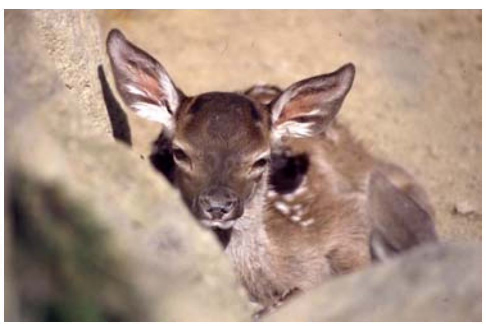
agresearch Farming, Food and Health. First

Te Ahuwhenua, Te Kai me te Whai Ora. Tuatahi

What major nutrient limits lactational yields of red deer hinds …. energy or protein?

July 2006



2020 SCIENCE

New Zealand's science. New Zealand's future.

Client Report

Report prepared for DEEResearch

Contract 5.02

What major nutrient limits lactational yields of red deer hinds …. energy or protein?

July 2006

G.W. Asher, D.R. Stevens, J.A. Archer, I.C. Scott and J. Lach

What major nutrient limits lactational yields of red deer hinds …. energy or protein?

For DEEResearch Ltd

July 2006

Inquiries or requests to:
Geoff Asher
AgResearch Limited, Agricultural and Environmental
Private Bag 50034, Mosgiel, New Zealand

Geoff Asher
Programme Leader : Deer Systems.

Contents

1 Lay Summary

- Red deer calf growth rates from birth to 12 weeks of age seldom exceed 450 g/day on the best quality ryegrass/white clover pastures offered to lactating hinds over summer. However, the genetic potential for calf growth exceeds that observed on most farms.

- The metabolisable energy (ME) content of feed is traditionally used as the measure of feed quality for lactating hinds, with a general recommendation that energetic values of 10-11 megajoules ME per kg dry matter (MJME/kg DM) are required for optimal calf growth.

- The present study investigated the possibility that protein, rather than energy, content of forage may be an equally important determinant of hind lactational performance and calf growth, and that protein availability may be often limiting in the New Zealand pastoral systems for red deer.

- A total of 16 mature red deer hinds pregnant to a red deer stag were calved indoors in individual pens. For the duration of their 12-week lactation they were each given daily *ad libitum* offers of pellet ration (+ 5% by weight of lucerne hay) that contained either low energy/low protein (LE/LP), low energy/high protein (LE/HP), high energy/low protein (HE/LP) or high energy/high protein (HE/HP) (i.e. n=4 per treatment). Calves and hinds were weighed weekly during the study.

- Hinds varied greatly in their average daily intakes across the four treatment groups. One hind/calf pair on the LE/LP diet performed poorly, with the hind exhibiting low intakes throughout the study. The pair was "rescued" (placed on a higher nutrient offer) and removed from the trial.

- Overall, the mean intake of hinds was significantly higher (by about 35-40%) for hinds receiving low energy rations (i.e. LE/LP and LE/HP groups) irrespective of protein offer. This resulted in **all** treatment groups exhibiting the same average energy intake, providing strong evidence for "energy balancing" of feed intake (i.e. intake compensates for energy content of feed).

- As a consequence of "energy balancing" there was substantial between-treatment group variance in mean protein intake (400-1200 g crude protein/hind/day).

- However, there was no observable relationship between protein intake and calf growth performance. In contrast, regression analysis of individual hind variation in energy intake and calf grow revealed that energy intake over lactation was a major determinant of calf growth performance.

- Overall, calf growth over the 10-12 weeks of lactation was lower than expected within the indoor system, and probably reflects a low intake of pellets by the calves themselves.

- In summary, the results of the study strongly support the concepts of energy maximisation and do not support the central hypothesis of potential protein deficiency. Data from this experiment suggest that as little as 400 g/day crude protein intake is adequate for lactation in red deer hinds.

2 Introduction

The efficiency of production of venison is, in no small part, governed by the growth performance of young deer within the first 3-4 months of life, when they are dependant on their dam for the majority of their nutrition.

Weaning weight is largely driven by nutrition and the lactational outputs of the hind contribute significantly to calf weaning weight. However, we know very little about the effects of variable maternal nutrition on the quality of lactational outputs in red deer hinds.

Summer lactation of red deer often coincides with deteriorating pasture quality in the New Zealand pastoral environment (Nicol and Stevens, 1999) due largely to the effects of drought conditions in some regions and the general process of seasonal pasture senescence (Asher et al., 1996). In line with nutritional practices for traditional ruminant domesticants (sheep and cattle), farmers strive to provide pastures and supplementary feeds of high energetic value (i.e. >10 MJME/kg DM) in sufficient quantities to promote optimum lactational yields of hinds. This is indirectly measured by calf growth rates up to weaning (recognising that there is also a contribution of direct pasture intake by the calf from about six weeks of age).

On standard perennial ryegrass/white clover pastures managed optimally to provide the desired energetic level, growth rates of red deer calves approach 450 g/day over the first 12 weeks of life, resulting in calf weights of about 47-50kg in early autumn (actual weaning often occurs later than this on some farms). However, some on-farm observations, in which novel crop and forage species have been incorporated into the nutritional regimen over lactation, report growth rates in red deer calves up to 700 g/day (Beatson et al., 2000). This raises questions about the optimal nutritional requirements of lactating red deer hinds to express their true genetic potential for lactation and calf growth outputs. Do non-conventional crops and forages provide additional nutrients that support calf growth rates 30-40% higher than on standard pastures?

In this study we question the assumption that energy is the major determinant of lactational performance of red deer, as measured by calf growth. In both sheep and cattle, crude protein (CP) concentrations in the diet of 14 to 18% are required to maximise lactational output (ARC, 1980). Often summer pastures fall below this level and so we test the hypothesis that during lactation, protein availability may be limiting to red deer performance.

This hypothesis is based primarily on research that shows that red deer milk has a higher content of protein (12-13%) than is the case for sheep (5.5%) and cattle (3-4%) (Arman et al., 1974; Krzywinski et al., 1980). Furthermore, lactating hinds under severe nutritional constraint appear to rapidly catabolise their own muscular reserves of protein in order to support, albeit at reduced levels, offspring growth (although it is recognised that available fat reserves are probably previously exhausted at this point).

