

New Zealand Society of Animal Production online archive

This paper is from the New Zealand Society for Animal Production online archive. NZSAP holds a regular annual conference in June or July each year for the presentation of technical and applied topics in animal production. NZSAP plays an important role as a forum fostering research in all areas of animal production including production systems, nutrition, meat science, animal welfare, wool science, animal breeding and genetics.

An invitation is extended to all those involved in the field of animal production to apply for membership of the New Zealand Society of Animal Production at our website www.nzsap.org.nz

[View All Proceedings](#)

[Next Conference](#)

[Join NZSAP](#)

The New Zealand Society of Animal Production in publishing the conference proceedings is engaged in disseminating information, not rendering professional advice or services. The views expressed herein do not necessarily represent the views of the New Zealand Society of Animal Production and the New Zealand Society of Animal Production expressly disclaims any form of liability with respect to anything done or omitted to be done in reliance upon the contents of these proceedings.

This work is licensed under a [Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International License](http://creativecommons.org/licenses/by-nc-nd/4.0/).



You are free to:

Share— copy and redistribute the material in any medium or format

Under the following terms:

Attribution — You must give [appropriate credit](#), provide a link to the license, and [indicate if changes were made](#). You may do so in any reasonable manner, but not in any way that suggests the licensor endorses you or your use.

NonCommercial — You may not use the material for [commercial purposes](#).

NoDerivatives — If you [remix, transform, or build upon](#) the material, you may not distribute the modified material.

<http://creativecommons.org.nz/licences/licences-explained/>

SOME IMPLICATIONS OF SWARD CHEMICAL AND PHYSICAL CHARACTERISTICS FOR THE NUTRITION OF GRAZING RUMINANTS

T. P. HUGHES, D. POPPI and A. R. SYKES

Lincoln College, Canterbury

The regulation of the voluntary feed intake of ruminants is a complex subject (Baile and Forbes, 1974; Baile, 1975; Forbes, 1977) but the superimposition of the problems of feed prehension (Hodgson, 1977; Arnold and Dudzinski, 1978) and the measurement of intake (Langlands, 1975) further complicates the subject in the grazing animal. As a consequence simplistic relationships have been drawn between quantity and quality of dry matter (DM) available to the animal and the intake these will support in animals in different physiological states. These currently provide a crude but powerful extension tool which allows rapid capitalization on existing knowledge, but will not, in the long term, allow animal production from pasture to be optimized. The potential variation in nutritional value of swards in the broadest sense — for example, in ability to supply amino acids, minerals and energy to tissues — must be considered. In addition, the spatial distribution of DM within the sward profile and the density and heterogeneity of swards influence intake. Further, there is variation between classes of stock in ability toprehend feed and then promote passage of undigested material through the gastrointestinal tract. The critical importance to the productivity of pastoral systems of maintaining high grazing intake dictates that these influences on intake and animal performance are described in some detail. A list of factors of importance in determining intake is given in Fig. 1.

Pastoral production systems match animal nutrient requirement with seasonal variation in feed supply. These never fit precisely, and, moreover, intake and performance may be deliberately compromised to maintain continuity of herbage supply. Periods of rapid herbage production must, however, be exploited to promote maximum digestible nutrient intake by highly productive livestock, namely, lactating and growing animals. It is this category of herbage and class of livestock on which the review concentrates.

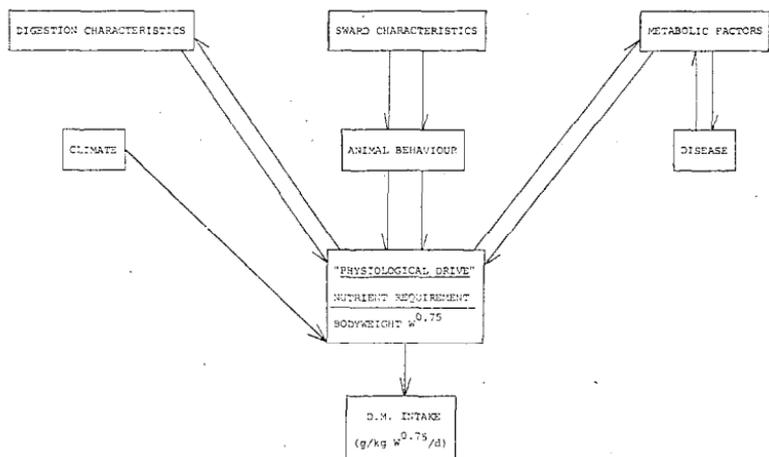


FIG. 1: Schematic representation of factors contributing to intake in grazing ruminants

PHYSIOLOGICAL DRIVE

The genetic potential for growth in lambs has probably been most closely achieved indoors on rations precisely formulated to meet requirement, or in grazing livestock which have been heavily supplemented. Growth rates of lambs at pasture have rarely matched those of 300-400 g/day recorded indoors (Table 1) and results have been extremely variable. Growth rates of 1.4 kg/day, comparable to those observed indoors, have occasionally been attained in cattle at pasture. Milk yields of cattle of 40 kg/day are achieved indoors (Flatt *et al.*, 1969; Broster and Swan,

TABLE 1: GROWTH RATES (g/day) OF WEANED LAMBS: POTENTIAL AND REALIZED AT PASTURE IN NEW ZEALAND

Growth Rate	References
Indoors:	
360 — 409	Fraser and Orskov (1974)
364	Frood and Owen (1974)
323 — 345	Orskov <i>et al.</i> (1974)
Pasture (grazed on: L — lucerne; c — clover; r — ryegrass):	
114R — 360c	McLean <i>et al.</i> (1965)
156R — 331c	Ulyatt (1971)
218L — 280L	Jagusch <i>et al.</i> (1970)
80L — 271c	McLean <i>et al.</i> (1962)
100RC — 250RC	K. G. Geenty <i>et al.</i> (unpublished)
114RC — 257L	Ratray <i>et al.</i> (1976)
47RC — 183RC	Jagusch <i>et al.</i> (1979)

1979), compared with a maximum of about 28 kg/day at pasture. For the lactating ewe we have less reliable data.

