

## Fragmenta Theriologica

### Dry Matter and Energy Intake in Relation to Digestibility in Desert Bighorn Sheep <sup>1</sup>

POBRANIE MATERII I ENERGII W STOSUNKU DO STRAWNOSCI U OWCY KANADYJSKIEJ

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Dry matter intake (DMI), and dry matter digestibility (DMD) were determined for three diets, using three desert bighorn sheep, *Ovis canadensis mexicana*. Bighorn sheep were placed in individual cages and fed three diets: high and low quality alfalfa, and Bermuda grass (*Cynodon dactylon*). Mean DMI of high quality alfalfa, low-quality alfalfa, and Bermuda grass was 1,281.3, 1,512.0, and 1,084.0 g/animal/day, respectively, with corresponding DMD's of 68.5, 64.1, and 57.7%. Dry matter digestibility was improved with increased crude protein and cell solubles, and with decreased neutral detergent fiber and hemicellulose. Mean digestibility energies for the high quality alfalfa, low quality alfalfa, and Bermuda grass were 642.6, 626.6, and 412.3 kJ/kg BW<sup>0.75</sup>/day, respectively.

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#### 1. INTRODUCTION

Prior to the arrival of European man desert bighorn sheep (*O. c. nelsoni*, *O. c. mexicana*, *O. c. cremnobates*, and *O. c. weemsi*) inhabited dry, barren mountain ranges in the southwestern United States and northwestern Mexico. Over 1,000,000 bighorn sheep were dispersed throughout the western United States early in the nineteenth century (Buechner, 1960; Manville, 1980; Cooperrider, 1985). With the arrival of European man, desert bighorn sheep began to decline in response to man's impact on the environment. The introduction of livestock exposed bighorn sheep to disease and depleted forage (Packard, 1946). Thousands of bighorn

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sheep were slaughtered for meat and their hides (Manville, 1980). Hunting also diminished herds and by 1894 desert bighorn sheep were scarce in northwestern Mexico (Mearns, 1907).

Habitat modification was, in part, responsible for the decline of desert bighorn sheep. The periodic drying up of rivers from drought and irrigation may have forced sheep into new habitats of lesser quality (Russo, 1956). Additional habitat alteration and destruction by man has eliminated many desert bighorn sheep populations and <12,000 desert bighorn sheep remain in isolated populations scattered throughout their former range (Monson, 1980). Weaver (1975) identified 77 populations of desert bighorn sheep in California; only 15 of them contain  $\geq 100$  individuals. In Arizona  $\geq 59$  populations of sheep exist but <7 are known to have  $\geq 100$  individuals in the population (Krausman & Leopold, 1986b). This pattern is similar throughout the southwest; small isolated populations ( $\leq 100$ ) constitute a significant proportion of the remaining desert bighorn sheep. Many of the remaining populations are separated from former ranges by highways, fences (Leslie & Douglas, 1979), railroads, agriculture, canals, and housing developments (Gionfriddo & Krausman, 1986). With the rapid development by man and subsequent destruction of desert bighorn sheep habitat, managers need additional information to manage the remaining populations of bighorn sheep. This is especially true in Arizona where desert bighorn sheep are one of the most sought after trophy animals.

Reintroductions have been successful in increasing bighorn sheep populations throughout the southwestern United States (Tsukamoto & McQuivey, 1977; deVos *et al.*, 1981; Morgart & Krausman, 1981; Elenowitz, 1982) and habitat manipulation may enhance desert bighorn sheep populations. However, any manipulation of habitat quality will be expensive. Habitat use data for desert bighorn sheep are available (Gionfriddo & Krausman, 1986; Krausman & Leopold, 1986a). Because desert bighorn sheep are difficult to obtain and maintain in captivity, their energy requirements and ability to digest different forages are not documented. The objective of our study was to estimate the energy requirements of captive adult male bighorn sheep which were fed high quality alfalfa, low quality alfalfa, and low quality grass (*Cynodon dactylon*).

## 2. METHODS AND MATERIALS

Three semi-tame, adult (3.5–4.5 years old) male desert bighorn sheep were housed in an enclosure (<0.5 ha) at the Campbell Avenue farm, University of Arizona, Tucson. During the summer of 1986 sheep were placed in individual vented metal cages where we could measure forage intake and feces output. Three feeding trials were conducted using high and low quality alfalfa, and

Bermuda grass. Bighorn sheep consumed the experimental diet for five days prior to each five day feeding trial. During feeding trials, forage intake and feces production were measured. Animals were fed twice daily all they would eat and water was available at all times. Sheep were weighed prior to the first trial and following the last feeding trial.

