
Wheaten hay	54.6	56.3	55.7	57.1	9.2	9.3
Straws						
Pea straw	45.7	50.1	46.5	51.3	7.3	8.4
Barley straw	53.1	54.4	na	54.5	8.0	8.3

DMD: dry matter digestibility; OMD: organic matter digestibility; DE: digestible energy content (air dry basis); na: not available.

2.4 Discussion

2.4.1 *In vivo* digestibility

The outcome of the *in vivo* experiment confirms the difference in digestion between sheep and deer. However, the interaction between animal species and feed ingredient make it difficult to generalise the digestion capability of sheep and deer, suggesting that the digestibility data for sheep cannot be applied to deer for all ingredients. Such interactions have also been reported by other researchers. For example, Palmer and Cowan (1979) found no difference between sheep and white-tailed deer in the digestibility of protein, fibre and energy although the DMD was higher for sheep than deer fed on lucerne chaff. Likewise Milne et al. (1976, 1978) reported sheep digested the *Agrostis-Festuca spp*. better than red deer, while red deer digested the *Calluna vulgaris* better than sheep. These differences in digestibility between sheep and deer can be explained by a number of factors including rate of passage of digesta, structure of the digestive tract, chemical composition of feed and recycling of urea.

Most researchers believe the lower digestibility in feed by red deer is due to the faster rate of hay passage through the digestive tract of deer compared with sheep (Grimes, 1968; Palmer and Cowan, 1979; Milne et al., 1976), but other dietary factors and the difference in the structure of digestion tract may also contribute to the interaction observed between animal species and feed ingredient. For instance, Francoise Domingue et al. (1991) and Fennessy et al. (1980) found deer can digest fibre, especially lignin, better than sheep. Milne et al. (1978) showed red deer had a high digestibility on pasture with a high lignin content (19-21% on DM basis) in comparison with low lignin pasture (4.4% on DM basis), probably due to the rapid fermentation and brief retention of digesta of deer associated with deer having a shorter small intestine than sheep. The large caeco-

colon of deer may also contribute significantly to the improved fibre digestion, but the rumen capacity in comparison with colon is relatively low for deer than sheep, with a colon:rumen capacity of 1:14-15 for red and fallow deer and 1:27-30 for sheep (Hofmann, 1985). This suggests deer might digest feed better than sheep, depending on the fibre content of the pasture and the quality of feed ingested by deer. Under grazing condition, the better conversion of pastures may also be associated with a higher quality of pasture ingested by deer which are more selective graziers than sheep.

The high digestibility of crude protein by sheep fed medics is difficult to explain. However, it has been confirmed that white-tailed deer can recycle more urea than sheep or cattle and the recycled urea in the lower digestive tract cannot be completely reabsorbed, resulting in a higher metabolic faecal nitrogen estimate (Robbins et al., 1974). It is not clear whether the low protein digestibility of deer is associated with the formation of tannin-protein complexes known to increase the nitrogen excretion through faeces (Nishimuta et al., 1973).

The similar digestibility of red and fallow deer was expected given their similar fermentation capability. Red and fallow deer have a similar ratio of small and large intestines, colon and rumen capacity (Hofmann, 1985), and there is no difference in weight ratios of different stomach compartments relative to live weight between red and fallow deer (Nagy and Regelin, 1975)

2.4.2 *In vitro* digestibility

Sheep had the lowest digestibility for all straws and hays except for legume pastures. This is not surprising as the *in vivo* studies indicate that deer can digest fibre, especially lignin, better than sheep (Francoise Domingue et al., 1991; Fennessy et al., 1980). While some of the difference in *in vivo* digestibility result from the difference in the structure of digestive tract, the *in vitro* results can only be attributed to the bacterial activity as the feed samples were incubated under the same conditions and the same diet was fed to animals before the rumen fluid was sampled. This experiment suggests the *in vitro* data from sheep might not be a reliable indicator for deer and an *in vitro* system for deer is required to develop a rapid feed evaluation system.

The *in vitro* DMD and DE were lower than *in vivo* values, but the *in vitro* and *in vivo* data overall was significantly correlated as found in sheep (Miao et al., 1991). The high *in vivo* digestibility is often expected because the digestion is a function of physical and biochemical activities involving in mastication, rumination and contraction of digestion tract and the influence of multiple enzymes in the digestion tract. However, the *in vitro* system used in the current experiment only involves a single enzyme (pepsin) although the incubation tubes were shaken continuously.

Other factors contributing to the lower *in vitro* digestibility includes buffer pH, the type of basic diets fed to animals for supplying rumen fluid, and the quality of feed samples for testing. Burbank et al. (1979) found that the *in vitro* digestibility was lower in the system buffered at pH 5.6, compared to pH 7.0. The pH of rumen flora of deer (white-tailed deer) can vary from 5.1 to 6.5 depending on the type of pastures, seasons and the individual deer. The variation in pH of rumen fluid and the extent of the fermentation of the samples governed by the chemical composition of the feed, especially carbohydrate make it difficult to incubate the sample at an optimum pH throughout the process.

The type of basic diet can also influence the *in vitro* digestibility measurement through changing pH of rumen fluid. For example, Robbins et al. (1975) reported that the *in vitro* DMD was close to the *in vivo* value for alfalfa and commercial rations when using the inocula from deer fed on lucerne. However, if the inocula was sampled from deer fed a commercial diet, the *in vitro* digestibility was

lower than the *in vivo* value for commercial diet. Thus McCullough, (1979) suggested ideally the basic diet should be similar to the test diet. To meet this ideal situation, the animals have to be fed a diet based on the test feed for a period before sampling rumen fluid. This is not practical as the objective of the *in vitro* system is to estimate nutritive value of feed rapidly. More importantly a large number of samples can be tested in a single batch, which means that the pH is optimised for some samples, but not others.

The quality of pastures might contribute to the low digestibility of straws and hays. The results of this study showed the *in vitro* digestibility of lucerne and medics is higher than other samples and similar to the *in vivo* data without significant difference between animal species, probably due to the high protein content and/or carbohydrates in legume pastures. McCullough (1979) demonstrated that addition of urea and/or starch increased the *in vitro* dry matter digestibility, with the effect being dependent on the quality of the herbage tested.

2.4.3 Relationship between *in vivo* and *in vitro* digestibility

The relationship between *in vitro* and *in vivo* data for deer indicates a potential of predicting feed digestibility using a rapid and inexpensive *in vitro* system. To develop a commercial service for the deer industry, it is recommended more samples be analysed and incorporated into the system to further validate the *in vitro* system which would allow deer farmers to adjust their feeding strategy quickly to meet the nutrient requirements for grazing deer. Because of the difficulty of maintaining deer with rumen fistula, the development of calibrations for near infra-red spectrophotometer (NIR) for the prediction of nutritive value of feed (an approach used for sheep and cattle industries) would be an ideal option.

2.5 Conclusion

In conclusion, there are differences in the *in vivo* digestibility between sheep and deer, depending on the type of feed ingredients. The *in vitro* system shows some potential for developing a rapid feed evaluation service for the deer industry. However, more samples need to be tested to validate the system. Due to the difficulty of deer handling, an NIR calibration, which is used commercially in the sheep and cattle industries, may be an ideal option in the future.

The data derived from this study on chemical composition and nutritive value of feed ingredients (Table 2.2 and 2.7) can be used to develop the supplementary diets for red and fallow deer to match their nutrient requirements during the season. It should be noted that energy value of feeds is expressed as digestible energy because we did not measure metabolisable energy due to the difficulty of urea collection from deer. However, most researchers and farmers are using metabolisable energy. In practice, digestible energy can be converted to metabolisable energy by a factor of 0.81 which is recommended for ruminants by ARC (1980).

3. Predicting Feed Intake of Fallow Deer (*Dama Dama*) Using Alkanes as a Marker

3.1 Introduction

Under a Mediterranean environment, the quantity of herbage in winter, quality of herbage in summer, and both quality and quantity of herbage in autumn are the key factors limiting deer growth. With current farming systems, deer producers often have to supplement hay or feed grains to ensure weaners reach market body weight at the end of the season. The current method of supplementary feeding of deer is a hit or miss strategy due to lack of knowledge of the seasonal feed intake and nutrient requirement of deer. To enable farmers to match the nutrient requirement with feed supply, it is essential to determine the nutrient intake that deer obtain from grazing during the season.

There are a number of methods used for estimating feed intake of ruminants while grazing. For example, exclusion cages have been used for measuring feed intake of sheep although this method cannot predict intake of individual animals. Chromium oxide has been used as an external marker to estimate individual forage intake for both grazing sheep and deer (Kusmartono et al., 1996). However, this method requires a digestibility value of the herbage for calculating feed intake.

Plant alkanes have been studied extensively as a marker for estimating feed intake of grazing sheep. N-alkanes are long-chain (C_{25-35}) hydrocarbons, predominantly with odd-numbered carbon chains, which occur in the cuticular wax of most plant materials. Dove and Moore (1995) and Dove and Mayes (1996) showed that feed intake, diet composition and supplementary feed intake of individual animals can be estimated from the pattern of alkanes in each component of the diet and the faeces. With the wide adoption of this method, a commercial alkane capsule has been developed for sheep. However, there has been no attempt to assess the potential of using the alkane technique to predict feed intake of selective grazing ruminants like deer. It is critical to determine the recovery of the marker from the faeces before n-alkanes can be used to measure feed intake and diet composition of deer under grazing condition. The objective of this experiment was to evaluate the potential of using alkanes to measure feed intake of fallow deer by measuring the faecal output of artificial and natural alkanes after dosing deer with alkane capsules.

3.2 Materials and Methods

3.2.1 Animals and housing

Nine male fallow deer (weaners), 8 months of age, were obtained from a commercial deer farm in South Australia. The average body weight was 26 kg. The deer were housed as a group in a 7 m x 7 m compound constructed in the middle of an animal house, with 1900 mm ring-lock fence strained 100 mm off the floor giving a 2 m high fence (Miao et al., 2001), in the Animal Research Centre at Roseworthy Campus, 60 km north of Adelaide and 10 km east of Gawler in South Australia.

After 2 months of training of the deer by hand-feeding of fresh lucerne or grains, 6 weaner deer were transferred into individual stalls with dimensions of 1200 mm long x 1950 mm high x 900 mm wide. Holes with a diameter of 100 mm were cut in the stalls to allow deer to view each other in the next stall and reduce factious behaviour. The feeder was fixed on the door with the water bucket next to the feeder. To reduce the stress on deer from fitting and using collection bags, a faecal collection net

was placed underneath each individual stall, similar to the faeces collector used in metabolic cages for sheep.

3.2.2. Feeding and faeces collection

The animals were fed the diet described in 2.2. Once the deer were housed in the individual stalls, artificial alkane capsules (produced by Captec Pty Ltd) were dosed via the oesophagus. The deer were fed *ad libitum* and water was available at all times. Faeces were collected daily (9:00 am) for 24 days from day one after dosing. Hair was removed manually from the faeces and 10% of the faeces were subsampled and freeze dried. All samples were milled through a 1 mm screen for alkane analysis. Daily feed intake was measured for 5 days between day 15 and 19 after dosing capsules to enable prediction of the daily feed intake. The alkane concentration in the faecal and pasture samples was analysed using a modified method of Dove and Combe (1992). To a dry sample of 100-500 mg, an appropriate amount (50-200 mg) of internal standard ($C_{34}H_{70}$ in dodecane) was added. The samples were then subjected to 1.5M ethanolic KOH in a heating-block at 90^{o}C for 1 hour with stirring. After cooling, the hydrocarbons were extracted in n-hexane several times, filtered, purified and quantified by gas chromatography. The recovery of alkanes was calculated based on total intake and faecal output of alkanes.

3.2.3 Calculation of feed intake

Feed intake was calculated using Eatwhat® software developed by Dove and Moore (1995). This software uses a least-squares optimisation procedure. An unresolved issue for this approach is the extent to which different alkanes might have different weightings in determining the feed intake in the mathematical equation. To attempt to solve this issue, the alkane concentrations in faeces and pastures were adjusted by multiplying a correction factor which was calculated as follows using C_{29} as an example;

Correction factor for C_{29}= Average (C_{29} for deer 1, 2…6)/Sum (C_{25}, C_{26}, C_{27}, …C_{33}). The sums of all correction factors for alkanes used for the prediction of feed intake should be 1.0.