Animals respond to increased nutrient demand by increasing intake within limitations imposed by the feed (Arnold and Dudzinski, 1978). The assumption that digestible energy or the associated undigestible material in plants are the inevitable regulators of nutrient intake should be avoided. However, for comparison, physiological drive to intake has been expressed as requirement for metabolizable energy (ME) per unit body weight ($\text{kg } W^{0.75}$) which has been converted to DM intake for feeds of differing quality (ME (MJ)/DM (kg)) or M/D . The data (Fig. 2) show the DM requirements of growing lambs and of lactating sheep and cattle with levels of production close to the maximum recorded on pasture to be similar, when expressed in relation to $W^{0.75}$. More importantly, they suggest that, even when consuming the most digestible parts of plants ($M/D = 12.5 - 13.5$), such animals must achieve herbage DM intakes of 100 to 120 g DM/kg $W^{0.75}$. Pasture intakes and growth rates of lambs have been reported by Langlands and Donald (1974), Penning and Gibb (1979) and Jagusch *et al.* (1979). With one exception (Jagusch *et al.*, 1979), intakes of lambs have been slightly lower, namely,

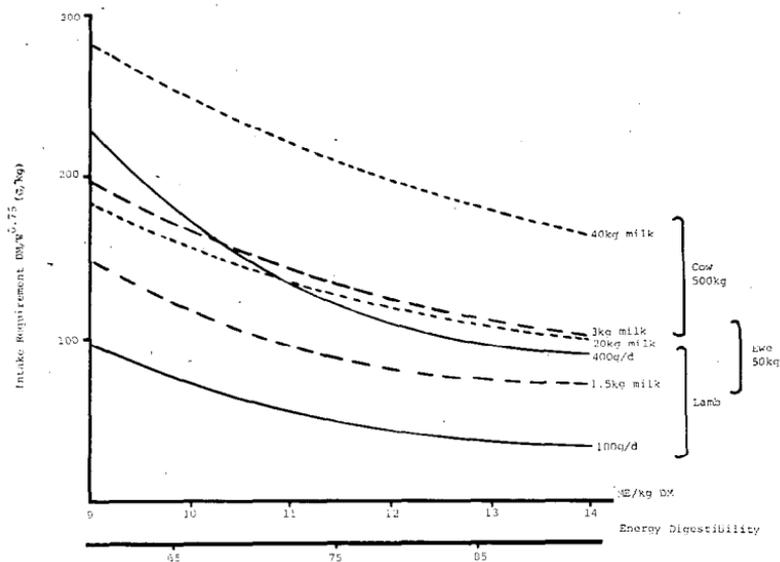


FIG. 2: Effect of herbage quality on feed requirement of several categories of livestock with different levels of production — g DM/kg $W^{0.75}$

75-90 g DM/W^{0.75}, than those required for maximum growth rate, though they have generally been higher than would have been predicted from lamb growth rates actually achieved (100 to 230 g/day — Fig. 2).

NUTRITIONAL AND METABOLIC EFFECTS

In feedlot systems rations are balanced to promote high growth rates, but in pastoral situations ability for such control is limited. Trace element deficiencies (Underwood, 1977) can be corrected to some degree by fertilizer policy or direct administration to stock. It is more difficult to supplement intakes of amino acids and of major mineral elements such as Ca, P and Mg, and these must be supplied directly in herbage. It is difficult, at this stage, to establish whether the supply of these nutrients does influence rate of growth and therefore intake.

Protein deposition and skeletal growth are highly correlated when expressed on a fat-free basis (Berg and Butterfield, 1976). Moreover, fat deposition is directly related to energy intake but inversely related to dietary protein concentration (Andrews and Orskov, 1970; Norton *et al.*, 1970) the latter presumably reflecting the energy cost of the increased protein deposition on high protein diets. Such an inverse relationship is assumed in the modelling of protein and fat deposition in pigs (Whittimore and Fawcett, 1974). The composition of growth as well as rate of growth may therefore be determined by the relationship between the rate of growth of the skeleton and energy intake.

Increased liveweight gains in sheep have been recorded to supplements of the bone minerals Ca and P (Gunn, 1969) and to protein supplementation (T. N. Barry, pers. comm.) in grazing ruminants. Furthermore, in pen-feeding trials, intake has been influenced by dietary Ca and P (Preston and Pfander, 1964; Little, 1968; Hodge *et al.*, 1973; Field, *et al.*, 1975) and protein (Preston and Willis, 1970; Orskov *et al.*, 1973) concentrations.

On the assumptions that optimal growth will be achieved when nutrients are supplied in balanced proportions in relation to the product of requirement for their deposition in tissue or secretion and the efficiency of the process, desirable nutrient concentrations in herbage can be calculated.

