A FORMULATED RATION FOR CAPTIVE MOOSE

Charles C. Schwartz, Kenai Moose Research Center, Alaska Department of Fish and Game, Soldotna, Alaska 99669

Wayne L. Regelin, U. S. Fish and Wildlife Service, Denver Wildlife Research Center, Kenai, Alaska 99611

Albert W. Franzmann, Kenai Moose Research Center, Alaska Department of Fish and Game, Soldotna, Alaska 99669

Abstract: A formulated ration suitable for animal maintenance or experimental purposes has been developed for moose (*Alces alces*). It contains 11.8 percent crude protein and has an apparent dry matter digestibility of 64 percent. Performance was measured over 1.5 years with data from six moose. Daily gain from weaning to 1 year of age was 0.62 ± S.D. 0.4 kg. Possible diet problems and improvements are presented. Aspen (*Populus tremuloides*) sawdust the primary constituent, is believed to be the major reason for the diet's success. A discussion based on extensive literature review is presented concerning fiber types, and their effects on animal welfare.

1/ Research funded in part by Federal Aid in Wildlife Restoration, Projects W-17 and W-21.

Recent studies (Moen 1973, Robbins 1973, Wallmo et al. 1977) have advanced the concept of predicting carrying capacity of ungulates based upon an understanding of animal nutrition. The concept of biological carrying capacity integrates the nutritional requirements of the animal with the nutrients supplied from the vegetation. Crude protein and digestible energy were considered by most nutritionists to be the most important nutrients supplied by range forage (Moen 1973, Wallmo et al. 1977). Other important nutritional entities were requisite to the health of ungulates but were seldom the primary limiting factor.

Available literature concerning nutrient requirements, metabolic rates, and digestive capabilities for white-tailed deer (*Odocoileus virginianus*) and mule deer (*O. hemionus*) is extensive. The literature is replete with food habit studies of moose, (see Peek 1974 for review) but very little is known or understood about the nutritional requirements of moose. Gasaway and Coady (1974) reviewed the energy requirements of moose and other ruminants. Most of their discussion regarding moose requirements, by necessity, was inferred from other species. Many statements in their publication verified this fact. For example "estimates of BMR (basal metabolic rate) of moose is difficult, particularly considering that metabolic data have not been reported for this species (moose)" or, "Energy requirements by moose for thermoregulation in cold have not been studied" and finally, "food intake, passage rates and digestibility in moose have received little consideration."

In the past, moose have been maintained for studies either in facilities containing enough natural vegetation to support the animals, or by harvesting and transporting native browse to moose in confinement. Cutting browse was time consuming and expensive.

Nutritional studies with moose, initiated at the Moose Research Center, Kenai, Alaska in 1978, required that captive moose be maintained on a diet that was: (1) readibly available, (2) inexpensive, (3) reproducible, (4) suitable to constituent alterations, and (5) able to meet the nutritional requirements of moose. These requisites made it necessary to use a formulated ration rather than natural browse. An extensive literature review revealed that no such diet was available.

Development of a formulated ration for moose and a review of the literature dealing with forage fibers, voluntary intake, and rates of passage as they relate to ration development are presented in this report. The authors wish to express their thanks to M. Schwartz, D. Johnson, and D. C. Johnson for their help with animal care and digestion experiments. K. Schneider and D. McKnight reviewed the manuscript.

BACKGROUND

In general, satisfactory rations provide a balance of essential requirements like protein, energy, minerals and vitamins. Adequate levels of nutrients are generally obtained by adding various amounts of concentrates (feed grains) and roughages (hays and crop residues) to a ration and balancing the minerals and vitamins with added supplements. Most roughages used in formulated diets for ruminants are cultivated hays (i.e. grass and legume crops) and crop residues (beet pulp, corn husks and cobs, etc.); very little woody vegetation (i.e. sawdust or wood pulp) has been utilized.

