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Range Nutrition in an Arid Region

Lorin E. Harris

Utah State University

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RANGE NUTRITION
IN AN ARID REGION

Lorin E. Harris
Honor Lecture 36
January 17, 1968
THIRTY-SIXTH FACULTY HONOR LECTURE

RANGE NUTRITION

IN AN ARID REGION

LORIN E. HARRIS
Professor of Nutrition, Animal Science Department

THE FACULTY ASSOCIATION
UTAH STATE UNIVERSITY
LOGAN, UTAH

January 17, 1968
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THE COVER:
Dr. Lorin E. Harris is shown here in front of a "Home on the Range." Usually the camp tender and herder stay in a camp such as this. It is moved over the range every 2 to 6 days depending on feed and weather conditions. The mutton is wrapped up and put in the bed during the daytime to keep it from spoiling. Most of our research work was conducted on the range.

FRONTISPIECE:
Sheep eating supplements in individual portable pens.
FOREWORD

Range nutrition has not received attention commensurate with its significance in the economy of the Western States. The critical point to apply the research is on each range unit. It is here that the real battles are being waged. This lecture has been prepared to emphasize some of the range livestock nutrition problems and how they may be solved to increase livestock production.

I appreciate this honor of being the Faculty Research Lecturer for 1967-68. I have drawn freely on the ideas and data of my colleagues to prepare my lecture. I wish to acknowledge their help and the assistance of staff members, and the authors of the books and articles which served as sources of material. Sincere appreciation is given to the graduate students, postdoctoral research associates, and undergraduates at Utah State University who made major contributions to the research work briefly referred to in this lecture; to Millard E. Wilde and J. Malcolm Asplund for helpful suggestions with the manuscript; and to Dorothy Smith for typing the manuscript.

The financial support from Swift and Company, Chicago; the American Dehydrators Association, Kansas City; International Minerals and Chemical Corporation, Chicago; and from Utah State University is greatly acknowledged. I wish to thank Wilford and Wallace Winch, and Israel Hunsaker for furnishing the sheep, James and Carl Deardon, and the Vernon Cattlemen’s Association for furnishing the cattle. Range and living quarters were furnished at various times by the Intermountain Forest and Range Experiment Station, Ogden.

I give many thanks to my wife Vola, and my family, who have spent many days without me while I was on the desert and have encouraged me during the past 22 years in pursuit of my range research.

— THE AUTHOR
RANGE NUTRITION
IN AN ARID REGION

LORIN E. HARRIS
Professor of Nutrition

INTRODUCTION

On the mountains, in the valleys, on the foothills and on the deserts of the Intermountain West grow millions of tons of vegetation. The chemical energy stored by these plants is a potential source of useful energy for man. Some of the plant material has been used for fuel, other has been used as a source of lumber, chemicals, and paper, but the major part of this vast reservoir is useful to man because it is utilized by livestock. This native vegetation is grazed by livestock and they convert the plant energy to high quality, desirable food energy for man.

In the Intermountain area a major portion of the sheep and cattle subsist on open range all year long. Range plants supply the bulk of the nutrients which support survival and production. To utilize various ranges and to adapt to various climatic conditions, the livestock are grazed in several different environments during the year. In the winter, they graze on semi-deserts (figure 1), in the spring and fall on foothills, and in the summer on the higher mountains. These ranges have a diversity of soil, climate, topography, and vegetation. Therefore, the foraging animal's diet is usually highly variable. The diet may be deficient in essential nutrients or may actually contain certain constituents that are toxic or poisonous.

It is necessary to know what nutrients the vegetation supplies, what it lacks, and how grazing may best be managed to permit livestock to utilize it efficiently yet maintain ecological stability. This presents a classical nutritional problem: How may an existing food supply be altered to meet the metabolic needs of the animal subsisting on it? This would also suggest a classical approach to the problem: (1) Determine the nutrient content and digestibility of the feed, (2) determine the animal's requirements, and (3) supplement the feed until it matches the animal's requirements.
However, the obvious logical approach presents some of the most challenging problems faced by a nutritional scientist. The nutrient requirements of range livestock are not fixed. They vary with the grazing environment and stages of the life cycle of the animal. Under certain conditions, maximum gain may be desired. At other times, survival alone or reproductive efficiency may be the criteria of need.

The diet of a grazing animal is not an easily definable entity. Range livestock graze selectively, eating only certain plants or parts of plants. Their selectivity even on a given range will vary with climatic conditions and the season.

Assuming that both animal requirements and dietary intake could be measured so that a proper supplement could be devised, there is still a third problem. Even though a theoretical supplementation program is known it may not be economical or practical or even possible to supply this material to grazing livestock under some range environments.

In view of these problems, a large part of research in range nutrition has been, and is being devoted to the development and use of refined
techniques for studying this classical nutritional problem under the conditions encountered on the arid ranges of America.

The first task in range nutrition research is to measure the nutritive value of the plants which the animals consume. The phases in this first approach have been outlined by Harris et al. (1952). They include (1) the determination of factors that affect the chemical composition of a given plant species on the range (Cook and Harris, 1950a), (2) the botanical composition and nutritive content of the animals' diet (Cook et al., 1948; Cook et al., 1951; Cook et al., 1952; Lancaster, 1954; Torell, 1954; and Cook et al., 1954), and (3) the feeding of supplements to correct dietary deficiencies or toxicities (Van Horn et al., 1952; and Harris et al., 1956).

The second task is to obtain animal measures which reflect the nutritive state of the animal. Body weight changes and visual evaluation of the condition of the animal have been and will continue to be valuable indices of range utilization (Clanton et al., 1959). However, more refined techniques which indicate nutritional status with respect to specific nutrients are also being tested and used. These include the nitrogen-creatine ratio to predict protein deficiency (Butcher and Harris, 1957), hypoproteinemia (low blood protein) (Stare et al., 1958), blood phosphorous level, and level of vitamin A and carotene in the blood and liver (Guilbert, 1937).

In many cases, it is necessary to collect data from animals that are under controlled or partially controlled environments to establish a basis for comparison. This approach has been highly developed in human medicine. However, more and better ways of measuring the nutritive status in animals need to be devised before they can be efficiently applied to range environments.

Under these broad terms of reference, the range nutrition researchers of the Intermountain area have made rapid strides during the past two decades in developing adequate techniques and applying them successfully to current problems in range nutrition.

In this paper I will review with you how my colleagues and I, as researchers, have recognized and attempted to solve some of the perplexing nutritional problems associated with livestock production in an arid or semi-arid region. The review is divided essentially into four parts as follows:

**Basic Methods for Range Nutrition Research**

**Experiments in Range Nutrition in an Arid Region**

**Utilization of Reseeded Grasses in an Arid Region**

**Fulfillment**
BASIC METHODS FOR RANGE NUTRITION RESEARCH

Measuring Intake and Digestibility

Reviews on methods of determining the consumption and digestibility of herbage by grazing animals have been prepared by Schneider et al. (1955), Vallentine (1956), Reid and Kennedy (1956), Raymond et al. (1956), Harris et al. (1959) and Bohman et al. (1967).

To accurately determine the nutritional value of an animal's diet it is necessary to know the amount of each kind of feed consumed and the digestibility of the feeds. These requisites are impossible to obtain completely for animals grazing the range. As a result, feed intake and digestibility must be estimated by indirect means.

In making these indirect estimates, indicators are used. Indicators include (a) "internal" which occur in the plant and are used to estimate apparent digestibility (those which have been used include lignin, plant chromogens, nitrogen, "normal acid fiber," the methoxyl group, and silica), and (b) "external" indicators which are fed to the animals to estimate feces output without a feces bag and include chromic oxide (chromium sesquioxide), iron oxide, and monastral blue.

When animals are fed in pens, external indicators may also be mixed with the total ration and will serve to estimate digestibility and intake of feed (if total feces are collected with a bag) or feces output (if total intake of feed and external indicator are measured). It should be emphasized that these two uses may be independent and on pasture and range it is not possible to mix the indicator with the feed in a constant proportion.

An important foundation point is that if digestibility of a component of a diet is known and if the fecal output of the component is known, then the intake can be calculated. The measurement of feces output by a grazing animal can be obtained by (1) a feces bag which collects the total feces output or by (2) feeding an "external" indicator to the animal. It is important to keep in mind that the only purpose of the external indicator is to estimate feces output without a feces bag for grazing animals.

All formulas for calculating forage intake and digestibility for grazing animals are based on the application of the above information.
Two techniques highly useful to the range nutritionist are those known as (a) the ratio technique and (b) the fecal index technique.

**The ratio technique**

If the herbage ingested is properly sampled, and the internal indicator is completely indigestible, dry matter intake can be calculated as follows:

\[
\text{1 Dry matter consumed} = \frac{\text{weight of internal indicator in total fecal output}}{\text{level (\% of indicator in forage)}}
\]

The following data are used to illustrate the use of formulas I to V:

A grazing sheep on a shadscale (*Atriplex confertifolia*) diet:

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Fed</td>
<td>10 g</td>
<td>Chromic oxide per day</td>
<td></td>
</tr>
<tr>
<td>2. Shadscale</td>
<td>13.0 %</td>
<td>lignin (dry basis)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>7.7 %</td>
<td>protein (dry basis)</td>
<td></td>
</tr>
<tr>
<td>3. Feces</td>
<td>1.15 %</td>
<td>chromic oxide (dry basis)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>22.6 %</td>
<td>lignin (dry basis)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>6.0 %</td>
<td>protein (dry basis)</td>
<td></td>
</tr>
<tr>
<td>4. Feces output</td>
<td>870 g</td>
<td>(dry basis — collected with bag or calculated by formula V)</td>
<td></td>
</tr>
</tbody>
</table>

\[
\frac{870 \text{ (dry wt of feces)} \times 22.6 \text{ (\% lignin in feces)}}{13 \text{ (\% lignin in shadscale)}} = 1512 \text{ g dry matter consumed}
\]

The apparent digestion coefficient for each nutrient is calculated as follows:

\[
\text{II Apparent digestion coefficient (\%)} = 100 - \left[ \frac{100 \times \frac{\% \text{ internal indicator in forage}}{\% \text{ internal indicator in feces}} \times \frac{\% \text{ nutrient in feces}}{\% \text{ nutrient in forage}}} {100 - (100 \times 0.575 \times 1)} \right]
\]

\[
100 - \left[ 100 \times \frac{13.0 \text{ (\% lignin in shadscale)}}{22.6 \text{ (\% lignin in feces)}} \times \frac{6.0 \text{ (\% protein in feces)}}{7.7 \text{ (\% protein in shadscale)}} \right] = 55.2\% \text{ apparent digestibility of protein}
\]

and

\[
100 - \left[ 100 \times \frac{13.0 \text{ (\% lignin in shadscale)}}{22.6 \text{ (\% lignin in feces)}} \times \frac{100 \text{ (\% dry matter in feces)}}{100 \text{ (\% dry matter in forage)}} \right] =
\]

\[
100 - (100 \times 0.575 \times 1) = 42.5\% \text{ apparent digestibility of dry matter}
\]

Indigestible internal indicators which have been used in the ratio technique include lignin, silica, and methoxyl group. The ratio technique
works well if (1) a method is used to obtain an accurate sample of the forage consumed by the animal and (2) if the indicator is completely indigestible.

Methods which have been used to sample the forage to estimate the diet of a grazing animal include (1) the "before and after method," (2) the esophageal-fistula method, and (3) the rumen-evacuation method. These methods are discussed below.

In some situations, the internal indicator is not always indigestible and also it is sometimes difficult to obtain an accurate sample of the animal's diet. To overcome these difficulties, the fecal index technique has been developed.

**Fecal index technique**

To obtain basic data for this method, it is necessary to clip forage and feed it in a conventional digestion trial in which the forage intake and feces are quantitatively measured. The feed and feces are then analyzed for an internal indicator, such as chromogen, lignin, nitrogen, methoxyl group, or silica; and for gross energy, organic matter, nitrogen, silica free dry matter, or dry matter. For the fecal index technique, the internal indicator does not need to be indigestible, although that would be ideal. Correction is made for digestibility in the regression equation calculated as indicated below.

At the same time, animals equipped with fecal bags or animals fed an external indicator to calculate total fecal output are grazed on the pasture. Regression equations for the data on the animals fed in the conventional digestion trial are then calculated as shown in figure 2.

After the regression equation in figure 2 is worked out, the concentration of the internal indicator is determined in the feces of the grazing animals. The percent digestibility of the forage can then be calculated by the regression equation.

After the regression equation is established for a particular set of pasture conditions, it is not necessary to have a set of animals fed clipped forage for subsequent trials. The digestibility can be calculated from the concentration of the internal indicator in the feces. *A regression equation under one set of conditions does not work under all sets of conditions. Therefore, each research worker should determine his own regression equation or should make sure that someone else's equation applies to his own experimental conditions.* The regression formula for the line will not always be linear, however, the steeper the slope, the more reliable the estimate will be. Given the data used in the previous sample the dry matter intake can be calculated as follows:
III  \[\%\text{ indigestibility of dry matter} = 100\% - \%\text{ digestibility of dry matter}\]

\[100\% - 42.5\% (\%\text{ digestibility of dry matter from equation 1}) = 57.5\%\text{ indigestibility of dry matter}\]

NOTE: In actual practice the digestibility of dry matter, 42.5\%, would be predicted from the regression equation (figure 2).

IV  

\[\text{Dry matter consumption} = \frac{\text{Total amount of dry matter in feces} \times 100}{\%\text{ indigestibility of dry matter}}\]

\[\frac{870 \text{ (g dry matter in feces)}}{57.5\% (\%\text{ indigestibility of dry matter})} = 1513 \text{ g dry matter consumed}\]

The most widely used internal indicators are chromogen and lignin. Chromogen appears to be a good indicator for many species (Reid, et al., 1952); however, it does not seem to work for many shrubs on the western ranges (Cook and Harris, 1951). It was found that chemical analyses of the lignin and chromogen content of range forage could be determined with equal accuracy. The differences between duplicate samples and duplicate determinations of the same sample were insignificant at the 1-percent level in all cases. However, when differences among animals were compared by the two methods for various forage species, the lignin ratio technique gave considerably less variability than the chromogen method (table 1).