The requirement of the animal for amino acid nitrogen (aaN) has been related to net energy (Black and Griffith, 1975) or ME (Orskov, 1977) utilized, on the assumption that energy requirements are satisfied, since protein and energy metabolism

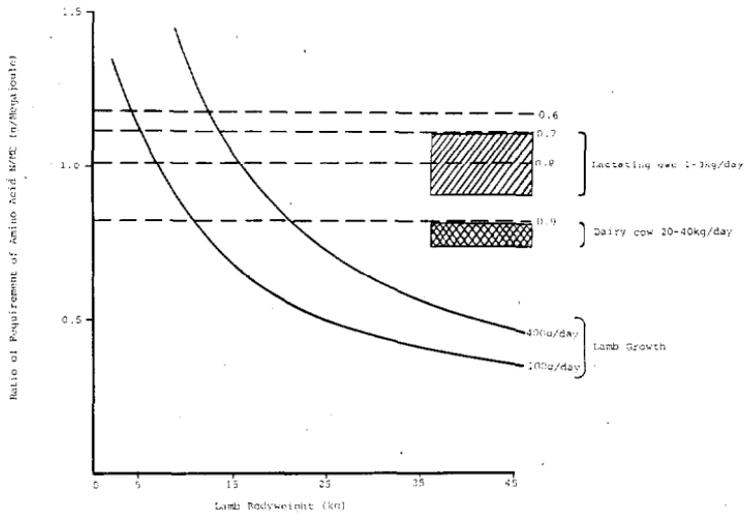


FIG. 3: *The theoretical ratio of requirement of amino acid N to metabolizable energy in lambs with varying growth rates at different body weights. Also shown are the ratios of requirement of amino acid N/ME of a 500 kg dairy cow producing between 20 and 40 kg milk/day and a 50 kg ewe producing between 1 and 3 kg milk/day. The theoretical ratios of supply of aaN/ME of a herbage with CP of 240 g/kg DM and M/D = 12 with protein degradabilities of 0.6, 0.7, 0.8 and 0.9 are also given.*

are intimately related. In Fig. 3 the requirement for amino acid nitrogen (g) per MJ of ME (aaN/ME) is presented for different categories of ruminants. These show the manner in which the optimum ratio of supply of aaN to ME declines from 1.05 to 0.6 during growth from 15 to 35 kg at a rate of 400 g/day, and declines from 0.7 to 0.45 when growth rate is 100 g/day. It can be calculated that the lactating ewe has a requirement for a similar high ratio of aaN/ME to the young, rapidly growing lamb but that the lactating cow requires only a relatively low ratio.

Protein metabolism in the ruminant is complicated by transactions in the rumen. The amount of protein available at the duodenum is determined by the amount of dietary protein escaping rumen breakdown — namely, its undegradability, and the energy and nitrogen available for rumen microbial protein synthesis. Reliable estimates for these parameters on fresh herbage are scarce and variable and make precise estimates of amino acids reaching the duodenum difficult. Data from the literature are summarized in Table 2. Estimates of the efficiency of absorption of amino acids from the duodenum show concordance but estimates of the proportion of dietary protein reaching that site vary

TABLE 2: EXTENT OF DEGRADATION OF DIETARY PROTEIN IN THE RUMEN; RUMEN MICROBIAL N SYNTHESIS AND PROPORTION OF AMINO ACIDS ABSORBED IN THE SMALL INTESTINE

Herbage	Rumen Degradability %	Microbial N Synthesis (g/kg OM apparently digested in rumen)	Apparent Absorption of Amino Acid in Intestine
Grass/Clover	0.52 ^a	25 — 26	
Perennial ryegrass		17 — 24 ^b	0.71 ^d
Subterranean clover		28 — 31 ^c	
		15.5 — 26.4 ^e	
S.24 ryegrass	0.52 ^b		
<i>L. multiflorum</i> × <i>perenne</i>			0.74 ^d
Red clover		26	0.71
Ruanui	0.70 ^d	25 — 41 ^c	
Manawa	0.69 ^d	49	
White clover	0.72 ^d	32	
		26 — 49 ^c	
Lucerne		28 — 36 ^c	
Wheaten hay		20 — 22 ^c	
Tama ryegrass		32 — 48 ^c	

(a) Hagemeister and Kaufmann (1974)

(b) Beever *et al.* (1974)

(c) Hume and Purser (1975)

(d) Ulyatt *et al.* (1975)

(e) Walker *et al.* (1975)

considerably. Degradability has ranged from 0.5 to 0.7 and rates of rumen microbial protein synthesis show a two-fold range, possibly dependent on plant species (Ulyatt *et al.*, 1975).

The writers have calculated the theoretical supply of amino acids to tissues, as aaN/ME, for forages (Table 3) for a range of recorded digestion characteristics. These data suggest that herbage may not provide adequate amino acids for a lactating ewe or a lamb of body weight less than 25 kg. The data of McRae and Ulyatt (1974) and Ulyatt *et al.* (1975) were obtained at restricted levels of feeding and the authors cautioned against extrapolation beyond their intake range. They observed marked differences between plant species in sites of digestion and protein flow and variable effects of level of feeding. More marked differences may occur with grazing ruminants at levels of intake close to the maximum. Similarly, there may be changes with increasing animal maturity in the extent of digestion in the rumen (Weston and Margan, 1979).

TABLE 3: CALCULATED RATIOS OF SUPPLY TO TISSUES OF aaN/MJ ME FOR DIETS CONTAINING 12 MJ ME/kg DM AND 240 g/kg CRUDE PROTEIN, AND WITH DIFFERENT DIETARY PROTEIN DEGRADABILITY AND RATES OF RUMEN MICROBIAL PROTEIN SYNTHESIS

Degradability	Rate of Microbial Protein Synthesis		
	20 g N/kg DOM	30 g N/kg DOM	50 g N/kg DOM
0.9	0.61	0.84	1.30
0.7	0.94	1.17	1.67

Assuming that the coefficients of absorption and utilization of amino acids are 0.7 and 0.75, respectively.