Dry matter was determined by heating samples to a constant weight in a convection oven at 35°C. This process was usually accomplished in 48 hours. Dried material was ground to a 2-mm particle size with a Wiley laboratory mill for further analytical procedures. The percentage of ether extract (lipid) was determined by the procedure described by the Association of Official Agricultural Chemists (1980). Fiber, lignin and cellulose determinations were made according to Goering and Van Soest (1970). Percent nitrogen was determined using a micro-Kjeldahl H<sub>2</sub>SO<sub>4</sub> digestion procedure. Calcium and phosphorus content of feed and feces were determined with an atomic absorption spectrophotometer. Nitrogen, calcium, and phosphorus determinations were verified using micro-Kjeldahl H<sub>2</sub>SO<sub>4</sub> digestion and an autoanalyzer. Total energy was calculated with bomb calorimetry.

### 3. RESULTS

The nutritional quality of the forages used in the feeding trials (Table 1) varied. The high quality alfalfa had higher levels of protein and cell solubles, and lower levels of neutral detergent fiber (NDF), acid detergent fiber (ADF), cellulose, and hemicellulose when compared to Bermuda grass. The low quality alfalfa values generally were between those of the other two forages. Individual daily DMI ranged from 1,178 to 1,369 g with high quality alfalfa, 1,352 to 1,738 g with low quality alfalfa and 988 to 1,170 g with Bermuda grass. In all trials the lightest sheep consumed the least and the heaviest sheep consumed the most.

Table 1  
Composition of forages used in desert bighorn sheep digestion trials (100% dry matter basis) in Arizona, summer 1986.

Forage component	High quality alfalfa	Low quality alfalfa	Bermuda grass
Dry matter	90.5	92.5	93.3
Total ash	9.9	11.7	11.0
Ether extract	2.1	1.2	1.3
Crude protein	18.5	17.6	13.8
Neutral detergent fiber	41.7	61.8	81.8
Acid detergent fiber	32.8	46.7	41.4
Lignin	8.5	12.6	8.3
Cellulose	24.5	34.0	28.9
Hemicellulose	8.9	15.1	40.4
Cell solubles	68.8	46.3	25.4
Calcium	2.2	1.6	0.6
Phosphorus	0.2	0.3	0.2
Gross energy (kJ/g)	18.4	17.6	17.6

The same pattern was repeated when intake was calculated per kg  $BW^{0.75}$ .

While daily DMI for low quality alfalfa was 15% higher than for high quality alfalfa, digestible energy calculated on a  $BW^{0.75}$  basis was similar for both forages (642.6 vs. 626.6 kJ, respectively) (Tables 2 and 3). With the Bermuda grass diet, consumption was 15 and 28% less when compared to the high and low quality alfalfa diets, respectively (Table 2).

Table 2

Daily intake and fecal extraction of forages used by three desert bighorn sheep ( $\bar{x} \pm SD$ ) in Arizona, summer 1986.

Item	High quality alfalfa	Low quality alfalfa	Bermuda grass
Food intake:			
g dry wt/animal	1281.3 $\pm$ 95.4	1512.0 $\pm$ 201.3	1084.7 $\pm$ 91.5
kJ/animal	23524.9 $\pm$ 1751.4	26291.8 $\pm$ 3500.3	19128.8 $\pm$ 1614.1
Feces:			
g dry wt/animal	402.7 $\pm$ 28.9	542.0 $\pm$ 52.0	459.3 $\pm$ 31.9
kJ/animal	7469.1 $\pm$ 578.9	10447.4 $\pm$ 913.8	8717.8 $\pm$ 884.5

Table 3

Apparent digestibilities (%) of selected chemical components of three experimental diets by three desert bighorn sheep ( $\bar{x} \pm SD$ ) in Arizona, summer 1986.

