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The random bouncing ball

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Abstract

A retrospective, biased, personal review of a contribution to animal production research. The review covers aspects of animal behaviour; maternal behaviour, and deer behaviour. It recalls studies on the effect of the heat of warming feed on the lower critical temperature of ruminants and summarises more recent studies on analgesia of the antlers of yearling stags. A significant proportion of the review revolves around work in grazing ecology mainly mixed animal species grazing. Deer are equivalent to sheep in grazing around cattle dung pats; goats have a similar dietary preference for clover as sheep unless the clover is short; cattle are disadvantaged when continuously grazed with sheep, but not with rotational grazing; diet composition is markedly affected by mixed grazing.

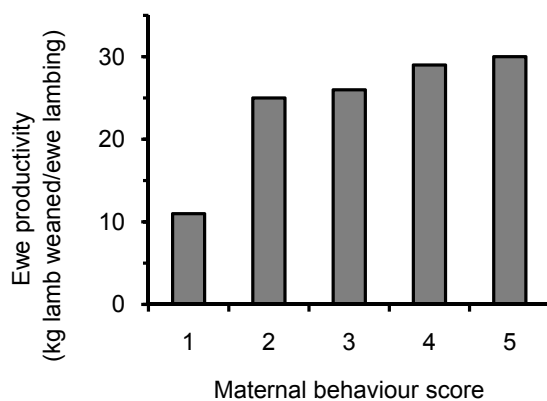
Keywords: review; behaviour; metabolic rate; velveting; grazing

Introduction

I found the invitation to prepare a ‘Living Legend’ paper an enigma. It is hopefully not a posthumous, retrospective review, nor can it be an independent assessment of a contribution to science; it can only be my biased, selective, personal review. The title, ‘The random bouncing ball’ reflects the frustration of my line-managers over the years, with my propensity to accept any question, as long as a good hypothesis could be derived, in any area of animal production, particularly if the idea originated from a bright student. ‘Why don’t you concentrate on one area and be good at it’ was the reprimand.

I hope that I can demonstrate that there were some common threads running through the randomness. To this end I have selected three threads: applied animal behaviour, ruminant physiology and grazing ecology.

Figure 1 The influence of ewe maternal behaviour score (MBS) on ewe productivity (kg lamb weaned per ewe lambing). MBS 1 = Poor, 5 = Excellent. (from O’Connor et al. 1985).



Applied animal behavior

Maternal behaviour

Ron Kilgour is considered to be the father of animal behaviour research in New Zealand and in 1972 he initiated work on the behaviour of ewes at lambing (Kilgour 1972). In the mid-1980s, there were a multitude of breeds and cross-bred ewes involved in the Booroola evaluation trial at Ashley Dene, Lincoln University’s dryland farm. These ewes provided a good resource for a study on ewe maternal behaviour using the scoring system developed by Ron and George Alexander (Alexander et al. 1983). For her honours project, Cheryl O’Connor and the farm staff scored ewes on their propensity to flee or stay-around when a shepherd tagged and weighed their lambs within 24 hours of birth. It was perhaps not surprising that ewes with a high maternal score, those that stayed-around, reared more lambs than those that ran off. It was less predictable that, even adjusted for litter size, high maternal behaviour score (MBS) ewes reared heavier lambs to weaning, leading to greater overall productivity (Fig. 1, O’Connor et al. 1985). Cheryl extended this work for her PhD at Edinburgh University and we published an early estimate of the heritability of maternal behaviour (Parker et al. 1985). A number of subsequent presentations to this Society have furthered this theme with recent examples being Corner et al. (2005) and Everett-Hincks et al. (2007).

Another excursion into maternal-offspring behaviour involved Dr Mamdouh Sharafeldin who visited Lincoln College on sabbatical leave with Professor Coop. Mamdouh had monitored behaviour of sheep in Egypt. While he was at Lincoln, he and I observed the sucking behaviour of pure-bred and cross bred beef calves at Ashley Dene and demonstrated that the 10% increase in milk production of the cows suckling cross-bred calves was associated with greater suckling activity (Nicol

& Sharafeldin 1976) supporting the recommendation that cows suckling cross-bred calves should be given preferential feeding over those with pure-bred offspring.