3 Materials and Methods

3.1 Composition of feed rations

The experiment was a two by two factorial design with four replicates. The factors were energy and protein. Diet energy densities were approximately 10.3 and 12.4 MJME/kg DM for low and high energy diets respectively. Diet protein densities were approximately 120 and 230 g CP/kg DM for low and high protein diets respectively.

Pelletised rations were formulated to contain known but differing ratios of energy to protein content (Table 1). This was achieved by altering the ratios of several primary ingredients, principally grass seed fibre, barley/wheat, molasses and soybean meal. The 'standard' pellet was a commercially available mix formulated for deer but containing similar principal ingredients.

Table 1: Energy/protein (E/P) concentrations, dry matter content and ingredients of pelleted rations used in the study

	Ration Nutrient Status (Energy/Protein)				
	Standard	1 (LE/LP)	2 (LE/HP)	3 (HE/LP)	4 (HE/HP)
Dry Matter (%)	87.7	89.3	89.3	88.8	88.8
Energy (MJME/kg DM)	10.5	10.3	10.3	12.5	12.3
Protein (g/kg DM)	140	121	241	120	212
Ingredients (g/kg as fed)					
Grass seed fibre		654	509	-	-
Barley		145	-	390	-
Wheat		-	-	500	671
Molasses		40	40	40	40
Soy bean meal		-	290	19	230
Oaten chaff		60	60	-	-
Mineral mix[1]		101	101	60	60

[1]Mineral mix included bentonite, limestone, dicalcium phosphate, sodium chloride, calcined magnesite and a trace element mix, in the ratio 50:30:10:7:3:1 for low energy diets and 10:20:10:7:3:1 for high energy diets.

3.2 Animals and management

- A pool of 24 mature (>4 years old), parous red deer hinds (*Cervus elaphus scoticus x hippelaphus*), with known conception dates in 2005, was selected in June 2005 (around Days 70-90 of pregnancy). They were maintained as a single group on the Invermay Flats Farm from early July 2005.

- Based on assessment of temperament, 18 of these hinds were selected in September 2005 to calve indoors within individual pens. It was anticipated that 16 of these hinds, based on successful calving, would enter the trial near their parturition date.

- The 18 hinds were pre-conditioned to "standard" pellet rations (Table 1) at pasture from 3 November to pen entry on 14 November. During pre-conditioning, the hinds within this group were offered amounts of supplementary pellet rations increasing from 200g/head/day to 1kg/hind/day 10 days later.

- Hinds were individually housed in their pens from 14 November on total *ad-libitum* concentrate rations based on "standard pellets" and of lucerne chaff at 5% by weight of the previous days intake for roughage.

- Pens were of a minimum area of $10m^2$, had natural lighting and ad-libitum water. The flooring was a deep (10cm) layer of untreated *Pinus radiata* sawdust over timber or concrete. One corner of each pen contained a calf refuge area of ~$0.5m^2$ that could not be accessed by the hind. Feed to hinds was placed in wooden feed bins approximately 1.0 m above floor level. Calf refuges also contained a small feed bin accessible by calves only. Hinds had visual contact with other hinds via netting or slatted wood partitions.

- Feed was offered daily while hinds were released into large outside pens for exercise. Residuals from the previous day's allocation were weighed before providing the current offer. If no residuals were present the offer was increased by ~10% from the previous day until approximately 10% of the offered feed was refused. Intake was calculated as the difference between offer and residual within each 24-h period, corrected for dry matter.

- As hinds calved, they were individually allocated to treatment group, approximately balanced for birth date and calf sex. Calves were tagged and weighed within 24h of birth, but never within the first 4 hours.

- Once hinds had calved, the treatment ration was introduced over 10 days by replacing the "standard" pellet at a rate of 10% per day. Thereafter, the hind remained on the allocated treatment ration (1, 2, 3 or 4) until calf weaning at 12 weeks of age. Calves received a ration offer of Ration 4 (HE/HP) and chaff weighed and replaced on a weekly basis or as necessary.

- Hinds were weighed weekly from 3 November until calf weaning. Calves were weighed at birth, a fortnight later and thereafter weekly until 10 weeks of age (weight data for weeks 11 and 12 were collected but lost through an electronic storage error). For daily feeding, hinds were separated from their calves for 30-60 minutes. Calves remained within the pen until ~6 weeks of age, at which point they were also placed in outside pens with other calves during feed offer replacements.

- Hinds were weaned off their calves at the calf's 12-week anniversary. Animals were all returned to pasture at completion of the trial.

3.3 Ethical considerations

- Hinds considered temperamentally unsuited to indoor housing were excluded from the study prior to feed conditioning. Assessment was based on general yarding temperament towards handlers and reaction to humans within the field.

- A contingency was established to remove any hind/calf unit from the indoor trial if weekly weighing of calves indicated failure of a calf to achieve a minimum of 200g/day growth rate during the preceding week.

3.4 Statistical analysis

Daily intake, energy and protein data, and weekly calf and hind live weights and growth rates, were analysed by analysis of variance at each time, with the treatment structure given by the factorial interaction of dietary energy and protein treatments. Appropriate summary statistics for these variables were analysed in the same way. Individual calf and hind live weight changes from two to 10 weeks were analysed by linear regression against both total energy intake and total protein intake, also fitting calf sex and its interaction with the respective explanatory variables. Statistical significance was assessed at the 5% level unless otherwise indicated.

4 Results

4.1 General

Of the 18 hinds that calved indoors, 16 produced viable singleton calves that survived to weaning at 12 weeks of age (Table 2). Two of the hinds presented stillborn calves, including a set of twins.

One hind/calf unit in Group 1 (LE/LP) was effectively removed from the study due to failure of the calf to attain the threshold growth rate of 200g/day between weeks 7 and 8 from birth. The hind exhibited an unusually low voluntary intake of Ration 1 (~1-1.5kgDM/day). The pair were placed on a "rescue" ration (Ration 4, HE/HP) until calf weaning at 12 weeks of age ; and the data for this pair were excluded from the analysis.

Table 2: Summary statistics for hinds :calves within the study.