Fiber Analysis and Classification

The term fiber in animal nutrition has been defined in various ways, but generally refers to the "hard to digest carbohydrates" (Ensminger and Olentine 1978) found in a food. Quantitatively, fiber has been determined by chemical analysis. The Weende system of proximate analysis, (Henneberg and Stohmann 1960) partioned forage into the soluble fraction (nitrogen free extract, NFE) and the insoluble fraction (crude fiber). Studies with ruminants (Ely and Moore 1959) demonstrated that in some instances the crude fiber portion was more digestible than NFE. Criticism of this sytem led to the development of the Van Soest system of fractionation (Van Soest 1963, 1965b; Van Soest and Wine 1967, Goering and Van Soest 1970). This system separated the plant cell into two components: (1) the cell soluble portion, consisting of sugars, soluble carbohydrates, proteins, and lipids (which were almost completely available to the animal) and (2) cell wall constituents, comprised of cellulose, hemicellulose, lignin, and minerals. The Van Soest system of fractionation allowed for a more accurate separation of chemical constituents in terms of nutritional availability to the ruminant animal.

Components of Voluntary Intake

Milchunas (1977) and Milchunas et al. (1978) provided an excellent review of the variables affecting voluntary intake (VI) and rates of passage in ruminants. In summary, VI was a function of rumen fill and food turnover time under bulk-limiting conditions. Evidence that ruminants were bulk-limited was provided by the observed reduction in voluntary intake when water-filled bladders (Campling and Balch 1961, Egan 1972), polypropylene fibers (Welch 1967), polyvinyl chloride, sawdust (Egan 1972, Weston 1966), or feed (Egan 1972, Weston 1966) were introduced into the rumen. Work by Campling et al. (1963), Freer and Campling (1963), and Ulyatt et al. (1967) suggested that animals ate to a constant level of dry matter in the rumen. Therefore, rumen capacity could limit intake before the animal's requirement for energy was met. However, when the energy requirement was met, it appeared that chemostatic or thermostatic regulation of intake occurred (Ammann et al. 1973, Baumgardt 1970, Montgomery and Baumgardt 1965).

The gut capacity of an animal has fixed and variable components. Hofmann (1968, 1973) studied ruminal structures in relation to feeding habits and observed two basic morphological types: (1) those of quality selective feeders, and (2) those of bulk, large quantity grazers. Hofmann surmised that several structural components of the stomach determined the physical regulation of food intake. Capacity, size of communication ostia, barriers, subdivisions or contractive mechanisms for the delay of food passage were so firmly established that they remain unaffected by dietary changes, and therefore determine the limits of the adaptive ability of a species.

Turnover time was the relatively variable component of voluntary intake in that, within the fixed limits imposed by rumen structure, it was a function of the variable rates of digestion and propensity for particle size reduction of different forage species. This, in turn, depended on the physical and chemical nature of the forage and rumination time.

Forage turnover time was dependent on the rapidity of clearance of forage from the digestive tract, which then allowed further intake. Clearance may be accomplished by means of excretion or absorption. Mertens (1973) concluded that the lower tract did not limit passage. Excretion appeared to be controlled by the reticulo-omasal orifice which acted as a filter for large forage particles. Balch and Campling (1962, 1965) and Troelsen and Cambell (1968) found marked differences in relative particle size of ruminal and omasal digesta. When propylene fibers of varying length were introduced into the rumen, longer fibers caused longer and more prolonged reductions in intake (Welch 1967). Pouring water into the rumen did not affect intake (Campling and Balch 1961, Moore et al. 1960); cell contents were soluble and occupied essentially no volume when dissolved (Van Soest 1971 in Robbins 1973). Therefore, the fibrous fraction of a forage limits the rate of passage. As this fraction increases, voluntary intake declines with an increasingly negative slope (Van Soest 1965a).

Mastication, rumination, and digestion are the means by which particles are reduced for passage. Welch and Smith (1969, 1970) found high correlations between cell wall content of the diet and rumination time. The relative rates of breakdown and mode of breakdown of coarse roughage by artificial mastication have been thought to relate to voluntary consumption by sheep (Troelsen and Bigsby 1964, Troelsen and Campbell 1968).

Campling (1970), Van Soest (1965a), and Weston (1968) emphasized that the importance of rate of digestion on rate of disappearance on turnover time is of a dual nature: (1) digestion of cellulose weakens cell wall structure, thereby contributing to ease of particle size reduction, hence, rate of passage and (2) digestion of cellulose may contribute directly to the reduction of volume of material in the rumen. Considering that cell solubles, when dissolved, do not contribute to bulk reduction and that digestion of cellulose contributes to bulk reduction, primarily through its effect on particle size reduction, then rate of passage is the primary component of turnover time. This explains the low correlation of rate of fermentation to voluntary intake (Mertens 1973, Thornton and Minson 1973) and the rather consistent relationship of VI to cell wall (Van Soest 1965a).