The well know behavioural issues of homosexuality and robust physical activity in groups of adolescent bulls in ‘bull-beef’ production systems are well known (Kilgour et al. 1977) and pose potential animal welfare problems and increased farm repairs and maintenance. A serendipitous mixing of groups of separately grazing steers and bulls in a student demonstration suggested that these problems were reduced in the mixture. This lead to a formal study by Aaron Meikle as a summer scholarship project, which confirmed that the agonistic interactions between bulls were reduced in various mixtures with steers (Fig. 2). This seemed to be mainly a dilution effect with less bulls per unit area (Nicol & Meikle 1997). This result was the stimulus of work which showed the welfare of rams in live exports was improved by penning them with wethers (Black 1997).

Figure 2 The incidence of agonistic behaviour of bulls and steers in differing mixtures (from Nicol & Meikle 1997). Standard error of the mean = 0.06.

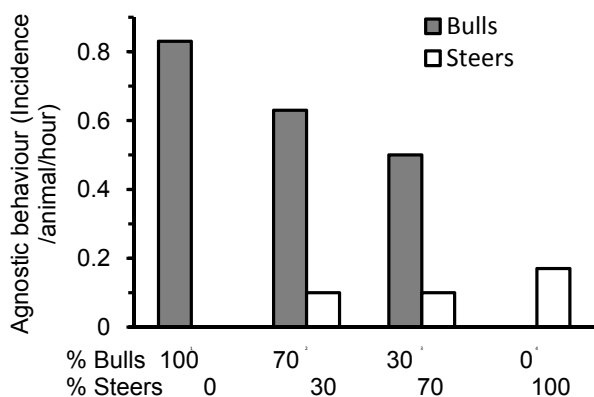
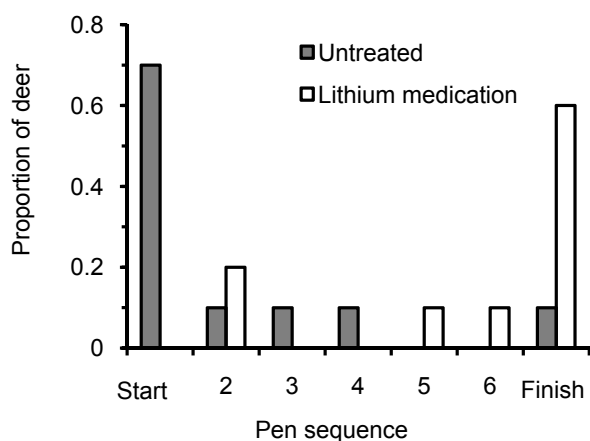


Figure 3 The proportional distribution of yearling stags after 150 seconds in a maze (from Prouting et al. 2004).



Deer behaviour

Changes in stag behaviour during the rut involving noise, physical injury, pasture damage and reduction in feed intake contributing to a 30% body weight loss during the roar, are the bane of velvetting stag operations. Although castration solves the problem of aggressiveness and liveweight loss of stags, it is not a commercial solution in the velvetting industry as castrated stags do not shed and re-grow antlers. Perhaps cryptorchidism would modify behaviour, prevent weight loss but not interfere with velvet production? On-farm trials in which groups of adult stags were tranquilised, crptoorchidism induced with application of a standard tailing ring and compared with controls, showed that some behaviour, such as roaring and fence-pacing were reduced (Nicol & Keeley 2002). There was no reduction in the weight loss of cryptorchid stags compared to entires during the rut, so although there was no effect of cryptorchidism on subsequent velvet production, the technique was not going to catch on.

Another approach to potentially modify deer behaviour was to add lithium to their drinking water. As her honours project Mel Prouting compared the behaviour of treated and untreated young stags. We were not game enough to do a pilot study with adult stags. The most interesting outcome was that lithium treated stags took less time to navigate a maze than their non-medicated peers (Fig. 3). They seemed to try and work it out rather than bash their way through (Prouting et al. 2004). The practicality of adult stags self-medicating on lithium curbed the enthusiasm for furthering this concept.

An interesting comment by a visiting farmer who ran sheep and cattle close to a bush area was that when their freezer was low in venison he would go into a paddock grazing cattle, not sheep to replenish his supplies. This was the precursor of our most recent deer behaviour observation made by Steven

Figure 4 The distribution of yearling hinds on pasture pre-grazed by cattle or sheep 1–3 days and 21–24 days after removal of cattle or sheep (from Foote et al. 2009).