Treatment Group	Ration (E/P)	Number of hind:calf units	Calf sex ratio (M:F)	Mean (±SEM) calf birth weight (kg)	Mean (±SEM) calf wean weight at 12 weeks (kg)	Mean (±SEM) calf growth weight (g/day)
1	LE/LP	3*	2:1	9.6 (0.19)	37.4 (2.1)	386 (27)
2	LE/HP	4	3:1	9.8 (0.59)	38.5 (1.)	404 (20)
3	HE/LP	4	2:2	9.8 (0.43)	37.5 (2.7)	394 (32)
4	HE/HP	4	2:2	9.7 (0.54)	38.5 (1.4)	403 (26)

*n=3 in group 1 following "rescue" of one hind : calf unit

4.2 Feed intake

While attempts were made to prevent calves accessing feed offered to their dams, casual observation indicated that some, if not all, calves ingested some of the dam's feed offer from about 6-8 weeks of age. Few calves ingested pellets offered to them within their refuge areas. Therefore, the "dam" feed intake data are deemed to represent combined intakes of the dam/calf unit, with the calf contribution to feed disappearance occurring in the latter half of the study period.

Daily dry matter (DM) intakes varied enormously between individuals and days, ranging from <1.0kg to >7.0kg. Mean intakes for treatment groups (Figure 1) generally increased from around 2.2-2.4kg DM/d around calving to a plateau of 3.5-5.0kg DM/d 20-40 days later. Overall mean intake, either per hind or adjusted to liveweight/metabolic body weight, was significantly higher (by about 35-40%) for hinds receiving low energy rations than those receiving high energy rations, irrespective of crude protein level ($P<0.05$). Average energy intake (Figure 2) was similar across all treatment groups ($P>0.1$), whether on an absolute basis or corrected for body mass. Consequently, average protein intake (Figure 3) varied enormously across treatment groups ($P>0.001$), with a range at mid-late lactation of <400g to >1000 g/d from Group 3 (HE/LP) and Group 2 (LE/HP), respectively.

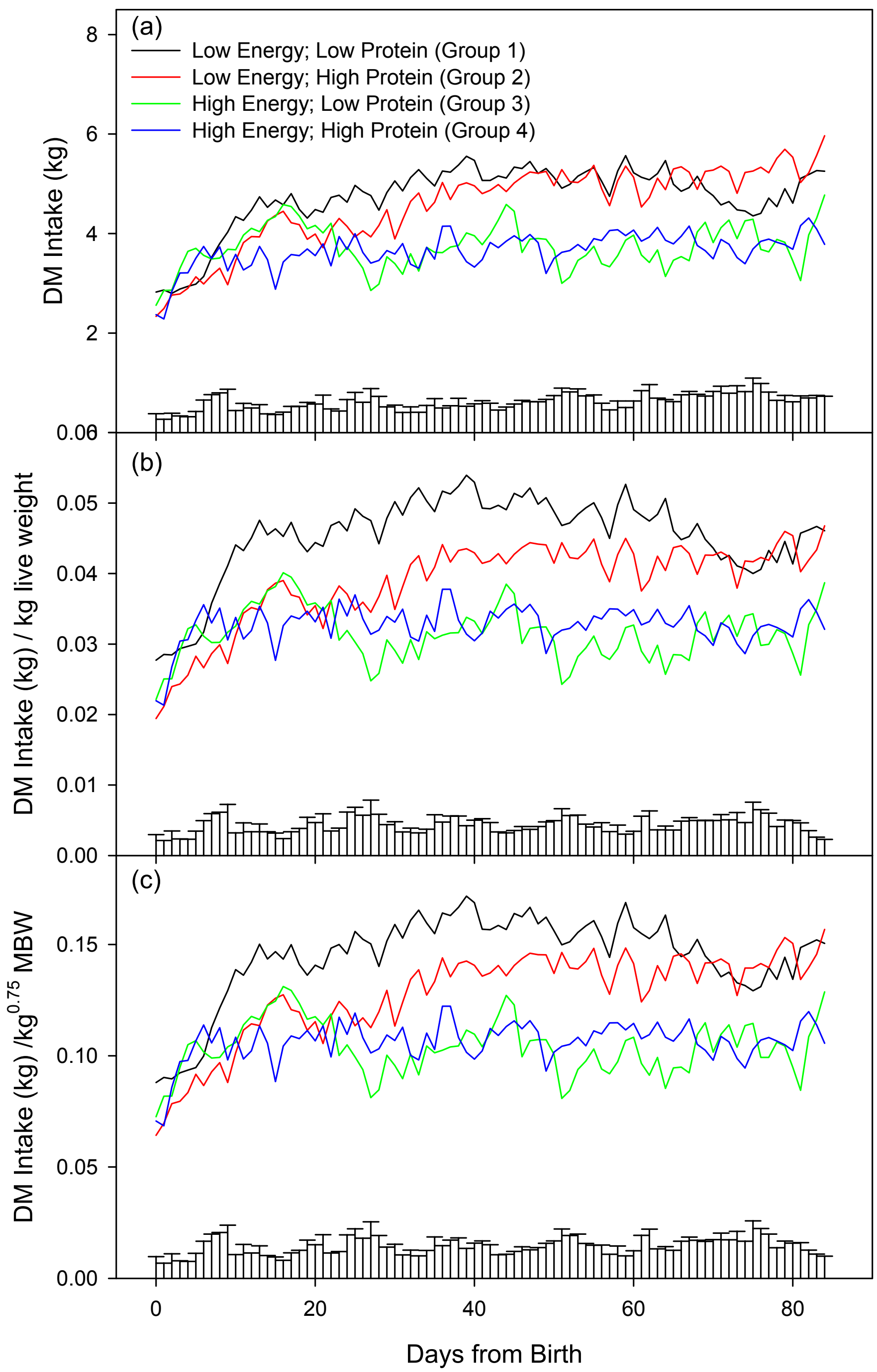


Figure 1: Mean (+sed) daily dry matter intake for hinds in Groups 1, 2, 3 and 4 relative to calving date: (a) total intake per hind, (b) intake per kg liveweight and (c) intake as a function of metabolic body weight.