Balch and Campling (1962, 1965), Hungate (1966), Troelsen and Cambell (1968), Van Soest (1966), and Welch (1967) indicated the importance of rate of particle size reduction in determining rate of passage. Rumination time is highly correlated to cell wall content of the diet (Cammell and Osbourn 1972, Welch and Smith 1969, 1970) as it may also be to lignin content (Mertens 1973). Cell wall content and lignin have thus been regarded as inhibitors to physical breakdown and, therefore, rate of passage. Also, since cell contents are almost completely digested by the ruminant, and cell wall is of variable availability, high cell wall and/or lignin composition with other factors constant indicates relatively lower digestibility. Low digestibility seemingly implies a slower rate of passage because rate of digestion is one of the components of rate of passage. Therefore, high fiber, lignin, and low digestibility are generally considered synonymous with a slower rate of passage. With respect to lignin, Mertens (1973) theorized that with lignin, somewhat the opposite could be true; that lignin provides rigidity to wood cell walls, while cellulose provides flexibility. Therefore, high lignin content would suggest greater shattering ability while high cellulose content would suggest greater resistance to mastication. Van Soest (1966) observed that although lignin content was directly related to feed particle size, it was inversely related to fecal particle size. Therefore, the largest, most lignified feed particles are transformed into the smallest most lignified fecal particles.

One additional facet of the particle size reduction phenomenon is pertinent in this discussion before a hypothesis is presented concerning the development of a formulated ration for moose. Mertens (1973) reviewed the work of Troelsen and Campbell (1968) with respect to particle shape. Omasal particles in domestic sheep fed on alfalfa were short and broad with a more cubical shape, whereas omasal particles in grass-fed animals were long, thin, and more fiber-like. At the same level of intake, more large particles passed into the omasum when the animal was fed alfalfa than when fed grass. Yet, within the legume or grass families, the more lignified material passed slower because of the need for increased rumination. Mertens concluded that lignin would therefore have two opposing influences. Increased lignin requires greater rumination, yet the particles produced are of a more optimum shape for passage.

The opposing influence of lignin on rate of passage may explain several seemingly contradictory results. For example, contrary to Troelsen and Campbell's (1968) observation of more lignified material passing slower, Smith (1968), feeding sheep cell wall of a constant average particle size and varying lignin content, observed similar rates of passage although rate of digestion was negatively influenced by increasing lignification. In a study by Milchunas (1977), highly lignified *Vaccinium* had a faster rate of passage than *Epilobium angustifolium* or *Agropyron spicatum* when fed to deer. Also with respect to the *Agropyron*, a grass, relatively large fecal particles were observed compared to the *Epilobium* and *Vaccinium*. Thus, the work of Smith (1968), Van Soest (1966) and Milchunas (1977) all support Merten's (1973) hypothesis that high lignin content may provide greater shattering ability.

Forage Fiber Content

Chemically, fiber composition varies considerably between grass, forbs and shrubs/trees. In general, grass species have a high cell wall content and low lignin content (Van Soest 1973). Likewise, grasses have a much greater amount of hemicellulose than legumes (Gaillard 1965). Analysis of Kenai Peninsula moose browse (Oldemeyer et al. 1977) revealed apparent differences between grasses, forbs, and woody vegetation. If one looks at the ratio of lignin/cell wall constituents (lig/CWC) certain trends are apparent. Grasses have a very low lig/CWC ratio, while browse, including the leaves, has a high lig/CWC ratio (Table 1). Forbs are intermediate. This lig/CWC ratio represents the percentage of lignin making up the fiber portion of the forage. Browse, including leaves, is high in total fiber lignin, while grass is low in fiber lignin.