The coefficient of variation for lignin content of feces among animals grazing big sagebrush (Artemisia tridentata) was 11.9 percent com-

Figure 2. Schematic diagram of regression equation to predict digestibility from concentration of internal indicator in feces.
Table 1. A comparison of the lignin and chromogen content in the feces of six sheep from two forage sources

<table>
<thead>
<tr>
<th>Sheep</th>
<th>Big sagebrush</th>
<th>Shadscale</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Lignin content</td>
<td>Chromogen content</td>
</tr>
<tr>
<td></td>
<td>%</td>
<td>units/g</td>
</tr>
<tr>
<td>1</td>
<td>23.4</td>
<td>58</td>
</tr>
<tr>
<td>2</td>
<td>24.6</td>
<td>44</td>
</tr>
<tr>
<td>3</td>
<td>26.2</td>
<td>50</td>
</tr>
<tr>
<td>4</td>
<td>22.3</td>
<td>50</td>
</tr>
<tr>
<td>5</td>
<td>24.2</td>
<td>52</td>
</tr>
<tr>
<td>6</td>
<td>24.0</td>
<td>56</td>
</tr>
</tbody>
</table>

Mean

- Big sagebrush: 24.1 %, 52 units/g
- Shadscale: 24.2 %, 104 units/g

Standard deviation

- Big sagebrush: 2.9 units/g, 11.1 units/g
- Shadscale: 2.0 units/g, 20.8 units/g

Coefficient of variation

- Big sagebrush: 11.9, 21.3
- Shadscale: 8.3, 20.0

pared to 21.3 percent for chromogen content. A similar relationship was found when comparing the lignin and chromogen content of feces from animals grazing shadscale. The coefficients of variation in this comparison were 8.3 percent for lignin and 20.0 percent for chromogen.

The amount of chromogen recovered in the feces while sheep grazed big sagebrush and black sage (*Artemisia nova*) was markedly less than the amount consumed, showing that some of the chromogen was lost or was changed during digestion to give different light absorption values on the spectrophotometer. This of course gave negative digestion coefficients and indicated extremely low quantities of consumed forage (table 2). However, in the case of squirreltail grass the chromogen recovery in the feces seemed high and gave a coefficient of digestibility for dry matter of 68.7 percent which is excessively high for mature dry grass that has been exposed to weathering for a considerable length of time. In addition, calculated dry matter intake was almost 3.2 kilograms (7 pounds) for a 44-kilogram (142-pound) wether which is beyond the amount generally consumed by sheep of this size. Values obtained by the lignin ratio technique agrees rather closely with calculated dry matter intake as presented by the National Research Council (1964) and digestibility of dry matter of similar forages presented by Schneider (1947). Brisson *et al.* (1953) also have shown that the accuracy of chromogen depends on an isoelectric point which may vary under various conditions. Other workers have also shown that chromogen does not work with range plants (*Kennedy et al.*, 1959 and *Wheeler*, 1962). However, *Reid, et al.*, (1952), *Connor et al.* 1963 and *Ridley et al.* (1963) have shown that the chromogen technique works well for determining the apparent digestibil-
Table 2. Digestibility and dry matter intake of winter range forages calculated by the lignin ratio technique as compared to the chromogen method

<table>
<thead>
<tr>
<th>Forage species</th>
<th>Number of animals</th>
<th>Average animal weight</th>
<th>Lignin</th>
<th>Chromogen</th>
<th>Dry matter intake</th>
<th>Dry matter digestibility</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>kg</td>
<td>%</td>
<td>units/g</td>
<td>kg/day</td>
<td>Lignin tech.</td>
<td>Chromogen method</td>
</tr>
<tr>
<td></td>
<td>%</td>
<td>%</td>
<td>units/g</td>
<td>kg/day</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Big sagebrush</td>
<td>6</td>
<td>66.2</td>
<td>11.9</td>
<td>24.1</td>
<td>1.44</td>
<td>0.20</td>
</tr>
<tr>
<td>Shadscale</td>
<td>6</td>
<td>69.4</td>
<td>12.4</td>
<td>24.1</td>
<td>1.33</td>
<td>1.21</td>
</tr>
<tr>
<td>Winterfat</td>
<td>2</td>
<td>68.0</td>
<td>8.1</td>
<td>11.5</td>
<td>1.50</td>
<td>1.23</td>
</tr>
<tr>
<td>Black sage</td>
<td>2</td>
<td>59.4</td>
<td>16.1</td>
<td>27.0</td>
<td>1.39</td>
<td>0.72</td>
</tr>
<tr>
<td>Squirreltail grass</td>
<td>2</td>
<td>64.4</td>
<td>8.2</td>
<td>15.4</td>
<td>1.86</td>
<td>3.15</td>
</tr>
<tr>
<td>Alfalfa</td>
<td>2</td>
<td>.......</td>
<td>7.9</td>
<td>21.1</td>
<td>.......</td>
<td>.......</td>
</tr>
</tbody>
</table>
ity and forage intake of animals consuming succulent green forage during the summer.

It appears, therefore, that the lignin ratio technique works well with winter range plants high in lignin and that the chromogen ratio technique works well with succulent green forage during the summer.

**Estimation of total feces by grab samples**

Total feces output for a grazing animal can be determined (1) by using a collection bag or (2) by feeding a quantitative amount of an external indicator to an animal and collecting *grab* samples of feces. A *grab* sample of the feces consists of collecting a small amount at various times during the day instead of collecting the total amount. Total fecal dry matter can be calculated from *grab* samples. This calculation, using the data given in the previous example, is as follows:

\[
\text{Fecal dry matter output} = \frac{\text{amount external indicator fed} \times 100}{\% \text{ external indicator in feces grab sample (dry basis)}}
\]

\[
= \frac{10 \text{ (g chromic oxide)} \times 100}{1.15 \text{ (\% chromic oxide in feces grab sample)}} = 870 \text{ g fecal dry matter output}
\]

Using formulas I and II under the ratio method or the regression equation and formulas III and IV under the fecal index method, the dry matter consumption and digestibility can be calculated by collecting *grab* samples of feces without a fecal bag. Chromic oxide appears to be the best external indicator for this purpose. Blank samples containing feces without chromic oxide should be run to correct for naturally occurring materials.

Chromic oxide has been used with success when it has been mixed with the feed or fed as a supplement with the total ration (Edin, 1944; Hamilton *et al.*, 1927-28; Kane *et al.*, 1949; and Schurch *et al.*, 1950). However, with grazing animals it is necessary to feed it apart from the feed. The reliability of capsule feeding of chromic oxide is controversial (Crampton and Lloyd, 1951, and Brannon *et al.*, 1954). A diurnal variation of chromic oxide excretion occurs which must be established under each set of conditions. The usual procedure is to take *grab* samples at times which will represent 100 percent recovery of the chromic oxide, or, if the samples are taken at other times, appropriate corrections for apparent recovery of other than 100 percent must be calculated (Lucas, 1952). The number of *grab* samples to be taken for accurate measurements depends on the frequency of chromic oxide administration. If chromic oxide is administered twice daily to cattle at least 50 *grab* samples must be taken to be within a 5 percent error at any *grab*
sampling time (Brisson\textsuperscript{1}). For reliable results, Brisson \textit{et al.} (1957) and Border \textit{et al.} (1963a) have found that the preliminary feeding period prior to the start of sampling should be at least 10 days.

Chromic oxide appears to work best when incorporated into paper (Corbett \textit{et al.}, 1960, Border \textit{et al.}, 1963a) or on cellulose (Bohman \textit{et al.}, 1967).

To overcome some of the problems mentioned above, the following recommendations are suggested:

1. Administer paper or cellulose impregnated with chromic oxide and enclosed in a gelatin capsule or mix chromic oxide in the feed. If it is administered in the feed, make up a paste of flour, or a portion of one of the ingredients in the diet and chromic oxide. Bake the paste and grind through a mill, then mix it with the feed.

2. The preliminary period should be at least 10 days in length.

3. The collection period should be at least 7 days in length. Collect at least 50 grab samples from each animal.

4. To overcome diurnal variation, collect random samples of feces in the pasture or pen. Each dropping can be marked with lime. If more than one animal is in a pasture, colored polyethylene particles may be administered to the animals so the feces from one animal may be distinguished from another.

\section*{Obtaining Samples of Actual Forage Ingested}

The "before and after" method

Under winter range conditions in the Great Basin, the sheep's diet is composed of a variety of browse species such as black sage, big sagebrush, shadscale, winterfat (\textit{Eurotia lanata}) and grasses such as galleta grass (\textit{Hilaria jamesii}), Indian ricegrass (\textit{Oryzopsis hymenoides}) and squirreltail grass (\textit{Sitanion hystrix}). In the winter, these species are mature and relatively high in lignin and low in chromogen.

With mixed species of this type, it has been impossible to collect forage samples in the field which represent the animal's diet and feed them in conventional stalls to obtain a regression equation for the fecal index technique. In many cases, the sheep refuse to eat collected forage. With these thoughts in mind, we have used the "before and after" method to predict the percentage nutrient composition of the diet and the lignin

\textsuperscript{1} Brisson, G. J., Personal communication (1958).
ratio technique to predict the dry matter intake and digestibility of the diet.

The “before and after” method of determining the sheep’s diet consists of measuring the dry weight and chemical composition of the available forage of each species before and after grazing (Cook et al., 1948, 1950b, and 1951). The difference represents the animal’s diet. The

Figure 3. An observation (A) containing many units is collected for browse species such as big sagebrush (Artemisia tridentata). Before grazing units (B) and after grazing units (C) consisting of the current year’s growth are picked off the observations.
amount of available forage is measured by collecting plant units from each species before and after grazing along transect lines. The unit in the case of most browse plants can be confined to twigs of current year’s growth (figure 3); for bunch grasses, the entire clump; for semi-bunch grasses, only the individual stem; for sod grasses, 1/16 square foot or individual tiller stems; for annuals and most forbs, either the entire plant or an individual stem; and for some coarse broad-leafed forbs, only the leaf and leaf stem.

An illustration of the method of calculating the botanical and chemical composition of a sheep’s diet when grazing on the Great Basin winter range is given in table 3.

Total intake of forage and digestibility of the protein and crude fiber of the diet in table 3, can be obtained by the lignin ratio method. This method is particularly applicable on the winter range of the Great Basin. During the winter, the plants are relatively dormant and corrections do not need to be made for growth between collections before and after the sheep graze. The plant species (predominantly browse) are far enough apart so that shattering and trampling are not problems (figure 1).

**Esophageal fistula method**

A representative sample of a grazing animal’s diet is best obtained by the foraging animal. Collection of animal gathered samples was first accomplished in California by means of esophageal fistula (Torell, 1954). The fistula in the esophagus was closed by pulling the wool over the opening. We modified this technique by inserting a plastic cannula with a cap into the esophagus (Cook *et al.*, 1958). Improved operative techniques have been outlined by Bohman *et al.* (1967). Animals are fitted with plastic bags to obtain a sample of the sheep’s diet (figure 4). This method works well in sampling many types of plants.

The esophageal fistula is an accurate method of obtaining a sample of the sheep’s diet under most conditions. However, if used for chemical analysis certain corrections need to be made for contamination by the saliva (Bath *et al.*, 1956 and Van Dyne and Torell, 1964). There seems to be little contamination of protein, but considerable contamination of minerals. Intake and digestibility are calculated by the ratio-technique using formulas I and II.
<table>
<thead>
<tr>
<th>Species and sample</th>
<th>Column no.</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Species density† per 100 sq m</td>
<td>Units per sq m</td>
<td>Average wt per unit</td>
<td>Wt per sq m density (col 2x3)</td>
<td>Total wt per 100 sq. m (col 4x1)</td>
<td>Amount consumed</td>
<td>Utilization %</td>
<td></td>
</tr>
<tr>
<td>Atriplex confertifolia</td>
<td>sq m</td>
<td>no</td>
<td>g</td>
<td>g</td>
<td>g</td>
<td>g/100 m²</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Before grazing</td>
<td>1.3</td>
<td>4370</td>
<td>.1231</td>
<td>538</td>
<td>699</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>After grazing</td>
<td>1.3</td>
<td>4370</td>
<td>.0921</td>
<td>402</td>
<td>523</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Diff. (ingested)</td>
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<td></td>
<td></td>
<td>176</td>
<td>25.2</td>
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<tr>
<td>Eurotia lanata</td>
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<td>2282</td>
<td>.5264</td>
<td>1201</td>
<td>3843</td>
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<tr>
<td>Before grazing</td>
<td>3.2</td>
<td>2282</td>
<td>.3321</td>
<td>758</td>
<td>2426</td>
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<td>After grazing</td>
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<td>1417</td>
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<td></td>
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<tr>
<td>Diff. (ingested)</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gutierrezia sarothrae</td>
<td>2.4</td>
<td>6480</td>
<td>.0946</td>
<td>613</td>
<td>1471</td>
<td></td>
<td></td>
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<tr>
<td>Before grazing</td>
<td>2.4</td>
<td>6480</td>
<td>.0854</td>
<td>553</td>
<td>1327</td>
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<td>After grazing</td>
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<td></td>
<td>144</td>
<td>9.8</td>
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<tr>
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<td></td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>Sporobolus cryptandrus</td>
<td>1.7</td>
<td>180</td>
<td>3.443</td>
<td>6197</td>
<td>10535</td>
<td></td>
<td></td>
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<tr>
<td>Before grazing</td>
<td>1.7</td>
<td>180</td>
<td>2.843</td>
<td>5117</td>
<td>8699</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>After grazing</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1837</td>
<td>17.4</td>
<td></td>
</tr>
<tr>
<td>Diff. (ingested)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3573</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Totals (ingested)</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Percent in diet</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

† This represents normal ground cover of each species without artificial rearrangement of the foliage to a

Figure 4. This sheep is equipped with an esophageal fistula. As the sheep eats, the diet is sampled and falls into the bag. When not sampling forage the fistula is closed by putting a plastic cap on the cannula which is in the fistula.
Rumen evacuation method

To sample the grazing animal's diet by the rumen evacuation technique a cannula is inserted into the rumen as described by Binns and James (1959). For diet sample collection the contents of the rumen and reticulum are removed thoroughly (Lesperance et al., 1960). It is usually advisable to quickly rinse the rumen and then remove the water with a small pump before sampling. The animals are then allowed to graze for 0.5 to 2 hours depending on the availability of the forage. The forage sample is removed from the rumen and reticulum and the original contents are put back in.

The diet sample collected by this method is contaminated with saliva and corrections need to be applied as was described above for the esophageal diet samples. This method does give a total collection (Lesperance et al., 1960), and is better than the esophageal method for sampling some coarse dry grasses.

Measuring Metabolizable Energy of Range Plants

When the total digestible nutrient (TDN) content of big sagebrush, black sage and other similar browse plants was determined, it appeared
that these plants were exceptionally high in TDN compared to their observed value as forage plants.