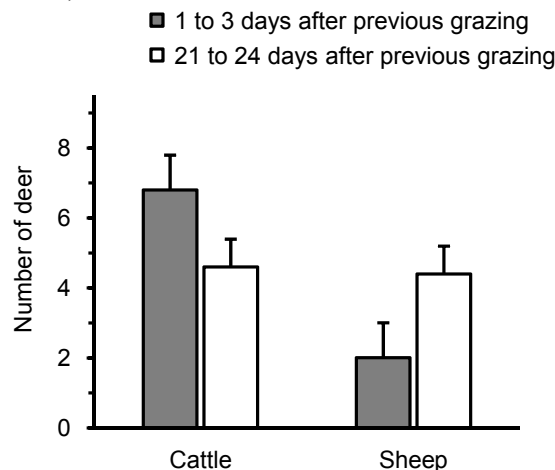


Table 1 The effect of the heat of warming on the lower critical temperature of cattle and sheep (from Nicol & Young, 1981, see paper for details of the methodology). m = Surface area of the animal (m^2); W = Heat production of the animal (watts).

Animal	Insulation	Level of production	Climate	Total body thermal insulation ($^{\circ}C/m^2/W$)	Heat production (W/m^2)	Lower critical temperature ($^{\circ}C$)	
						Non-feeding	During feeding
Weaner steer	Winter hair cover	Maintenance	Dry & calm	0.50	120	+12	+5
	Thin hair cover	Maintenance	Dry & calm	0.40	120	-2	+12
	Winter hair cover	0.5 kg/d	Calm	0.50	155	-30	-12
Beef cow	Winter coat	Maintenance & good condition	Dry & calm	0.54	107	-13	+6
	Winter coat	Maintenance & good condition	16 k/h wind	0.42	107	-2	+12
	Winter coat	Maintenance & good condition	Rain & 10 km/h wind	0.37	107	+4	+17
Dairy cow	Summer coat	20 L milk/d	Dry	0.45	154	-23	-7
Ewe	Woolly (100 mm)	Maintenance	Dry	1.1	60	-11	+13
	Shorn (7 mm)	Maintenance	Dry	0.24	60	+28	+33
	Woolly	2/3 pregnant	Dry	1.1	90	-42	-18
	Shorn	2/3 pregnant	Dry	0.24	90	+20	+25

Foote in his honour's project. He showed that in 77% of observations, deer preferred to graze on areas previously grazed by cattle than on those grazed by sheep for the previous six weeks (Fig. 4) (Foote et al. 2010). This grazing preference was not based on pasture mass or pasture composition as these were similar for both areas. The preference was short-lived as three weeks after removal of the sheep and cattle, deer showed no systematic preference for either area. Steven hypothesised that urine distribution may have contributed to the difference in early preference but no work has been done to substantiate this or to determine whether this preference for cattle pasture was associated with a difference in grazing intake of the deer.

Ruminant physiology

Heat of warming

When Tom Barry and I wrote a chapter on brassicas for Occasional Publication No 7 'Supplementary Feeding', one hypothesis we expounded for the lower than expected performance of livestock on brassicas in winter, was that the energy cost associated with heating the large volume of water consumed in these low dry matter feeds may increase their maintenance costs. The 'heat of warming' had been dismissed by Blaxter (1967) as an insignificant cost based on his calorimetric work using high dry matter feeds. This topic formed the basis of my PhD studies in Canada. A Canadian winter is a great source of cold everything. The indirect calorimeters at the University of Alberta, originally established by John Webster were then under the control of Australian, Bruce Young, who supervised them and myself. A series of trials in which the changes in body and skin temperature and metabolic rate of sheep subjected to moderate to extreme rumen cooling via a cooling

coil, or iced water infusions ensued (Nicol & Young 1990). In the end, we concluded that in many scenarios, ruminants produce sufficient 'spare' heat and simply divert this into the rumen and lose less through the body surface. However, at low feed intake and low environmental temperatures (Fig.5) metabolic rate can be significantly increased by the heat of warming. The implication of this heat diversion is an increase in the lower critical temperature of the animal. Critical temperature is the temperature below which, metabolic rate and thus maintenance requirement would increase. Table 1

Figure 5 Metabolic heat production of sheep measured at an ambient temperature of $+10^{\circ}C$ (open symbols) and $-20^{\circ}C$ (closed symbols) during ruminal infusion of water of $2^{\circ}C$ (square symbols) or $38^{\circ}C$ (round symbols). The volume of water was equivalent to 10% feed DM (from Nicol & Young 1990). W (vertical line) = Watts; m = Metre; W (horizontal line) = Live weight; SEM = Standard error of the mean.