Food habits of moose (LeResche and Davis 1973, Peek 1974) indicate their diet is composed almost entirely of woody vegetation and leaves. With the above variables in mind, we hypothesized that moose, as ruminants, evolved with certain mechanisms to process woody vegetation but may lack the ability to process grasses and many forbs. Browse as

Table 1. Quality of moose forage collected during July 1974 on the Kenai Peninsula, Alaska[1]

Species	IVDMD (%)[2] Moose	IVDMD (%) Dairy cow	Fiber (%) Cell walls	Fiber (%) ADF	Fiber (%) Lignin	Lig/CWC	Protein %
Grass							
Bluejoint	48.1	55.9	69.8	37.8	3.7	.053	9.8
Carex sp.	41.4	53.8	78.4	33.4	5.9	.075	9.9
Forbs							
Menyanthes trifoliata	92.3	85.9	30.4	16.1	3.6	.118	13.9
Fireweed	62.2	64.7	23.8	19.3	5.4	.227	11.9
Lupine	56.9	84.4	23.1	18.8	3.7	.160	24.3
Potamogeton sp.	73.1	80.7	32.2	17.7	2.4	.075	17.1
Shrubs							
Paper birch Leaves	43.1	47.6	29.0	19.5	8.3	.286	16.9
Twigs	25.8	23.5	56.1	43.2	16.8	.299	9.0
Combined	42.6	38.6	38.3	26.0	11.8	.287	13.9
Dwarf birch	42.6	38.1	36.5	27.3	14.5	.397	16.8
Aspen Leaves	56.8	57.6	36.3	29.9	17.6	.484	13.8
Twigs	64.1	56.1	46.2	36.5	13.4	.290	8.3
Combined	--	57.4	36.8	28.6	14.4	.391	12.6
Willow Leaves	54.8	41.2	27.6	22.2	11.6	.420	13.5
Twigs	42.6	43.3	44.9	40.6	18.2	.405	6.9
Combined	57.8	41.7	26.6	23.9	12.7	.477	13.2
Lowbush cranberry	44.3	38.5	50.5	44.6	23.8	.471	7.6
Highbush cranberry	52.8	64.4	37.8	28.2	13.1	.347	10.3

1/ Data from Oldemeyer et al. 1977.
2/ In vitro dry matter digestion.

a food is composed of two components: (1) the bark and bud which provide the available nutrients, and (2) a core which is composed of lignified woody material. Although the entire package (bud, bark and woody core) is relatively low in nutrients, moose are able to meet their nutritional requirements because the non-nutritive core can be rapidly broken down into small particles capable of passing from the rumen. Thus, rates of passage are sufficient to allow moose to digest and assimilate nutrients from the bark and bud, and not be bulk-limited by the woody core. This situation is not true for grasses and many forbs. Consequently, moose fed diets which contain large quantities of fibrous material from grasses and forbs (most hays and crop residues) become bulk-limited because of reduced rates of passage and cannot extract enough nutrients to survive. Most formulated rations for domestic and zoo ruminants contain large quantities of grass or alfalfa hay and, consequently, are not suitable as moose foods. It is for these reasons that our formulated diet for moose contains sawdust as the primary fiber component.

PROCEDURES

Six hand-reared captive moose calves were used to evaluate the formulated ration. Development and testing of the ration followed recommendations of Ensminger and Olentine (1978). In general, the ration was evaluated on the basis of (1) physical characteristics, (2) chemical analysis and (3) biological evaluation.

The diet was analyzed chemically for crude protein (kjeldahl NX6.25), gross energy, ash, and minerals (A.O.A.C. 1965). Cell wall constituents (CWC), acid-detergent fiber (ADF), and acid-detergent lignin, were determined by procedures outlined in Van Soest and Wine (1967), Van Soest (1963), and Goering and Van Soest (1970). Physical characteristics including pelleting ability, lack of crumbling of prepared pellets, and acceptance of various pellet sizes, were evaluated subjectively.

Biological evaluation consisted of two parts. Conventional digestion and balance trials (Ensminger and Olentine 1978, Schneider and Flah 1975, Church 1969) were used to evaluate the animals' ability to process, digest, absorb and assimilate the various nutrients. Wooden digestion stalls (3.1 X 2.4 X 2.4 m), designed to permit complete and separate collection of feces and urine, were utilized. The floors of the stalls were fitted with expanded metal sheeting to permit fecal and urine separation. During phase 1, animals were enclosed in 3.1 X 15.2 m enclosures for 10 days during which average daily food consumption was measured. During phase 2, moose were kept in the same enclosures and fed 90 percent of their phase 1 intake for 3 days. This was done to level out feed consumption, fecal output, and eliminate the need to analyse orts. During the third phase, the moose were placed in the digestion cages, offered 90 percent of their phase 1 intake, and feces and urine were collected daily for 7 days. Water was available *ad libitum*. At the end of the digestion trial, a composite sample of the diet was analyzed in triplicate for moisture. Orts were subsampled and analyzed in a similar fashion. Excreta was collected once daily, weighed or the volume measured and subsampled at 20 percent by weight and 5 percent by volume for feces and urine, respectively. Urine samples were acidified with 6N H_2SO_4 to lower the pH to below 4 to prevent the loss of ammonia nitrogen. Both feces and urine were frozen (-12C) until analyzed.