3.3 Results

The alkane concentrations (C_{32} and C_{36}) in the faeces were stable from day 7 - 19 after dosing (Figure 3.1). Fallow deer excreted about 40 mg C_{32} and 37 mg C_{36} of alkanes daily during this period. After day 19, the concentration of alkanes in the faeces dropped rapidly.

The faecal recovery of alkanes was incomplete. The recovery of alkanes for all diets ranged from 43% to 89%. The recovery of alkane C_{31} was 2% units lower than for C_{29} and 6% units lower than for C_{33}, but the recoveries of natural alkanes tended to increase with the increase in carbon-chain length (Table 3.1). The variation in the faecal recovery of alkanes between diets was not evaluated due to the limited number of animals per diet.

There was no difference ($P>0.05$) between predicted and actual total feed intake and the intake of lucerne chaff in the diet (Table 3.2). The actual intake was strongly correlated with the predicted intake using alkanes as a marker (Figure 3.2, $R^2 = 0.52$, $P<0.05$ and Figure 3, $R^2 = 0.96$, $P<0.01$). More importantly, the weighting procedure used in this study did not improve the accuracy of the prediction of feed intake.

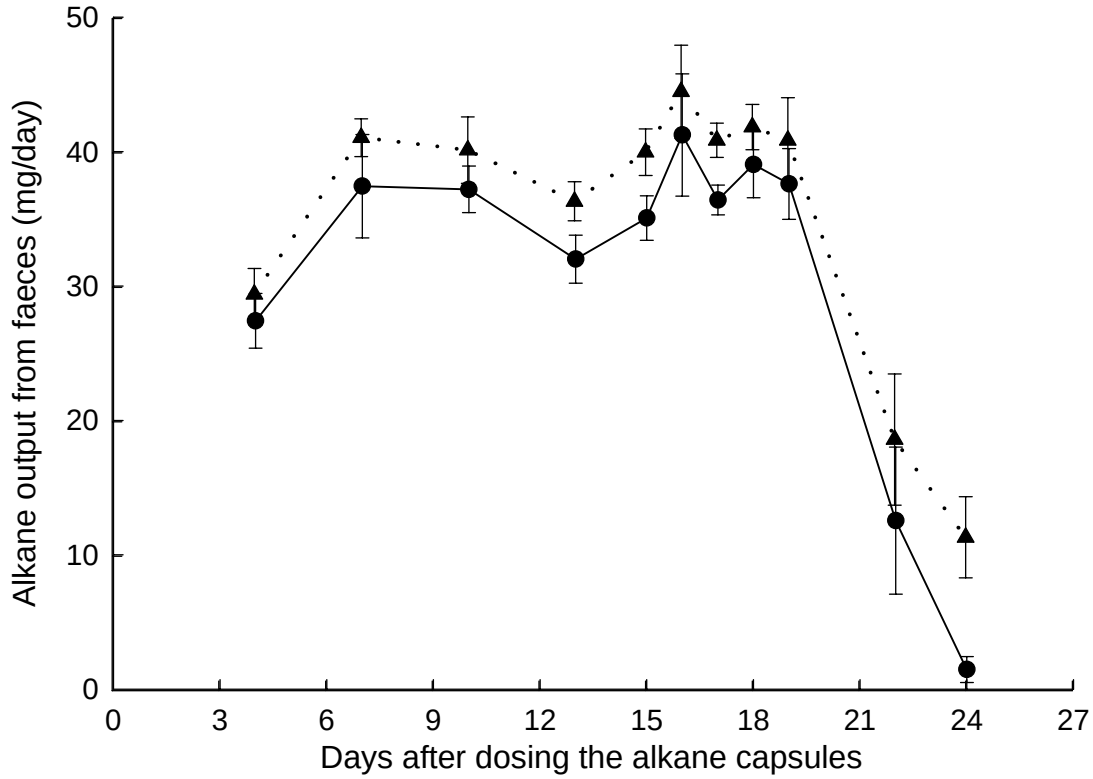

Figure 3.1. Daily output of alkane C_{32} (□) and C_{36} (□) from faeces of fallow deer after dosing alkane capsule (error bars are standard error)

Table 3.1. The faecal recovery of alkanes in plant materials by fallow deer

Alkanes	Means (n=6)	SE
C_{25}	0.427	0.031
C_{27}	0.625	0.026
C_{28}	0.817	0.085
C_{29}	0.845	0.024
C_{31}	0.822	0.038
C_{33}	0.886	0.030

SE = standard error

Table 3.2. Actual feed intake and estimated intake using the alkane technique over 5 days for deer of 8 months of age

Composition	Mean intake (kg DM/day)	SE
Predicted intake without weighting		
Other feed	0.464	0.058
Lucerne	0.354	0.058
Total	0.818	0.030
Predicted intake with weighting		
Other feed	0.483	0.062
Lucerne	0.342	0.060
Total	0.825	0.031
Actutally measured feed intake		
Other feed	0.425	0.054
Lucerne	0.394	0.057
Total	0.819	0.025

SE = standard error; DM = dry matter

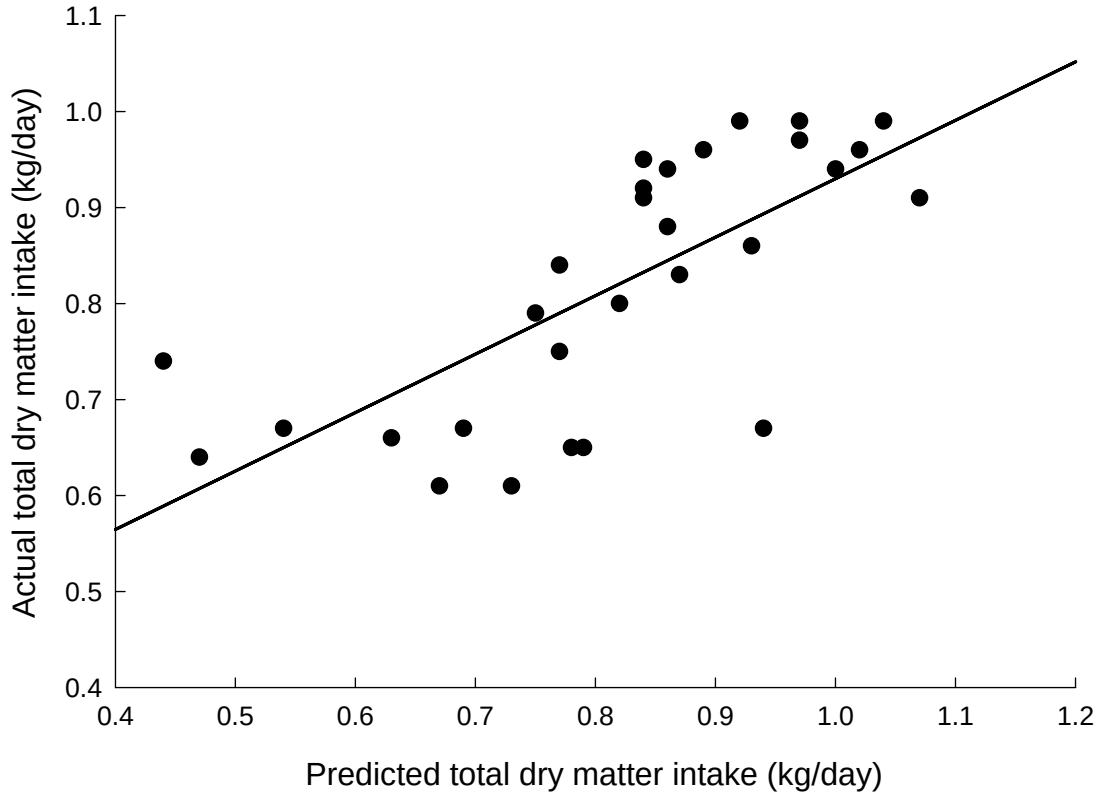

Figure 3.2. The relationship between actual total dry matter intake and the intake estimated using n-alkanes as a marker of fallow deer fed diets mixed with different proportions of lucerne chaff (Y=0.32+0.61X, R^2 = 0.52, P<0.05)

3.4 Discussion

This research has demonstrated that n-alkanes can be used as a marker to estimate feed intake of deer. The commercial alkane capsules designed for sheep are suitable for deer, although deer showed different rates of release of alkanes (C_{32} and C_{36}) when compared with sheep as suggested in the use instruction by Captec Pty Ltd. Nevertheless, the excretion pattern of alkanes are similar for deer and sheep, indicated by the stable concentration over day 7 - 19 after dosing. This suggests that the faecal samples need to be taken regularly during this period for estimation of intake. Deer are more difficult to handle than sheep and it is suggested faecal samples be taken 3-4 times during this period to provide a minimum amount of dry material for chemical analyses.

It should be noted that deer excrete only 40 mg C_{32} and 37 mg C_{36} alkanes daily, which is significantly lower than the values recommended by the capsule manufacturer for sheep (50 mg/day for both C_{32} and C_{36} alkanes). This discrepancy may be associated with difference in metabolism between the animal species. However, the result is similar to that reported by Dove et al. (1991) where the alkane release rates in sheep were 40.06 mg/day and 41.77 mg/day for C_{28} and C_{32}, respectively. In practice, these values should be used to estimate daily faeces output of deer instead of the recommended values reported by the capsule manufacturer.

Alkanes cannot be fully recovered in the faeces although the recovery rate of natural alkanes increases with the increase in carbon-chain length, as found in sheep. The actual values of faecal recoveries of alkanes are within the range reported by Dove and Olivan (1998) and Mayes et al. (1988) for sheep. The values reported by Dove and Olivan (1998) and Mayes et al. (1988) are higher than values derived from the current research except for C_{28}. The discrepancy between experiments is also apparent in comparison to reports by Dove and Coombe (1992). For example, the recovery of alkane C_{33} was similar (0.872 *vs* 0.886), but the recovery for alkane C_{29} was higher in the current study (0.765 *vs* 0.845). However, it has been proven that the faecal recovery of natural alkanes is not associated with diet composition (Dove and Coombe, 1992; Dove and Olivan, 1998). Therefore the average recovery of different diets for individual natural alkanes obtained from this experiment can be used to adjust the estimation of feed intake of grazing fallow deer.

The intake of lucerne and other feed components in the mixed diets predicted using alkane method was positively related to the actual intake, indicating a great potential of using the alkane technique for measuring feed intake of individual fallow deer under grazing conditions. However, the weighting system tested in this experiment did not improve the accuracy of feed intake prediction. Further research is required to resolve the weighting system for alkanes where there are different concentrations in the pasture or faeces.

3.5 Conclusion

N-alkanes have potential for estimating feed intake of grazing deer. The commercial alkane capsules can be directly used for this purpose given the daily output of C_{32} and C_{36} is accurately measured. It is important that faecal recoveries of natural alkanes are used to adjust the predicted intake assuming that dietary composition has little effect on the recovery of alkane. If this assumption is not valid, the measurement of feed intake of deer using n-alkane will be impossible due to the difficulty of obtaining the recoveries of alkanes for different types of diets.

4. Predicting n-Alkane Concentration in Pastures and Deer Faeces for Dietary Composition and Digestibility Measurement Using Near Infrared Spectroscopy (NIR)

4.1 Introduction

To develop a cost-effective supplementation strategy for grazing deer under a Mediterranean environment, it is essential to know the seasonal feed intake. While there are a number of methods used for estimating feed intake of grazing ruminants (Dove and Mayes, 1996), the most advanced technique is the alkane method. The principle of this technique is that n-alkanes, long-chain (C_{25-35}) hydrocarbons, predominantly with odd-numbered carbon chains, occur in the cuticular wax of most plant materials and are substantially indigestible. These alkanes can be used, in combination with orally dosed even-chain alkanes to estimate intake. Dove and Moore (1995) also showed that diet composition of individual animals could be accurately estimated from the pattern of alkanes in each component of the diet and the faeces. With the wide adoption of this method, a commercial alkane capsule has been developed for estimating pasture intake in sheep and cattle. These capsules were tested for estimating feed intake of deer indoors (Ru et al., 2002a). The results clearly indicated that intake of individual deer could be accurately predicted although the recovery of alkanes in deer faeces was incomplete, and the amount of dosed alkanes as commercial capsules excreted from faeces was lower than recommended for sheep. Through this study, it was found that the high cost of alkane capsules and alkane analysis is a key factor limiting the wide adoption of this technique in deer research.