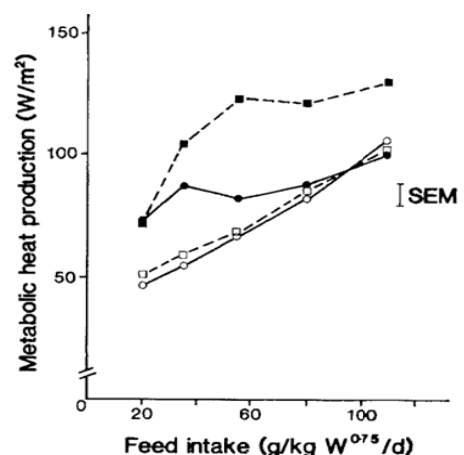
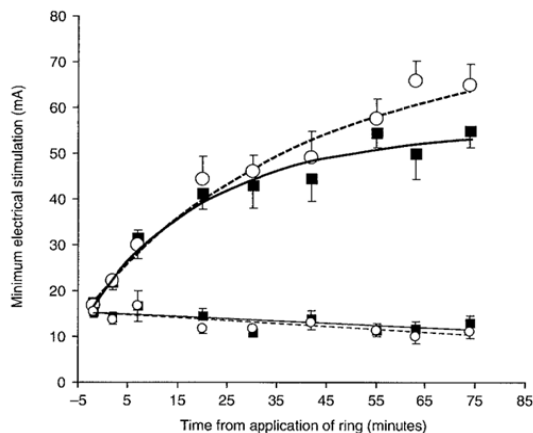


Figure 6 Minimum electrical stimulation required to elicit a behaviour response after application of a rubber ring applied by the cable-tie method (circles) or standard method (squares) to the pedicle of yearling stags. Measurements made above the ring (thick line) and below the ring (thin lines) (from Nicol et al. 2009).



shows some of these likely increases in lower critical temperature for a range of livestock types (Nicol & Young 1981). This aspect of energy metabolism may have relevance to some of the current wintering practices of dairy cows.

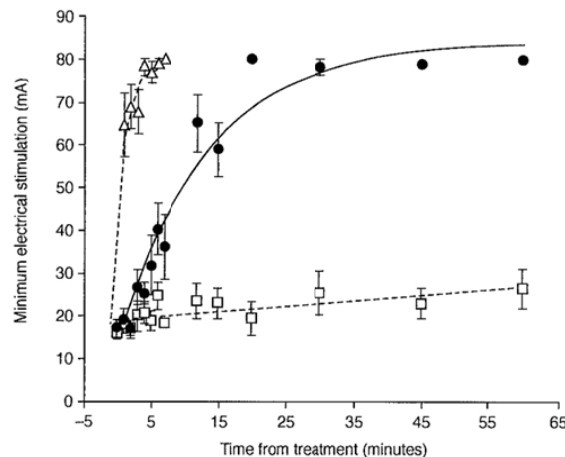
Velveting

Velveting of stags is a sensitive issue both in terms of animal welfare and market access (Wilson & Stafford 2002). The second example of my straying into the discipline of animal physiology was stimulated by an approach from local Canterbury deer farmers who had developed an alternative method for the application of rubber rings to the pedicle of yearling stags to produce analgesia in the antler. They wanted proof that their method, which involved pulling the ring around the pedicle, was as effective as the standard method of slipping the ring down over the antler. Easier said than done! The area of pain perception and the response to pain is a difficult one, even for physiologists such as my colleague Graham Barrell.