RESULTS AND DISCUSSION

Ingredients (Table 2) used in the formulated moose ration, here after referred to as the "MRC Special," were selected to provide one or more of the following: (1) essential nutrients, (2) increased palatability, (3) improved ingredient pelleting, or (4) reduced spoilage. Aspen sawdust was used as a fiber source rather than cultivated hays or crop residues because of its fiber form and woody nature.

Sawdust was obtained from a local sawmill shortly after milling operations. Initially, we used the sawdust on an "as is" basis when preparing the ration, but because of its high moisture content, several batches of feed molded. This problem was corrected by air drying the sawdust until the moisture content was below 30%. We have used sawdust from both summer and winter harvested trees with apparent success. Trees logged during summer contained more sap and, consequently, the sawdust required a longer time to dry.

Aspen was chosen as a sawdust source because it was: (1) eaten by moose, (2) abundant and easy to obtain, (3) lacking in terpenes or resins, and (4) successfully fed to domestic cattle. We are currently experimenting with cottonwood (*Populus tacamahacca*) and white spruce (*Picea glauca*) sawdust, but results are not available at this time.

Although spruce sawdust was more readily available than aspen sawdust, we were reluctant to use it initially, because of the terpenes it contained. Work by Nagy et al. (1964) with sagebrush (*Artemesia*

Table 2. Composition of the "MRC Special" diet formulated for captive moose[1/].

Ingredient	Percent
Corn, ground yellow	28.7
Sawdust[2/]	25.9
Oats, rolled	17.2
Soybean meal, powdered	7.2
Cane molasses, dry	5.7
Barley, ground	5.7
Beet pulp, ground	5.7
Vitamin premix[3/]	0.3
Trace mineral salt[4/]	0.7
Dicalcium phosphate[5/]	1.3
Pelaid[6/]	1.4
Mycoban [7/]	T

1/ The diet was formed in 4.8 mm pellets.

2/ Aspen sawdust from sawmill.

3/ Each kg contained 5004.4 USP units vitamin A, 13228 IC units vitamin D_3, and 44 I units vitamin E.

4/ Guaranteed analysis: NaCl 95-98%, Zn 0.35%, Mn 0.28% Fe 0.175%, Cu 0.035%, I 0.007%, Co 0.007%.

5/ Guaranteed analysis: P 18.0%, Ca 31.0-34.0%.

6/ Pelaid, Rhodeia Inc., Ashland Ohio, is a wood byproduct used to enhance pelleting.

7/ Mycoban, Van Waters and Rogers, Anchorage Alaska, inhibits mold growth. T = 0.5 lbs/ton (0.025%).

tridentata), Oh et al. (1967) with Douglas-fir (*Pseudotsuga menziesii*), and Schwartz et al. (1980a,b) with *Juniperus* spp. has indicated that volatile oils and terpenes were inhibiting to mule deer rumen bacteria and reduced palatability of feed.

Protein and energy levels of the MRC Special (Table 3) were based on dietary requirements for dairy cattle. The 11.75% crude protein level and associated digestible energy appeared adequate for moose calf growth from weaning to 1 year of age. Growth, as measured by weight gain, for 6 moose fed the MRC Special, was similar to that for wild moose calves on the Kenai Peninsula through October (Franzmann et al. 1978). After November, the moose receiving MRC Special continued to gain weight throughout the winter, while the wild moose calves lost weight. The average daily gain from weaning (August 15) until May 31 the following year was 0.62 kg± S.D. 0.02. These 6 moose continued to gain weight throughout their second summer until early October when rutting activity began. Average daily weight gains from May 31 until October 1 were 0.74 kg± S.D. 0.09. Animals experienced slight loss of weight during the rutting period and throughout the winter. Weight loss per day was minimal and only amounted to 0.04 kg± S.D. 0.02 from November 1 through March 25. Weight loss was a result of reduced feed intake and consequent fat metabolism. Similar weight loss has been observed in white-tailed deer offered *ad libitum* feed throughout winter.