TABLE 4: THE THEORETICAL MINIMUM DIETARY REQUIREMENT¹ FOR Ca AND P OF A LAMB GROWING AT 400 g/day. CONSUMING HERBAGE WITH ME CONCENTRATION OF 12 MJ/kg DM

Dietary Concentration	15	Body weight (kg)		45
		25	35	
Ca (g/kg DM)	14.0	10.0	8.0	6.7
P (g/kg DM)	6.2	4.4	3.6	3.0

¹ Assuming Agricultural Research Council (1980) values for:

	Ca	P
Endogenous loss (mg/kg/day)	12	12
Mineral content of gain (g/kg)	11	7
Availability	0.40	0.60

TABLE 5: HERBAGE CONCENTRATIONS (g/kg DM) OF CALCIUM AND PHOSPHORUS (Hughes and Sykes, unpublished)

	Ca		P
Ryegrass:			
Leaf	2.0	— 4.4	4.2
Stem	2.8	— 5.2	4.3
Clover:			
Leaf	7.6	— 11.8	3.7
Stem	8.9	— 11.0	3.7
Lucerne		14.0	4.0

There must be similar uncertainties regarding the adequacy of Ca intake during early growth of weaned lambs. Calcium supplied by milk (2 g Ca/kg DM) has an availability of about 90% and can thus meet about 75% of the animal's theoretical requirement. In weaned animals, availabilities may be only 40% (ARC, 1980), and the dietary concentration necessary to meet nutrient requirement would therefore be 10 to 14 g/kg DM (Table 4). Herbage Ca concentrations in the Lincoln region (Table 5) suggest that ryegrass could be Ca-deficient. Indeed, dietary Ca concentrations of between 2 and 3 g/kg in milk resulted in growth retardation in lambs (Hodge *et al.*, 1973). The superior value of clover or lucerne compared with ryegrass in promoting liveweight gain may, in part, be associated with its superior mineral concentration. Reliable estimates of Ca availability in herbage are required.

DIGESTION CHARACTERISTICS

A general relationship between digestibility of feed and its intake has long been recognized, although differences in intake can occur at the same digestibility. In seeking to describe in more detail the plant and animal factors contributing to digestion and to intake, modelling approaches to events in the rumen (Waldo *et al.*, 1972; Nolan and Rowe, 1975; Ulyatt *et al.*, 1976; Baldwin *et al.*, 1977; Mertens, 1977; Mertens and Ely, 1979) and in the field (Rice *et al.*, 1974) have been used. These assume that ingested feed disappears from the rumen by digestion and absorption of end products and by passage of material through the reticulo-omasal orifice, the latter containing an indigestible fraction which is never available to the animal (Fig. 4). These processes have rate constants k_d and k_p , respectively.

Model simulation has shown that changes in k_p and in potential digestibility have a greater effect on intake than changes in actual digestion rate (k_d); Mertens and Ely (1979), for example, predicted a 1% change in intake for a 1% change in potential digestibility. Potential digestibility of young, fresh forage grown in New Zealand is 0.8 to 0.9 or greater and there is little scope for improvement.

Ulyatt *et al.* (1976) and Baldwin *et al.* (1977) have described the factors which influence these rate constants. These include chemical composition of the plant material, microbial activity and factors relating to the size of particle, their specific gravity and the flow of fluid through the reticulo-omasal orifice.

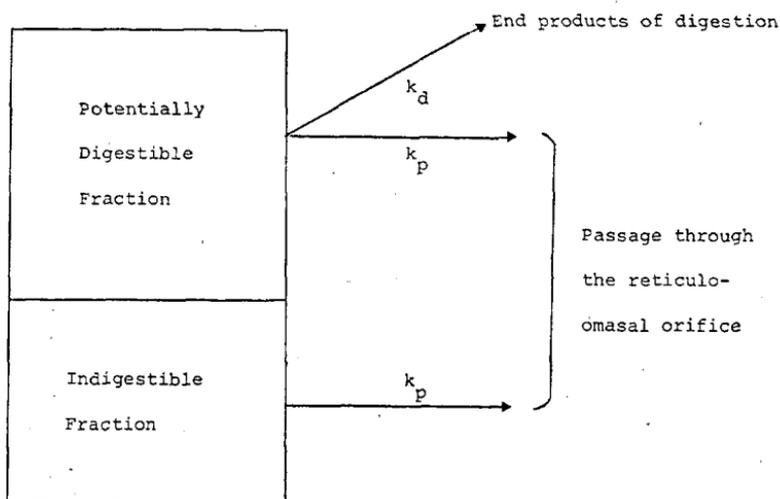


FIG. 4: *The disappearance of feed from the rumen.*

The passage rate constant (k_p) appears to have greatest influence on intake and is considered to be determined by the rate of breakdown of particles to a size capable of escaping from the rumen (Balch and Campling, 1962; Freer *et al.*, 1962). Reid *et al.* (1977) have suggested that the rate of disappearance of small particles may be more important since they comprise approximately 60% of rumen dry matter (Ulyatt *et al.*, 1976). Important in this regard are the specific gravity of plant parts, the structure of the rumen mass and therefore ease of dispersion of particles in the rumen, as well as the flow of saliva into and water from the rumen (Evans *et al.*, 1973; Sutherland, 1975; Waghorn and Reid, 1977; Welch *et al.*, 1978). Satiety associated with intestinal distension does not appear to limit the rate of passage of material from the rumen (Grovmum and Phillips, 1978).