In view of these facts, methods were devised to determine the metabolizable energy (ME) of range plants (Cook et al., 1952). Metabolizable energy is defined as follows (Harris, 1966):

\[ \text{ME} = \text{gross energy intake} - \text{feces energy} - \text{urine energy} - \text{methane energy} \]

The method consisted of using wethers equipped with fecal bags and urinals in temporary enclosures (figure 5). Methane was calculated from the following formula (Swift et al., 1948):

\[ \text{methane (gas)} = 2.41 \frac{X}{100} + 9.8 \]  

(X represents grams of digestible carbohydrates)

Each gram of methane has a calorific value of 13.34 kilocalories.

Since our work was done, Baxter (1962), has suggested that methane may be calculated from the gross energy consumed.

Comparative energy values are given for three plants in table 4. Black sage and big sagebrush are high in gross energy (GE), TDN, and digestible energy (DE), while squirreltail grass is rather low in GE and about equal to the other plants in TDN and DE. However, black sage

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Figure 5. A sheep equipped to collect feces and urine while grazing on the range so that the energy of the feces and urine may be determined. These values are needed to calculate metabolizable energy.
and big sagebrush are much lower in ME than squirreltail grass. It is believed that this difference is caused by the large content of volatile oils in black sage and big sagebrush. Therefore, ME is a better index of energy value of range plants than DE or TDN. We have also devised methods to collect feces and urine from cattle when they are grazing (Border et al., 1963b).

**Methods of Expressing Energy Values**

The requirements of animals and the energy value of feeds and diets in the United States have been expressed primarily on the TDN system. However, in 1955 the Animal Nutrition Committee of the National Research Council (NRC) passed a resolution to express energy requirement in terms of calories and expressed the desire that information be gathered on the GE, DE, ME, and net energy (NE) of feeds and diets in order that the TDN system can be replaced. In view of this resolution, I prepared a glossary of energy terms for the Animal Nutrition Committee of the National Research Council based on the calorie system (Harris 1962, 1966). The conventional system is briefly outlined in figure 6. The calorie system is now being used in all the NRC Nutrient Requirement Reports, and by the NRC Animal Nutrition Committee on Feed Composition (Crampton and Harris, 1964).

Any change from the use of TDN to DE, ME, or NE, in feed description or in nutrient requirement tables, will make it necessary either

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**Figure 6.** The conventional scheme of partition of food energy as it is utilized by the animal.
Table 4. Comparison of methods of expressing the energy value of three common desert
range plants

<table>
<thead>
<tr>
<th>Species</th>
<th>Gross energy kcal/kg</th>
<th>TON</th>
<th>Digestible energy kcal/kg</th>
<th>Metabolizable energy kcal/kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black sage</td>
<td>5101</td>
<td>49.5</td>
<td>2124</td>
<td>1044</td>
</tr>
<tr>
<td>Big sagebrush</td>
<td>4830</td>
<td>43.4</td>
<td>1948</td>
<td>1130</td>
</tr>
<tr>
<td>Squirreltail grass</td>
<td>3787</td>
<td>50.4</td>
<td>2022</td>
<td>1704</td>
</tr>
</tbody>
</table>

to abandon the present extensive TDN data or to find means of converting these values to accurate corresponding calorie figures. Crampton et al., (1957), and Swift (1957), have worked out satisfactory procedures to make this conversion.

The Animal Nutrition Committee of the National Research Council in their November, 1958 meeting adopted 4.409 kilocalories per gram (2,000 kilocalories per pound) of TDN to convert it to DE. A summary of the formulas to be used by the NRC Animal Nutrition Committee on Feed Composition are as follows:

\[ \text{DE (kcal/kg)} = \frac{\text{TDN} \%}{100} \times 4409 \]

\[ \text{ME (kcal/kg) for ruminants} = \text{DE (kcal)} \times 0.82 \]

\[ \text{ME (kcal/kg) for swine} = \text{DE (kcal/kg)} \left( \frac{96 - 0.202 \times \text{protein} \%}{100} \right) \]

Net energy values for some cattle feeds including net energy for maintenance (\( \text{NE}_m \)) and net energy for gain (\( \text{NE}_{\text{gain}} \)) may be estimated from formula developed by Lofgreen.³

\[ \log F = 2.2577 - 0.2213 \times \text{ME} \]

\[ \text{NE}_m = \frac{77}{F} \]

\[ \text{NE}_{\text{gain}} = 2.54 - 0.0314 \times F \]

The terms used in the formulas are those defined by Harris (1966) and are on a dry matter basis (moisture free).

--- 24 ---

² Earle W. Crampton and Lorin E. Harris, unpublished data.
³ Personal communication.
1. ME is the metabolizable energy in kcal/g of dry matter (DM) (or megcal/kg DM).

2. F is the grams of dry matter per unit of $W^{0.75}$ required to maintain energy equilibrium.

3. $N_{Em}$ is the net energy for maintenance in kcal/g DM (megcal/kg DM).

4. $N_{Egain}$ is the net energy for gain in weight in kcal/g DM (megcal/kg DM).

To convert $N_{Em}$ and $N_{Egain}$ to kcal/kg the values are multiplied by 1000.

Some of the formulas were developed under farm conditions and not under range conditions. However, they may be used until more adequate ones are devised.

**Range Meters for Measuring the Distance Traveled by Sheep and Cattle**

Cattle and sheep travel long distances to obtain feed and water when grazing on the range. Since considerable energy is expended in these activities, we decided it was important to determine the distance traveled by range animals in order to obtain information for calculating the energy requirements.

Our first studies involved the use of a range meter (figure 7) which
we developed for measurement of the distance traveled by sheep (Cresswell and Harris, 1959). In a pasture of 259 hectares (1 mile square) on a winter saltbush-type range, we found that sheep traveled an average of 4.6 kilometers (1.6 miles) a day to obtain their feed (Morris et al., 1965).

In another experiment we tested the range meter on four Hampshire ewes and four Rambouillet ewes. Rambouillet ewes traveled about 25 percent farther than Hampshire ewes in a 1.0 hectare (2.5 acre) pasture.

This difference between breeds presents some interesting considerations. The Rambouillet breed originated from the Spanish Merino. Merino sheep were developed to graze the rather arid, hilly areas of Spain in an environment not unlike the Intermountain West. The utility of this breed depended upon its ability to graze over a wide area of sparse vegetation to obtain feed as well as its propensity to flock together. On the other hand, the Hampshire breed was developed to be useful in lush, small enclosed pastures in England. Neither foraging aggressiveness nor flocking ability were of concern.

On western ranges, most of the sheep have considerable Rambouillet breeding even though crosses with the British breeds are being introduced. It is a challenging breeding problem to improve the mutton producing ability of the range sheep without losing the vital abilities of aggressive foraging and flocking. One new breed, the Columbia, developed from a cross of the Rambouillet and Lincoln breeds, traveled distances intermediate to the Rambouillet and Hampshire when foraging.

While active foraging may provide a sheep with an increased supply of feed, it may also increase its energy requirements. Breed differences must be considered in range nutrition experiments.

We have also developed a range meter for cattle (figure 8). However, it has not been tested under range conditions.4

Weighing Range Animals

Methods of weighing animals on experiments have been reviewed by Baker et al. (1947); Bean (1948); Lush et al. (1928); Patterson (1947); Whiteman et al. (1954); Balch and Line (1957); and Koch et al. (1958).

With portable equipment and three to five men, we have found it possible to individually weigh 60 to 100 sheep or cattle per hour. This

4 Cresswell and Harris, unpublished data.
handling has not adversely affected the animal response, as animals that were weighed frequently responded equally well when compared to animals weighed less frequently.

The important thing in weighing animals in pastures or ranges is to avoid bias between treatments, and attempt to have all animals at the same intestinal fill within a replication or within a block of treatments.

Allen (1946), weighed animals at 0.5 hour-intervals throughout the day and reported that weighing just before feeding time in the morning "was found to be the time when the average variation from day to day was least and when the range between extremes was narrowest. These facts indicate that just before feeding is probably the most suitable time for weighing when changes in weight are being studied." . . . "For milking cows, variation can be further reduced at this time, which precedes the normal milking time, by deducting the contents of the udder as determined by subsequent milking."

With these facts in mind it is suggested that weighing procedures be standardized as follows:

Figure 8. A range meter to measure the distance traveled by cattle.
1. Gather animals late at night and put them in a corral without feed or water or corral animals at daylight (before they have eaten) and keep them off feed and water. Begin weighing soon after daylight, but give the animals sufficient time to urinate and defecate before weighing is started. Follow the same procedure each time.

2. Mix all animals in a large corral within a replication or block of treatments and weigh at random. Avoid weighing animals by lot, pasture or treatment as this creates a bias among treatments.

3. Deduct the contents of the udder of milking cows as determined by subsequent milking.

4. One-day weights are sufficient if there are a number of animals per treatment. If accuracy is wanted on individual animals, two or three day weights should be taken (Koch et al., 1958).

5. Weather changes on the day or days immediately prior to weighing influence body weights by plus or minus 5 percent. That is, if the weather has been warm, but if the day before weighing is cold, a sharp drop in weight will be expected. This seems to be related to water fill, even though the animals are off feed and water for 12 to 16 hours.

6. Animals taken from dry feeding and put on pasture lost intestinal fill (Balch and Line, 1957). If absolute gains in weight are needed, a standardizing period with the same kind of feed at the beginning and end of the trial is desirable to reduce variability of intestinal fill.

7. Where scales are not available in some field experiments, relatively accurate data can be obtained by measuring the heart girth and calculating the weight (Kendrick et al., 1936; and Gaines et al., 1941).

Environmental Influences on Animal Response

Weather is a very common environmental influence (Butcher and Harris, 1962). By comparing range animals and animals under controlled feeding (both under similar weather conditions) it has been found that the weather, especially snow, has its greatest influence in reducing feed availability rather than the direct effect of the snow and cold on the animal itself. Under extreme conditions, however, there may be death losses from cold, especially if the cold is associated with snow or rain. Sheep that have been recently shorn are especially sensitive to cold and wet storms.

There is an indirect effect of weather which causes large variations in amount of feed available on ranges and the season that this feed is available. This results in great variations in animal diets and requires
careful management to recognize the nutritive state of the animal. For instance, carotene supplementation has been shown to give little response when animal blood measures indicated a borderline carotene or vitamin A deficiency. A similar situation was found with vitamin A injection. However, during the season of these range experiments our uncontrolled weather provided rain or snow at such a time that all animals had access to enough green feed, even in late winter, to apparently meet the vitamin A requirement of the animals.

Snow was found to be completely adequate as a water source for sheep on winter range or even on alfalfa hay. Not only was the snow adequate, but there was no measurable added feed cost or reduced productivity of sheep with 5 or more centimeters (1.95 inches) of wool when snow was the only source of water.

All environmental factors are very important in designing and evaluating range experiments. Most range experiments are actually designed as a means of modifying the environment.

EXPERIMENTS IN RANGE NUTRITION
IN AN ARID REGION

Characteristics of the Intermountain Range

The Intermountain range area lies between the Rocky Mountains and the Sierra Nevada and Cascade Ranges. It includes the major part of Utah and Nevada, and it extends into western Colorado, northern Arizona, eastern California, and much of the western half of Wyoming. Its northern boundary includes about one-fourth of the southeast portion of Oregon and most of the southern half of Idaho.

This region has an irregular topography and hence is highly variable in soil and climate. Precipitation is low, especially in the foothills and on the deserts, and tends to be more abundant in the non-growing season and the summers are hot and dry as a result.

The vegetation over the majority of the area is predominantly deeply rooted, semi-desert shrubs, almost all of which belong either to the Compositae or to the Chenopodiaceae families.

While our research was conducted primarily in the Great Basin area, the results generally can be applied to this entire region.

As far as livestock are concerned, this region may be divided into three general range areas depending on use: winter range, spring and
fall range, and summer range. Cattle and sheep graze on the winter range from about November to March. They are then trailed or trucked to the spring range where they stay until the latter part of June. They are then trailed or trucked to the high mountains (National Forest) or summer range where they graze until about September 15 to October 15. Then they are trailed or trucked to the fall range where they stay until they are taken again to the winter range.

Of course, many ranch operators have a base farm. This farm may produce alfalfa and meadow hay or meadow pasture. If the winter is severe, some of the hay may be fed as emergency feed on the range. Some operators feed meadow hay in the winter and use the range during the spring, summer, and fall.

Winter range

The winter range area consists of valley floors and low mountains containing numerous coves and alluvial fans which separate the valley basins varying from 6.2 to 9.3 kilometers (10 to 15 miles) in width (figure 1).

Poor drainage conditions coupled with low precipitation result in concentration of salt in most of the soil profiles. In general, the salt is near the surface of the valley floor, and at deeper levels on the slopes.

The annual precipitation of 152 to 178 millimeters (6 to 7 inches) occurs principally as winter snows and spring rains or sleet. Only occasional summer showers occur which vary in intensity and generally are local in nature. There is considerable freezing and thawing, and for much of the winter cold weather predominates. Usually the snow is less than 150 millimeters (6 inches) deep. This is ideal for grazing livestock as the snow furnishes water and softens the dry, dormant vegetation making it more palatable. However, when the snow is deep, it covers most of the vegetation and the livestock must be fed emergency feeds such as alfalfa or meadow hay or a low protein pellet. Summers are hot and dry and are characterized by maximum temperatures of 32 to 38 C (90 to 100 F).

The vegetation consist mainly of the northern desert shrub saltbush type. Dominant shrubs are *Atriplex spp.*, chiefly shadscale, greasewood (*Sarcobatus vermiculatus*), black sage, big sagebrush, yellow bush (*Chrysothamnus stenophyllus*), winterfat, and desert molly (*Kochia vestita*). Grasses are subdominant and are generally sparse. Important species are Indian ricegrass, squirreltail grasses, galleta
grass, and blue grama grass (*Bouteloua gracilis*). Forbs are of little significance. Locally, annual invaders such as Russian-thistle (*Salsola kali var. tenuifolia*) and cheatgrass (*Bromus tectorum*) may furnish large percentages of the forage, especially in the fall and early spring. Halogeton (*Halogeton glomeratus*) a poisonous plant, which causes some livestock losses, was introduced a few years ago and has now spread over this entire area.