Near infrared spectroscopy (NIR) has been used successfully for rapid estimation of chemical composition and nutritive value of feed and food (Ru and Glatz, 2000). The NIR analysis is simple, non-destructive and accurate. This is particularly valuable for faecal samples of deer, which are difficult to collect under grazing conditions. The objective of this study was to develop and subsequently validate NIR calibrations for the prediction of alkane contents in deer faecal samples and in various pasture species grazed by deer.

4.2 Materials and Methods

4.2.1 Samples

Samples of faeces and pastures were obtained from two experiments conducted at SARDI Livestock System Alliance at Roseworthy, South Australia. Briefly, in Exp. 1, 6 fallow deer, 8 months of age, were housed in individual stalls with dimensions of 1200 mm long x 1950 mm high x 900 mm wide. Holes with a diameter of 100 mm were cut in the stalls to allow deer to view each other in the next stall and reduce fractious behaviour. The feeder was fixed on the door with the water bucket next to the feeder. Deer were fed a diet comprising straw and lucerne chaff. Once the deer were housed in the individual stalls, artificial slow-release alkane capsules were dosed via the oesophagus. The deer were fed *ad libitum* and water was available at all times. All faeces were collected daily (9:00 am) for 24 days from day one after dosing. Hair was removed manually from the faeces and 10% of the faeces were subsampled and freeze-dried. All samples were milled through a 1 mm screen for alkane analysis and NIR scanning. Details of the experimental procedure are described by Ru et al. (2002a).

In Exp. 2, 36 fallow deer were grazed on medic and ryegrass-based pastures in three groups on the Roseworthy Deer Farm from May to October. Three groups were supplemented with a concentrate based on barley and lupin (*Lupinus angustifolius*) from May to August 2000. Deer were dosed with

artificial slow-release alkane capsules in May, June, July, September and October. From day 10 after dosing, faeces were collected every second day over 6 days. During each faecal collection, pasture samples were taken by cutting 3 cm above ground level and separated into legume and grass. Samples of faeces, mixed pastures, legume and grass were freeze-dried and milled through a 1 mm screen for alkane analysis and NIR scanning.

After scanning the faecal samples from the two experiments, it was found that all samples fell into the same population, thus faecal samples from both experiments were pooled for the development of NIR calibration. Total number of faecal and pasture samples were 242 and 119, respectively.

4.2.2 Alkane analysis

Alkane concentrations in faeces and pastures were analysed at University of New England in Armidale, New South Wales. The analytical method used to determine alkane contents in the samples was a modified method of Dove (1992). In brief, to a dry sample of 100-500 mg, an appropriate amount (50-200 mg) of internal standard ($C_{34}H_{70}$ in dodecane) was added. The samples were then subjected to 1.5M ethanolic KOH in a heating-block at 90^{o}C for 1 hour with stirring. After cooling, the hydrocarbons were extracted in n-hexane several times, filtered, purified and quantified by gas chromatography**.** The alkanes were analysed including the following: C_{24}, C_{25}, C_{26}, C_{27}, C_{28}, C_{29}, C_{30}, C_{31}, C_{32}, C_{33}, C_{35} and C_{36}.

A relatively small percentage of analyses was performed in duplicate. These duplicate reference data were used to determine the standard error of the reference method which was used for comparison to primarily assess the validity of the calibration. Based on the available laboratory data, the calculation of the error was only possible for faecal samples. The formula used was for Standard Error of Laboratory (SEL) which is a standard error of variance between replicates analysed by the reference method and is defined as :

$$SEL = \sqrt{\frac{\sum_{i=1}^{N} (Yi - \overline{Yi})^2}{N}}$$

The calculated SEL values ranged for all measured constituents from 0.30 to 13.56 ppm.

4.2.3 NIR scanning

NIR reflectance spectra of all available samples were recorded using a Foss NIRSystem Model 6500 Spectrophotometer (FossNIRSystem Inc., Silver Spring, MD, USA) and Intrasoft International (ISI) WINISI software (FossNIRSystem Inc., Silver Spring, MD, USA). Scanning was performed via a transport module in reflectance mode over the wavelength range 400-2500 nm at 2 nm intervals using a small ring cup. Examination of final spectra was conducted in second derivative using SNV and Detrend scatter correction. An identical scanning procedure was applied to faecal and pasture samples.

4.2.4 Population structuring

Both sample sets were examined using the population structuring software in order to identify spectral outliers. To identify patterns in the group of spectra that contribute the most to the variation among the spectra, Principal Component Analysis (PCA) was used. An average Mahalanobis distance (Global H) was calculated and H values for individual samples were standardised by dividing by the average H value. Any sample with a spectrum more than 3.0 standardised units above the mean of the sample set was regarded as a spectral outlier. An identical population structuring procedure was applied to both types of samples.

For development of the calibration, both sample sets were randomly divided into calibration and validation groups. As a result, 212 faecal samples were used for the calibration, with the remaining 30 randomly selected faecal samples used in the validation. Similarly, the number of pasture samples for the calibration modelling was 99 with 20 remaining samples used for the validation.

4.2.5 Calibration development

The applied calibration technique involved SNV and Detrend scatter correction method and modified partial least squares (MPLS) regression of derivatised spectra. The superlative math treatment was 2,5,5,1. The same calibration procedure was used for both calibration sample sets. The calibration equations were produced for the 1,100 – 2,500 nm segment of wavelengths.

The Standard Error of Cross Validation (SECV) was used as a measure of accuracy of calibrations in each case. Final equations were chosen according to a combination of the lowest SECV and the highest 1-VR value (coefficient of determination for cross validation). Calibration equations were developed for each of the 12 analysed constituents for both faecal and pasture samples.

4.2.6 Validation

The validation sample sets were used to test the performance of the calibration equations. The monitoring program within ISI software was used to test the calibration equations against independent sample sets. The NIR predicted constituent content was compared with laboratory measured values using a t-test.

The Standard Error of Prediction (SEP) was used as a calibration performance indicator. In addition, a ratio of SEP to Standard Deviation (SEP/SD) was used in the test. For superior calibrations this ratio should ideally be less than 0.3, although calibrations with the value below 0.6 are still regarded auspicious.

4.3 Results

No spectral outliers were found for faecal and pasture samples, so all samples were included in the calibration and validation sample sets. There were differences in the second derivatives in the spectra between faecal and pasture samples over the wavelength of 1977-2498 nm (Figure 4.1 and 4.2).

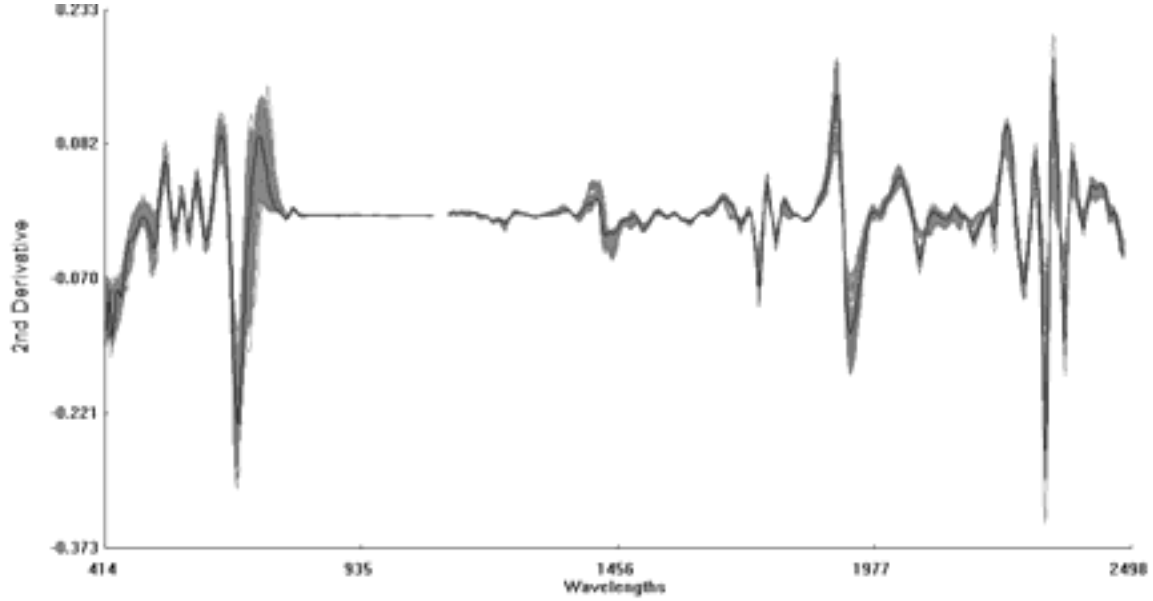

Figure 4.1. NIR spectra of deer faecal samples (calibration set).

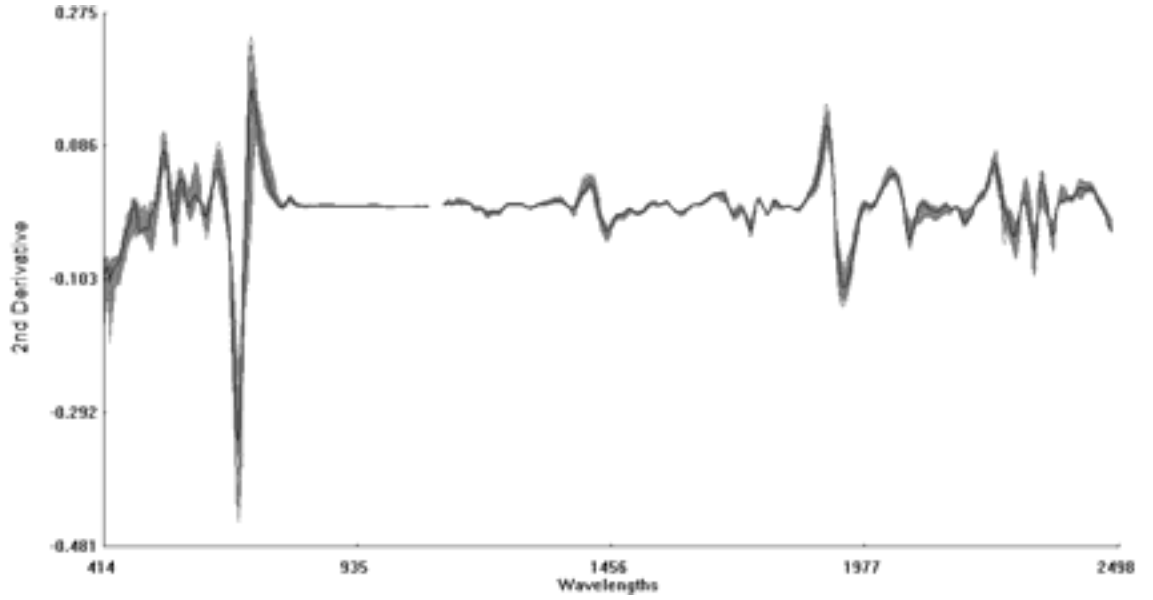

Figure 4.2. NIR spectra of pasture samples (calibration set).

The 1-VR and R^2 values for NIR calibrations were <0.6 for alkanes C_{24}, C_{26}, C_{32} and C_{36} in faecal samples, but were > 0.8 for other alkanes examined. The SECV value was relatively high for alkane C_{31} (Table 4.1). The NIR validation also showed lower R^2 values for alkanes C_{24}, C_{26}, C_{32} and C_{36} with rather high SEP/SD ratios, although statistically there was no difference between NIR predicted and laboratory measured values for all alkanes (Table 4.2). The correlation results tended to be higher for long chain alkanes except for C_{32} and C_{36}, which were dosed with artificial capsules. Alkane C_{25} had a reasonable R^2 value for calibration, but a relatively poor one for validation.