There may be considerable differences between forages in the intakes they promote which are not associated with differences in the level of rumen fill (Blaxter *et al.*, 1961; Ulyatt *et al.*, 1967; Thornton and Minson, 1972, 1973). Divergence in the level of rumen fill has occurred on protein-deficient diets (Egan, 1970, 1972). Limited studies with grazing animals (McLean *et al.*, 1962; Ulyatt, 1971; Rattray *et al.*, 1976) have shown low levels of rumen fill on legume diets despite high intakes, and these have been attributed to low retention times.

REMOVAL OF DIGESTA FROM THE RUMEN

For intakes of $110 \text{ g DM/W}^{0.75}/\text{day}$ to be realized in growing lambs on feeds with different retention times, theoretical rumen fills of organic matter can be calculated. Values have been derived as:

$$\text{rumen organic matter fill (g)} = \frac{\text{retention time (h)} \times \text{required organic matter intake (g/day)}}{24}$$

which is derived from the formula given by Ulyatt (1971).

These have been plotted in Fig. 5 for animals of differing weight and for plant species promoting different retention times of organic matter in the rumen. Data for actual gut fill in replete animals at pasture were derived from McLean *et al.* (1962), Jagusch *et al.* (1976) and Rattray *et al.* (1976) and have been superimposed. Retention-time data for temperate forages were derived from Ulyatt (1971) and for tropical forages from Thornton and Minson (1972, 1973). The calculations assume steady state conditions, although grazing animals will depart from this state. In the latter studies and those of Ulyatt (1971), legume diets consistently promoted a smaller rumen fill and greater intakes, the latter being attributed to a lower retention time of the legumes in the rumen. For any liveweight or retention time, the rumen fill necessary to allow the target intake can be seen and compared with published data. This assumes that retention time

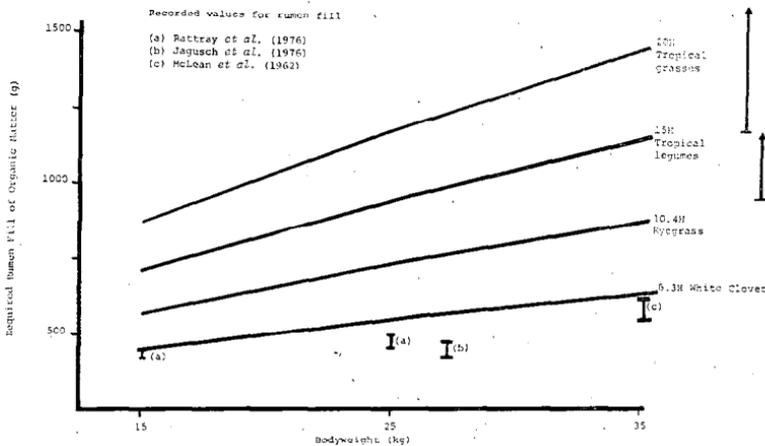


FIG. 5: The effect of retention time (h) of organic matter in the rumen on the theoretical rumen fill required to promote a dry matter intake of $110 \text{ g/kg W}^{0.75}$ in lambs of varying body weight.

is solely a feed characteristic. Alternatively, assuming that published values for rumen fill are maxima, the retention time consistent with the desired intake is given. The models of Waldo *et al.* (1972) and Ulyatt *et al.* (1976) indicate the areas in which further data are required. Data are scarce for adult animals consuming dry forages and no data appear to exist for growing ruminants offered fresh herbage. We have therefore concentrated on total disappearance of organic matter from the rumen and have not distinguished between digestion and passage.

The calculation of retention time in the field as indicated by Ulyatt (1971) has potentially large errors and was based on animals of 50 kg body weight. However, rumen retention times for organic matter of white clover of approximately 6 hours should allow intakes in lambs sufficient to support growth rates of 400 g/day. Indeed, even in the early stages of growth, rumen fill of animals eating legumes is below that of grasses and below the calculated minimum fill required. Some mechanism other than rumen fill may regulate intake in these circumstances.

Retention times of ryegrasses have varied from 5 to 10 h (Ulyatt, 1971), and have generally been between 8.5 and 10.5 h. It seems unlikely that young lambs could remove digesta sufficiently rapidly to achieve their growth potential without substantially increasing rumen fill above levels so far recorded.

Tropical forages appear to have even worse characteristics than temperate species and it seems doubtful whether high rates of intake could be achieved in view of the reported retention times (Thornton and Minson, 1972; 1973).

SWARD CHARACTERISTICS AND GRAZING BEHAVIOUR

The relationship between the animal and the sward is a dynamic one, the optimum being that equilibrium at which pasture growth and animal intake are both maximized, with the latter consuming uniform material of high digestibility. In practice, and for many reasons such as climatic variables and changing animal requirement, this is rarely achieved. It is useful, however, for this discussion to assume, initially, that such conditions apply. In these circumstances daily intake depends on the product of the size of bite of the animal, its rate of biting, and the amount of time spent in grazing each day. This interrelationship has been shown to vary with the density of the sward, measured in terms of weight per unit area, and its height (Arnold and Dudzinski, 1969; Allden and Whittaker, 1970; Jamieson, 1974; Stobbs, 1974; Chacon and Stobbs, 1976; J. A. Milne, pers. comm.).