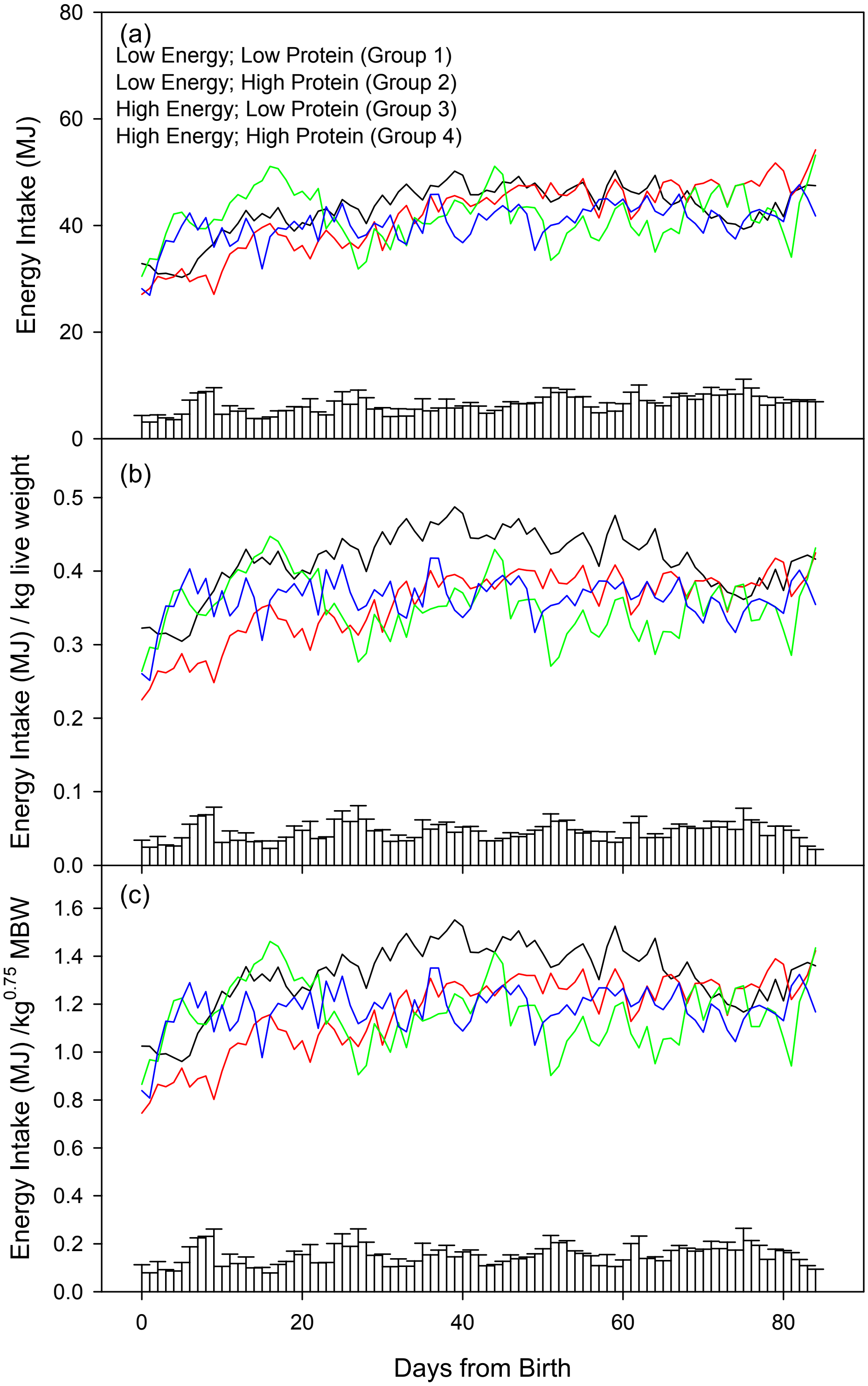


Figure 2: Mean (+ sed) daily energy intake (MJME) for hinds in Groups 1, 2, 3 and 4 relative to calving date: (a) total energy consumption per hind, (b) consumption per kg liveweight and (c) consumption as a function of metabolic bodyweight.