Apparent digestion of dry matter of the MRC Special was 64.3% ± S.D. 2.3% as determined in vivo with 4 moose. Data on energy partioning and protein and fiber digestion were not available for reporting at

Table 3. Chemical composition and apparent digestibility of the "MRC Special" diet formulated for captive moose.

Analysis	Amount and units
Dry matter	80.0%
Crude protein	11.75%
Cell wall constituents	47.2%
Acid-detergent fiber	26.5%
Gross energy	4.45 Kcal/gram
Calcium	9750 ppm
Potasium	7140 ppm
Sodium	2910 ppm
Phosphorus	2106 ppm
Magnesium	205 ppm
Iron	62 ppm
Zinc	23 ppm
Copper	6 ppm
Selenium	0.22 ppm
Cobalt	0.1 ppm
Chromium	0.1 ppm
Dry matter digestion (in vivo)	64.3%

this time. However, digestibility appears adequate in light of weight gains and general health and vigor of the moose receiving the diet.

Consistency of the feces, which was used as a gross indicator of digestive upset, was similar to that of wild moose. Only rarely were "loose stools" observed. One calf raised in 1979 had persistent diarrhea of unknown etiology for over 60 days. This condition cleared in early winter and the animal now appears normal and is gaining weight. We do not know if its digestive problem was associated with the MRC Special.

We did lose one calf early in 1979 when it was less than 2 months old. Its death was probably a result of bloat associated with excessive feeding of the MRC special. However, this particular animal had experienced some digestive difficulties prior to being brought to the MRC. The animal was accidently given *ad libitum* feed when it was initially introduced to the diet. This problem may have been alleviated by gradual introduction to the diet, thereby allowing the animal's digestive system adequate time to adjust to the dietary change. This is a standard practice in animal feeding. The loss of this animal does not reflect an imbalance in the feed.

While our preliminary report on the MRC Special suggests it is useful for maintaining moose, its composition should not be considered final. Continuing research into nutritional requirements of moose, particularly calves and reproductive females, will doubtless indicate modifications which will improve the ration. However, we feel it is important to make these preliminary findings available because: (1) the diet appears to be adequate to sustain moose, (2) feeding the

MRC Special is cheaper (cost $260.00/ton on April 1, 1980) than cutting browse, and (3) and with additional agencies using this diet, the MRC Special will be tested over a wider range of conditions and, hopefully, it will be improved faster.

LITERATURE CITED

Ammann, A. P., R. L. Cowan, C. L. Mothershead, and B. R. Baumgardt. 1973. Dry matter and energy intake in relation to digestibility in white-tailed deer. J. Wildl. Manage. 37:195-201.

A.O.A.C. 1965. Official methods of analysis. 10th edition. Association of official Agricultural Chemists, Washington D.C. 957p.

Balch, C. C., and R. C. Campling. 1962. Regulation of voluntary food intake in ruminants. Nutr. Abstr. Rev. 32:669-686.

Balch, C. C., and R. C. Campling. 1965. Rate of passage of digesta through the ruminant digestive tract. In Physiology of digestion in the ruminant. R. W. Doughorty (Ed.). Butterworth's, Washington D.C.

Baumgardt, B. R. 1970. Control of feed intake in the regulation of energy balance. In Physiology of digestion and metabolism in the ruminant. Proc. Third Int'l. Symp. Canbridge, England. A. J. Phillipson (Ed.). pp. 235-253.

Cammell, S. B., and D. F. Osbourn. 1972. Factors influencing the total time spent chewing by sheep given diets containing long, dried forages. Proc. Nutr. Soc. 31:63A-64A.

Campling, R. C. 1970. Physical regulation of voluntary intake. In Physiology of digestion and metabolism in the ruminant. Proc.

Third Int'l. Symp., Cambridge, England. A. J. Phillipson (Ed.). pp. 226-234.

Campling, R. C., and C. C. Balch. 1961. Factors affecting the voluntary intake of food by cows. 1. Preliminary observations on the effect, on the voluntary intake of hay, of changes in the amount of the reticulo-ruminal contents. Brit. J. Nutr. 15:523-530.