Increased physiological drive for intake — caused by high growth potential in young animals, poor body condition, pregnancy, lactation and inclement weather — increases grazing time (Arnold, 1975; Arnold and Birrell, 1977). Data on the grazing behaviour of young lambs is scarce, but means and ranges of grazing time for dairy cattle and adult sheep of 8.5 h (4-13) and 9 h (3-13), respectively, have been reported. However, there are some data which indicate that high-producing cows may spend more time grazing than their herd mates (Hancock, 1954; Brumby, 1959).

Under steady state conditions, rate of biting appears to be relatively constant and differences in intake appear to be due to changes in size of bite or in grazing time or both.

WEIGHT OF HERBAGE PER UNIT AREA

Pasture weight is the product of the height and density of the sward. Hodgson (1977) summarized the relationships between the weight of herbage per unit area and intake in cattle, and demonstrated two-fold variation (1100 to 2500 kg DM/ha) in the critical weight below which pasture intake decreased. Similar variability has been reported for sheep (Arnold, 1964; Langlands and Bennett, 1973). This large variation may be attributable to differences between experiments in height of sward and in the heterogeneity of the sward profile.

HEIGHT OF HERBAGE

Significant positive relationships between sward height or tiller length and intake were reported by Arnold and Dudzinski (1967) for sheep, Jamieson (1974) for calves, and Chacon and Stobbs (1976) for dry cows when pasture weight was being depleted. However, plateau rates of intake under steady state conditions were reported at a height of 10 cm by Allden and Whittaker (1970) and at 20 cm by J. A. Milne (pers. comm.) in sheep. Indirect evidence for an effect of pasture height on intake was apparent in the data of Le Du and Baker (1977) and of Reardon (1975) in lactating and growing cattle, respectively, though under non-steady state conditions. In the data of Reardon, density and height were confounded but intake increased when additional dry matter was offered by increasing the amount per unit area rather than by increasing the area.

DENSITY OF SWARD

There are few data on effects of sward density on intake, although Arnold and Dudzinski (1969) reported a reduction of 50% in intake when density was decreased at the same pasture height. These results agree with those of J. A. Milne (pers. comm.), who suggested that the major effect could be attributed to a reduction in bite size.

HETEROGENEITY OF SWARD

Steady state conditions are rarely attained under New Zealand conditions. As a consequence, sward heterogeneity will increase and therefore the need for opportunity for selection to increase if intake is to be maintained.

The degree of selection by the animal depends on the parameters described and on the heterogeneity of the sward (Arnold, 1964; Arnold and Dudzinski, 1978). The herbage offered is rarely all available. Dry and dead materials are discriminated against, the green components and therefore those of high digestibility being preferentially selected (Arnold, 1964; Hamilton *et al.*, 1973; Hodgson, 1975; Langlands, 1975; Guy, 1979) (see Fig. 6). As dead matter in the pasture increases, ability to select green material decreases (Arnold *et al.*, 1966; Hamilton *et al.*, 1973). The need for increasing selectivity presumably reduces bite size, intake then being dependent on compensation by increased biting rate or time spent grazing. Selection appears to decline at low herbage weights. Evidence for such selection comes from oesophageal extrusa samples, which invariably are of higher digestibility than herbage obtained by cutting (Arnold, 1964; Hodgson, 1977; Le Du and Baker, 1977; Penning *et al.*, 1977; Guy, 1979; Penning and Gibb, 1979). Sheep select diets with more green material of higher nutritive value than do cattle on the same sward (Langlands and Sanson, 1976), possibly because cattle have a larger mouth and use the tongue toprehend forage.

CONCLUSIONS

The relationship between the animal and its sward is complex. It is inevitable, therefore, that simple descriptions of the optimum relationship, such as dry matter/stock unit and percentage utilization, will result in large variation in production. For example, the relationships between pasture offered and liveweight gain of

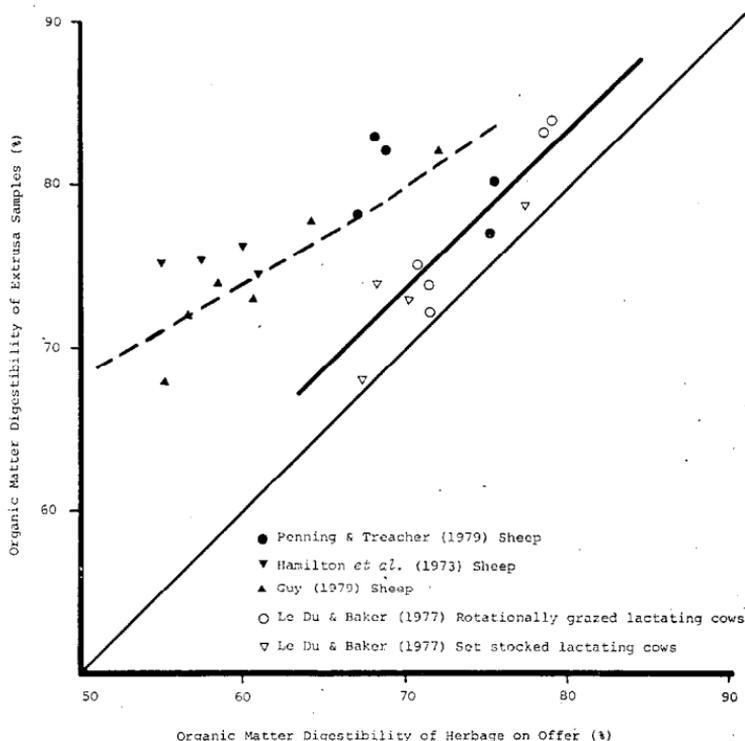


FIG. 6: *The relationship between digestibility of herbage on offer and herbage selected by sheep and cattle.*

Marsh (1977) can be recalculated to show that growth rate varied between -100 and 400, 280 and 680 and between 350 and 850 g/day at herbage allowances of 5, 7.5 and 10 kg DM/head/day. Animal production from pasture will be optimized when the physical and nutritional attributes of the sward, and limits within which intake is sensitive, are described in detail. It is axiomatic that the impact of the measures used to attain this optimum no herbage dry matter production are simultaneously monitored.