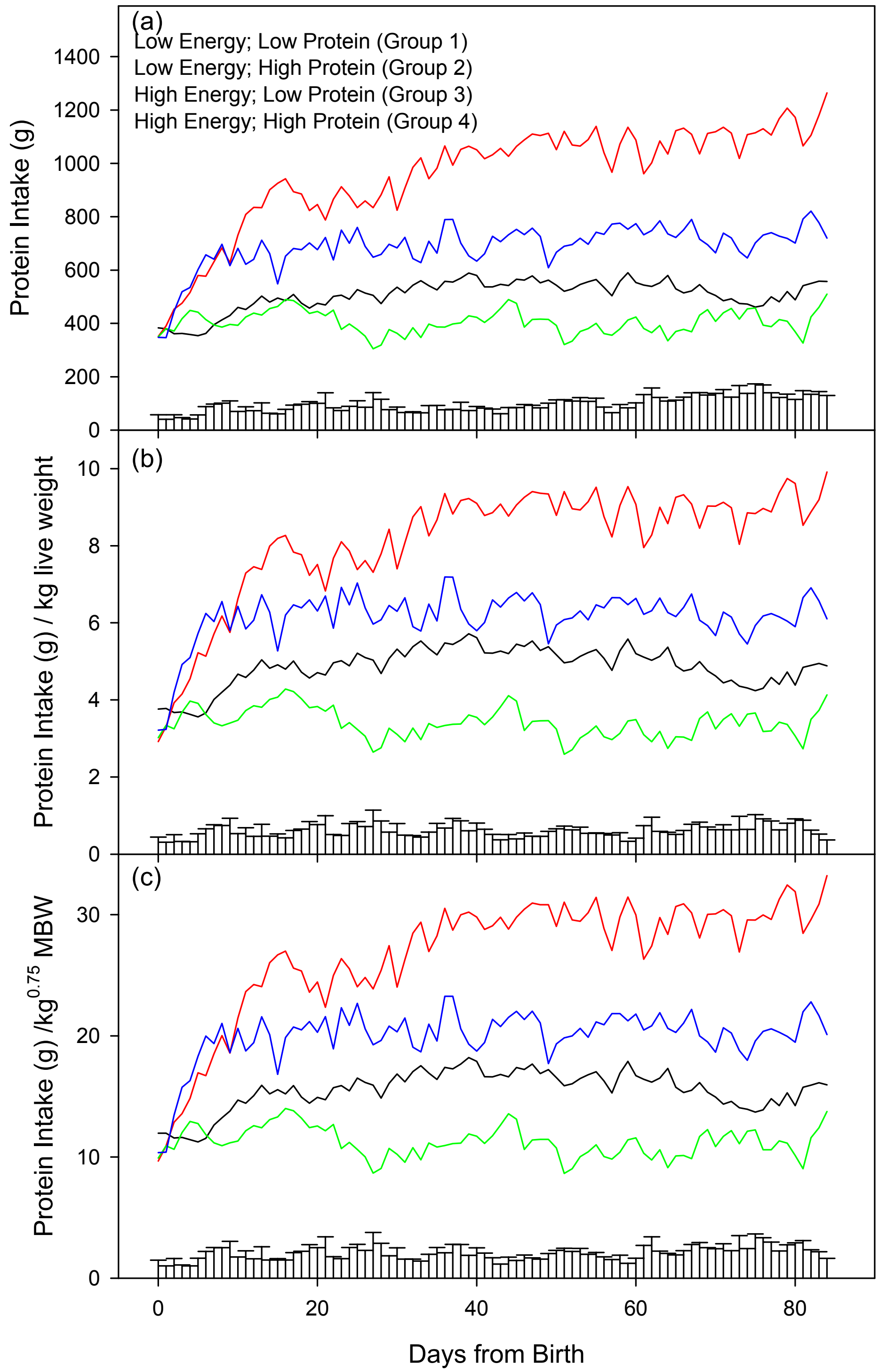


Figure 3: Mean (+sed) daily protein intake for hinds in Groups 1, 2, 3 and 4 relative to calving date: (a) total protein consumption per hind, (b) consumption per kg liveweight and (c) consumption as a function of metabolic body weight.

4.3 Calf growth rate

Mean calf growth rates did not vary significantly between treatment groups (Figure 4), ranging from 500-600g/day within the first two weeks to ~350 g/day for the remainder of the suckling period.

Ten-week weights averaged ~40kg. However, there was considerable individual calf variation in growth rate within each treatment.

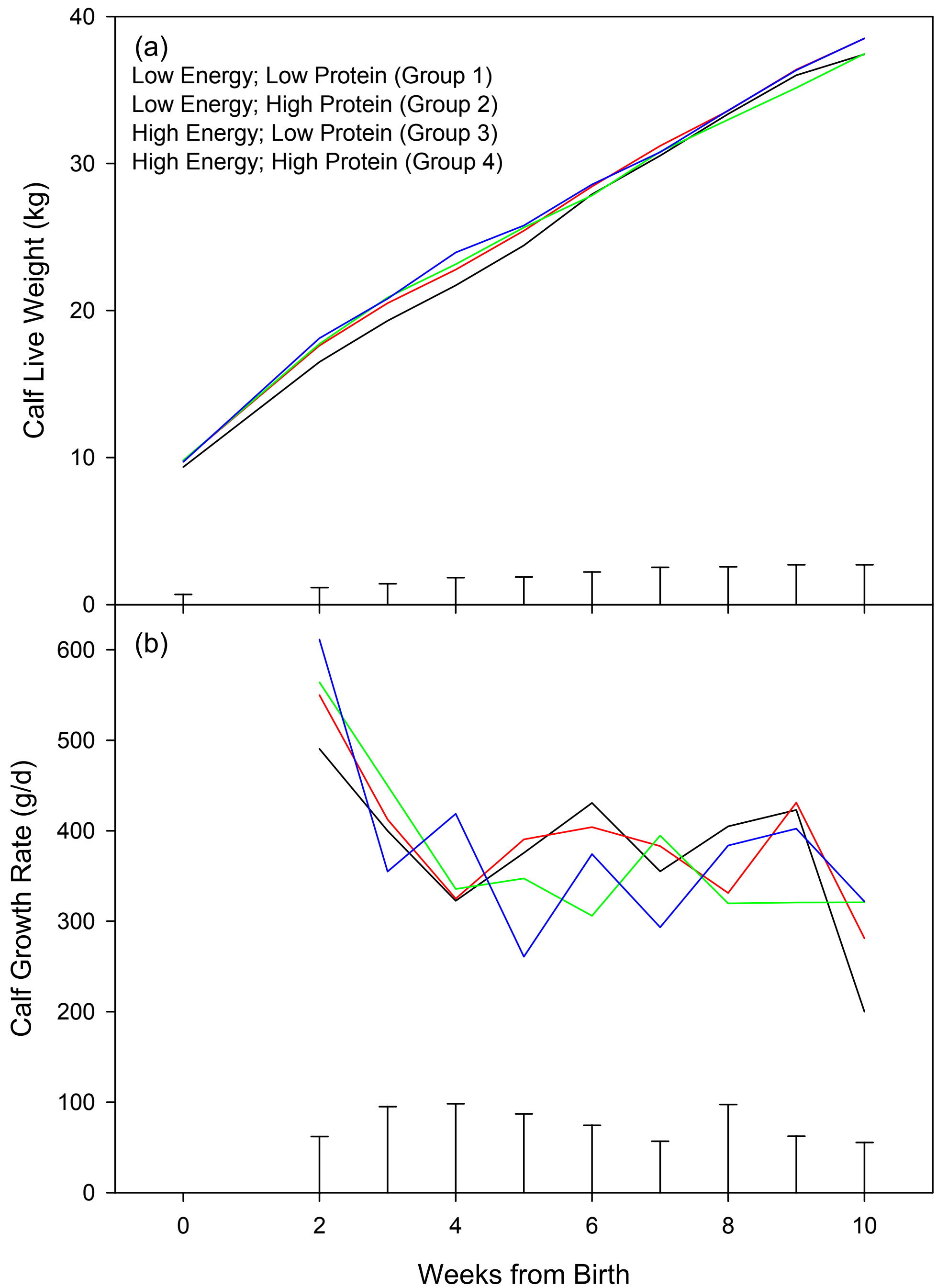


Figure 4: Mean (+sed) liveweight profiles (a) and weekly growth rates, (b) of calves born to hinds in Groups 1, 2, 3 and 4.