One approach used in studies on antler analgesia is to electrically stimulate the antler and record the presence of a pain sensation, or absence using analgesia, of specific behavioural responses. A criticism of this methodology is that stags may become refractory or 'stoic' to the stimulus and thus not show the response even although they may still sense pain. We thought we had avoided this issue by being able to electrically stimulate both below and above the ring and thus demonstrate (Fig. 6) that stags remained sensitive to a low level of electrical stimulation below the ring but quite quickly became unresponsive to a high level of stimulation above the ring.

We were able to show that this pattern of response was similar for rings applied by either method but this was not good enough for journal

Figure 7 Minimum electrical stimulation of velvet antler required to elicit a behaviour response after local anaesthetic (triangles), rubber ring applied by the cable-tie method (closed circles) and controls (open squares) (from Nicol et al. 2009).



referees who rejected the paper because it had not included a treatment of the so-called 'gold standard', an infusion of local anaesthetic around the base of the antler. The work was repeated to include this treatment (Fig. 7) (Nicol et al. 2009) and subsequently the alternative method of applying a ring, now known as the 'cable-tie' method, was accepted by the National Animal Welfare Advisory Committee of the Ministry of Agriculture, as a compliant method and is widely used due to the increase in the proportion of yearling stags growing branched antlers.

Grazing ecology

My initial interest in grazing ecology and in particular mixed species grazing ecology was kindled by dissatisfaction with the assessment of the relative profitability of sheep and beef cattle enterprises on the basis of their return per stock unit or more recently cents/kg of dry matter. It is simple to model a scenario where the performance of sheep is improved by the co-grazing of cattle, so that a 'credit' needs to be given to cattle before a financial comparison is made. For example, if say, the gross margin (GM) per stock for sheep and cattle co-grazed was \$110 and \$90 respectively, it is tempting to suggest that sheep should replace cattle. However if the GM per stock unit SU was \$100 for both sheep and cattle when run alone, then the co-grazed GMs should be adjusted to account for the co-grazing effect. Real data were needed to quantify this model. There is a large amount of literature on mixed grazing such as Nolan et al. (1989) and Wright et al. (1995), but the methodology is fraught with problems and there is a wide range of combinations and permutations of mixed grazing. Perhaps I should have taken heed of Frank Sinatra crooning 'Fools rush in where wise men never go' but in we went! This

Table 2 The mean sward height close to cattle dung pats and pegs when grazed by deer or sheep (from Trotter et al. 2006).

Grazing species	Sward height (cm)	
	Grazing close to cattle dung pats	Grazing close to pegs
Deer	9.0 ^a	7.4 ^b
Sheep	8.3 ^a	8.0 ^b

Table 3 Mean digestible organic matter intake of cattle (CA), sheep (SA) and goats (GA) grazed alone or mixed (CS, SC, GC, CG) (from Collins & Nicol 1989).

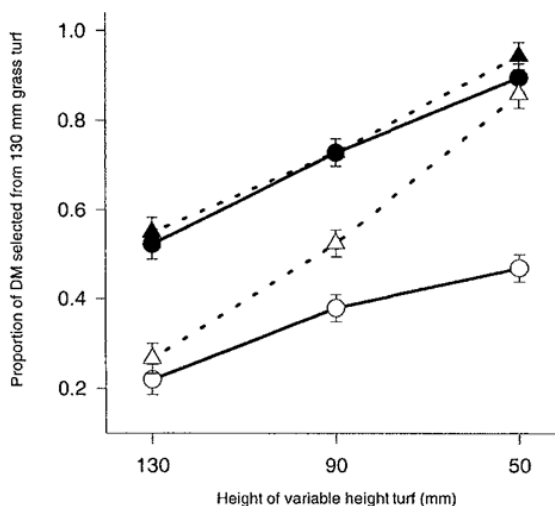
Treatment	Digestible organic matter intake (g/kg W ^{0.75} /day)									
		CA	24.6	SA	22.3	GA	17.7	CA	24.6	CG
Mixing effect (%)		-19		+11		+42		+24		

work involved, cattle, sheep, goats, deer, old and young animals, rotational and continuous grazing. It may not have taken us a lot further forward but a few questions have been addressed. Now for some examples.

Are deer like sheep?