Table 4.1. NIR calibration equations statistics developed for determination of alkane content in deer faeces (N=212)

Constituent	Mean (ppm)	Range (ppm)	SD	R^2	SECV	1-VR
C_{24}	4.21	1.44 - 28.14	2.62	0.01	2.67	-0.04
C_{25}	15.67	2.96 - 48.20	9.36	0.82	4.21	0.80
C_{26}	4.74	1.86 - 32.11	1.69	0.44	1.51	0.21
C_{27}	55.55	10.57 - 144.67	33.27	0.96	8.17	0.94
C_{28}	17.45	1.31 - 36.26	9.46	0.94	2.73	0.92
C_{29}	397.82	53.49 - 948.44	248.28	0.97	48.96	0.96
C_{30}	20.77	3.52 - 69.93	19.57	0.98	3.86	0.96
C_{31}	524.15	1.10 - 3752.88	414.80	0.89	183.56	0.80
C_{32}	175.39	11.55* - 320.75	44.79	0.46	33.72	0.43
C_{33}	83.34	20.29 - 235.48	45.90	0.97	9.99	0.95
C_{35}	6.83	2.72 - 17.51	2.78	0.93	0.92	0.89
C_{36}	161.30	3.59* - 326.49	42.59	0.56	29.24	0.53

SD, standard deviation; SECV, standard error of cross validation; 1-VR, coefficient of determination for cross validation; * faecal samples without dosing slow-release alkane capsules.

Table 4.2. NIR validation statistics for determination of alkane content in deer faeces performed on 30 randomly selected samples

Constituent	Range (ppm)	Mean value (ppm)		SEP	R^2	SD	SEP/SD ratio	P-value
		Laboratory	NIR					
C_{24}	3.59 – 4.58	5.67	4.22	5.60	0.05	0.31	18.06	0.24
C_{25}	5.45 – 21.07	16.24	14.97	6.27	0.60	8.38	0.75	0.28
C_{26}	1.29 – 6.93	6.92	4.52	7.06	0.01	1.20	5.88	0.11
C_{27}	12.88 – 117.13	54.17	53.31	9.36	0.93	35.03	0.27	0.62
C_{28}	1.92 – 31.03	15.63	15.98	4.35	0.86	10.34	0.42	0.71
C_{29}	54.78 – 827.71	395.47	389.70	49.85	0.96	253.16	0.20	0.54
C_{30}	3.11 – 68.66	22.28	21.81	3.10	0.98	20.10	0.15	0.49
C_{31}	139.76 – 1796.98	716.58	589.35	540.89	0.80	465.31	1.16	0.21
C_{32}	117.16 – 228.72	161.81	171.20	46.67	0.22	29.74	1.57	0.28
C_{33}	32.07 – 193.98	83.85	83.63	10.02	0.96	46.63	0.21	0.91
C_{35}	2.95 – 13.28	6.46	6.36	0.87	0.92	2.60	0.33	0.62
C_{36}	111.88 – 222.76	145.87	157.09	46.75	0.18	31.67	1.48	0.19

SEP, standard error of prediction; SD, standard deviation

Both 1-VR and R^2 results of the calibrations developed on pasture samples were favourable for alkanes with chains from C_{27} to C_{35}. Alkanes C_{24}, C_{25}, C_{26} and C_{36} had lower coefficients of determination for cross validation (1-VR, Table 4.3). The validation results also showed these

alkanes had lower R^2 values and higher SEP/SD ratios. However, the alkane concentrations between the NIR predicted and laboratory measured values were similar (P-value, Table 4.4).

Table 4.3. NIR calibration equations statistics developed for determination of alkane content in medic and ryegrass based pastures (N=99).

Constituent	Mean (ppm)	Range (ppm)	SD	R^2	SECV	1-VR
C_{24}	4.61	1.20 – 22.76	2.51	0.80	1.69	0.55
C_{25}	17.37	0.62 – 67.01	8.95	0.79	5.82	0.58
C_{26}	3.67	0.80 – 31.39	1.81	0.09	1.78	0.04
C_{27}	43.96	7.18 – 119.65	23.43	0.89	10.68	0.79
C_{28}	10.96	1.05 – 24.98	5.69	0.87	2.30	0.84
C_{29}	239.78	1.00 – 494.49	141.11	0.97	31.79	0.95
C_{30}	9.36	0.67 – 19.73	5.37	0.94	1.81	0.89
C_{31}	226.14	0.80 – 530.52	130.21	0.97	30.98	0.94
C_{32}	4.42	0.52 – 16.99	2.71	0.93	1.02	0.86
C_{33}	47.01	8.94 – 114.98	28.13	0.98	6.16	0.95
C_{35}	4.30	1.09 – 9.10	2.10	0.95	0.70	0.89
C_{36}	1.83	1.03 – 5.14	0.38	0.22	0.36	0.17

SD, standard deviation; SECV, standard error of cross validation; 1-VR, coefficient of determination for cross validation

Table 4.4. NIR validation statistics for determination of alkane content in medic and ryegrass based pastures performed on 20 randomly selected samples.

Constituent (alkane)	Range (ppm)	Mean value (ppm)		SEP	R^2	SD	SEP/SD ratio	P-value
		Laboratory	NIR					
C_{24}	1.26 – 15.84	5.09	4.33	3.47	0.25	2.21	1.57	0.35
C_{25}	2.96 – 55.59	19.15	16.83	7.55	0.71	9.45	0.80	0.17
C_{26}	1.99 – 23.94	4.93	3.72	5.18	0.00	0.60	8.63	0.34
C_{27}	8.44 – 118.16	48.63	50.85	15.27	0.71	26.50	0.58	0.53
C_{28}	2.47 – 22.15	11.14	11.47	2.73	0.73	4.87	0.56	0.60
C_{29}	43.83 – 464.43	253.40	257.58	28.23	0.95	124.23	0.23	0.52
C_{30}	2.56 – 19.73	11.74	11.42	2.27	0.84	5.46	0.42	0.54
C_{31}	70.90 – 512.76	294.67	294.35	20.59	0.98	135.21	0.15	0.95
C_{32}	2.07 – 13.08	6.85	6.24	1.51	0.92	2.64	0.57	0.07
C_{33}	11.29 – 114.98	46.02	45.26	4.61	0.97	27.15	0.17	0.48
C_{35}	1.38 – 9.10	3.94	3.84	0.40	0.98	2.35	0.17	0.43
C_{36}	1.60 – 3.81	2.07	1.84	0.62	0.04	0.18	3.44	0.10

SEP, standard error of prediction; SD, standard deviation

4.4 Discussion

The outcomes of this study indicate that NIR calibrations can be used to estimate the concentrations of some alkanes in faecal and pasture samples. These calibrations will facilitate the measurement of dietary composition and digestibility of grazing fallow deer, which consequently can be used for the development of feeding strategies for deer farmers.

The successful prediction of alkanes using NIR calibrations developed in this study will stimulate the application of this technology in deer research. Compared with traditional laboratory alkane

determination, a NIR-based assay offers lower cost of analysis and is less time consuming. More importantly, NIR assay will not destroy samples, especially faeces, which are extremely difficult to collect from grazing deer due to the difficulty in handling deer. After NIR scanning, the material can be used for other chemical analyses. However, the application of these calibrations to other types of pastures requires further examination. The calibrations for the faecal samples developed in this study may only apply to deer, and their relevance to sheep is unknown.

In the current study, NIR was unable to predict the concentrations of alkanes C_{24} and C_{26} in both faecal and pasture samples. It appears that the ability of NIR to predict the concentration of a particular natural alkane in a sample was related to the level of that alkane. Thus when the concentration of the alkane was high, its predictability was also high. The concentrations of C_{24} and C_{26} in grass and faecal samples were less than 5mg/kg. Determination of such trace levels of alkanes using the current chemical method was probably not appropriate since the error level associated with the chemical determination was extremely high. The R^2 values of the calibrations and validations tended to be higher for longer chain alkanes. However, the C_{32} and C_{36} alkanes (dosed alkanes) in faecal samples cannot be estimated using NIR, presumably due to the lack of structural interactions between artificially dosed alkanes and other chemical components in the samples or other properties of the samples used in these calibrations.

The poor prediction of C_{32} and C_{36} in faecal samples may limit the application of these calibrations in the forage intake measurement because C_{32} and C_{36} alkanes dosed to animals are essential for intake estimate. However, these calibrations are useful when natural alkanes in plant materials are used to determine the botanical composition of available or consumed herbage by grazing animals. Under field conditions, the understanding of pasture species selected by grazing animals and their utilisation is of great importance for the development of pasture management strategies. Research reviewed by Dove and Mayes (1991) suggests that cuticular wax alkanes can be used to estimate the botanical composition of mixed herbage or of the whole diet using simultaneous equations, assuming that the faecal recovery of an individual alkane is constant across a range of herbage species.

The application of NIR calibrations will accelerate the estimation of diet digestibility of grazing deer. Dove and Moore (1995) developed an Eatwhat® software to estimate the proportion of pasture species consumed by grazing animals to produce 1 kg dry faeces. Based on this software, dry matter digestibility of the diet can be estimated without using the dosed artificial alkanes. It is expected that these predictions can be performed rapidly and cheaply for deer if these NIR calibrations are used for the measurement of alkanes in pasture and deer faeces.

4.5 Conclusion

NIR can be used to predict alkanes in pasture and deer faeces with chain lengths of C_{27}-C_{35}, except for C_{32} in faecal samples. The application of these calibrations will assist the rapid measurement of diet composition and digestibility of grazing deer for the development of feeding strategies. However, the influence of type of pastures on the accuracy of these calibrations requires further examination.

5. Forage Intake, Protein and Energy Requirements of Grazing Fallow Weaner Deer

5.1 Introduction

Research with subterranean clover indicates that dry matter digestibility can be as high as 80% in winter and early spring, and as low as 40-50% in summer (Ru, 1996). The decline of nutritive value of subterranean clover occurs mainly after initiation of flowering (Ru, 1996). It has been well documented in a Mediterranean environment that the quantity of herbage in winter, quality of herbage in summer, and both quality and quantity of herbage in autumn are the key factors limiting animal production in a number of species.

In southern Australia, fallow deer start fawning in November and generally weaning occurs in March. From March to July, good quality feed is needed to reduce the post weaning stress and to enable deer to reach a market live weight in November. Due to the limited pasture availability at this time of the year, supplementary feeding in early winter and summer is often required. However, the current supplementary feeding for deer production is a hit or miss strategy due to the lack of information on nutrient requirements and seasonal forage intake of grazing deer.

While the seasonal energy requirements for fallow deer have been published in New Zealand by Milligan (1984) and Asher (1992) based on interpolations from red deer data (Fennessy et al., 1981), there has been limited experiments conducted to measure the energy requirement of weaner fallow deer during the grazing season. Preliminary research in Australia by Flesch et al. (1999), using fallow weaner deer fed in pens with imbalanced gender showed that energy intake ranged from 10-11 MJ ME/day between 12 to 20 weeks of age, equivalent to a metabolic body weight energy intake of 0.95 MJME/kg $^{0.75}$/day. To develop a supplementary feeding strategy data on the nutrient intake of grazing deer from pastures is required, but no such data is available in Australia. The current study was conducted to measure seasonal feed intake and to define the energy and protein requirements of fallow weaner deer grazing annual pastures in southern Australia.

5.2 Materials and Methods

5.2.1 Pasture and grazing management

A paddock of 5 ha was fenced into three small paddocks with equal size on the Roseworthy Deer Farm, Roseworthy, South Australia. Medics and oats were regenerated. In April, 60 fallow weaners, including 30 males and 30 females were selected. Deer were randomly divided into three groups with balanced sex in each group. Three groups were randomly allocated into the three paddocks and supplemented with a diet including 2% minerals, 30% lupin and 68% barley. The diet contained 13.0 MJ DE/kg and 168.8 g/kg protein. Group 1 was fed *ad libitum* and group 2 was fed 400g/day while group 3 was fed 200 g/day. Supplementation ceased at the end of July. Body weight of deer was measured fortnightly. Pastures were sampled monthly for *in vitro* dry matter digestibility, digestible energy and crude protein analyses. Sward height was measured using a ruler (to 0.1 cm) monthly on 6 randomly selected locations in each paddock.