4.4 Hind liveweight changes

Mean liveweights of hinds generally increased by ~10 kg during the 10-week period immediately post-calving. While there was a 10 kg difference in mean post-partum weights of hinds across groups (an artefact of treatment allocation based on birth date and calf sex), there were no significant treatment group differences in mean liveweight change over the next 10 weeks of lactation (Figure 5). However, as with calf growth, there was wide within-treatment group variation between individuals.

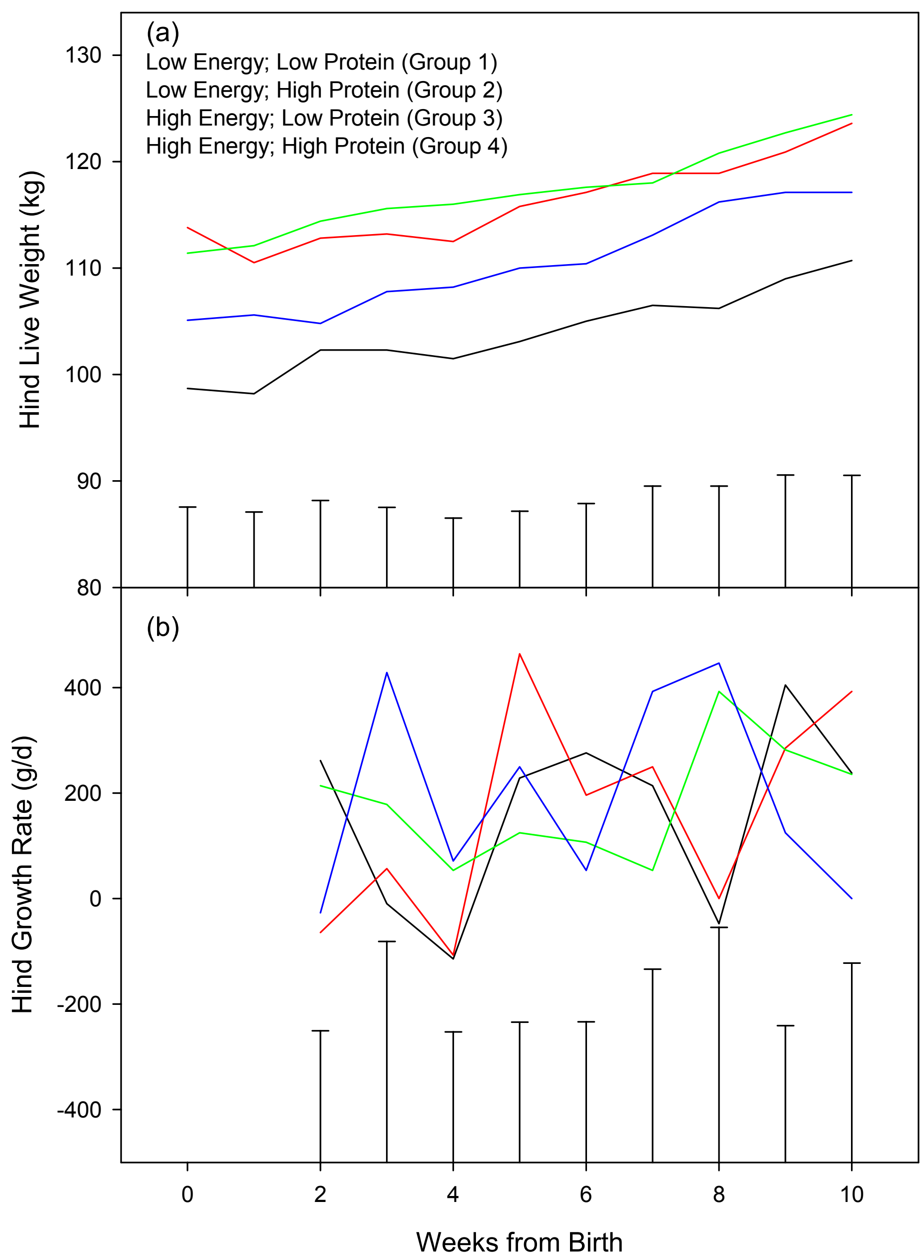


Figure 5: Mean (+sed) liveweight profiles (a) and weekly liveweight changes, (b) of hinds in Groups 1, 2, 3 and 4.

4.5 Relationships between nutrient intake and hind/calf performance

Regression analysis of the relationships between nutrient intake (energy and protein) and liveweight change in calves and hinds, based on wide individual animal (i.e. within treatment) variation for these variables (Figure 6) revealed that total energy intake had significant effects on calf and hind growth/liveweight change (P<0.005), with a marked calf sex effect in relation to change in calf weight (P<0.05). However, there were no significant effects of variation in protein intake on any growth/liveweight parameter (Figures 6 (b) and 6 (d)).

Figure 6(a) shows the relationship of calf live weight on total hind energy intake. An increase of 100MJ in hind energy intake corresponded to an increase in calf weight of 2.5 kg (SED 0.66 kg; P<0.01) for both males and females, with males on average 3.1 kg (SED 0.63 kg; P<0.001) heavier than females at any given level of hind energy intake.

Figure 6(c) shows the relationship of hind live weight on total energy intake. An increase of 100MJ in hind energy intake corresponded to an increase in hind live weight of 0.67 kg (SE 2.9 kg; P<0.05), with no evidence of difference with calf gender (P>0.05).