Component of diet	High quality alfalfa	Low quality alfalfa	Bermuda grass
Dry matter	68.5 $\pm$ 1.6	64.1 $\pm$ 1.3	57.7 $\pm$ 2.4
Combustible energy	68.9 $\pm$ 2.3	60.1 $\pm$ 1.3	54.2 $\pm$ 2.4
Cell solubles	81.9 $\pm$ 0.4	68.0 $\pm$ 1.1	29.7 $\pm$ 9.1
Crude protein	81.5 $\pm$ 1.8	76.7 $\pm$ 0.4	66.2 $\pm$ 0.5
Neutral detergent fiber	49.7 $\pm$ 3.5	60.7 $\pm$ 1.7	62.4 $\pm$ 2.3
Acid detergent fiber	52.1 $\pm$ 3.1	59.2 $\pm$ 1.8	52.2 $\pm$ 2.3
Lignin	28.0 $\pm$ 6.2	41.4 $\pm$ 3.1	40.0 $\pm$ 5.2
Cellulose	62.3 $\pm$ 2.5	66.6 $\pm$ 1.3	62.5 $\pm$ 2.5
Hemicellulose	40.5 $\pm$ 3.7	65.5 $\pm$ 1.3	72.8 $\pm$ 2.7
Energy retained as digestible energy (kJ/kg $BW^{0.75}$ )	642.6 $\pm$ 38.5	626.6 $\pm$ 75.8	412.3 $\pm$ 39.8

Digestible energy on a  $BW^{0.75}$  basis was also lower (412.3 kJ) for the Bermuda grass diet compared to the alfalfa diets (Table 3). There were no body weight differences noted in any of the sheep between the start and finish of the trials ( $\bar{x}$   $BW$  = 74.0 kg, range = 69.7—78.5 kg).

When the bighorn sheep were fed low quality alfalfa with a DMD lower than that of high quality alfalfa they ate enough additional feed to allow retained energy (digestible energy) to be similar to that when high quality alfalfa was fed (Tables 2 and 3). However, when Bermuda grass with a lower digestibility than low quality alfalfa was fed, con-

sumption also declined (Table 2). The implication is that desert bighorn sheep to some degree can make up for lowered forage quality by eating more.

Dry matter digestibility of the three forages used in this experiment were correlated to some extent with their chemical composition (Table 3). A decrease in protein or cell solubles resulted in a general decrease in digestibility of the forages. The opposite trend was true for NDF and hemicellulose; their higher concentrations in all diets adversely affected digestibility. The concentrations of the other chemical components did not correlate as well with the digestibility data for a given forage. When the data on digestibility (Table 3) are compared with the chemical composition of the two alfalfa diets (Table 1) an increase in lignin and cellulose contents in the low quality alfalfa diet somewhat depresses its digestibility (Table 3). However, the Bermuda grass that contained less lignin and cellulose than the low quality alfalfa reduced it drastically. We compared the apparent digestibilities of the components of the three diets (Table 3) with forage consumption. The digestibilities of crude protein, cell solubles, NDF, and hemicellulose correlated well with an overall DMD of a given forage (Table 3). The digestibilities of crude protein and cell solubles are positively correlated with DMD and the digestibilities of NDF and hemicellulose are negatively correlated. The digestibilities of ADF and its two principle components (cellulose and lignin) were positively correlated with voluntary food intake.

#### 4. DISCUSSION

The relationship between digestibility of a forage and its voluntary intake found in desert bighorn sheep corresponds with the results obtained in experiments involving domestic sheep. In trials with domestic sheep the maximum consumption values of 56–82 g dry weight/kg/day were 60–62% within the range of digestibilities (Baumgardt, 1970; Greenhalgh & Reid, 1973) with the voluntary intake decreasing with changes in digestibility of forage. A similar pattern is found in wapiti or red deer (*Cervus elaphus*) (Maloiy & Kay, 1971; Mould & Robbins, 1982), roe deer (*Capreolus capreolus*) (Drożdż & Osiecki, 1973; Perzanowski, 1978; Drożdż, 1979), and white-tailed deer (*Odocoileus virginianus*) (Ammann *et al.*, 1973).

Increases in voluntary forage intake with the elevation of food digestibility reflects a breakdown rate in the rumen, and perhaps a difference in the size of the omasum that serves as a specific filter by restricting large particles of food from passing on. Less digestible forage (low quality) requires longer handling time in the rumen thus blocking this part of

the stomach and reducing consumption. Hence, it represents a physical regulation of food intake. When a critical digestibility is reached (*i.e.*, the values at which the animal attains its highest voluntary intake) there is another blockage; this time of the abomasum and intestine. High quality food is rapidly broken down into small particles and results in a high flow rate through the omasum. Excessive amounts of digested food cannot be rapidly absorbed in the abomasum and intestine, resulting in switching the regulation of intake to a physiological mechanism (Robbins, 1983).