One of the demonstrated advantages of co-grazing of sheep and cattle was the greater utilisation of the grazing resource through sheep grazing closer to cattle dung patches than cattle will. Mixed grazing is adopted by the majority of deer farmers (Nicol et al. 2007) and Craig Trotter was charged with the question as to whether deer would be as effective in grazing around cattle dung pats as sheep were. He showed (Table 2) that both species grazed similarly close to both dung pats and inanimate pegs (Trotter et al, 2006) so deer could be considered a substitute for sheep in this regard.

Figure 8 The proportion of grass (130 mm high) selected by sheep and goats from paired swardlets of grass:grass or grass:clover as the height of the paired swardlet declined (solid symbols grass:grass, open symbols grass:clover, solid lines sheep, broken lines goats (from Concha & Nicol 2000).



Goats

Another common observation in grazing ecology is that pastures grazed by goats maintain a higher clover content than those grazed by cattle or sheep. It had not been resolved whether this was a result of a low partial preference of goats for clover or a result of their grazing in the upper sward horizons. Andrea Concha addressed this question by offering sheep and goats paired 'swardlets' of pure clover and grass of varying sward height, and measured their relative preference by the proportion of each removed. She showed (Concha & Nicol 2000) that sheep and goats have a very similar partial preference for clover and grass when both pasture species are offered at the same sward height, but as soon as the height of the clover fell below that of the

grass, goats increased their partial preference for grass whereas sheep tried to maintain a higher preference for clover (Fig. 8).

Continuous versus rotational grazing

Reviews of mixed grazing generally show that, any benefits accrue more often to sheep than cattle. We (Kitessa & Nicol 2001) hypothesised that the competition between co-grazing sheep and cattle would be greater under continuous stocking than rotational stocking where the grazing resource is renewed regularly. Continuous and rotational grazing systems are notoriously difficult to compare, so we used an animal based 'driver' – equal sheep liveweight gain, to compare between grazing systems and equal pasture availability, to compare cattle alone with cattle plus sheep within a grazing system. The hypothesis was confirmed with cattle continuously grazing with sheep growing 30% slower than their counterparts grazing alone, whereas the difference in cattle liveweight gain was not significantly different between cattle grazed alone or with sheep with rotational grazing (Fig. 9).

Figure 9 Liveweight gain (kg/day) of cattle grazing alone or with sheep under continuous or rotational stocking (from Kitessa & Nicol 2001). Asterisk indicates significance ($P < 0.05$).

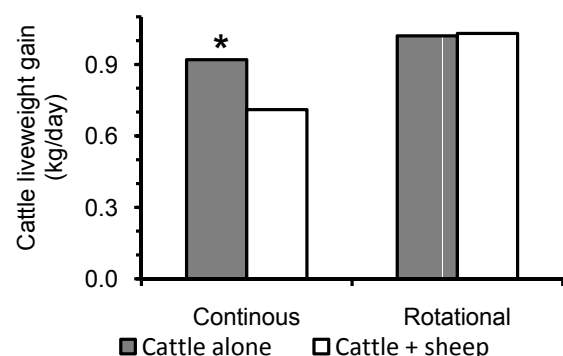
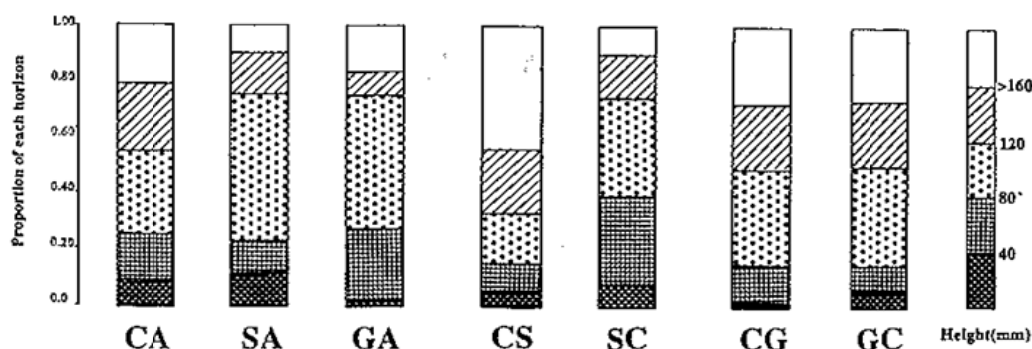


Figure 10 The proportional distribution of five sward horizons to the diet selected by cattle (CA), sheep (SA) and goats (GA) grazing alone or in mixtures (CS, SC, GC, CG) (from Nicol & Collins 1981).