Campling, R. C., Freer, and C. C. Balch. 1963. Factors affecting voluntary intake of food by cows. 6. A preliminary experiment with ground pelleted hay. Brit. J. Nutr. 17:263-272.

Church, D. C. 1969. Digestive Physiology and nutrition of ruminants. Vol. 1., Digestive physiology. Dept. Animal Sci., Oregon St. Univ. Corvallis. 316pp.

Egan, A. R. 1972. Nutritional status and intake regulation in sheep. VII. Control of voluntary intake of three diets and the responses to intraruminal feeding. Aust. J. Agric. Res. 23:347-361.

Ely, R. E., and L. A. Moore. 1959. The nutritive value of forages with emphasis on the polysaccharide fraction. Pages 173-185. In H. B. Sprague, ed. Grasslands. Publ. No. 53. Am. Assoc. Adv. Sci., Washington D.C.

Ensminger, M. E., and C. G. Olentine. 1978. Feeds and nutrition - complete. Ensminger Publishing Co. Calif. 1417pp.

Franzmann, A. W., R. E. LeResche, R. A. Rausch, and J. L. Oldemeyer. 1978. Alaskan moose measurements and weights and measurement-weight relationships. Can. J. Zool. 56:298-306.

Freer, M., and R. C. Campling. 1963. Factors affecting the voluntary food intake by cows. 5. The relationship between the voluntary intake of food, the amount of digesta in the reticulo-rumen and the rate of disappearance of digesta from the alimentary tract with diets of hay, dried grass, or concentrates. Brit. J. Nutr. 17:79-88.

Gaillard, B. D. E. 1965. Comparison of the hemicelluloses from plants belonging to two different plant families. Phytochem. 4:631-634.

Gasaway, W. C., and J. W. Coady. 1974. Review of energy requirements and rumen fermentation in moose and other ruminants. Naturaliste Can., 101:227-262.

Goering, H. K., and P. J. Van Soest. 1970. Forage fibre analyses. Agricultural Research Service. USDA Agric. Handbook No. 379.

Henneberg, W., and F. Stohmann. 1960. Bergundung elner rationeller Futterung der Wiederkaver. Vol. I. Schwetschtke U. Sohn. Braunschweig. 4.

Hofmann, R. R. 1968. Comparisons of the rumen and omasum structure in East African game ruminants in relation to their feeding habits. Symp. Zool. Soc. London. 21:179-194.

Hofmann, R. R. 1973. The ruminant stomach. Stomach structure and feeding habits of E. African game ruminants. E. Afr. Monogr. in Biol. 2:38-45.

Hungate, R. E. 1966. The Rumen and its Microbes. Academic Press, New York. 533pp.

LeResche, R. E., and J. L. Davis. 1973. Importance of nonbrowse foods to moose on the Kenai Peninsula, Alaska. J. Wildl. Manage. 37(2):279-287.

Mertens, D. R. 1973. Application of theoretical mathematical models to cell wall digestion and forage intake in ruminants. PhD. Thesis. Cornell University, Ithaca. 187pp.

Milchunas, D. G. 1977. In vivo - in vitro relationships of Colorado mule deer forage. M.S. Thesis. Colo. State Univ., Fort Collins. 133pp.

Milchunas, D. G., M. I. Dyer., O. C. Wallmo, and D. E. Johnson. 1978. In-vivo/in-vitro relationships of Colorado mule deer forages. Colo. Div. of Wildl. Special Report No. 43. 44pp.

Moen, A. N. 1973. Wildlife Ecology: an analytical approach. W. H. Freeman and Co. San Francisco. XVIIiii + 458pp.

Montgomery, M. J., and B. R. Baumgardt. 1965. Regulation of food intake in ruminants. 2. Rations varying in energy concentration and physical form. J. Dairy Sci. 48:1623-1628.

Moore, L. A., J. W. Thomas, and J. F. Sykes. 1960. The acceptability of grass/legume silage by dairy cows. Proc. VIII Int'l. Grassl. Cong. p. 701-704.

Nagy, J. C., H. W. Steinhoff, and G. M. Ward. 1964. Effects of essential oils of sagebrush on deer rumen microbial function. J. Wildl. Manage. 28:785-790.

Oh, H. K., T. Sakai, M. B. Jones, and W. M. Longhurst. 1967. Effects of various essential oils isolated from Douglas fir needles upon sheep and deer rumen microbial activity. Appl. Microbiol. 15:777-784.