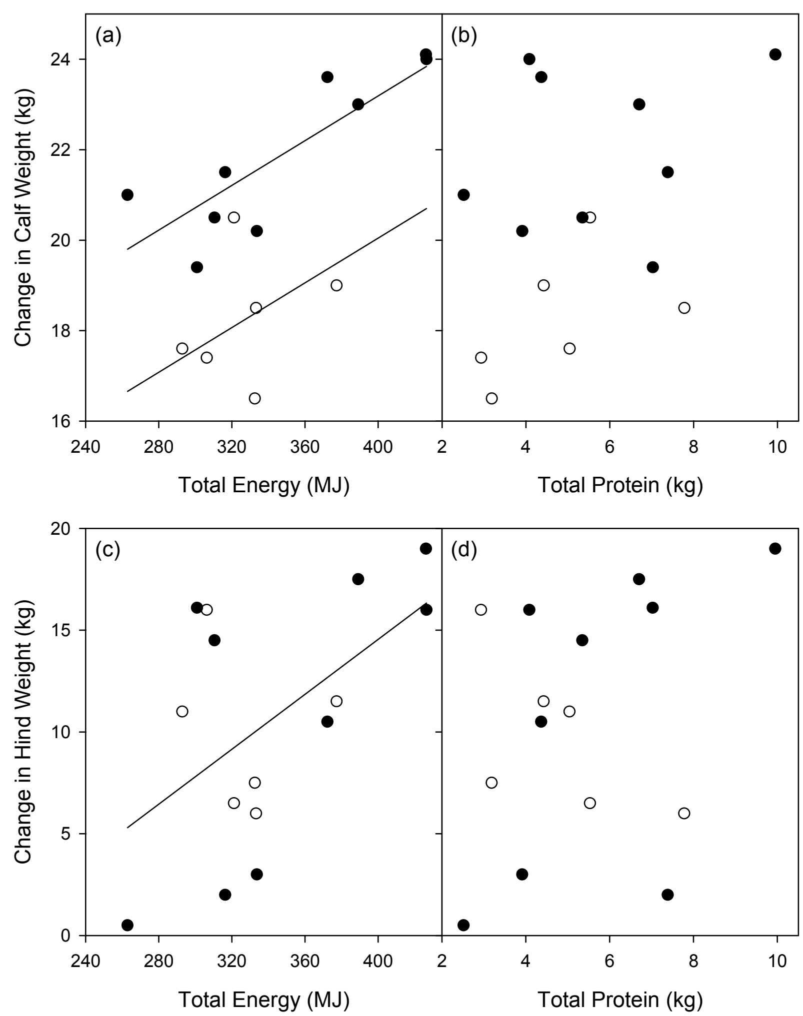


Figure 6: Regression plots of total energy (a) and total protein (b), intake of individual hinds (n=15) on change in calf liveweight between 2 and 10 weeks of age; and regression plots of total energy (c) and total protein (d), intake of individual hinds (n=15) on their own liveweight change between 2 and 10 weeks from parturition. The plots differentiate calf sex (○=female; ● = male).

5 Discussion

5.1 What drives lactational performance in red deer hinds … energy or protein?

The ME content of feed for grazing ruminants, has long been viewed as the primary measure of feed quality (AAC, 1990; ARC, 1980; NRC, 1985). For lactating red deer hinds, feed quality recommendations indicate a desirable ME content of about 10-11 MJME/kgDM to enable high lactational outputs (Beatson et al., 2000). For traditional perennial ryegrass/white clover pastures in New Zealand, the ability to provide feed of such quality can be difficult over summer months due to dry conditions in many regions and the natural process of seasonal pasture senescence due to reproductive partitioning of growth of grasses (Asher et al., 1996; Nicol et al., 2000; Nicol and Stevens, 1999).

Prevention of the reproductive state of ryegrass through judicious utilization of leaf prior to seed head formation can lead to forage of 10-11 MJME/kg DM over summer lactation if other factors are not limiting (e.g. water availability and high temperatures). However, even under such conditions of quality pasture supply most farmers experience red deer calf growth rate caps of ~450 g/day between birth and weaning three months later (Beatson et al., 2000). The demonstration that the genetic potential for growth of young red deer exceeds this cap (Beatson et al., 2000) raises questions about factors limiting expression of growth potential.

The hypothesis proposed in the present study argues that the amount of protein in forage may be a major determinant of milk production, and hence calf growth, in red deer. Current recommendations in sheep and cattle recommend between 14 and 18% crude protein in the diet to achieve maximum lactational output (ARC, 1980). Often summer pastures are low in protein due to dead material build up and slow pasture growth (Litherland et al., 2002; Waghorn and Barry, 1987). In other words, protein availability within summer pastures may be limiting to hinds achieving their true potential for lactation. While, protein availability is not seen as limiting under pastoral systems for sheep and cattle, these species lactate during spring rather than summer and may differ in their protein requirements from red deer due to the high protein content of red deer milk (Arman et al., 1974; Krzywinski et al., 1980).

Previous research has shown that animals are able to adjust voluntary feed intake to meet energy demands when given pelleted diets of varying energy density (Dinius and Baumgardt, 1969, 1970; Webster et al., 2000). Pelleted diets have a small particle size and therefore give the animal the opportunity to attain their metabolic requirements for energy and protein without the bulk limitations associated with variations in energy density in forages such as pasture. Therefore, this research has given us the ideal regimen to investigate the true role of protein in determining lactational output from hinds without the limitations to intake that may be exerted in pasture diets.

The experimental regimen has provided evidence that energy intake of the hind and the calf will be the most important driver of calf and hind liveweight changes during lactation. The bulk limitations that lower quality pasture exerts on voluntary feed intake have not been well defined for red deer, but the variation in calf liveweight gain due to changes in energy density of the pastures offered to red deer during lactation (Stevens, 1999) does give us a clue to its effects. So while energy density does not affect energy intake when the diets are presented as a pellet, it does appear to have some effect on calf growth rate in the field. Further research is required to adequately demonstrate the relative importance of the contribution of hind lactation and calf forage intakes in achieving the final calf performance from birth to weaning.

Perhaps the most striking feature of these data is the clear demonstration that energy content of feed drives potential voluntary feed intake. Lactating red deer hinds compensate for low energy intakes in feed by increasing their voluntary intake in an attempt to meet their energy requirement. Thus, while hinds on low energy rations (10 MJME/kg DM) exhibited higher voluntary intakes than those on high energy rations (12.5 MJME/kg DM), irrespective of protein levels, the overall mean energy intakes of all groups were the same at equivalent stages of the lactation cycle (e.g. 1.2-1.4 MJ/kg MBW/day >20 days from birth).

In essence, the results of the present study strongly support the concepts of energy maximisation and do not support the central hypothesis of potential protein deficiency. Data from this experiment suggests that as little as 400 g/d is adequate for lactation in red deer hinds. The lack of interaction between protein and energy suggests that if 5 kg DM/d was eaten then the protein concentration could be as low as 8% with no detrimental impact on lactational output. However, in normal pasture situations forage with 8% crude protein will also have a very low energy density and a high bulk limitation to intake. This would then limit intake to below 5 kg DM, and so increase protein requirements. Therefore, extrapolating protein requirements beyond pelleted diets would be unwise.