**Spring and fall range**

The spring and fall range consists largely of the foothills and depleted dry farm land. This type of range lies in a zone of 279 to 356 millimeters (11 to 14 inches) of rainfall. About 75 percent of the precipitation falls during the 8 months from October to May. Probably 60 percent of the yearly total falls as snow. There is more summer precipitation in the southern part than in the northern part of this area. Summer precipitation often comes as thunder showers, sometimes with cloudburst intensity. The elevation of these ranges is 1524 to 2134 meters (5000 to 7000 feet). Much of this area is now being reseeded to drought resistant grasses such as crested wheatgrass (*Agropyron cristatum*), Russian wildrye (*Elymus junceus*), intermediate wheatgrass (*Agropyron intermedium*), and tall wheatgrass (*Agropyron elongatum*).

In the spring and fall there are intermittent periods of freezing and thawing weather with rain and snow. This type of weather is rather unfavorable for lambing and calving operations. Because of the inclement weather, some operators use portable shelters for lambing ewes, others use canvas covered sheds and corrals where the ewes may be fed supplementary feed while they are lambing. Calving sheds have also been developed in some areas, particularly where meadow hay is available to feed the heifers and cows just before calving.

The dominant shrubs on the spring and fall range include big sagebrush, rubber rabbitbrush (*Chrysothamnus nauseosus*) and bitterbrush (*Purshia tridentata*). Much of the area is being slowly invaded by various species of Juniper such as *Juniperus utahensis*.

Grass species include bluebunch wheatgrass (*Agropyron spicatum*), Sandberg bluegrass (*Poa secunda*), western wheatgrass (*Agropyron smithii*), Indian ricegrass, squirreltail grass, Great Basin wildrye (*Elymus cinereus*), and cheatgrass, an introduced annual that has spread over much of the western spring and fall range and is present in varying amounts.

Prominant forbs on the spring and fall ranges of this area are desert globemallow (*Sphaeralcea ambigus*), Nevada lupine (*Lupinus nevadense*—31—
sis), Utah sweetvetch (*Hedysarum boreale*), longleaf phlox (*Phlox longifolia*), false dandelion (*Agoseris* spp.), loco (*Astragalus cibarius*), and such annuals as Russian thistle, clasping pepperweed (*Lepidium perfoliatum*), and halogeton.

**Summer range**

The summer range includes primarily the National Forest and some private areas. These areas are usually above 2,134 meters (7,000 feet). Livestock utilize them only during the summer. Precipitation is 375 to 875 millimeters (15 to 35 inches). Most of it falls as snow, but there are some spring, fall, and summer rains. Because of the high altitude, this range is cool in the summer.

The terrain is characterized by steep slopes and ridges. However, there are grassy parks and meadows in some high mountainous areas. Soils are often shallow with little soil maturity in the profile.

The vegetation is lush during the spring and early summer, but may become dry during late summer. There are a great many species of range plants on this area (Cook *et al.*, 1948). The dominant browse species include big sagebrush (very little is consumed on the summer range), aspen (*Populus tremuloides*), snowberry (*Symphoricarpos rotundifolius*), chokecherry (*Prunus demissa*), and serviceberry (*Amelanchier alnifolia*). Some of the prominent grasses include mountain brome (*Bromus carinatus*), beardless wheatgrass (*Agropyron inerme*), basin wildrye (*Elymus cinereus*) and Kentucky bluegrass (*Poa pratense*), an introduced species.

There are many forbs, a few of the most important include western yarrow (*Achillea lanulosa*), hoary aster (*Aster canescens*), fremont geranium (*Geranium fremontii*), aspen peavine (*Lathyrus lanceanthes*), tailcup lupine (*Lupinus candatus*) and mulesears wyethia (*Wyethia amplexicaulis*).

**Examples of Range Experiments**

Our research has been conducted on the winter desert range, on the spring and fall range in the foothills, and on the summer range in the high mountain areas. Of these ranges, the first two are more likely to produce forage which is deficient in nutrients. Of course, reseeded summer range in the foothill areas may also be low in nutrients.
Following are some examples of our research on the winter range and spring and fall range which have utilized some of the techniques discussed above to solve some of our range nutrition problems. For examples of our experiments on the mountainous summer range see Cook et al. (1965, 1967).

An Experiment on the Winter Range

Our first experiment was conducted in Pine and Wah Wah Valleys, west of Milford, Utah, in 1946-47 (Harris et al., 1956). I have chosen this experiment as an example because it describes how we developed and applied several classic techniques (Harris et al., 1952) to solve nutrition problems on the winter range.

The nutrient content of the grazing sheep's diet

Our experimental area was on a typical shadscale winter desert range. We first determined the percentage composition of the diet of our experimental sheep by using the "before and after" method. Digestibility and dry matter intake were determined by the lignin ratio technique. Metabolizable energy was determined by collecting and analyzing the feces and urine for energy and estimating the energy in the methane as described previously.

When the nutrient content of the diet of our sheep was compared with the nutritive requirements of a 130-pound ewe as proposed by the National Research Council (1949), it was found to be low in phosphorus, protein, and energy (figure 9). However, it was exceedingly high in calcium.

Experimental plan

Using the above data as a guide, various amounts of phosphorus, protein, and energy supplements were fed to experimental ewes and the effects on maintenance of weight and production of wool and lambs were measured. In November 1947, 144 ewes were selected at random from a typical range herd. They were segregated into six groups: lambs, yearlings, 3-year olds, 4-year olds, 5- to 6-year olds, and over 6-year olds, and allotted at random to the treatments outlined in table 5. Thirty-six animals were not fed supplements and they served as controls. In addition to the controls, the treatments consisted of two levels of phosphorus, two levels of protein, and two levels of energy supplements for a total of seven treatments. The phosphorus supplements consisted of monosodium phosphate fed at the rate of 13 grams (0.029 pound) each.
second day for the first level and 17 grams (0.038 pound) for the second level. Protein supplement consisted of solvent extracted soybean meal pellets fed at two levels, 128 grams (0.28 pound) and 256 grams.

**Figure 9.** The National Research Council nutrient requirements for sheep show that shad-scale type winter range forage supplies 50 percent of the phosphorus, 46 percent of the protein, and 80 percent of the metabolizable energy needed by range ewes.

**Table 5.** Experimental design to compare six ages of sheep when fed two levels each of whole barley grain, solvent extracted soybean meal pellets, and monosodium phosphate, 1947-48

<table>
<thead>
<tr>
<th>Control</th>
<th>3 year-olds</th>
<th>4 year-olds</th>
<th>5 to 6 year-olds</th>
<th>Over 6 year-olds</th>
<th>Total sheep numbers</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Barley, grain</td>
<td>182 g</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Barley, grain</td>
<td>364 g</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Soybean meal</td>
<td>128 g</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Soybean meal</td>
<td>256 g</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Monosodium phosphate</td>
<td>13 g</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Monosodium phosphate</td>
<td>17 g</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Total sheep numbers</td>
<td>18</td>
<td>18</td>
<td>18</td>
<td>18</td>
<td>18</td>
</tr>
</tbody>
</table>

† Three replications (twice as many control ewes as other ewes).
(0.56 pound) each second day. The energy supplement was supplied in the form of whole barley grain fed at the rate of 182 grams (0.40 pound) and 364 grams (0.80 pound) each second day.

The sheep were grazed together on the open range during the day and were corralled each night (figure 10). They were put into individual pens at dawn and were fed their designated supplement individually in buckets. Using this procedure and 56 individual pens, it was possible to feed all the sheep on the experiment in less than 2 hours. Whole barley (energy) and solvent extracted soybean meal pellets (protein) were weighed into paper bags and put into a tray with individual compartments. Each bag had a number corresponding to the brand number of the sheep to receive it. The monosodium phosphate was weighed into bottles, dissolved in water, and fed as a drench. Experimental results have shown that such individual feeding can be practiced on the range without adversely affecting the performance of the sheep (Harris et al., 1952).

Supplementary feeding was started November 25, 1947 and continued until April 28, 1948. The sheep then left the winter range and trailed from Wah Wah Valley to the Salina Canyon foothill spring range, a distance of 150 miles. The ewes were fed supplements every second day on the trail until they reached the foothill ranges May 14. To accomplish this, the portable pens were moved to a new location every second day. The ewes reached the lambing grounds on May 16 and lambing started May 23.

During the winter, the ewes were weighed approximately every 28 days and also at shearing time before starting on the trail, and at the end of trailing (figure 11). The lambs were weighed at birth and at weaning time.

To determine if the ewes were deficient in phosphorus or vitamin A and to note the effect of feeding the supplements, blood samples were taken February 13 and 14, from two-thirds of the ewes selected at random within each treatment. Vitamin A was determined by the method of Dann and Evelyn (1938). Blood hemoglobin was determined by the acid hematin method of Cohen and Smith by using a Fisher electrophotometer as outlined by Hawk, Oser, and Summerson (1937). Inorganic plasma phosphorus was determined by the modified Fiske and Subbarow method as given by Kock (1935). We used a field laboratory (Harris et al., 1952).

The grease weight of the fleeces of all the ewes was obtained at shearing time on April 21 and 22. Side samples were scoured to determine yield of clean wool. Staple length was determined by making three measurements of the side samples.
Figure 10. Individual portable pens for sheep. Holding corrals are on each end. Pens are moved every 2 to 3 weeks. Trays are used to hold each sheep's feed. Sheep are fed in buckets. We have also devised portable pens for cattle (Harris et al., 1957).
Live weight changes

With the exception of ewes receiving the high level of monosodium phosphate, all supplemented ewes maintained weight through the winter better than unsupplemented ewes (figure 12). Ewes receiving the low level of barley maintained their weight considerably better than the controls but not nearly as well as the other groups.

While the ewes were being trailed from April 28 to May 14, supplements had little effect on gains. During this time the ewes had access to green, growing range forage. The most critical period on the winter range was from mid-February to the first part of April. To prevent death loss during the periods of stress on the trail such as inclement weather, it is important that ewes be fed during January and February. However, if a supplement is fed on the trail, a low protein supplement should be fed because the range forage is usually growing at this time and is high in protein.

The ewes body weight from November 17 to May 14 represents the developing lamb as well as the body weight of the ewe. Weight gains decreased as age increased after animals reached 1 year of age. Older

Figure 11. Portable weighing crate and platform scale. Back door of weighing crate is raised as front door is raised. This entices sheep to enter crate.
Figure 12. The cumulative gain or loss in live weight of ewes fed various quantities of supplements every second day.
ewes were subject to excessive weight losses during cold and stormy weather and recovered more slowly than younger animals.

**Blood chemistry**

The control ewes had less phosphorus in their blood than any group receiving supplements. There was no significant difference among the groups receiving supplements. Ewes receiving the high level of phosphorus had less hemoglobin than those receiving the low level (tables 6 and 7). Supplements had no significant effect on vitamin A in the blood plasma. Hemoglobin tended to increase with the age of the ewe up to 5 or 6 years of age; then there was a decline. The level of blood phosphorus decreased as the ewes became older. The average values

<table>
<thead>
<tr>
<th>Supplement</th>
<th>Level of supplement each 2nd day</th>
<th>Hemoglobin</th>
<th>Phosphorus</th>
<th>Vitamin A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>.....</td>
<td>11.6</td>
<td>3.14</td>
<td>19.4</td>
</tr>
<tr>
<td>Barley, grain</td>
<td>182 g</td>
<td>11.3</td>
<td>3.41</td>
<td>20.0</td>
</tr>
<tr>
<td>Barley, grain</td>
<td>364 g</td>
<td>15.5</td>
<td>3.56</td>
<td>17.9</td>
</tr>
<tr>
<td>Soybean meal</td>
<td>128 g</td>
<td>11.4</td>
<td>4.08</td>
<td>20.2</td>
</tr>
<tr>
<td>Soybean meal</td>
<td>256 g</td>
<td>11.7</td>
<td>3.62</td>
<td>22.3</td>
</tr>
<tr>
<td>Monosodium phosphate</td>
<td>13 g</td>
<td>11.6</td>
<td>4.02</td>
<td>19.2</td>
</tr>
<tr>
<td>Monosodium phosphate</td>
<td>17 g</td>
<td>10.5</td>
<td>3.96</td>
<td>16.7</td>
</tr>
</tbody>
</table>

**Table 6.** Values for blood hemoglobin, plasma inorganic phosphorous, and plasma vitamin A for ewes fed various supplements from November 25 to February 13

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>Degrees of freedom</th>
<th>Mean squares</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Hemoglobin</td>
</tr>
<tr>
<td>Treatments</td>
<td>6</td>
<td>1.97</td>
</tr>
<tr>
<td>Control vs. treatment</td>
<td>1</td>
<td>0.90</td>
</tr>
<tr>
<td>Kinds of supplements</td>
<td>3</td>
<td>1.34</td>
</tr>
<tr>
<td>Barley, grain 1 vs. 2</td>
<td>1</td>
<td>1.34</td>
</tr>
<tr>
<td>Soybean meal 1 vs. 2</td>
<td>1</td>
<td>0.30</td>
</tr>
<tr>
<td>Monosodium phosphate 1 vs. 2</td>
<td>1</td>
<td>0.77</td>
</tr>
<tr>
<td>Age</td>
<td>5</td>
<td>7.15*</td>
</tr>
<tr>
<td>Treatment x age</td>
<td>30</td>
<td>6.41**</td>
</tr>
<tr>
<td>Error</td>
<td>42</td>
<td>1.64</td>
</tr>
<tr>
<td>Total</td>
<td>83</td>
<td></td>
</tr>
</tbody>
</table>

*Significant at 0.05 level  
**Significant at 0.01 level
were: lambs, 4.29 milligrams phosphorus per 100 milliliters; yearlings 4.26; 3-year olds, 3.75; 4-year olds, 3.32; 5- to 6-year olds, 3.38; and more than 6-years old, 3.11. The age of the ewes did not have any significant effect on vitamin A in the blood plasma.