5.2.2 Forage intake measurement

From May to October, 6 males and 6 females from each group were selected randomly and dosed via the oesophagus with a slow-release alkane capsule (produced by Captec Pty Ltd). After 10 days, faeces were collected every second day in the morning over 6 days as recommended by Ru et al. (2002a). Faeces collected over three days were bulked, freeze dried and then milled for alkane analysis using a modified method of Dove (1992).

Deer were fasted overnight before dosing alkane capsules. The body weight were measured in the morning when dosing alkane capsules. After finishing faeces collection, deer were fasted overnight and weighed in the morning. The daily body weight gain was calculated for this period for establishing the relationship between growth rate and nutrient requirement.

Before dosing alkane capsules, 4 exclusion cages with a size of 0.5 m^2 were set up randomly in each paddock. After finishing faeces collection, pasture samples were taken by cutting pastures in the exclusion cages at the same height as the grazed area. Pasture samples were freeze dried and then milled for alkane analysis. Daily feed intake was estimated using the following equation;

Daily herbage intake (kgDM/day)=(Fi/Fj*(Dj+I*Cj)-I*Ci)/(Hi-Fi/Fj*Hj) (Dove and Mayes, 1991); where Fi and Hi are faecal and herbage concentrations of the odd-chain alkanes; Fj and Hj are faecal and herbage concentrations of the even-chain alkanes; Dj is the daily dosed even chain alkane; I is concentrate intake; Cj and Ci are even-chain and odd-chain alkanes in concentrate supplement.

5.2.3 *In vitro* digestibility measurement

Fallow deer (male, 8-10 months old) were obtained from Farm Services, University of Adelaide, Roseworthy Campus. For each batch, two deer were slaughtered and the rumen fluid collected for *in vitro* digestibility estimation. CO_2 was passed through the rumen fluid to maintain anaerobic conditions and the container was sealed and kept in a water bath at 39 ^oC before adding to the incubation tubes. The time from collection to completion of the inoculation process was less than 2 hours as recommended by Schwartz and Nagy (1972).

The *in vitro* dry matter digestibility (DMD) and digestible energy (DE) content was determined using the Tilley-Terry method (Tilley and Terry, 1963). In brief, a sample of the feed (0.5 g) was weighed into incubating tubes and 10 ml of rumen fluid and 40 ml of buffer (pH=5.8) were added. Tubes were flushed with CO_2 and capped immediately. Ten replicates of each sample were incubated in a shaking water bath at 39 ^oC for 48 hours. After the samples were centrifuged at 3000 rpm for 15 min. and washed with distilled water, 50 ml of pepsin solution was added to each tube and incubated for another 48 hours at 39 ^oC. After incubation, the samples were centrifuged (3000 rpm) and the residues dried at 60 ^oC overnight. In each batch, a quality control lucerne sample of known *in vivo* digestibility and DE content was included.

5.2.4 Chemical analysis

All pasture and faecal samples were freeze dried and milled through a 1 mm screen. Dry matter and gross energy were analysed using standard methods (AOAC, 1980). Alkane concentrations in faeces and pastures were analysed by Animal Science Laboratory at University of New England in Armidale, New South Wales. The analytical method used to determine alkane contents in the samples was a modified method of Dove (1992). In brief, to a dry sample of 100-500 mg, an appropriate amount (50-200 mg) of internal standard ($C_{34}H_{70}$ in dodecane) was added. The samples were then subjected to 1.5M ethanolic KOH in a heating-block at 90^oC for 1 hour with stirring.

After cooling, the hydrocarbons were extracted in n-hexane several times, filtered, purified and quantified by gas chromatography. The alkanes analysed included C_{24}-C_{36}.

5.2.5 Statistics

The effect of supplementary feeding level and sex on the growth rate of deer was assessed using a general linear model in Systat software. Individual deer were used as replicates. The relationships between daily weight gain and digestible energy intake, between sward height and nutrient intake were established using correlation analyses using Systat software (Wilkinson et al., 1996).

5.3 Results

There was a significant decline in *in vitro* dry matter digestibility, digestible energy content and crude protein after July as the pastures matured (Figure 5.1). Crude protein, *in vitro* DE and DMD declined 0.60, 0.05 and 0.49 unit/week, respectively, from May to October. The decline was more rapid in the last 40 days, where crude protein, *in vitro* DE and DMD dropped at 1.30, 0.27 and 0.90 unit/week, respectively.

There was no difference in body weight between high and medium groups while the low group had a lighter bodyweight, especially late in the season (Figure 5.2). Female deer grew slower than male deer ($P<0.05$). The difference in growth rate between sex was more significant after August (Figure 5.3).

The crude protein, DE and DM intake increased from 40.6 g/d, 1.95 MJ/d and 0.14 kg/d in May to 203.4 g/d, 14.3 MJ/d and 0.9 kg/d in October, respectively. However, the forage intake was influenced by the level of supplementation during early winter. The group with a lower supplementation had a higher forage intake ($P<0.05$). However, the difference in forage intake between the three groups was not significant after August when no supplement was offered (Table 5.1). Female deer ingested less pastures than male deer, especially after August (Table 5.2).

There was a strong correlation between intake of dry matter (kg/day), DE (MJ/day) and crude protein (g/day) and sward height (cm) (Figure 5.4). The correlation equations established using a regression analysis are;

DM intake = -0.0634+0.3128*ln (sward height) $R^2 = 0.848$; n = 12
DE intake = -1.6863+4.9365*ln (sward height) $R^2 = 0.884$; n = 12
Crude protein intake = 6.711+63.9272*ln(sward height) $R^2 = 0.812$; n = 12.

The digestible energy and crude protein requirements were strongly correlated with body weight gain (Table 5.3). The digestible energy and crude protein requirements for different growth rates are present in Table 5.4 and 5.5, respectively. The energy requirement per kg $W^{0.75}$ for maintenance was highest in July.

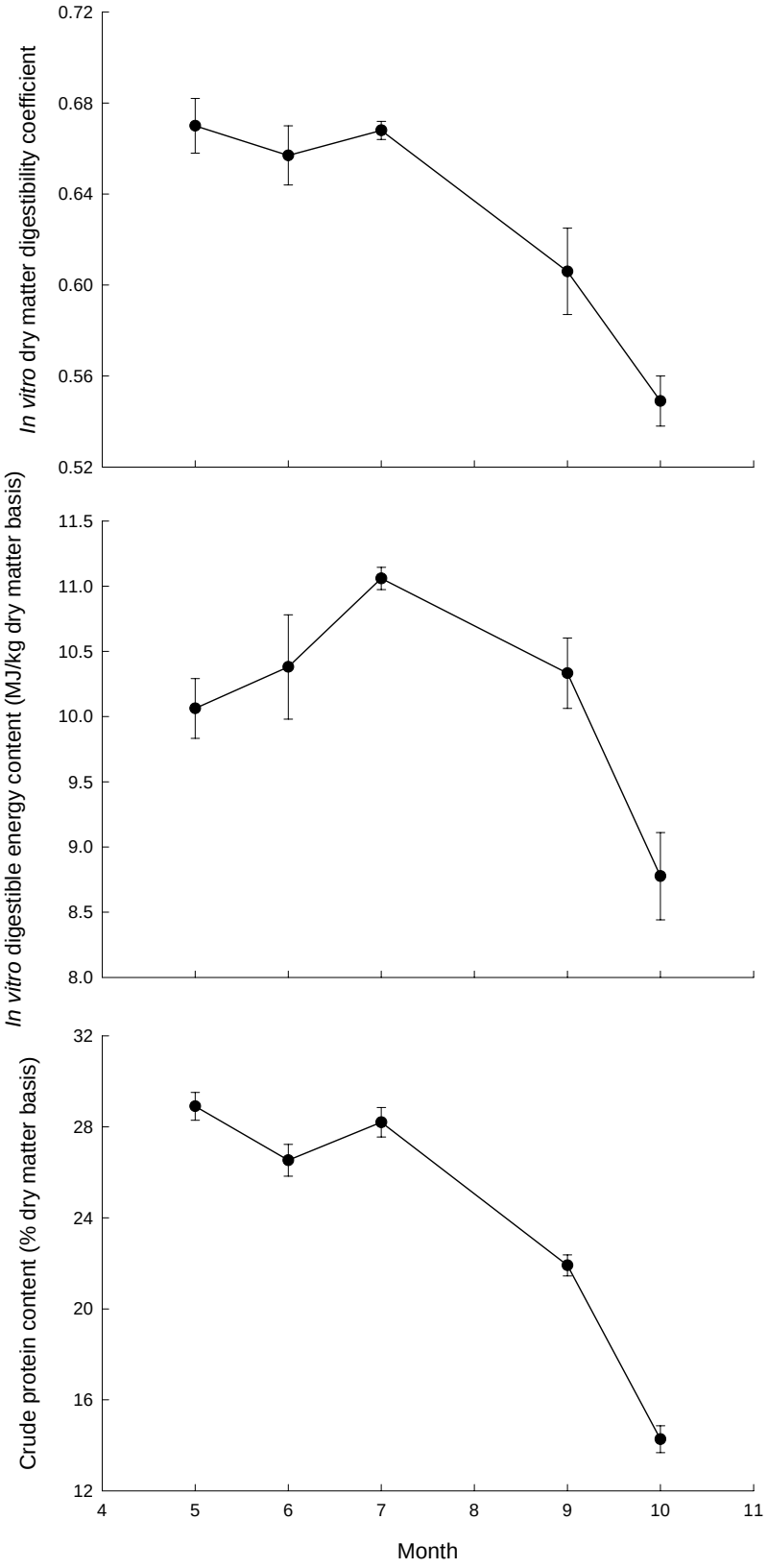

Figure 5.1. Seasonal changes in *in vitro* dry matter digestibility, digestible energy content and crude protein content of a medic and oats based pasture.

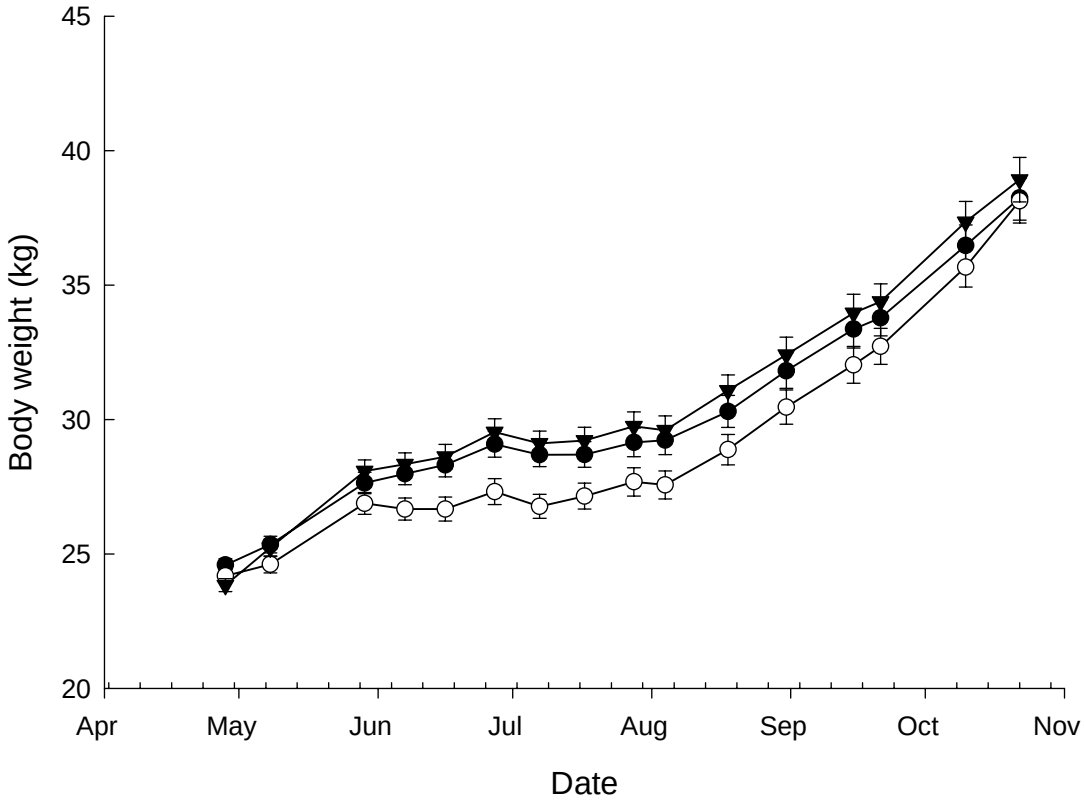

Figure 5.2. Bodyweight changes of three groups of deer fed high, medium and low concentrate diets during the season (high, medium and low).