REFERENCES

- Allden, W. G.; Whittaker, I. A. McD., 1970. *Aust. J. agric. Res.*, 21: 755.
 Andrews, R. P.; Orskov, E. R., 1970. *Anim. Prod.*, 12: 335.
 A.R.C., 1980. *The Nutrient Requirements of Farm Livestock*. Agricultural Research Council, London.
 Arnold, G. W., 1964. In *Grazing in Terrestrial and Marine Environments* (Ed. D. J. Crisp), p. 133. Blackwell, Oxford.
 ———, 1975. *Aust. J. agric. Res.*, 26: 1017.
 Arnold, G. W.; Birrell, H., 1977. *Anim. Prod.*, 24: 343.

- Arnold, G. W.; Dudzinski, M. L., 1966. *Proc. XI int. Grassld Congr. Finland*, p. 367. Valtioneuvoston Kirjapaino, Helsinki.
- ; ———, 1967. *Aust. J. agric. Res.*, 18: 657.
- ; ———, 1969. In *Intensive Utilization of Pastures* (Ed. B. J. F. James), p. 42. Angus and Robertson, Sydney, N.S.W.
- ; ———, 1978. In *Ethology of Free-ranging Domestic Animals*. Elsevier, New York.
- Baile, C. A., 1975. In *Digestion and Metabolism in the Ruminant*. University of New England Publishing Unit, Armidale.
- Baile, C. A.; Forbes, J., 1974. *Physiol. Rev.*, 54: 160.
- Balch, C. C.; Campling, R. C., 1962. *Nutr. abstr. Rev.*, 32: 669.
- Baldwin, R. L.; Koong, L. J.; Ulyatt, M. J., 1977. *Agric. Systems*, 2: 255.
- Beever, D. E.; Thomson, D. J.; Harrison, D. G., 1974. In *Digestion and Metabolism in the Ruminant*. University of New England Publishing Unit, Armidale.
- Berg, R. T.; Butterfield, R. M., 1976. In *New Concepts of Cattle Growth*. Sydney University Press.
- Black, J. L.; Griffith, D. A., 1975. *Br. J. Nutr.*, 35: 399.
- Blaxter, K. L.; Wainman, F. W.; Wilson, R. S., 1961. *Anim. Prod.*, 3: 51.
- Broster, W. H.; Swan, H., 1979. In *Feeding Strategy for the High Yielding Dairy Cow*. Granada, London.
- Brumby, P. J., 1959. *N.Z. J. agric. Res.*, 2: 797.
- Chacon, E.; Stobbs, T. H., 1976. *Aust. J. agric. Res.*, 27: 709.
- Egan, A. R., 1970. *Aust. J. agric. Res.*, 21: 735.
- 1972. *Aust. J. agric. Res.*, 23: 347.
- Evans, E. W.; Pearce, G. R.; Burnett, J.; Pillinger, S. L., 1973. *Br. J. Nutr.*, 29: 257.
- Field, A. C.; Suttle, N. F.; Nisbet, D. I., 1975. *J. agric. Sci., Camb.*, 85: 435.
- Flatt, W. P.; Moe, P. W.; Muuson, A. W.; Cooper, T., 1969. In *Energy Metabolism in Farm Animals*. (Eds K. L. Blaxter; K. G. Thorbe; J. Kielanowski), Oriel Press, Newcastle upon Tyne.
- Forbes, J. M., 1977. *Anim. Prod.*, 24: 91.
- Fraser, C.; Orskov, E. R., 1974. *Anim. Prod.*, 18: 75.
- Freer, M.; Campling, R. C.; Balch, C. C., 1962. *Br. J. Nutr.*, 16: 279.
- Frood, I. J. M.; Owen, E., 1974. *Proc. Br. Soc. Anim. Prod.*, 3: 100.
- Grovum, W. L.; Phillips, G. D., 1978. *Br. J. Nutr.*, 40: 323.
- Gunn, R. G., 1969. *J. agric. Sci., Camb.*, 72: 371.
- Guy, M., 1979. M.Agr.Sc. thesis, Massey University.
- Hagemeister, H.; Kaufmann, W., 1974. *Keiler Milcher forschung*, 26: 199.
- Hamilton, B. A.; Hutchinson, K. J.; Annis, P. C.; Donnelly, J. B., 1973. *Aust. J. agric. Res.*, 24: 2, 271.
- Hancock, J., 1954. *J. agric. Sci.*, 44: 420.
- Hodge, R. W.; Pearce, G. R.; Tribe, D. E., 1973. *Aust. J. agric. Res.*, 24: 229.
- Hodgson, J., 1975. *Proc. Br. Grassld Soc., occ. Symp. No. 8*: 93.
- 1977. *Proc. int. Mtg Anim. Prod. from Temperate Grasslds*. An Foras Taluntais, Dublin.
- Hume, I. D.; Purser, D. B., 1975. *Aust. J. agric. Res.*, 26: 199.
- Jagusch, K. T.; Clark, V. R.; Jay, N. P., 1970. *N.Z. J. agric. Res.*, 13: 808.