**Wool production**

The high level of soybean meal produced significantly more clean wool than any of the other treatments (tables 8 and 9). The high level of phosphorus and the high level of soybean meal both produced significantly higher yields of clean wool than did the lower levels. The high and the low levels of barley gave about the same wool yields, both considerably higher than the controls. The high level of soybean meal produced longer wool than the low level. There was a decline in weight of clean wool and length of wool with age above 1 year. Lambs produced

**Table 8. Weight of clean wool of ewes in six age groups fed three supplements at two levels compared to ewes receiving no supplement, November 25 to April 14**

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Supplement fed each 2nd day</th>
<th>Lambs</th>
<th>Ages of ewes in years</th>
<th>Weight of wool for each age</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td></td>
<td>kg</td>
<td>1 3 4 5 to 6 Over 6</td>
<td>kg kg kg kg kg kg kg kg kg</td>
<td></td>
</tr>
<tr>
<td>Barley, grain</td>
<td>182 g</td>
<td>1.79</td>
<td>1.92 1.89 2.31 1.72 1.39 1.83</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soybean meal</td>
<td>256 g</td>
<td>1.98</td>
<td>1.87 2.01 2.00 2.10 1.69 1.94</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soybean meal</td>
<td>128 g</td>
<td>1.51</td>
<td>2.35 2.18 1.68 1.52 1.69 1.82</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soybean meal</td>
<td>13 g</td>
<td>1.65</td>
<td>1.69 1.59 1.56 1.43 1.58 1.58</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soybean meal</td>
<td>17 g</td>
<td>1.43</td>
<td>1.90 2.23 2.04 1.86 1.58 1.84</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Means</td>
<td></td>
<td>1.64</td>
<td>1.93 1.92 1.90 1.77 1.51 1.78</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Table 9. Analysis of variance of clean wool weights and length of wool**

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>Degrees of freedom</th>
<th>Mean square Weight</th>
<th>Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatments</td>
<td>6</td>
<td>1.1268*</td>
<td>0.2536</td>
</tr>
<tr>
<td>Kinds of supplements</td>
<td>3</td>
<td>0.5229</td>
<td>0.0642</td>
</tr>
<tr>
<td>Soybean meal levels</td>
<td>1</td>
<td>0.0036</td>
<td>0.2178</td>
</tr>
<tr>
<td>Monosodium phosphate levels</td>
<td>1</td>
<td>2.3716**</td>
<td>1.0000**</td>
</tr>
<tr>
<td>Age</td>
<td>5</td>
<td>3.3801**</td>
<td>2.4876**</td>
</tr>
<tr>
<td>Treatment x age</td>
<td>30</td>
<td>0.5609</td>
<td>0.1649</td>
</tr>
<tr>
<td>Error</td>
<td>102</td>
<td>0.3890</td>
<td>0.1263</td>
</tr>
<tr>
<td>Total</td>
<td>143</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Significant at 0.05 level
**Significant at 0.01 level
slightly more wool than the ewes over 6 years of age and had wool about as long as the 3-year-old ewes.

Clean wool and grease wool were significantly increased by phosphorus and protein supplements. Barley alone increased the amount of wool only slightly.

Lamb crop

All ewes receiving supplements had a higher lamb crop than the controls with the exception of those fed barley (figure 13). The high level of soybean meal and the low level of phosphorus produced a larger lamb crop at docking time than the other feeds. However, animals receiving both levels of phosphorus and both levels of protein produced appreciably higher lamb crops at lambing than did the controls. The supplements did not affect the weaning weight of the lambs.

Comparison of experimental controls and controls in a large herd

The experiment described above is a fairly simple one; however, it did show that some of the classic procedures for conducting nutritional research could be used on the range. For example, it was found that sheep could be herded in a small group and could be fed individually on

<table>
<thead>
<tr>
<th>Control</th>
<th>100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barley, grain, whole 182 g</td>
<td>107</td>
</tr>
<tr>
<td>Barley, grain, whole 364 g</td>
<td>71</td>
</tr>
<tr>
<td>Soybean meal pellets 128 g</td>
<td>107</td>
</tr>
<tr>
<td>Soybean meal pellets 256 g</td>
<td>121</td>
</tr>
<tr>
<td>Monosodium phosphate 13 g</td>
<td>153</td>
</tr>
<tr>
<td>Monosodium phosphate 17 g</td>
<td>108</td>
</tr>
</tbody>
</table>

Figure 13. Percentage lamb crop of ewes fed three supplements at two levels compared to ewes receiving no supplement, November 25 to May 14.
the range. The handling of the sheep did not affect them adversely. To test this, we had a random sample of ewes in the regular large herd of 2,000 ewes to compare with our experimental controls. The data in table 10 shows that the experimental control ewes did as well as those in the large herd. When I was in Australia and Scotland a few years ago, I found that our individual feeding technique was being used in both countries.

In a later experiment, we used a factorial design and fed three levels of barley, three levels of soybean meal, and three levels of monosodium phosphate (Harris et al., 1956). The results of this trial were similar to the ones described. The following conclusions and recommendations are based on both trials.

Conclusions and recommendations

Supplemented animals produced higher lamb crops than those not supplemented. Generally, the low levels were just as effective as the high levels in increasing lamb numbers. Lambs and yearlings gained more than older animals. Ewes over 6 years old gained little weight during the winter. Two- and 3-year-old ewes produced the heaviest fleeces. As the age of the ewe advanced beyond 5 years, the amount of wool declined. Ewes from 2 to 5 years old produced the most lambs per ewe bred. Old ewes produced less wool and less lambs and death losses were higher. In addition, these ewes consumed feed which otherwise could be used by younger and more productive ewes.

From these experiments, we found that range sheep go through cycles of inadequate and adequate nutrition. During summer they gain and in the fall and early part of winter they usually maintain their weight or gain slightly. During winter there is a critical period some time between January and April when inclement weather and sometimes poor

<table>
<thead>
<tr>
<th>Item</th>
<th>1947 Expt. controls</th>
<th>1947 Large herd</th>
<th>1948 Expt. controls</th>
<th>1948 Large herd</th>
<th>1949 Expt. controls</th>
<th>1949 Large herd</th>
<th>Average Expt. controls</th>
<th>Average Large herd</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gain Nov. to May kg</td>
<td>1.82</td>
<td>0.44</td>
<td>0.53</td>
<td>-0.17</td>
<td>1.56</td>
<td>2.58</td>
<td>1.32</td>
<td>0.95</td>
</tr>
<tr>
<td>Grease wool kg</td>
<td>4.14</td>
<td>3.84</td>
<td>3.70</td>
<td>3.67</td>
<td>4.31</td>
<td>4.39</td>
<td>4.06</td>
<td>3.96</td>
</tr>
<tr>
<td>Scoured wool kg</td>
<td>1.76</td>
<td>1.67</td>
<td>1.50</td>
<td>1.32</td>
<td>1.60</td>
<td>1.65</td>
<td>1.62</td>
<td>1.61</td>
</tr>
<tr>
<td>Staple length cm</td>
<td>5.67</td>
<td>5.46</td>
<td>4.84</td>
<td>4.87</td>
<td>5.82</td>
<td>5.79</td>
<td>5.44</td>
<td>5.38</td>
</tr>
<tr>
<td>Lamb crop %</td>
<td>114</td>
<td>104</td>
<td>92</td>
<td>78</td>
<td>89</td>
<td>100</td>
<td>98</td>
<td>94</td>
</tr>
<tr>
<td>Ewes lambing %</td>
<td>82</td>
<td>88</td>
<td>70</td>
<td>66</td>
<td>79</td>
<td>77</td>
<td>77</td>
<td>77</td>
</tr>
</tbody>
</table>
range conditions cause excessive weight loss. As plant growth starts in early spring, they again gain rapidly. If conditions are severe, some supplement should be fed to prevent excessive weight losses during the winter. However, it would not be economical to feed supplements to even maintain the weight of the ewes during this period.

In the early National Research Council’s recommendations for feeding ewes, the nutrient requirements were planned to have sheep lose weight in the spring and summer (lactation period) and gain weight during the winter (pregnancy period). Our range work has shown that western range ewes gain weight during the summer and lose weight during the winter. Using the results of our research, we now have a section on range nutrition in the latest National Research Council (1964) Nutrient Requirement Report on Sheep.

With the above thoughts in mind, our latest nutrient requirements for range ewes are shown in table 11. These requirements apply only to range sheep during the winter.

There was significant variation response to feeding in different years. Because of changing weather conditions, the sheep operator must exercise judgment and skill in feeding supplements to obtain maximum economic returns. A phosphorus supplement probably should always be fed on winter range since it can be supplied at nominal cost. The feeding of protein and energy should be determined by the condition of the sheep, the kind and amount of the forage available and climatic conditions. Observation showed that certain ewes, particularly those 2, 3, or 4 years of age stayed in good flesh and produced well on little supplemental feed. Supplementing all ewes in a band regardless of age and condition may not be the most practical for a rancher. It may be cheaper to separate the lambs, yearlings, old ewes, and those in poor condition and operate them separately.

Table 11. Suggested nutrient requirements for a 130 pound ewe for most efficient economic production on winter range of the Intermountain Region

<table>
<thead>
<tr>
<th>Daily intake of dry matter</th>
<th>Digestible protein (dry basis)</th>
<th>Metabolizable energy (dry basis)</th>
<th>Phosphorus (dry basis)</th>
</tr>
</thead>
<tbody>
<tr>
<td>digestible met. kcal/kg</td>
<td>digestible met. kcal/lb</td>
<td>digestible met. kcal/kg</td>
<td>digestible met. kcal/lb</td>
</tr>
<tr>
<td>Range forage</td>
<td>1.50</td>
<td>3.30</td>
<td>2.6</td>
</tr>
<tr>
<td>Supplement</td>
<td>0.13</td>
<td>0.29</td>
<td>24.9</td>
</tr>
<tr>
<td>Requirement</td>
<td>1.63</td>
<td>3.59</td>
<td>4.4</td>
</tr>
</tbody>
</table>

†When these requirements are used it is assumed that the ewes will graze on mountainous (National Forest) land during the summer.
Nourishing the Rumen Microorganisms

The demonstration in earlier experiments that animal performance could be improved by supplementary feeding of small amounts of phosphorus and protein (Harris et al., 1956), raised several basic biological questions which were further investigated. A large population of bacteria and protozoa exists in the rumen and reticulum, the first two of the four stomach compartments of ruminant animals (figure 14). These microorganisms are a necessary adjunct to the digestive capacity of the host. Among other functions, they convert otherwise unavailable highly polymerized polysaccharides such as cellulose and pectins to volatile fatty acids which are used by the host as a source of energy. They also convert non-protein nitrogen materials in the plant and other compounds such as urea and ammonium salts to bacterial protein which, in turn, may be digested by the host animal to amino acids and utilized.

In view of the above facts, we designed an experiment to determine if the beneficial effects of supplementation could be the result of increas-

![Figure 14. Ruminants have a four compartment stomach as shown in this schematic diagram. When a non-protein nitrogenous compound such as urea is fed to a ruminant the following takes place:](image)

- Urea plus urease (in rumen) → ammonia
- Ammonia + rumen juices + bacteria → bacterial proteins
- Bacterial proteins + enzymes in digestive tract → amino acids which are absorbed and converted to meat, milk and wool

When a ruminant consumes cellulose, the following takes place:

- Cellulose + bacteria in rumen → butyric, propionic and acetic acids
- These acids are absorbed and utilized as energy by the host animal.

---

44
ing the activity of rumen microorganisms by supplying additional nutrients to this symbiotic culture (Morris et al., 1965). This was studied by using rumen-fistulated sheep on a typical winter desert shrub range (figure 1) on which the dominant species of shrubs were winterfat and shadscale and the grasses were Indian ricegrass and galleta grass.

The sheep were kept in a 259 hectare (1 section) pasture at the Desert Range Experiment Station. We developed a portable laboratory in a "Home on the Range" to handle many of the chemical determinations.

**Experimental plan**

The sheep were supplemented with 0, 3 grams, (0.0066 pound) or 6 grams (0.013 pound) of nitrogen from wheat gluten and 0, 2, grams (0.0044 pound) or 2.65 grams (0.0058 pound) of phosphorus from monosodium phosphate in a 3 x 3 factorial design. Rumen fluid samples were withdrawn at 0, 3, 6, 9, and 12 hours after the administration of the supplement and analyzed for phosphorus, ammonia, and volatile fatty acid content. Cellulose digestion was estimated by determining the loss of weight in digestion of cotton thread suspended in a Dacron chiffon bag in the rumen. Seven coils of thread 3 meters (9.8 feet) long were placed in the bag in the rumen at the beginning of a determination. One coil was removed after 24 hours in the rumen; thereafter, one coil was removed at each 72 hour interval until all seven coils were removed. A linear regression equation was computed for rate of cellulose digestion for each sheep.

The diet of the sheep was sampled by esophageal-fistulated sheep (figure 4). Dry matter intake and digestibility were calculated by the lignin-ratio technique. Metabolizable energy was determined by collecting total feces and urine (figure 5) and calculating methane as described above.

**Results and conclusions**

Phosphorus supplementation increased the concentration of phosphorus in the centrifuged rumen liquor (figure 15). The effect of a supplement of 2 or 2.65 grams (0.0044 or 0.0058 pound) of phosphorus as monosodium phosphate was still evident 24 hours after supplementation. At zero hours the level of phosphorus in centrifuged rumen liquor of unsupplemented sheep was less than 15 milligrams per 100 milliliters, whereas, the phosphorus supplemented sheep had levels of about 30 milligrams per 100 milliliters. Anderson et al. (1956) reported that 40 to 80 micrograms of available phosphorus per milliliter of fermenta-
tion medium met the requirements for *in vitro* cellulose digestion by rumen microorganisms, whereas, Hubbert *et al.* (1958), reported that additions of as much as 100 milligrams of phosphorus per milliliter did not depress *in vitro* cellulose digestion. Since both the control and supplemented sheep had rumen phosphorus levels in the range of these two reported values, it would be expected that phosphorus supplementation as practiced in this experiment would neither be beneficial nor deleterious to cellulose digestion.

The lower response in weight gain in sheep reported by Harris *et al.* (1956), when given 17 grams (0.038 pound) as compared to 13 grams (0.029 pound) of monosodium phosphate, was probably not caused by an excess phosphorus concentration which depressed cellulose digestion.
Except for the effect of the gluten supplement on valeric acid concentration, neither the individual concentrations of the other acids, the molar percent of all acids, nor the level of total volatile fatty acids were influenced by nitrogen supplementation (table 12). The increase in valeric concentration was almost certainly a result of deamination of amino acid residues from the wheat gluten. El-Shazly (1952 a,b) and Annison (1954, 1956) demonstrated that proteins favor the formation of higher volatile fatty acids in the rumen. The enhancement of cellulose digestion in vitro by the addition of straight and branched chain volatile fatty acids has been demonstrated by Bentley et al. (1954, 1955), Bryant and Doetsch (1955), and Johnson et al. (1958).

The rumen-ammonia concentration curves for sheep fed the three levels of nitrogen supplementation paralleled each other and exhibited maximum concentration 9 hours after the beginning of grazing. Phosphorus supplementation did not affect rumen-ammonia concentration.

Neither phosphorus nor nitrogen supplements influenced the rate of cellulose digestion (as measured by the cotton thread technique), the apparent digestibility coefficient of cellulose, or gross energy.