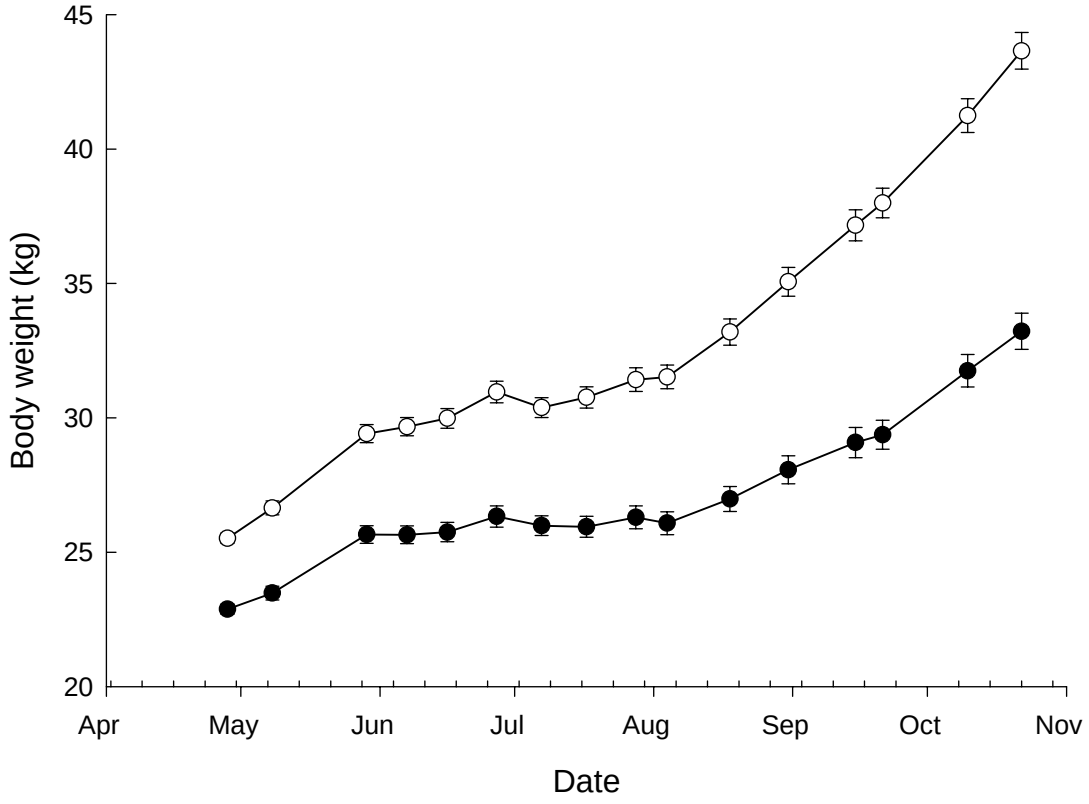

Figure 5.3. The bodyweight changes of male ( ) and female ( ) fallow weaner deer during the season

Table 5.1. Daily nutrient intake from pastures by grazing fallow deer during the season

Treatment	Nutritional component					
	DM (kg/day)		DE (MJ/day)		CP (g/day)	
	Means	SE	Means	SE	Means	SE
			May			
H	0.148a	0.025	1.95a	0.30	44.2a	7.3
M	0.199a	0.021	2.62a	0.26	57.5a	5.9
L	0.300b	0.022	3.05b	0.26	83.5b	6.2
Stats	**		**		**	
			June			
H	0.137a	0.015	1.75a	0.30	37.7a	4.0
M	0.185a	0.016	2.45a	0.31	49.6b	4.2
L	0.304b	0.018	3.61b	0.35	76.5c	4.7
Stats	**		**		**	
			July			
H	0.504a	0.037	8.09a	0.57	137.3a	10.3
M	0.297b	0.035	4.29b	0.54	82.9b	9.9
L	0.534a	0.035	8.06a	0.54	157.3a	9.9
Stats	**		**		**	
			Aug-Sept			
H	0.96	0.074	14.00	1.21	213.0	16.3
M	0.953	0.081	13.95	1.32	214.8	17.9
L	0.997	0.078	15.04	1.27	209.5	17.1
Stats	*ns*		*ns*		*ns*	
			October			
H	1.153	0.084	15.23	1.37	159.1	13.2
M	1.248	0.082	17.28	1.34	173.4	12.9
L	1.225	0.079	16.76	1.28	183.6	12.4
Stats	*ns*		*ns*		*ns*	

** Values are significantly different between treatments in each month at P<0.01, ns. Not significant

Table 5.2. Difference in nutrient intake from pastures between sex

Sex	Nutritional component					
	DM (kg/day)		DE (MJ/day)		CP (g/day)	
	Means	SEM	Means	SEM	Means	SEM
			May			
Male	0.213	0.018	2.58	0.22	61.1	5.2
Female	0.217	0.019	2.86	0.22	62.9	5.4
Stats	*ns*		*ns*		*ns*	
			June			
Male	0.237	0.014	2.88	0.26	62.2	3.6
Female	0.179	0.013	2.33	0.26	47.0	3.5
	**		ns		**	
			July			
Male	0.497	0.029	7.47	0.44	140.8	8.3
Female	0.397	0.028	6.16	0.45	110.9	8.0
Stats	*		*		*	
			Aug-Sept			
Male	1.095	0.063	16.23	1.02	239.9	13.8
Female	0.845	0.065	12.44	1.05	185.0	14.2
	*		*		**	
			October			
Male	1.417	0.065	19.49	1.06	201.4	10.2
Female	0.999	0.068	13.36	1.11	142.7	10.7
Stats	**		**		**	

* Values are significantly different between sex in each month at P<0.05, ** Values are significantly different between sex in each month at P<0.01, ns. Not significant

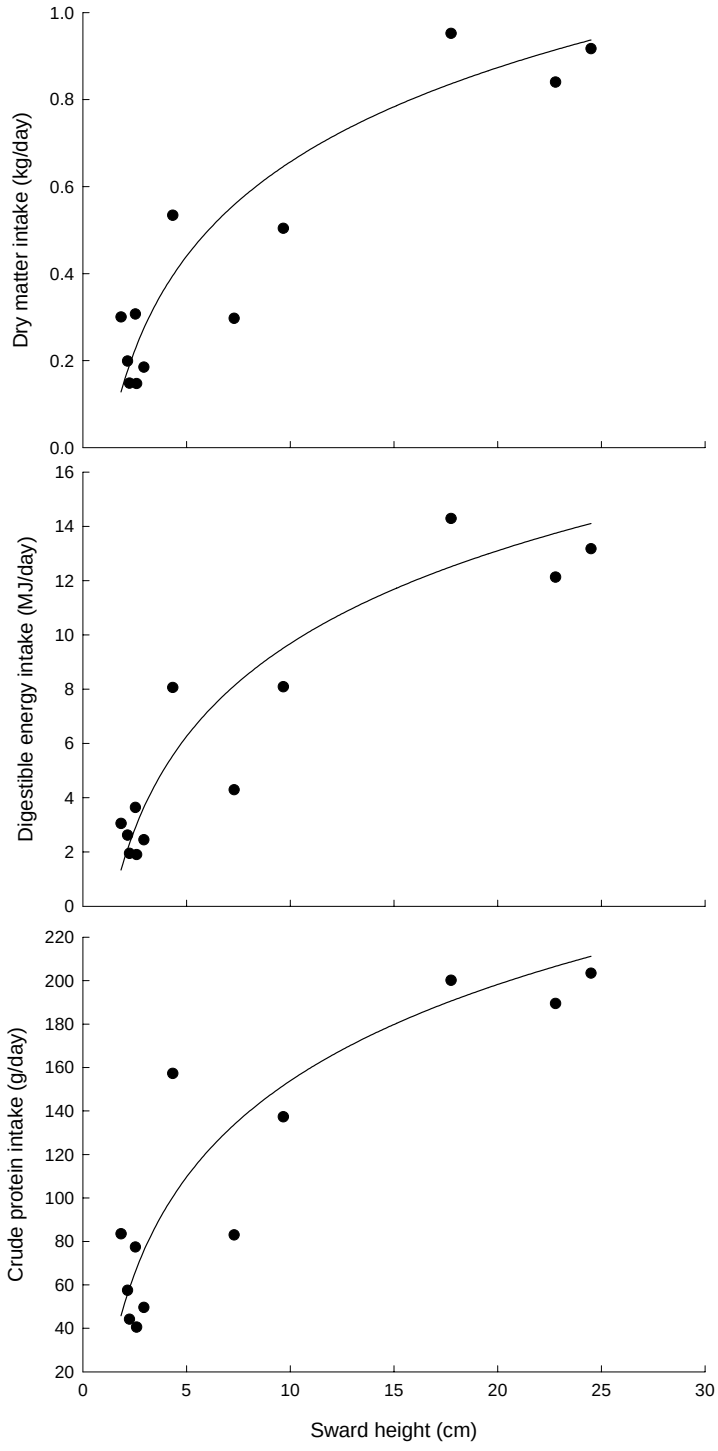

Figure 5.4. The relationship between nutrient intake from pastures by fallow deer (weaners) and sward height

Table 5.3. Correlations between digestible energy (DE MJ/day) and crude protein (CP g/day) intake and bodyweight gain (g/day) of grazing fallow weaner deer (mixed sex) during the season

Date	Equation	r	P	n
	DE			
May	DE=7.252+0.019 Gain	0.45	0.014	29
June	DE=8.220+0.018 Gain	0.66	0.000	26
July	DE=10.249+0.029 Gain	0.47	0.005	35
Aug-Sep	DE=10.227+0.034 Gain	0.68	0.000	25
Oct	DE=10.661+0.049 Gain	0.62	0.000	31
	CP			
May	CPI=135.49+0.292 Gain	0.49	0.007	29
June	CPI=148.616+0.262 Gain	0.66	0.000	26
July	CPI=180.218+0.553 Gain	0.52	0.001	35
Aug-Sep	CPI=162.9+0.390 Gain	0.58	0.000	25
Oct	CPI=125.039+0.392 Gain	0.55	0.001	31

Table 5.4. Energy requirement of grazing fallow deer for different growth rates during the season estimated using the relationship between energy intake and growth rate

Date	Liveweight (kg)	Gain (g/day)	DE		ME	
			MJ/d	MJ/W $^{0.75}$	MJ/d	MJ/W $^{0.75}$
		0	7.25	0.65	5.95	0.54
May	24.8	50	8.20	0.74	6.73	0.61
		100	9.15	0.82	7.50	0.68
		0	8.22	0.70	6.74	0.57
June	26.9	50	9.12	0.77	7.48	0.63
		100	10.02	0.85	8.22	0.70
		0	10.25	0.86	8.40	0.70
July	27.4	50	11.70	0.98	9.59	0.80
		100	13.15	1.10	10.78	0.90
		0	10.23	0.75	8.39	0.61
Aug-Sept	32.8	50	11.93	0.87	9.78	0.71
		100	13.63	1.00	11.17	0.82
		150	15.33	1.12	12.57	0.92
		0	10.66	0.73	8.74	0.60
Oct	36.0	50	13.11	0.89	10.75	0.73
		100	15.56	1.06	12.76	0.87
		150	18.01	1.23	14.77	1.01