Diet composition

Perhaps the most intensive of the mixed grazing experiments was the one which compared cattle, sheep and goats grazing separately with cattle grazing with sheep or with goats by Holly Collins. One of the problems in the design of much mixed grazing work has been picking an appropriate substitution rate of one species for the other, because unless this is realistic, a mixed grazing experiment can become a stocking rate experiment. She avoided this problem by maintaining the same rate of pasture disappearance for all groups by individually adjusting the grazing area available to each treatment. Relative stocking rate could be back-calculated. She confirmed that competition between sheep and cattle penalised the average intake of cattle by 19%, but there was true complementarity when cattle were mixed with goats (Table 3) (Collins & Nicol, 1989).

The data gathered in this experiment included the botanical composition in five components of each of the swards harvested in five vertical horizons combined with the analysis of oesophageal extrusa samples from all three species which were dissected into the same five botanical components – in hindsight, a massive undertaking. These data gave us the opportunity (Nicol & Collins 1990) to statistically match using a least squares procedure, the proportional source of the diet from each of the five horizons. This showed (Fig. 10) that cattle grazing with sheep had a diet which consisted of a greater proportion of material from the upper horizons of the

sward made up of stem and seedhead than when grazing on their own. On the other hand, sheep co-grazing with cattle increased the proportion of their diet from the mid-horizons comprising clover and green leaf. The differences were not nearly as marked in the cattle:goat combination. The hypothesis that the animal combination which gave the greatest opportunity for diet selection, sheep grazing with cattle, might have the greatest proportion of unexplained variance in the least square solution proved true with residual variances of 184, 83, 394, 775, 577 and 446 for cattle alone, cattle with sheep, sheep alone, sheep with cattle, goats alone, and goats with cattle respectively.

A chance co-seating arrangement of myself and Alan Stewart, PGG Wrightson Seeds on an AirNZ flight lead to a further interpretation of these data (Nicol et al. 2005). Alan introduced me to the well-known ecological concept that the proportional distribution of species in any environment conforms to a simple model:

$$P_R = 100(1-k)k^{R-1}$$

where P is the proportion of a species, R is the rank coefficient and k is the diversity coefficient, with a high or low value representing a more or less diverse environment respectively. We applied this model to the dietary components in the oesophageal extrusa samples from the mixed grazing experiment and found (Table 4) that the model predicted a reduced diet diversity in the mixtures to that when the animal species grazed alone.

Table 4 Dietary diversity coefficients (k) and *in vitro* dry matter digestibility of oesophageal extrusa of cattle, sheep and goats grazed alone or conjointly (from Nicol et al. 2005). DMD = Digestible dry matter; DDM = Dry matter digestibility; DM = Dry matter; SEM = Standard error of the mean.

Animal	Dietary diversity coefficient (k)				<i>In vitro</i> DMD (g DDM/kg DM)			
	Alone	Conjoint	Average	SEM	Alone	Conjoint	Average	SEM
Cattle	0.582	0.522	0.552 ^c		613	595	604 ^c	
Sheep	0.505	0.431	0.468 ^d	0.025	619	641	630 ^d	6
Goats	0.504	0.401	0.452 ^d		617	632	324 ^d	
Average	0.530 ^a	0.451 ^b		0.021	616 ^a	624 ^b		5

However this decline in diet diversity was associated with an increase in *in vitro* digestibility for sheep and goats but a decline in dry matter digestibility for the cattle. The interpretation of this observation, which is supported by Fig. 10, is that sheep reduced the diversity of their diet by out-competing co-grazed cattle for the higher digestibility sward components while cattle reduced their dietary diversity through being forced to eat more of the lower digestibility parts of the sward. The moral of this exercise is that the more detailed and careful the experimental observations, the greater the opportunity for intellectual stimulation.

Conclusion

I am not totally convinced that I have established a case for an organised and logical approach to my contribution to agricultural science, but if the random bouncing ball has to persist it does so with the understanding that I enjoyed its bouncing and thank all those, especially my student co-workers, who helped me bounce.

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