It was shown earlier that the metabolizable energy was lower in range shrubs containing high amounts of volatile oils. In a recent report, Nagy et al. (1964) obtained volatile oils from the current annual growth of leaves, twigs, flowers, and shoots of big sagebrush, bud sage (Artemisia spinescens) and fringed sage (Artemisia frigida). In general, the

<table>
<thead>
<tr>
<th>Acid</th>
<th>0</th>
<th>3</th>
<th>6</th>
<th>9</th>
<th>12</th>
<th>Standard error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Valeric</td>
<td>0.9</td>
<td>1.2</td>
<td>1.1</td>
<td>1.2</td>
<td>1.0</td>
<td>0.018</td>
</tr>
<tr>
<td>Butyric</td>
<td>5.2</td>
<td>5.1</td>
<td>5.5</td>
<td>6.7</td>
<td>6.4</td>
<td>0.060</td>
</tr>
<tr>
<td>Propionic</td>
<td>16.6</td>
<td>15.2</td>
<td>16.1</td>
<td>20.1</td>
<td>19.7</td>
<td>0.149</td>
</tr>
<tr>
<td>Acetic</td>
<td>66.7</td>
<td>63.9</td>
<td>69.1</td>
<td>86.2</td>
<td>84.0</td>
<td>0.482</td>
</tr>
<tr>
<td>Total</td>
<td>89.4</td>
<td>85.4</td>
<td>91.8</td>
<td>114.2</td>
<td>111.1</td>
<td>0.668</td>
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<table>
<thead>
<tr>
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<th>1</th>
<th>1.1</th>
<th>1.2</th>
<th>1.1</th>
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<th>0.018</th>
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<tbody>
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<td>6.0</td>
<td>6.0</td>
<td>5.9</td>
<td>5.8</td>
<td>0.042</td>
</tr>
<tr>
<td>Propionic</td>
<td>18.6</td>
<td>17.9</td>
<td>17.6</td>
<td>17.6</td>
<td>17.8</td>
<td>0.072</td>
</tr>
<tr>
<td>Acetic</td>
<td>74.4</td>
<td>74.7</td>
<td>75.2</td>
<td>75.2</td>
<td>75.2</td>
<td>0.082</td>
</tr>
</tbody>
</table>

†Data derived from replications I and II, period I; and replications II and III, period II (n = 540)

‡Means for all acids differ significantly (P < .01) among hours
highest oil content was found in big sagebrush leaves and twigs (approximately 2 to 5 percent on a dry matter basis), followed by bud sage (1 to 2 percent).

The antibacterial action of the oils of big sagebrush was investigated on aerobic bacteria species as well as on rumen bacteria obtained from wild and domestic deer. Bacterial response varied significantly according to species of bacteria. There were significant differences in response to the oils of wild deer rumen microorganisms as compared with captive deer. This finding suggests that volatile oils in range plants may affect the way the microorganisms digest cellulose.

The mean daily forage dry matter and metabolizable energy intakes were 985 grams (2.17 pounds) and 1,223 kilocalories, respectively. Phosphorus supplementation significantly reduced the metabolizable energy intake from 1,303 kilocalories for control sheep to 1,086 kilocalories for sheep receiving 2.65 grams (0.0058 pound) of phosphorus per day.

Since this experiment did not demonstrate beneficial effects in improving the utilization of range forage, we are currently doing in vitro and in vivo experiments to determine how to nourish the microorganisms so the sheep can better utilize range forage.

**Influence of Nitrogen Intake upon Rumen Function**

Although nitrogen and phosphorus are required by the rumen microorganisms, it is difficult to study the effects of dietary additions of these nutrients because of the phenomenon of recycling. Ruminants secrete a large volume of saliva which contains considerable amounts of urea and phosphate salts. There is also appreciable diffusion into the rumen of these nutrients through the rumen wall. Thus materials are recycled into the rumen and augment the dietary supply of nutrients to the rumen microorganisms. This process has very direct bearing in studies on the nutritional adequacy of range plants and on the effects of supplementation.

**Experimental plan**

Since the host animal depends on the symbiotic relationship with the microorganisms, it is difficult to study the effects of nutrient deficiencies in the rumen without finding a way to nourish the host animal and the microorganisms separately. To accomplish this, we fed the host animal through a duodenal fistula (figure 16) and varied the diet to nourish the microorganisms in the rumen.
In one experiment to study the above principles we used Columbia wethers. They were housed in our metabolism building and confined in individual pens with slatted hardwood floors, feed mangers and water bucket. Water was supplied *ad libitum*. Canvas bags were attached to the sheep by light leather harnesses to catch the feces so digestion coefficients could be determined.

During March, April and May, the temperature within our metabolism building ranged from 7 to 15°C (45 to 59°F), then increased

Figure 16. This sheep is equipped with a duodenal fistula, a urinal, and a feces bag. Casein is being introduced through the duodenal fistula. This makes it possible to nourish the host animal through the duodenum. The diet may then be varied so the nutrient requirements of the rumen microorganisms may be determined. When the feces and urine are collected, digestion coefficients and metabolizable energy may be determined.
gradually to 25 °C (77 °F) at the end of the experiment in August. There was little temperature variation in the semi-basement during the winter months.

The basal diet is shown in Table 13. The nitrogen content of this ration was varied by adding casein (15 percent nitrogen) and urea (42.6 percent nitrogen), each supplying one-half the added nitrogen. The initial ration contained a total of 12.2 grams of nitrogen and thereafter the nitrogen intake was reduced each second week by decreasing each nitrogen source by 10 percent. The other constituents remained constant, but the dry matter intake was slightly reduced (range 824 to 797 grams per day). The starch, sugar, molasses, casein, and urea were dissolved or suspended in water, then mixed with the straw and minerals in a dough mixer. This mixture was then put into a polyethylene dish and presented to the sheep each morning at 9 a.m. It was eaten avidly.

Prior to the commencement of the experiment, the sheep were fed a ration containing 12.2 grams of nitrogen for approximately 1 month. The pre-feeding periods started March 8 and collections commenced March 17. Each of the following periods consisted of 2 weeks. Collections for digestion data were made over the last 7 days.

Table 13. Basal ration used in the experiment. The nitrogen was varied by replacing cornstarch with casein and urea

<table>
<thead>
<tr>
<th>Constituents</th>
<th>Dry weight</th>
<th>Dry matter</th>
<th>Nitrogen</th>
<th>Crude fiber</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oat straw, alkali-treated †</td>
<td>550</td>
<td>87.8-94.1</td>
<td>0.41-0.54</td>
<td>55.5-59.1</td>
</tr>
<tr>
<td>Cornstarch</td>
<td>125</td>
<td>88.4-91.0</td>
<td>0.02-0.09</td>
<td>-</td>
</tr>
<tr>
<td>Sugar (sucrose)</td>
<td>100</td>
<td>99.8-100.0</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Sugarcane molasses</td>
<td>50</td>
<td>70.2-76.3</td>
<td>0.66-0.69</td>
<td>-</td>
</tr>
<tr>
<td>Mineral mix ‡</td>
<td>30</td>
<td>100.0</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Water ‡</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

†Bales of oat straw (Avena sativa) were placed on wire slings and totally immersed in cold 1.5 percent (weight per volume) sodium hydroxide. The straw was then lifted out, drained for a few minutes, placed in another tank and washed thoroughly using an automatic siphon which gave 5 to 6 changes of washing water per hour. Alkali free conditions were obtained in 18 to 20 hours. The straw was then drained, dried for 48 hours in a forced draft at 55 °C and put through a chaff cutter.

‡The mineral mix consisted of the following: (in percent) NaCl, 40; CaCO₃, 17; Ca₂HPO₄, 20; MgSO₄·7H₂O, 12; KCl, 8; and trace elements, 3. The trace element mixture consisted of: (in grams) FeC₆H₅O₇·3H₂O, 150; CuSO₄·5H₂O, 60; MnSO₄, 9; KI, 1.5; CoCl₂·6H₂O, 6; ZnCO₃, 15; Na₂SO₄, 1008.5; Na₂SeO₃·10H₂O, 1.35. The trace element mixture supplied the following amounts in the daily ration: (in milligrams) Fe, 20; Cu, 10; Mn, 2; I, one; Co, one; Zn, 10; S, 166; and Se, 0.2.

‡‡The constituents were mixed with 400 ml of water.
Supplementation of the diet by supplying the sheep with casein through the duodenal fistula commenced after the third period. The purpose of this supplementation was to bypass the rumen and supply the host animal with nitrogen. As the nitrogen supplementation through the duodenal fistula was increased the nitrogen fed in the diet was decreased. This in effect produced a nitrogen deficiency in the rumen so that the symbiotic relationship of the microorganisms in the host animal could be studied.

The cotton thread technique was used to study the digestion of cellulose in the rumen. Rumen samples were taken before feeding at 9 a.m. then at 11 a.m., 1, 5 and 9 p.m. on Wednesdays and Thursdays of the collection week. These samples were taken from directly below the rumen fistula by means of a 15-millimeter bore glass tubing using gentle suction. Approximately 75 milliliters were collected on each occasion. The animals became so accustomed to sampling that they did not stand up if they were lying down or cease ruminating during the process.

Results and conclusions

The dry matter intake and rate of eating of the sheep supplemented by the duodenum remained almost constant throughout the range of diets fed, in which the nitrogen varied stepwise from 12.2 to 2.5 grams per day. The dry matter intake and the rate of eating of the unsupplemented sheep, in contrast, were both greatly reduced when the nitrogen intake was decreased by 6 grams per day.

On the basis of differences in data between the supplemented and unsupplemented sheep, it was estimated that at least 3.5 grams of nitrogen per day were recycled to the rumen.

As the amount of nitrogen in the diet decreased the rate of cotton thread digestion in the rumen decreased. In figure 17 is shown the relationship of the percentage of cotton thread remaining (z), against nitrogen intake (y), and days in the rumen (x) for sheep 474, 454 and 455. The regression \( z = 114.9 - 0.494x^2 - 1.8xy \), relating these three factors, is highly significant \( (P < .001) \).

The concentration of ruminal bacteria, as shown by direct count, was positively \( (P < .001) \) correlated with the nitrogen intake, both before and 8 hours after feeding; more than a tenfold decrease occurred within the range of nitrogen intake fed.

The changes in bacterial concentration were correlated significantly with cotton thread cellulose digestion (figure 18). It is concluded that
within the system examined, where close control was attained over recycled nitrogen and total intake, and hence substrate concentrations, the direct count of ruminal microorganisms reflects the functional capacity of the rumen.

This experiment outlines a classic technique for feeding the host animal through the duodenum while various other supplements may be administered to study how to best nourish the microorganisms. We believe this technique and modifications of it might be used to do basic research on how to nourish the microorganisms so sheep or cattle may utilize more of the range forage they consume.

Figure 17. The relationship between loss of cotton thread cellulose and the nitrogen intake (see text for regression).
Grazing Reseeded Grasses in the Spring

Winter grazing areas or supplies of hay are often depleted before native range areas are ready to graze in the spring. Because of this, late winter and early spring are the most critical times for livestock feed in the Intermountain region. Often cattle and sheep are in thin condition this time of year. Because of these facts, early spring range is needed. To develop this kind of range, we conducted an 11-year study (1948-1958) of grazing crested wheatgrass by cattle at Benmore, Utah (Frischknecht and Harris, 1968).

Figure 18. The regression of cotton thread remaining (z) on days (x) x bacterial concentration (y), $z = 113.46 - 0.47x^2 - 0.88xy$, showing the quantitative relationship between bacterial concentrations and the digestion of cotton thread cellulose.
Experimental area

The Benmore area was named for two early Utah families, the Bennions and the Skidmores. They and other pioneers in the valley, impressed by the abundance of native grasses, grazed their stock on the range the year around when snow conditions permitted. The area was later planted to dryland wheat. After several years, it was found that this was unprofitable and in 1934, the land was purchased by the Federal Government. Twelve hundred ninety-six hectares (3,200 acres) were set aside as an experimental area in the late 1930's. Twenty-eight 40.5-hectare (100-acre) pastures were fenced, seeded to grass, and water piped to each.

The area is considered to be a spring and fall range. It is bounded on the north by salt desert winter range and on the south by the mountainous summer range of the Sheep Rock Mountains. The south end of Rush Valley, where the range is located, is gently sloping though broken by shallow, intermittent stream channels. The elevation is approximately 1,768 meters (5,800 feet), and the average annual precipitation is about 300 millimeters (12 inches). Soils are mainly clay loams with generally small amounts of gravel in some locations.

At the start of the experiment, the grass stands were about 12 years old. Crested wheatgrass comprised about 95 percent of the forage, with minor amounts of western wheatgrass, bulbous bluegrass (*Poa bulbosa*), cheatgrass, squirreltail grass, and several forbs. Big sagebrush and rubber rabbitbrush were present in varying amounts but were seldom eaten by cattle in the experimental pastures.

Experimental plan

We used three intensities and four methods of grazing in two treatment replications (table 14) to determine the best management practices to graze this reseeded crested wheatgrass range. The intensities of grazing are shown in figure 19.

The classes of cattle used to graze the pastures were: yearlings, dry cows and steers over 1 year of age, pregnant cows calving in the pasture (for calculating gain of this class the gain in weight of the calf was added to the gain in weight of the cow), lactating cows, and calves entering the pasture with the mother cow. These cattle were furnished by about a dozen ranchers of the Vernon Cattlemen's Association. The cattle were put in the corral overnight, then weighed at random, and put into each pasture. Before each weighing, they were put in the corral and shrunk overnight.
They were identified with a number on a chain which was put around their necks. We like this method of identification because the number on the chain can be read in the pastures.

Changes in the vegetation were observed and recorded on 40 permanent plots per pasture. These plots were 0.89 square meters (9.6

Figure 19. Crested wheatgrass being grazed at three intensities for approximately 60 days during the spring grazing season: (A) light (53%), (B) moderate (65%), and (C) heavy (80%).
Table 14. Experimental design to compare three intensities of grazing and four methods of grazing

<table>
<thead>
<tr>
<th>Method of grazing</th>
<th>Intensity of grazing</th>
<th>Total number pastures</th>
<th>Total pasture compared</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Light 53%</td>
<td>Moderate 65%</td>
<td>Heavy 80%</td>
</tr>
<tr>
<td>Total I and II †</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rotation</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Continuous</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Delayed 10 days</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Removed 10 days early</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Total pasture compared</td>
<td>8</td>
<td>8</td>
<td>8</td>
</tr>
</tbody>
</table>

†The twelve pastures with the highest carrying capacity were assigned at random to replication I and the remaining 12 pastures were assigned at random to replication II. Approximately 250 head of cattle were assigned at random to each block of pastures. Each pasture contained 100 acres.