Like many experiments carried out on wild and domestic ruminants (Drożdż & Osiecki, 1973; Mitchell, 1973; Perzanowski, 1978; Drożdż, 1979), digestibility coefficients with desert bighorn sheep for various forages were correlated with the level of crude protein, cell solubles, and neutral detergent fiber. These authors reported negative correlations of digestibility coefficients with the lignin content in food. Although our data are limited we noted that a decrease in lignin content was not necessarily accompanied by an increase in digestibility. Presumably in some types of forage (*i.e.*, the Bermuda grass) it is not the actual content of lignin and hemicellulose that decide digestibility. It may be the thickness of cell walls that is important (Spalinger *et al.*, 1986). The digestibility of crude protein and cell solubles by desert bighorn sheep increased with a proportional increase in percentage of these components and agrees well with similar trends reported in feed trials involving wapiti and white-tailed deer (Mould & Robbins, 1982).

Because the weight of the desert bighorn sheep did not significantly change during the feeding trials we concluded that the diets were sufficient to cover the cost of maintenance while in metabolism cages. However, because the animals were not weighed between trials there is no way of knowing whether the feeding of a particular forage may have caused a weight increase while another may have resulted in an equal weight loss. In fact this may have occurred because digestible energy expressed as  $\text{kJ}/\text{BW}^{0.75}$  varied so widely between diets. It seems logical to assume that there were weight gains realized during the feeding of the alfalfa diets that were negated during the feeding of the Bermuda diet. According to Blaxter (1962) domestic sheep are able to obtain enough energy for maintenance while consuming *ad libitum* forage with a DMD of only 44%. This would also support the concept that forage with a relatively high DMD such as the alfalfa used in this experiment would cause weight gains when fed *ad libitum*. It then follows that the Bermuda grass diet should not have caused a weight loss if a 44% DMD would support constant weight.

While it seems logical that the experimental animals may have gained

weight on one diet with a high retention of digestible energy and lost it on another where the retention was lower, there is another possibility. The accepted daily maintenance requirement of digestible energy for domestic sheep is about 418.6 kJ/BW<sup>0.75</sup> (Louw *et al.*, 1972). As has been pointed out this level of digestible energy was exceeded by the two alfalfa diets and met almost exactly by the Bermuda grass diet. The alfalfa diets were fed to the sheep first. As has been noted the bighorn sheep were only semi-tame. During the alfalfa feeding trials the animals spent considerable time and energy trying to escape from the metabolic cages. By the time they were fed the Bermuda diets they had calmed down to some extent and were not expending as much energy on physical activity. It could be argued that during the alfalfa trials, the extra daily 209.3 kJ/kg BW<sup>0.75</sup> of digestible energy was used by the animals in aggressive physical activity.

Under the conditions of this study the digestibility of both types of alfalfa diets was higher (68.5 and 64.1%) in bighorn sheep than corresponding figures found for domestic sheep (Heaney, 1973). Also the digestibility of alfalfa by wapiti, red deer, and white-tailed deer (Maloiy & Kay, 1971; Mould & Robbins, 1982) was less than the value found in our experiments with desert bighorn sheep. The high digestibility achieved by desert bighorn sheep may have resulted from anatomical peculiarities of its alimentary tract and from the composition of rumen microflora. The digestibility of forages by ruminants depends to a large extent on the time of retention in the alimentary tract. Kay and Goodall (1976) found that the digestibility and retention were always higher and longer in the domestic sheep than for red deer. The weight of the rumen-reticulum (the system responsible for breaking food into smaller particles) full of food may, in domestic sheep, reach as much as 25% of total body weight (Leng & Brett, 1966; Purser & Moir, 1966), while in deer, this part of the stomach makes no more than 8 to 23% of the total body weight (Gill & Jaczewski, 1958; Short, 1963; Short *et al.*, 1969a; Short *et al.*, 1969b; Prins & Geelen 1971). Sheep may take in much more food at one time as a function of body weight. It is also possible that the omasum in sheep is smaller than that of red deer, white-tailed deer, and mule deer (*Odocoileus hemionus*) (Greenhalgh & Reid, 1973; Nagy & Regelin, 1975; Kay, 1985) which in effect increases the time of forage fermentation in the rumen and enhances the digestibility (Hofmann, 1973; Hopper, 1977).

In comparison to domestic sheep the desert bighorn sheep could have an enlarged rumen-reticulum, reduced omasum and slightly different rumen microflora. This would be of adaptive value to consumption of low-quality forage in habitats that is characteristic for the range of

this species. It should, however, be remembered that in our study no limitation of water was introduced and water influences the level of use of the natural forage supply. As limiting water during the experiments with domestic sheep suppressed both food intake and digestibility of forages (Maloiy *et al.*, 1970), the next feeding trials with desert bighorn sheep should also take into consideration limited water consumption.

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