- Jagusch, K. T.; Gumbrell, R. C.; Dellow, D. W., 1976. *Proc. N.Z. Soc. Anim. Prod.*, 36: 190.
- Jagusch, K. T.; Rattray, P. V.; Oliver, T. W.; Cox, N. R., 1979. *Proc. N.Z. Soc. Anim. Prod.*, 39: 254.
- Jamieson, W. S., 1974. Ph.D. thesis, University of Reading.
- Langlands, J. P., 1975. *Proc. 4th int. Symp. Ruminant Physiol.*, Sydney, p. 320.
- Langlands, J. P.; Bennett, I. L., 1973. *J. agric. Sci., Camb.*, 81: 205.
- Langlands, J. P.; Donald, G. E., 1974. *Anim. Prod.*, 21: 175.
- Langlands, J. P.; Sanson, J., 1976. *Aust. J. agric. Res.*, 27: 691.
- Le Du, Y. L. P.; Baker, R. D., 1977. *Proc. int. Mtg Anim Prod from Temperate Grasslds.* An Foras Taluntaí, Dublin.
- Little, D. A., 1968. *Proc. Aust. Soc. Anim. Prod.*, 7: 376.
- McLean, J. W.; Thomson, G. G.; Iversen, C. E.; Jagusch, K. T.; Lawson, B. M., 1962. *Proc. N.Z. Grassld Ass.*, 24: 57.
- McLean, J. W.; Thomson, G. G.; Jagusch, K. T.; Lawson, B. N., 1965. *Proc. Ruakura Fmrs' Conf.*: 34.
- McRae, J. C.; Ulyyat, M. J., 1974. *J. agric. Sci., Camb.*, 82: 309.
- Marsh, R., 1977. *Proc. N.Z. Soc. Anim. Prod.*, 37: 62.
- Mertens, D. R., 1977. *Federation Proc.*, 36: 187.
- Mertens, D. R.; Ely, L. O., 1979. *J. Anim. Sci.*, 49: 1085.
- Nolan, J. V.; Rowe, J. B., 1975. *Reviews in Rural Science, II*, p. 151. Univ. New England Publishing Unit, Armidale, N.S.W.
- Norton, B. W.; Jagusch, K. T.; Walker, D. M., 1970. *J. agric. Sci., Camb.*, 75: 287.
- Orskov, E. R.; Fraser, C.; Pirie, R., 1973. *Br. J. Nutr.*, 30: 361.
- Orskov, E. R.; Fraser, C.; McHattie, I., 1974. *Anim. Prod.*, 18: 85.
- Orskov, E. R., 1977. In *Protein Metabolism and Nutrition*. Butterworths, London.
- Penning, P. D.; Gibb, M. J., 1979. *Anim. Prod.*, 29: 53.
- Penning, P. D.; Penning, I. M.; Treacher, T. T., 1977. *J. agric. Sci., Camb.*, 88: 579.
- Preston, R. L.; Pfander, W. M., 1964. *J. Nutr.*, 83: 369.
- Preston, T. R.; Willis, M. B., 1970. In *Intensive Beef Production*. Pergamon Press, Oxford.
- Rattray, P. V.; Morrison, M. C. L.; Farquhar, P. V., 1976. *Proc. N.Z. Soc. Anim. Prod.*, 36: 179.
- Reardon, T. F., 1975. *Proc. Ruakura Fmrs' Conf.*: 14.
- Reid, C. S. W.; Ulyyat, M. J.; Monro, J. A., 1977. *Proc. N.Z. Soc. Anim. Prod.*, 37: 173.
- Rice, R. W.; Morris, J. G.; Maeda, B. T.; Baldwin, R. L., 1974. *Federation Proc.*, 33: 188.
- Stobbs, T. H., 1974. *Proc. Aust. Soc. Anim. Prod.*, 10: 299.
- Sutherland, T. M., 1975. *Reviews in Rural Science, II*, p. 65. Univ. New England Publishing Unit, Armidale, N.S.W.
- Thornton, R. F.; Minson, D. J., 1972. *Aust. J. agric. Res.*, 23: 871.
- ; ———, 1973. *Aust. J. agric. Res.*, 24: 889.
- Ulyyat, M. J., 1971. *N.Z. J. agric. Res.*, 14: 352.
- Ulyyat, M. J.; Blaxter, K. L.; McDonald, I., 1967. *Anim. Prod.*, 9: 463.
- Ulyyat, M. J.; MacRae, J. C.; Clarke, R. T. J.; Pearce, P. D., 1975. *J. agric. Sci., Camb.*, 84: 453.

- Ulyatt, M. J.; Baldwin, R. L.; Koong, L. J., 1976. *Proc. N.Z. Soc. Anim. Prod.*, 36: 140.
- Underwood, E. J., 1977. *Trace Elements in Human and Animal Nutrition*, 4th ed. Academic Press, N.Y.
- Waghorn, G. C.; Reid, C. S. W., 1977. *Proc. N.Z. Soc. Anim. Prod.*, 37: 176.
- Waldo, D. R.; Smith, L. W.; Cox, E. L., 1972. *J. Dairy Sci.*, 55: 125.
- Walker, D. J.; Egan, A. R.; Nader, C. J.; Ulyatt, M. J.; Storer, G. B., 1975. *Aust. J. agric. Res.*, 26: 699.
- Welch, J. G.; Palmer, R. H.; Gilman, B. E., 1978. *Am. Dairy Sci. Ass. 73rd Ann. Mtg.*: 231. Michigan State University.
- Weston, R. H.; Margan, D. E., 1979. *Aust. J. agric. Res.*, 30: 543.
- Whittimore, C. T.; Fawcett, R. H., 1974. *Anim. Prod.*, 19: 221.