Figure 20. Wire hoop encircling 0.89 square meter (9.6 square feet) was divided into sixths by crosswires to facilitate the recording of data on crested wheatgrass and other herbaceous species. Colored tape on crosswires, corresponding to subdivisions of 93 square centimeters (0.1 square feet), 465 square centimeters (0.5 square feet), and 930 square centimeters (1.0 square foot) within each 1488 square centimeter (1.6 square foot) section, facilitated estimating grass basal area to the nearest 93 square centimeters. Inner ring maintained accurate centering over plot markers.
Wire hoops segmented radially into sixths (figure 20) facilitated taking the following kinds of data on herbaceous species: (1) basal area to the nearest 93 square centimeters (0.1 square foot), an adaptation of the "square foot" method described by Stewart and Hutchings (1936); (2) numbers of plants by two sizes — less than 2.54 centimeters (1 inch) crown diameter and 2.54 centimeters and larger; (3) numbers of ungrazed or lightly grazed "wolf" plants. These data were recorded after grazing in the even numbered years from 1948 through 1958.

Every year a record of forage utilization on the permanent plots was taken after the final spring grazing by using the ocular estimate-by-plot method (Pechanec and Pickford, 1937). These data included the amount of remaining herbage, percentage of utilization, and stubble height. Yields of grass on each plot were calculated from estimates with amount left in percentage utilization. About 200 wire cages, each covering an area slightly more than 0.89 square meters (9.6 square feet) were distributed over the 24 pastures as guides in estimating utilization (figure 21). Some caged and some grazed plots were clipped during the grazing season to determine the progress of growth and utilization. Others were clipped at the end of the season prior to making the utilization survey of each pasture. In the even numbered years, the invasion of big sagebrush and rubber rabbitbrush was recorded. At the beginning of the
studies in 1948 wherever either of these species occurred on a permanent 0.89 square meter (9.6 square feet) plot, a 9.29 square meter (100 square feet) circular plot was superimposed for taking brush data. The data included (1) the counting of plants in two size classes — less than 10.2 centimeters (4 inches) high and 10.2 centimeters or more in height, and (2) estimating herbage yields in kilograms per acre.

In 1947 the pastures were all grazed at a uniform rate to establish the carrying capacity. These data were later used in covariance analyses to correct for differences in grazing capacity when calculating the total cattle gain per acre. The correcting of the data greatly reduced the experimental error (Harris, 1959).

Figure 22. Heavy grazing (80% utilization of grass) produced lowest daily gains for all classes of animals. Differences between light (53%) and moderate (65%) grazing were important only for lactating and pregnant cows.
Results and conclusions

Differences in daily gains of cattle were much greater between the 80 and 65 percent intensities of grass utilization than they were between the 65 and 53 percent intensities. Average daily gains for the three utilizations for the 11 years were:

<table>
<thead>
<tr>
<th>Percent Utilization</th>
<th>Gains</th>
</tr>
</thead>
<tbody>
<tr>
<td>53</td>
<td>1.29 kilograms (2.84 Pounds)</td>
</tr>
<tr>
<td>65</td>
<td>1.22 kilograms (2.69 Pounds)</td>
</tr>
<tr>
<td>80</td>
<td>0.98 kilogram (2.16 Pounds)</td>
</tr>
</tbody>
</table>

All five classes of animals showed significantly reduced daily gains when spring utilization increased from 65 to 80 percent (figure 22.)

Per acre gains under heavy grazing were initially high but dropped below those for moderate grazing after the second year because it was necessary to reduce the number of grazing animals as forage yields declined (figure 23). After 6 years per acre gains for heavy grazing declined below those of light grazing. Moderate grazing provided the best long term production (19.7 kilograms or 43.4 pounds) per acre for the season compared to 18.0 kilograms (39.7 pounds) and 16.7 kilograms (36.8 pounds) for heavy and light grazing, respectively. Heavy

![Figure 23](image_url)

Figure 23. Continued heavy grazing resulted in decreased forage yields, hence decreased per acre gains of animals. Over the years moderate grazing produced the most gain.
utilization produced the lowest daily weight gains for all five classes of cattle — lactating cows, pregnant cows, dry cows and steers, yearlings and calves. Dry cows and steers, yearlings and calves gained as well under moderate utilization (65 percent) as they did under light (50 percent) utilization. However, pregnant cows which calved after grazing began, gained 13.6 kilograms (30.0 pounds) more on lightly grazed range than on moderately grazed range, and cows that already had a calf when grazing began, gained 6.4 kilograms (14.0 pounds) more on lightly grazed range than on moderately grazed range.

This shows that gain of lactating cows was the most sensitive indicator of grazing intensity, but since there were no important differences in gain of calves between light and moderate grazing, we concluded that crested wheatgrass may be grazed year after year in the spring by all classes of cattle at 65 percent utilization.

The grazing system shortened at the end provided the heaviest average daily gains for all classes of cattle. Highest gains per acre resulted from either rotation or delayed grazing. Rotation was superior 7 out of the 11 years of the test. Average gains per acre for the 11-years were as follows:

<table>
<thead>
<tr>
<th>Methods of grazing</th>
<th>Gains</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rotation</td>
<td>19.5 kilograms (42.9 pounds)</td>
</tr>
<tr>
<td>Delayed-10-days</td>
<td>18.4 kilograms (40.6 pounds)</td>
</tr>
<tr>
<td>Continuous</td>
<td>17.7 kilograms (39.0 pounds)</td>
</tr>
<tr>
<td>Removed-10-days-early</td>
<td>16.9 kilograms (37.3 pounds)</td>
</tr>
</tbody>
</table>

The above experiment shows that crested wheatgrass can fill an important need for early spring grazing in the Intermountain region. Under conditions at Benmore, elevation 1,829 meters (6,000 feet), rainfall 330 millimeters (13 inches), crested wheatgrass may be grazed from about April 20 to June 20 at an intensity that allows utilization of approximately 65 percent of herbage by weight. This intensity of use will give optimum cattle gains per acre and maintain grass production.

Two important principles brought out in this study are: (1) delaying the start of grazing in the spring will contribute toward maximum basal area and yields of grass; (2) shortening the grazing season toward the end of the spring growing season will contribute toward maximum plant numbers. Combinations of these principles can mitigate adverse effects of heavy grazing.

Although shrub invasion increased with intensity of grazing, in "wet" years some sagebrush and rabbitbrush will invade crested wheat-
grass even under no grazing, if a seed source is present. Sagebrush depresses grass yields more than rabbitbrush. It is likely that brush control will be required when sagebrush seriously limits grass production.

The following daily gains may be expected at 65-percent utilization for the various classes of cattle:

<table>
<thead>
<tr>
<th>Class of cattle</th>
<th>Gains</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yearlings</td>
<td>1.18 kilograms (2.60 pounds)</td>
</tr>
<tr>
<td>Dry cows and steers</td>
<td>1.45 kilograms (3.20 pounds)</td>
</tr>
<tr>
<td>Pregnant cows calving in pasture</td>
<td>1.41 kilograms (3.10 pounds)</td>
</tr>
<tr>
<td>Lactating cows</td>
<td>1.22 kilograms (2.70 pounds)</td>
</tr>
<tr>
<td>Calves</td>
<td>0.82 kilograms (1.80 pounds)</td>
</tr>
</tbody>
</table>

Cows having suckling calves were the most sensitive animals to intensity of spring grazing.

The total gain per acre that may be expected at 65-percent utilization is approximately 19.5 kilograms (43 pounds). The rotation treatment produced the highest animal gain per acre in 7 out of 11 years; the delayed-10-days treatment produced the highest gains in the other 4 years. All systems of grazing, however, permitted sufficient gains on the cattle for efficient beef production providing the pastures were grazed at 65-percent utilization or less.

It takes about 2 hectares (5 acres) to graze a cow and a calf for the 60 day spring grazing season.

**Grazing Reseeded Grasses from April to December**

Because numbers of livestock permitted on the higher summer ranges have been reduced, it is important to obtain new sources of feed supply for the summer months. Crested wheatgrass has been used extensively for spring and fall grazing although it has been considered inferior to other grasses during the summer (Sarvis, 1941; Williams and Post, 1945; Barnes and Nelson, 1950; Cook et al., 1956). This experiment was designed to determine the merits of feeding a protein supplement to cattle grazing crested wheatgrass during summer and fall, combined with regular spring grazing (Harris et al., 1965).

We conducted our experiment on the Benmore experimental area already described. The purpose of our experiment was to determine if crested wheatgrass was a dependable source of forage for cattle from April to December. The experiment covered a 4-year period from 1961 to 1964.
Experimental plan

Ten treatments were used: early spring plus early fall; late spring; early summer; late summer; early fall; and late fall. All of the summer and fall treatments included grazing with supplement and without supplement. The treatments were assigned at random to three replications of ten 50-acre pastures. The early spring and late spring treatments were about 30 days in length while the summer and fall treatments were about 40 days in length.

Two yearlings and 8 to 12 cow-and-calf pairs were allotted at random to each pasture. Animals were shifted to new pastures at the beginning of each season, excepting that the three pastures grazed in early spring were also grazed in early fall.

Some shifting of animals was necessary to achieve the desired grass utilization of 60 to 70 percent. All animals were weighed individually after an overnight shrink in the corral before being placed in, or following removal from, a pasture. Cattle of Hereford breeding were provided by the Vernon Cattlemen's Association.

During summer and fall, half of the yearlings and lactating cows received in portable mangers the equivalent of 0.34 kilogram (0.75 pound) per day of a protein supplement on Monday, Wednesday, and Friday. The other half received no supplement. The supplement had the following percentage composition:

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soybean meal, solvent extracted, 44 percent protein</td>
<td>88.2%</td>
</tr>
<tr>
<td>Dicalcium phosphate</td>
<td>10.8%</td>
</tr>
<tr>
<td>Trace mineral salt</td>
<td>1.0%</td>
</tr>
</tbody>
</table>

Each 0.34 kilogram of supplement supplied 75 percent of the daily requirement of phosphorus.

All animals received rock salt during the spring periods, while during the summer and fall periods they received crushed salt in one side of a self feeder and one part trace mineral salt and one part dicalcium phosphate in the other half of the feeder.

Bulls were admitted to the pastures at the beginning of the late spring period. At the end of this period, part of the cattle were moved to the mountainous summer range (National Forest) south of the pastures. These cattle were rounded up and weighed at the beginning of the early fall period to provide data for comparison of pasture gains made on the higher summer range (National Forest).
Results and conclusions

Average daily gains for each season and precipitation data for the corresponding periods are shown in figure 24.

The gains of cows varied as a function of available green forage, this in turn being affected by the precipitation, except during late fall which was beyond the growing season. Calf gains did not change with available green grass since their gains depended on the milk supply of the cow.

Pastures which were grazed in early spring and again in early fall provided slight additional gains upon second grazing in 1962 and 1964 compared to pastures grazed only in early fall. In fact, gains for second grazing without supplement equalled or exceeded gains for single grazing with supplement. These years were dry and no summer or fall regrowth was produced. On the other hand, during the years of regrowth (1961 and 1963), early fall gains were higher for single grazing.

Gain per acre averaged highest for late spring and all spring grazing (figure 25). This corresponds to the period of maximum green forage. Substantial gains were also made during early summer. Average gains were slightly over 4.5 kilograms (9.9 pounds) per acre during late summer and early fall for cattle receiving supplement, while cattle without supplement gained only about half this amount. These differences were significant ($P < .05$). Late fall losses are attributed to the last two years, as explained under average daily gains.

Yearlings made substantial gains in all seasons except during late fall when they lost weight slightly (figure 26). They finished the entire
grazing period with an average gain of 102 kilograms (225 pounds). Calves gained at a steady rate, finishing in October with an average gain of 113 kilograms (249 pounds). It may be concluded that yearlings and calves did as well on crested wheatgrass as on the National Forest, and supplementation provided no additional gain.

Of the three classes of cattle, only cows showed significant response to the supplement, making an average gain of 57 kilograms (126 pounds) as compared to about 23 kilograms (51 pounds) for non-supplemented cows. Cows on the higher range (National Forest) made comparable gains to cows receiving supplement on crested wheatgrass (figure 27).

In pastures where the grazing capacity was not reduced by big sagebrush, the stocking level in early spring averaged about 2 hectares (5 acres) per cow (with a calf) month. At this rate, cows with suckling calves ate the grass as fast as it grew. Again, in early fall the stocking level on pastures that had been grazed previously in early spring averaged about 2 hectares (5 acres) per cow month. Thus, the total grazing capacity of these pastures was about 1 hectare (2.5 acres) per cow month which was about equal to that of pastures in the other treatments. The only difference was that half the capacity was taken in early spring and the other half in early fall, rather than in one period.

![Figure 25. Total gain per acre for the cattle grazing crested wheatgrass at various seasons of the year.](image-url)
Figure 26. Cumulative gain per animal for yearlings, cows and calves when grazing crested wheatgrass at various seasons of the year.
As the grass matured, cows became more selective of the areas grazed and the plant parts which they desired. In the spring, utilization of grass in swales and depressions averaged about 5 percent heavier than on ridges and flat areas. Utilization continued equally heavy in the swales in all seasons, but it became lighter on ridges and flats as the seasons progressed. By late fall, utilization of grass in swales and depressions was about 15 percent heavier than that on the ridges and flats.

In late summer and fall, cows ate the seedheads mainly on the dry grass on ridges and flats. The nutritive quality of seedheads was undoubtedly superior to that of the dry stems.

Control of Invading Sagebrush in Reseeded Range Grasses

Reinvasion of big sagebrush in crested wheatgrass stands is a major problem even if light grazing is practiced (Frischknecht et al., 1958). This reinvasion, however, can be controlled by sheep grazing in late fall. For most effective control, this practice should be inaugurated before brush becomes dense. Early results showed that brush declined most where there were approximately 22 sagebrush plants of varying ages per 100 square meters (2 sagebrush plants per 100 square feet) of area.