Oldemeyer, J. L., A. W. Franzmann, A. L. Brundage, P. D. Arneson, and A. Flynn. 1977. Browse quality and the Kenai Moose population. J. Wildl. Manage. 41:533-542.

Peek, J. M. 1974. A review of moose food habits studies in North America. Naturaliste Can. 101:195-215.

Robbins, C. T. 1973. The biological basis for the determination of carrying capacity. PhD. Thesis. Cornell University, Itahca. 239p.

Schneider, B. H., and W. P. Flah. 1975. The evaluation of feeds through digestibility experiments. Univ. Georgia Press, Athens. 423pp.

Schwartz, C. C., J. C. Nagy, and W. L. Regelin. 1980a. Juniper oil yield, terpenoid concentration, and antimicrobial effects on deer. J. Wildl. Manage. 44:107-113.

Schwartz, C. C., W. L. Regelin, and J. C. Nagy. 1980b. Deer preference for juniper forage and volatile oil treated foods. J. Wildl. Manage. 44:114-120.

Smith, L. W. 1968. The influence of particle size and lignification upon the rate of digestion and passage of uniformly labeled carbon-14 plant cell walls in sheep. Ph.D. Thesis, University of Maryland. 132pp.

Thornton, R. F., and D. J. Minson. 1973. The relationship between apparent retention time in the rumen, voluntary intake, and apparent digestibility of legume and grass diets in sheep. Aust. J. Agric. Res. 24:889-898.

Troelsen, J. E., and F. W. Bigsby. 1964. Artificial mastication - a new approach for predicting voluntary forage consumption by ruminants. J. Anim. Sci. 23:1139-1142.

Troelsen, J. E., and J. B. Campbell. 1968. Voluntary consumption of forage by sheep and its relation to the size and shape of particles in the digestive tract. Anim. Prod. 10:289-296.

Ulyatt, M. J., K. L. Blaxter, and S. McDonald. 1967. The relations between the apparent digestibility of roughages in the rumen and lower gut of sheep, the volume of fluid in the rumen and voluntary intake. An. Prod. 9:463-470.

Van Soest, P. J. 1963. Use of detergents in the analysis of fibrous feeds. II. A rapid method for the determination of fiber and lignin. J. Assoc. Off. Agric. Chem. 46:829-835.

Van Soest, P. J. 1965a. Symposium on factors influencing the voluntary intake of herbage by ruminants: voluntary intake in relation to chemical composition and digestibility. J. Anim. Sci. 24:838-843.

Van Soest, P. J. 1965b. Use of detergents in analysis of fibrous feeds. III. Study of effects of heating and drying on yield of fiber and lignin in forages. J. Assoc. Off. Agric. Chem. 48:785-790.

Van Soest, 1966. Forage intake in relation to chemical composition and digestibility: some new concepts. Proc. Southern Pasture Forage Crop Improvement Conf. 24p.

Van Soest, P. J. 1973. The uniformity and nutritive availability of cellulose. Fed. Proc. 32:1804-1808.

Van Soest, P. J., and R. H. Wine. 1967. Use of detergents in the analysis of fibrous feeds. IV. Determination of plant cell wall constituents. J. Assoc. Off. Anal. Chem. 50:50-55.

Wallmo, O. C., L. H. Carpenter, W. L. Regelin, R. B. Gill, and D. L. Baker. 1977. Evaluation of deer habitat on a nutritional basis. J. Range Manage. 30:122-127.

Welch, J. G. 1967. Appetite control in sheep by indigestible fibers. J. Anim. Sci. 26:849-854.

Welch, J. G., and A. M. Smith. 1969. Influence of forage quality on rumination time in sheep. J. Anim. Sci. 28:813-818.

Welch, J. G., and A. M. Smith. 1970. Forage quality and rumination time in cattle. J. Dairy SCi. 53:797-800.

Weston, R. H. 1966. Factors limiting the intake of feeds by sheep. I. The significance of palatability, the capacity of the alimentary tract to handle digesta, and the supply of gluconeogenic substrate. Aust. J. Agric. Res. 17:939-954.

Weston, R. H. 1968. Factors limiting the intake of feed by sheep. III. The mean retention time of feed particles in sections of the alimentary tract. Aust. J. Agric. Res. 19:261-266.