Table 5.5. Crude protein requirement of grazing fallow deer at different growth rates estimated using the relationship between protein intake and growth rate

Date	Liveweight	Gain	Crude protein	
		g/d	g/d	g/W $^{0.75}$
		0	135.49	12.19
May	24.8	50	150.09	13.51
		100	164.69	14.82
		0	148.62	12.58
June	26.9	50	161.72	13.69
		100	174.82	14.80
		0	180.22	15.04
July	27.4	50	207.87	17.35
		100	235.52	19.66
		0	155.52	11.36
Aug-Sept	32.8	50	175.02	12.78
		100	194.52	14.21
		150	214.02	15.63
		0	125.04	8.51
Oct	36.0	50	144.64	9.85
		100	164.24	11.18
		150	183.84	12.52

5.4 Discussion

5.4.1 Seasonal changes in pasture quality

The seasonal decline in nutritional quality of pastures is the key factor which must be considered for pasture management and supplementary feeding of grazing deer. The decline in pasture quality depends on the pasture species and grazing management, and has a strong impact on the quality of dry residues in early summer. For example, Hume and Purser (1972) reported that the rate of decline in DMD for Dinninup was 0.5 percentage unit/day after maturity while Radcliffe and Cochrane (1970) reported a rate of decline of 0.43 percentage unit/day for barley grass, annual ryegrass and Yarloop subterranean clover over a 14-week period. Ru and Fortune (2000) also found a large variation in the rate of decline in nutritive value among cultivars of subterranean clover. The previous and current research indicates that such a decline mainly occurs during flowering, is influenced by grazing intensity, and is associated with the increase in lignin and cellulose content (Hardwick 1954ab; Ru and Fortune 2000). This suggests that deer farmers need to select the proper pasture species or varieties. In addition, grazing the pastures at an optimum stocking rate will ensure that pasture quality is maintained by slowing the accumulation of fibre in the plant materials and reducing the dead material in the swards.

5.4.2 Forage intake and its prediction

The amount of supplementary feed required by deer is dependent on the nutrient intake from pastures under grazing conditions. It is difficult to accurately measure feed intake of grazing animals due to the lack of a reliable method. In the current research, the plant alkanes are used as a marker to estimate intake of individual deer and the outcomes of this study show that this methodology can be applied successfully for grazing deer. However, the high costs associated with this method limit its wide adoption by the deer industry. More rapid and cheaper methods need to be established. Ru et al. (2002c) have developed NIR calibrations for measuring alkane content in plant materials and deer faeces. The application of these calibrations will substantially reduce the cost of chemical analysis, but unfortunately the alkanes of C_{32} and C_{36} cannot be predicted accurately by NIR although these two alkanes are essential for estimating intake. However, the nutritive value of pastures (e.g. digestibility) can be estimated by measuring the alkane contents in pastures and deer faeces using these calibrations and EatWhat® software (Dove and Moore 1995).

Forage intake by grazing deer estimated in the current study cannot be directly extrapolated to other properties until some adjustments have been made. The seasonal trend of the intake would be similar for most southern Australian deer, but the actual nutrient intake is influenced by season, botanical composition of pastures, stocking rate and supplementation levels. For example, deer grazing 1 kg DM intake from legume or grass dominated pastures will have significantly different daily protein intake. It has been well documented in dairy that with increasing amount of supplementary feeding, the forage intake decreases, which is true for deer as found in the current research. Therefore, it is ideal to measure the forage intake of grazing deer under different types of pastures and under common management systems in southern Australia using a rapid and cheaper method. It could be more practical to measure dry matter intake of grazing deer and assess the digestibility and protein content of the herbage simultaneously to work out the actual daily nutrient intake. The current research has already demonstrated a strong relationship between sward height and dry matter intake. If this relationship is further developed and validated on different types of pasture, farmers can easily estimate dry matter intake by measuring sward height. Ru et al. (2002bd) also reported that *in vitro* method could be used to estimate digestibility of feed for fallow deer and near infrared spectroscopy (NIR) showed great potential for predicting these nutritional parameters at low cost and with a rapid turn over. Again, these NIR calibrations need further development and validation before using them commercially.

5.4.3 Nutrient requirement of deer at different growth rates

The daily energy requirement estimated from the current work is lower than those reported by Asher (1992) and Mulley and Flesch (2001). Using the ratio of 0.82 (digestible energy/metabolisable energy) suggested by ARC (1980), the predicted ME requirement for fallow weaner deer is 6.7, 7.5, 9.6, 9.8 and 10.8 MJ ME/day in May, June, July, September and October, respectively, at a growth rate of 50 g/day using the models developed in this study. If the growth rate is 80 g/day, equivalent to Mulley and Flesch's data (2001), the energy requirement in winter is 10.3 MJ ME/day in winter (July), close to values (10-11 MJ ME/day) reported by Mulley and Flesch (2001). This value is lower than the value reported by Asher (1992) for male fawns (11.8 MJ ME/day), but close to the value for female fawns (10.4 MJ ME/day). However, the winter growth rate for deer reported by Mulley and Flesch (2001) might not be achieved in southern Australia under grazing conditions.

Mulley et al. (1999), cited by Mulley and Flesch 2001, reported that energy intake from concentrate-fed weaners from 16 weeks of age was equivalent, if not marginally higher than that of adult does. In another study, Mulley and Flesch (2001) demonstrated that does at the second trimester of pregnancy had a slightly lower ME intake than fallow weaners (10.3 *vs* 11.5 MJ ME/day). Most

farmers also believe that fallow weaners have lower pasture requirement than adult does. The current study further proves that the actual energy intake of fallow weaners is determined by growth rate and gender. Thus it is difficult to compare the nutrient requirement defined in the current study with those reported by Asher (1992) due to the lack of expected growth rate of fawns at the recommended energy requirement. This further indicates the difficulty of the direct application of New Zealand data for the development of a supplementary feeding strategy for Australian deer farmers.

The ME and protein requirements for 1 kg empty body weight gain for fallow weaner deer were 15.6, 14.8, 23.8, 27.9 and 40.2 MJ and 292, 262, 553, 390 and 392 g protein in May, June, July, September and October, respectively, apart from maintenance requirement. The energy utilisation efficiency declines with the season. This decline is associated with pasture quality, the nutrient content in the empty body weight of animals, growth rate and maturity of animals. For example, for a growing castrated Merino sheep with a 30 kg body weight, the energy concentration for empty body weight is 17.5 MJ/kg and 21.7 MJ/kg (ARC, 1980) and protein content is 150g/kg and 146 g/kg (Langlands and Sutherland, 1969 cited by ARC, 1980) at growth rates of 50 and 200 g/day, respectively. The energy concentration for empty body weight increased from 15.6 to 31.0 MJ/kg, but protein content decreased from 148 to 136 g/kg when body weight of sheep increased from 20 to 45 kg (ARC, 1980). However, no data on the energy and protein content of deer carcass is available for calculating the ME utilisation efficiency for deer.

The energy requirement per unit body weight at 0 growth rate is higher in July than in any other month (Table 5.4). The energy requirement at 0 growth rate is not the exact maintenance requirement due to the changes in body composition, but is a reasonable indicator of maintenance requirement of grazing animals. In July, deer require more energy to maintain their body temperature, probably due to the low temperature in southern Australia although winter in southern Australia is not very cold compared to Europe . Therefore, the increase in nutrient intake through supplementation is essential for deer to maintain the maximum growth rate during this period of time when the quantity of pasture is limiting. Under commercial situations, most farmers may believe that green pasture should supply enough nutrients for grazing deer due to the high quality, but it should be noted that the low sward height at this stage may limit the intake rate of deer. However, the magnitude of such limitation is dependent on the type of pastures. For medics, subclover and other pasture species with a prostrate growth habit, sward height is a limiting factor for intake, but for some grasses, it may not be the case due to their erect growth (Ru, 1996).

Deer have a lower nutrient requirement than sheep for growth at similar body weight. For sheep with a 30 kg body weight, ME requirements are 11.8 and 13.1 MJ/day for males and 10.8 and 12.5 MJ/day for females for growing 50 and 100 g/day (ARC, 1980). For fallow deer with a similar body weight, the ME requirements were 9.8 and 11.2 MJ/day to achieve the same growth rates. This suggests that deer is a better converter compared to sheep and the nutrient requirements recommended for sheep cannot be directly applied to deer.

5.5 Conclusion

Forage intake of grazing fallow weaner deer increases with the progress of the season, decreases with the increase in the supplementation and is strongly correlated with sward height. Males have higher nutrient intake and growth rate compared with females. The energy and protein requirement of fallow weaners defined in this study can be used for the development of supplementary feeding strategies. However, the following information is required to assist farmers to explore the possible pasture and stock management practices to ensure that the genetic potential for growth is not limited by inadequate nutrition under southern Australian pasture conditions.

- Genetical potential for growth of fallow weaner deer in southern Australian environment. The information on potential growth rate will further define the valid range of the models developed in this study for the predication of energy and protein requirements at different growth rates.
- Establishment and validation of the relationship between forage intake and sward characteristics. The development of correlation between DM intake and sward height, plant density or other pasture characteristics for different types of pastures will enable deer farmers to quickly assess DM intake from pastures and adjust the level of supplementation feeding.
- Further development and validation of rapid feed evaluation. Based on the current study, it is impossible to estimate ME and protein intake of deer at different grazing systems. While the DM intake can be estimated, it is crucial to have information on the nutritional quality (ME and protein content) of the pastures. The current method for feed evaluation is time-consuming and costing, *in vitro* methods (Tilley-Terry and NIR) showed potential for a rapid assessment of nutritive value of pasture for deer (Ru et al., 2002bd).

6. Supplementary Feeding of Fallow Weaner Deer

6.1 Introduction

A study conducted by Revell and Tow (2000) on the Roseworthy Deer Farm suggests that there is a lack of compensatory growth of weaner deer during spring, despite the abundance of high quality annual medic pasture on offer. Therefore, it is important for the deer producers to supply additional feed in the first 1-2 months after weaning to avoid or minimise early setbacks in animal performance. Although the supplementary feeding will result in an extra cost to the deer enterprise, the selection of proper feed resources and feeding an optimum amount of supplements could reduce the cost. In the same study, Revell and Tow (2000) assessed different feedstuffs available locally and found that diets based on barley grains or barley/lupin seem to be better options than other feed resources (e.g. lucerne, oaten hay). In another experiment, the authors also found that deer fed barley grain post-weaning were heavier than those fed barley/lupins. Additional protein from lupins in the diet did not result in any improvement in growth performance of weaner deer. This may suggest that energy level is a key factor limiting deer growth in early winters. If this is the case, grains with a higher energy value such as oats should be used for supplementary feeding.

In the previous experiment within this study, the daily energy and protein requirements was defined. These data can be used a guideline for the development of feeding strategies. It was also observed that the high and medium supplementation levels resulted in similar body weight at the end of October. Deer in the medium group grazed more pastures in winter than those in high group, suggesting the *ad libitum* feeding is not necessarily the economic feeding strategy. More importantly, the deer in the low group grew at a higher rate during spring than those in the other two groups although Revell and Tow (2000) did not find any compensatory growth in their study.

The objectives of this experiment were to;

- Assess the amount of supplementation on the growth performance of weaner deer;
- Evaluate the effect of protein level on growth rate of weaner deer;
- Examine the performance of weaner deer fed on different types of grains.

6.2 Materials and Methods

6.2.1. Feeding level

Sixty fallow weaners (4 months old) including 30 females and 30 males were randomly divided into 6 groups, three male groups and three female groups with 10 animals/group. Deer were grazed on a medic and ryegrass based pastures and supplemented daily with a diet containing 2% minerals, 30% lupin and 68% barley. Three male and three female groups were supplemented at high, medium and low levels during April-July. Body weight was measured every 4 weeks after fasting overnight. The actual supplementary feed intake for the three groups for male and female deer is listed in Table 6.1.