A consequence of this "energy balancing" was the generation of substantial between-group variation in mean protein intake (i.e. 10-30g protein/kgMBW/day). The inability to demonstrate any effect of such variation in protein intake by hinds on calf growth rate and changes in hind weight clearly indicates that protein was not limiting in this study. This contrasted with a clear demonstration that between-hind variation in overall energy intake (despite similar group mean intakes) was positively correlated with calf growth rate and change in hand liveweight; supporting the notion that feed energy value is a major determinant of lactational performance of red deer hinds.

The calf growth rates measured in this study were below the 450 g/d exhibited in many pasture situations. This suggests that the calves were gaining most of their nutrition from the hind, with little intake of the pelleted diet. Of interest is the relationship between calf and hind liveweight gain and hind energy intake. The overall gain of the hind/calf unit was 3.17 kg/100 MJME. This then translates into an energy requirement for gain of 31.5 MJME/kg. This is similar to previous estimates of liveweight gain for young weaner stags (Fennessy et al., 1981) and lower than others (Suttie, 1987; Webster et al., 2000) and indicates that the breeding hind/calf pair converts energy intake to liveweight gain very efficiently.

5.2 The methodological model

While the results of the present study clearly indicate that energy, rather protein, may be the major determinant of lactational performance/calf growth in red deer, there were some issues encountered with the methodological model used. Indeed, the use of indoor housing of individual hinds during parturition and lactation is a radical departure from more conservative methodologies of outdoor group feeding used in the past. It did, however, provide a precise feeding model that generated detailed information on individual variation in feed, energy and protein intake over lactation that would not be possible in a group or field situation.

There were some ethical concerns raised prior to the start of the study, principally related to behavioural habituation of hinds/calves to an artificial indoor environment, and the ability of calves to seek protection from trampling should their dams become panicked at any stage. We offer the following observations from the study …

- Hinds were habituated to individual indoor confinement at least two weeks before expected parturition. While there was considerable individual variation in their responses to handlers (ranging from timid to aggressive), all hinds selected for the study (based on early observations of their temperament in the yards) adapted well to their environment. However, one hind exhibited very low intakes after calving, resulting in marked live weight loss and poor calf growth. This animal was of nervous disposition and seemed unable to cope with the particular diet on offer.

- A total of 16 out of 18 hinds exhibited uncomplicated birthing and bonded with their calves. At no stage were there any concerns with calf abandonment. Calves used their refuge areas frequently and there was no indication of calf injuries from trampling or aggression during the study.

- One hind presented stillborn twin calves, requiring veterinary assistance. The twinning was unexpected as it had not been previously detected by ultrasonography.

- Calves habituated well to handlers during daily hind/calf separation. Few incidences of panic occurred and most calves actually became very tame.

- However, the growth rate of the calves was lower than expected given the type of nutrition available to them and their dams. There was evidence that most calves relied entirely on their dam's milk for nutrition throughout the trial. A few calves ingested pellets from their dam's trough even though it was elevated >1.0m off the floor. The generally low pellet intake of calves may have limited their growth potential and raises questions over the influence of forage intake on their growth rates. Future studies of this nature may need to seek means of attracting calves to ingest forage.

6 Acknowledgements

This study was conducted under contract to DEEResearch Ltd. We thank all the Invermay staff who assisted with animal feeding and care.

7 References

AAC. 1990. Feeding standards for Australian livestock. Ruminants. CSIRO, East Melbourne.

ARC. 1980. The nutrient requirements of ruminant livestock. Agricultural Research Council, Farnham Royal.

Arman, P., R., N. B. Kay, E. D. Goodall and G. A. M. Sharman. 1974. The composition and yield of milk from captive red deer (*cervus elaphus* l.). Journal of Reproduction and Fertility 37: 67-84.

Asher, G. W., M. W. Fisher and P. F. Fennessy. 1996. Environmental constraints on reproductive performance of farmed deer. Animal Reproduction Science 42: 35-44.

Beatson, N. S., A. G. Campbell and H. G. Judson. 2000. Deer industry manual, new zealand. Herald Communications Ltd, Timaru.

Dinius, D. A. and B. R. Baumgardt. 1969. Regulation of food intake in ruminants. 6. Influence of caloric density of pelleted rations. Journal of Dairy Science 53: 311-316.

Dinius, D. A. and B. R. Baumgardt. 1970. Regulation of food intake in ruminants. 6. Influence of caloric density of pelleted rations. Journal of Dairy Science 53: 311-316.

Fennessy, P. F., G. H. Moore and I. D. Corson. 1981. Energy requirements of red deer. Proceedings of the New Zealand Society of Animal Production 41: 167-173.

Krzywinski, A., K., Krzywinska, J. Kisza, A. Roskosz and A. Kruk. 1980. Milk composition, lactation and artificial rearing of red deer. Acta Theriologica 25: 341-347.

Litherland, A. J. et al. 2002. Seasonal variations in pasture quality on New Zealand sheep and beef farms. Proceedings of the New Zealand Society of Animal Production 62: 138-142.

Nicol, A. M., H. G. Judson, D. R. Stevens and N. S. Beatson. 2000. The productivity of deer grazing permanent pasture. Asian-Australian Journal of Animal Science 13: 46-48.

Nicol, A. M. and D. R. Stevens. 1999. Trends in the use of forages in new zealand deer production. Proceedings of the Fifth International Symposium on the Nutrition of Herbivores.

NRC. 1985. Nutrient requirements of sheep. 6th ed. National Academy Press, Washington, DC.

Stevens, D. R. 1999. Late-lactation and post-weaning growth studies 1999., Deer Master, South Canterbury and North Otago Deer Farmers Association.

Suttie, J. 1987. Young hind growth: More energy required than expected. Deer Farming: 10.

Waghorn, G. C. and T. N. Barry. 1987. Pasture as a nutrient source. In: A. M. Nichol (ed.) Feeding livestock on pasture No. Occasional Publication 10. N.Z. Society of Animal Production.

Webster, J. R., I. D. Corson, R. P. Littlejohn, B. M. Masters and J. M. Suttie. 2000. Effect of diet energy density and season on voluntary dry-matter and energy intake in male red deer. Animal Science 70: 547-554.