6.2.2. Supplementary diet

Sixty fallow weaners (4 months old) including 30 females and 30 males were divided into three groups with 10 male and 10 female in each group. The three groups were grazed in 1.7 ha paddocks. Three diets were formulated based on oats, oats-lupin and triticale (Table 6.2). Each group of deer were randomly allocated to one experimental diet. Supplementary diets were offered *ad libitum* from April to July. Diet 1 and 3 cost about $175/tonne and diet 2 costs about $200/tonne.

Table 6.1. Actual supplement feed intake (kg/day) of deer during the season

Group	April	May	June	July	August
			Male		
High	0.41	0.64	0.73	0.75	0.75
Medium	0.23	0.36	0.37	0.36	0.33
Low	0.14	0.23	0.22	0.32	0.29
			Female		
High	0.41	0.59	0.60	0.59	0.53
Medium	0.23	0.36	0.37	0.36	0.33
Low	0.14	0.25	0.24	0.23	0.21

Table 6.2. Diet formulation for supplementary feeding

Ingredient	Diet 1	Diet 2	Diet3
Oats	97	75	
Lupin		22	
Triticale			97
Veg oil	1	1	1
Minerals	2	2	2
Total	100	100	100

The residue of the supplementary feed were collected and weighed weekly and the body weight of deer were monitored monthly.

6.3 Results and Discussion

6.3.1. Feeding level

The body weight was similar for the three feeding levels in April and May, but deer fed low level had a lower liveweight during July-October (P<0.05; Table 6.3). Deer in the medium group were only 1 kg lighter than those in the high group, but consumed 31.4 kg less concentrate. Female deer grew slower than male deer, especially in September and October(P<0.01; Table 6.4).

Table 6.3. The body weight during the growing season of fallow deer

Treatment	April_18	May_4	May_23	June _22	July_18	August_16	Sept_19	Oct_11
			Group					
High	20.3	21.7	23.1	25.1	26.6	28.9	32.8	36.6
Medium	19.7	21.7	22.6	23.8	25.9	28.2	31.9	35.6
Low	19.6	21.3	21.8	23.3	24.6	26.0	30.3	33.9
Stats								
P	*0.290*	*0.757*	*0.067*	*0.006*	*0.024*	*0.000*	*0.005*	*0.028*
SEM	*0.331*	*0.462*	*0.375*	*0.382*	*0.486*	*0.436*	*0.501*	*0.638*
			Sex					
Male	20.9	22.8	24.0	25.8	27.4	30.3	35.1	39.3
Female	18.8	20.4	21.1	22.4	24.0	25.1	28.3	31.4
Stats								
P	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*
SEM	*0.273*	*0.380*	*0.309*	*0.315*	*0.420*	*0.383*	*0.430*	*0.563*

Table 6.4. Growth rate (g/day) of male and female fallow weaner deer during the season

Sex	May	June	July	August	September	October
Male	64.6	64.2	71.3	63.2	137.7	201.7
Female	36.0	47.0	61.9	46.4	95.2	150.6
P	*0.197*	*0.115*	*0.547*	*0.704*	*0.000*	*0.000*
SEM	*15.714*	*7.651*	*11.281*	*32.047*	*6.046*	*14.094*

When comparing the results between trials conducted in 2000 and 2001, it was found that deer in 2001 had a lower bodyweight at commencement of the trial (Table 6.5). The bodyweight was similar at the end of the trial in October for high feeding level group, but was slightly lighter in 2001 for the other two groups. The daily growth rate was 10-20 g higher for deer in 2001 than in 2000 probably due to the different types of pastures used in the two trials. This results further confirm that the reasonable assessment of nutrient intake from pastures is crucial for the development of supplementation strategies.

Table 6.5. The difference in growth rate of deer between 2000 and 2001 trials

Treatment	Year	Start weight (kg)	Oct-11 (kg)	Duration (day)	Growth rate (g/day)
High	2000	24.6	36.5	163	73.0
	2001	20.3	36.6	174	93.7
Medium	2000	23.8	37.3	163	82.8
	2001	19.7	35.6	174	91.4
Low	2000	24.2	35.7	163	70.6
	2001	19.6	33.9	174	82.2

6.3.2 Supplementary diet selection

The predicted digestible energy and protein content were 13.5 MJ/kg, 10.8% for diet 1, 13.2 MJ/kg, 15.9% for diet 2, 13.5 MJ/kg and 10% for diet 3. The actual supplementary feed intake were 328, 423, 548 and 567 g/day in April, May, June and July, respectively. The feed intake was low, especially in April and May although feed was offered *ad libitum*. This is consistent with the previous observation.

No difference in body weight was found during the season between the three treatments ($P>0.05$), but male deer had heavier bodyweight than females ($P<0.01$; Table 6.6). As found in the previous experiment, the growth rate between male and female was significant from August to October (Table 6.7). The increase in protein level by including lupins in the diet (diet 2) did not improve the growth rate of weaner deer. This result is consistent with Revell and Tow's report (2000).

Based on the cost and the final body weight in October, it is obvious that oats and triticale is more cost-effective than barley/lupin. Due to the low intake in April/May, the increase in energy concentration in the supplementary diet by adding oil or tallow will improve the growth performance of weaner, but this practice should be based on the ratio of input/output.

Table 6.6. The body weight during the growing season of fallow deer

Treatment	April_14	May_25	June_19	July_17	August_15	Sept_19	Oct_11
				Diet			
Oats	21.8	24.3	25.9	25.9	27.8	32.5	35.7
Oats+lupin	22.2	24.7	26.1	26.1	28.0	32.0	36.4
Triticale	21.6	23.3	25.6	26.1	28.7	33.0	37.0
Stats							
P	*0.453*	*0.076*	*0.714*	*0.901*	*0.308*	*0.558*	*0.389*
SEM	*0.359*	*0.414*	*0.419*	*0.411*	*0.476*	*0.632*	*0.694*
				Sex			
Male	23.6	26.0	27.8	28.3	30.9	35.9	41.0
Female	20.1	22.2	23.9	23.8	25.5	29.1	31.8
Stats							
P	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*
SEM	*0.293*	*0.338*	*0.339*	*0.335*	*0.386*	*0.512*	*0.562*

Table 6.7. Growth rate of male and female fallow weaner deer during the season

Sex	May	June	July	August	September	October
Male	59.3	77.2	16.7	93.5	147.7	242.9
Female	52.0	69.8	-4.1	61.0	107.1	130.5
P	*0.399*	*0.543*	*0.145*	*0.035*	*0.000*	*0.000*
SEM	*6.103*	*8.603*	*10.041*	*10.477*	*6.518*	*15.923*

6.4 Implications

These experiments demonstrated that

- Oats and triticale are good feed resources for supplementary feeding of weaner deer. Feeding lupins in addition to oats did not show any benefit, but increased the feed cost.
- Feed intake of weaner deer in April and May was low although they were fed *ad libitum*. This suggests that diets with high energy concentration may be required to meet the energy requirement of weaners during the particular period.
- Female deer had a lower growth rate than males. It should be benefit if the male and female are grazed separately, especially when the supplementary feed is offered. Separate sex feeding will eliminate the potential of males or dominant animals consuming more concentrate than other animals and will assist feed allocation. The foreseeable benefit of this practice will be 1) the reduction of uneven growth; 2) the production of consistent quality venison and 3) improved herd performance.

7. Conclusions and Recommendations to the Industry

The major outcomes of this study were the determination of the nutritive value of some common feed ingredients and the seasonal forage intake and protein and energy requirements by fallow weaner deer at different growth rates. These data are required by the deer industry to develop cost effective supplementary feeding strategies to ensure that weaner deer will reach the marketable liveweight by early summer.

The interaction between pastures and animal species found in this study makes it difficult to conclude that data on nutritive value of feeds obtained from sheep can be directly used by the deer industry. The chemical composition and digestibility data of the 11 feed ingredients can be immediately used by the deer producer for diet formulation. While the feed resources are variable between regions, farmers and seasons, and more feed ingredients need to be assessed, the high cost associated with feed evaluation restricts further work in this area. Deer farmers should also use data derived from other deer research projects in Australia as guidelines.

Nutrient intake from grazing pastures increases with the season and is influenced by the amount of supplementary feed offered. The data on intake obtained from this study can be used by the industry in southern Australia as a guideline for supplementary feeding, but farmers should be aware of the difference in forage intake between male and female deer, and the influence of pasture species on actual nutrient intake. It would be easier for farmers to estimate dry matter intake based on some simple pasture characteristics such as sward height which showed a strong relationship with total dry matter intake. Then farmers need to assess the nutritional quality of their pastures with a rapid turn over time and at a low cost to adjust the level of supplementary feeding to optimise the feed utilisation. In this study, Tilly-Terry and NIR methods showed great potential for predicting nutritive value of pastures although these methods require further development.

The key for improving deer farming profitability is to match nutrient demand of grazing deer with cheap and largely available feed resources. This study defined protein and energy requirements of grazing weaner fallow deer at different growth rates. There are differences in data derived from the current research and those reported by Mulley and Flesch (2001) and Asher (1992), suggesting that environment and management have significant effect on nutrient demand and feed utilisation of grazing deer. The outcomes of this study also demonstrated that data generated from in-house study or studies in other countries with a different environment cannot be directly applied to southern Australian conditions. When applying the data on energy and protein requirements of weaner fallow deer to their farming conditions, farmers should be aware that the model developed from this project will only apply to the growth rates between 0-150 g/day in winter and 0-200 g/day in spring. Whether the model can be applied to deer with a growth rate beyond this range is not clear.

While a RIRDC funded project conducted by Revell and Tow (2000) demonstrated the feasibility of combining the use of grain supplements, annual medic pasture and lucerne pasture to achieve marketable weights of fallow deer by early summer, it should be noted that the performance of deer to certain degree is related to the amount of supplementary feed. The current research clearly shows that weaner fallow deer during April-July cannot ingest more than 0.8 kg concentrate, even when the feed was offered *ad libitum*. Feeding 0.4 kg/head/day resulted in a similar liveweight at the end of the season compared with those fed *ad libitum*. Protein level was not the key factor limiting deer growth and adding lupins in barley grain showed no additional benefit in deer performance. Revell and Tow (2000) also found similar results. Reducing the level of lupins in deer feed could improve the profit of deer farming by reducing the feed cost. If the energy level is a limiting factor for deer growth in the immediate post-weaning phase when the intake of weaner deer is not high, the increase in energy concentration in the supplementary diet may improve the deer performance. Apart from

barley grain, oats and triticale are also good resources with a lower price. Oats have higher energy value and fibre content than other grains, but the high fibre in oats will not reduce the value of oats for deer because deer can digest better than sheep.

In summary, this study evaluated some feed ingredients commonly used by the deer industry, and determined the forage intake and protein and energy requirements of fallow weaner deer under a Mediterranean environment. These data can be immediately adopted by the deer farmers for the development of supplementary strategies and pasture management during the season. This will ensure that southern Australia deer farmers are producing quality venison cost-effectively. Through this research, the following areas have also been identified for further research and development;

- The development of easy method for feed intake estimate under grazing conditions. As discussed in the report, farmers need to know the amount of nutrient that deer can obtained from pastures to assess the amount of supplement feed required. The current research demonstrated that sward characteristics such as height was strongly related to dry matter intake, but this relationship need to be further developed and validated for different type of pastures.
- The development of *in vitro* methods for feed evaluation. Deer farmers need to assess the nutritive value of pastures, but currently there is no rapid, low-cost methodology available to offer this service to the deer industry. Most deer producers are directed to test their feed using the NIR model developed for sheep. Current research and from others suggest that there are interactions between feed and animal species in digestibility. The Tilly-Terry and NIR methods showed potential for predicting nutritive value of feed for deer, but these methods should be further developed and validated.
- Genetic potential of fallow deer in southern Australian environments. While the current research modelled the nutrient requirement and growth rate of fallow weaner deer, the relationships may not be extended beyond the growth rate observed in this study. In another words, we don't know the upper limit of growth rate of fallow deer in this environment to match their nutrient requirements for a maximum growth.

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