5 Frischknecht and Harris, unpublished data.

Figure 27. When cows are fed a protein supplement they are in good condition at the end of the summer season. Their grains also compare favorably with cows grazing on the high range (National Forest).
Table 15. Changes in yields of big sagebrush during years of treatment

<table>
<thead>
<tr>
<th>Grazing treatment</th>
<th>Percent change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cattle early spring plus sheep early fall</td>
<td>+ 2</td>
</tr>
<tr>
<td>Cattle early spring</td>
<td>+ 56</td>
</tr>
<tr>
<td>Sheep early fall</td>
<td>+ 6</td>
</tr>
<tr>
<td>Cattle early spring plus sheep late fall</td>
<td>+ 16</td>
</tr>
<tr>
<td>Sheep late fall</td>
<td>- 52</td>
</tr>
<tr>
<td>No grazing</td>
<td>+ 51</td>
</tr>
</tbody>
</table>

Of the six treatments applied on the Benmore range (table 15), grazing in late fall by sheep gave the greatest percentage reduction in volume of big sagebrush. Brush increased most where cattle grazed in early spring.

On other units having a greater amount of brush, late fall sheep grazing reduced brush only slightly where there were 43 brush plants per 100 square meters (four brush plants per 100 square feet), but brush continued to increase where there were 108 plants per 100 square meters (10 plants per 100 square feet), of area. Of course, the alternative to grazing by sheep is periodic spraying of brush to help keep ranges productive. Sheep utilize brush forage that would otherwise be wasted, but there is a limit to the amount they will eat.

FULFILLMENT

Some Ideas for the Rancher

Supplements for sheep on the winter range

On some well-managed ranges with mixed species of vegetation, it may not pay dividends to feed a supplement. However, most of the winter ranges do not furnish sufficient protein, phosphorus, or energy to satisfy the animals’ requirements. If good management is practiced and the nutrient requirements are satisfied by feeding a small amount of supplement, we have found that the wool may be increased 1 pound per animal and the lamb crop increased 15 to 30 percent (figure 28).

The basis of formulating a supplement for range ewes is to determine the composition of the grazing sheep’s diet and then supply sufficient nutrients to meet any deficiency. In preparing the supplement, the following steps should be followed:

1. Determine how much supplement is to be fed and the form in which it is to be fed. In general, it will not be economical to feed supple-
ments at a level to keep ewes gaining or to maintain their weight throughout the winter months because they are usually in good condition when they go on winter range. The objective is to maximize the use of range and to supplement only at a level to prevent production losses. Supplements should, therefore, be the minimum amount that will insure sufficient and uniform intake of specific nutrients.

2. Add phosphorus to the supplement at a level to meet the recommended requirements for a 59-kilogram (130 pound) ewe.

3. Do the same with protein.

4. Under conditions in which carotene is likely to be deficient, supply sufficient vitamin A to meet the requirement. However, under Intermountain range conditions, animals will probably not be deficient in vitamin A.

5. Add 1 percent salt, preferably trace mineralized salt.

6. Make up the balance of the supplement with an energy feed so that the intended amount of supplement will supply the above nutrients uniformly to the whole herd.

Figure 28. These ewes were fed a balanced supplement with the correct amounts of protein, phosphorus and energy. By supplying such supplements, it is possible to increase wool production by about 1 pound and the lamb crop by about 15 to 30 percent. This practice has a potential of increasing wool production in Utah by 544,316 kilograms (1,200,000 pounds) and the number of lambs weaned by 120,000.
For the various types of range, this means that the general recommendations for supplements are as follows:

1. A 12-percent protein supplement in pellet or block form or a cereal grain of corn or barley should be used on sagebrush range types since the diets of sheep grazing on these areas are usually high in protein. Feed from 0.11 to 0.45 kilogram (0.25 to 1.0 pound) per day, depending on range and climatic conditions and the condition of the animals (table 16). These feeds can also be fed during deep snow emergencies along with alfalfa hay.

2. A 24-percent protein pellet or block fed at 0.11 to 0.23 kilogram (0.25 to 0.5 pound) per day is better adapted for feeding on mixed browse-grass types.

3. A 36-percent protein pellet or block or solvent extracted cottonseed meal fed at 0.11 to 0.15 kilogram (0.25 to 0.33 pound) per day should be used with saltbush types or where there is an abundance of grass or wherever grass predominates.

Salt is being used to regulate the consumption of supplements. This

<table>
<thead>
<tr>
<th>Feed</th>
<th>Recommended amount of protein</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>High</td>
<td>Medium</td>
</tr>
<tr>
<td>Barley, grain, ground</td>
<td>....</td>
<td>32.25</td>
</tr>
<tr>
<td>Corn, grain, ground</td>
<td>5.0</td>
<td>10.0</td>
</tr>
<tr>
<td>Sugarcane, molasses, or beet, molasses</td>
<td>5.0</td>
<td>10.0</td>
</tr>
<tr>
<td>Beet, pulp, dried</td>
<td>....</td>
<td>....</td>
</tr>
<tr>
<td>Cottonseed meal, solv. extd.</td>
<td>62.5</td>
<td>32.5</td>
</tr>
<tr>
<td>Soybean meal, solv. extd.</td>
<td>10.0</td>
<td>10.0</td>
</tr>
<tr>
<td>Dicalcium phosphate</td>
<td>4.0</td>
<td>3.0</td>
</tr>
<tr>
<td>Salt or trace mineralized salt</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Alfalfa, dehydrated or sun-cured meal</td>
<td>12.5</td>
<td>6.25</td>
</tr>
<tr>
<td>Total</td>
<td>100.0</td>
<td>100.0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Suggested composition</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Protein (N x 6.25) %</td>
<td>36.0</td>
</tr>
<tr>
<td>Phosphorus %</td>
<td>1.5</td>
</tr>
<tr>
<td>Carotene mg/kg</td>
<td>7.1</td>
</tr>
</tbody>
</table>

Rate of feeding (kg per day)              |

| Rate of feeding (lb per day)             |
|------------------------------------------|------|
| 0.25                                     |
| 0.33                                     |
| 0.20                                     |
| 0.50                                     |
| 1.00                                     |

...
method of feeding saves labor and is recommended where it is not possible to hand feed the animals — that is, where range sheep are handled under fence. It should be kept in mind, however, that salt is used to regulate the amount of meal consumed and it should not be used if the intake of supplement can be controlled by hand feeding.

Salt-meal mixtures greatly increase water consumption. If this method of feeding is followed, the animals should have access to water every day since the extra salt must be excreted through the urine. If sufficient water is not available, the animals dehydrate.

The choice of whether to hand feed pellets, feed a supplement with salt or to use a protein block should be decided by whichever method is cheaper. If pellets are used they may be fed every second day.

The animals should have free access to salt or trace mineralized salt in one side of a self feeder and a mixture of 1 part salt and 1 part dicalcium phosphate in the other side. If a commercial supplement is fed, it should contain at least 10 percent phosphorus.

Grazing scheme for spring and fall

Spring forage is woefully short in the Intermountain region. Proper grazing of crested wheatgrass can overcome this problem (figure 28). For early spring grazing there should be some growth remaining from the previous fall, since new growth is more rapid where there is some material left from the previous year. Of course, the animals prefer the young, tender grass, but in utilizing it they will also consume some of the dry growth from the previous year.

Fall regrowth occurs about one-half the time. Where there is no fall regrowth, any fall grazing must depend upon grass left from spring.

To perpetuate grass vigor pastures should not be grazed every year in the spring. Rotation grazing where the pastures are divided into three sections by electric fences, and each section grazed twice in regular order each spring, beginning with a different section each year, may fill this need.

Water should be provided. In late fall provision should be made to cope with freezing conditions. As on winter range, salt should be available at all times. In addition, during the fall cattle should have free access to a mixture of 1 part salt or trace mineralized salt and 1 part dicalcium phosphate or a commercial phosphorus supplement containing at least 10 percent phosphorus.
Figure 29. (A) There are about 20 million hectares (50 million acres) in the Intermountain region, and 2 million hectares (5 million acres) in Utah of spring and fall sagebrush and depleted dry farm land which would benefit from reseeding to drought-resistant grasses, such as crested, intermediate, or tall wheatgrass, or Russian wildrye.

On sagebrush land it takes 2.02 to 10.1 hectares (5 to 25 acres) to maintain a cow and a calf for 60 days in the spring. While on this range the cows gain about 0.5 kilograms (1.10 pounds) and calves gain about 0.67 kilograms (1.47 pounds).

(B) When sagebrush land is reseeded to crested wheatgrass and grazed to a utilization of 65 percent, it takes about 2 hectares (5 acres) for a cow and a calf for a 60-day grazing season. While on this type of spring range, cows gain from 1.13 to 1.39 kilograms (2.49 to 3.06 pounds), and calves gain about 0.80 kilograms (1.77 pounds). Reseeding this type of range is the best way to increase cattle production in the Intermountain West.
In the spring the following daily gains may be expected at 65 percent utilization for the various classes of cattle (assuming they are thin when put in the pastures):

<table>
<thead>
<tr>
<th>Class of cattle</th>
<th>Gains</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yearlings</td>
<td>1.18 kilograms (2.60 pounds)</td>
</tr>
<tr>
<td>Dry cows and steers</td>
<td>1.45 kilograms (3.20 pounds)</td>
</tr>
<tr>
<td>Pregnant cows calving in pasture</td>
<td>1.41 kilograms (3.10 pounds)</td>
</tr>
<tr>
<td>Lactating cows</td>
<td>1.22 kilograms (2.70 pounds)</td>
</tr>
<tr>
<td>Calves</td>
<td>0.82 kilogram (1.80 pounds)</td>
</tr>
</tbody>
</table>

In the fall cows will about maintain their weight on a crested wheatgrass pasture. If there is some rain and some regrowth they will gain slightly. For a 60-day grazing season in the spring, it takes about 2 hectares (5 acres) for a cow and a calf.

The grazing of sheep in late fall will control big sagebrush if the grazing is started when there are not more than 22 sagebrush plants of varying ages per 100 square meters (two sagebrush plants per 100 square feet).

**Grazing scheme from April to December**

When a rancher has limited permits for cattle on the National Forest range, or does not have meadows or irrigated pastures for summer grazing, it may be desirable to develop a system to graze grass from April to December on the spring and fall zone where there is a rainfall of 279 to 356 millimeters (11 to 14 inches).

1. *Early spring*. Cattle may be started to graze about April 10. The pasture used for this grazing should have been one that was grazed in such a manner the previous year that there is some old growth left.

2. *Late spring*. The pasture used for this grazing should have been one that was grazed in early fall or late fall the previous year.

3. *Early summer*. Use a pasture seeded to intermediate wheatgrass, because it stays green longer (Cook, 1966). Intermediate wheatgrass requires 305 millimeters (13 inches) of rainfall. If there is not this much rainfall, use crested wheatgrass or Russian wildrye.

Graze the same cows on this area every second year and on the higher land (National Forest) the other years. Feed the cows the equivalent of 0.34 kilogram (0.75 pound) of cottonseed meal daily in three
feedings per week or give them access to a protein block or access to a mixture of protein supplement and salt to control intake while on crested wheatgrass.

4. *Late summer.* Follow the same practices as outlined for early summer.

5. *Early fall.* Use a crested wheatgrass, Russian wildrye or intermediate wheatgrass pasture.

6. *Late fall.* Use a crested wheatgrass, Russian wildrye or intermediate wheatgrass pasture.

In the spring cattle may be grazed for about 60 days in a pasture, but in the summer and fall they should be moved to a new pasture about every 30 to 45 days. The pastures may be utilized to about 65 percent. The grazing capacity is the same as described above for spring and fall.

Water should be available. Feed minerals as recommended above for spring and fall ranges.

When big sagebrush invades it may be controlled as outlined above.

**A Glimpse into the Future**

As the questions we ask through our research become more exacting, the techniques at our disposal must become more accurate and reliable. Hence, part of our work, as in the past, must be concerned with the development of better techniques.

We need better methods to indicate the nutritive status of an animal by making measurements directly on the animal.

The apparatus we use to collect urine from grazing animals is cumbersome and difficult for the animal to carry. Some work has been done to devise an indicator for estimating urine output similar to estimating feces output by the use of chromic oxide. This work involves the use of creatinine *(Butcher and Harris, 1957).* Future research may show that a sustained release capsule implanted under the skin may be able to release a small amount of some substance so that total urine
output may be predicted from grab samples. If such a method is developed, digestion and balance trials could be carried out on the range without a harness on the animal.

As suggested before, we still do not have a completely satisfactory internal indicator for digestibility studies. The search for a chemically definable, indigestible substance should continue which, if successful, would open a whole new area of research.

Both rumen and esophageal samples are obtained contaminated with saliva. This makes some analyses such as for phosphorus somewhat difficult. Methods of accurately estimating saliva contamination or of sample collection without this contamination should be investigated and developed.

Under range conditions it is impractical to supplement often yet a sustained supply of nutrients may be necessary for optimum performance. The future should see satisfactory means of long-term supplementation with a minimum of handling of the livestock. For example, sustained released pellets are now being used to supply cobalt to sheep in deficient areas in Australia. A vitamin A supply for feedlot cattle sufficient for 90 days or more has been administered in one injection. These methods may be adapted for use in supplementation on our ranges. We are even now considering projects to develop nitrogen supplements containing biuret and other slowly soluble materials for a more sustained nitrogen supply to rumen microorganisms.

The symbiotic relationship between the microorganisms in the rumen and the host animal presents challenging problems. Perhaps we may be able to create an environment in the rumen which will permit a more rapid or more complete utilization of the polysaccharide energy present in range forage. Proper supplementation and even bacterial population manipulation with inoculation and antibiotics may improve the efficiency of rumen microorganisms in converting some of the indigestible fiber to human food.

Our increasing population continues to utilize more and more of our protein feeds such as soybean meal. At present, this valuable protein is being converted to substitute forms for meat, chicken, and milk. If we expect to continue eating beefsteak and lamb and drinking milk, we must find a more efficient way for ruminants to utilize poor range forage or corn stalks by utilizing nonprotein sources.

It has been shown that the amounts and proportions of volatile fatty acids can be altered in the rumen and that this alteration affects the effi-
ciency with which certain physiological functions occur. High levels of acetic acid promote increased heat production and milk-fat levels while an increase in propionic acid depresses milk-fat levels but improves efficiency of weight gain and protects against acetonemia. The manipulation of these factors could greatly improve the productivity of a given range.

Range cattle and sheep in the Intermountain region gain weight during the summer even though they are nursing a calf or lamb. In the winter they lose weight. The NRC nutrient requirements for these animals are based on farm conditions where they are fed to gain weight in the winter and lose weight in the summer. With the above thoughts in mind a separate set of nutrient requirements should be developed for range cattle and sheep.

The nutritionist cannot ignore the effects of environment on the animal, its nutrient requirements, and its diet. Our ranges have a varied, heterogeneous, rigorous environment. If we are to make good the nutrient deficiencies that may occur under these varied environmental conditions, then specific research must be conducted under controlled environments. For example, it has recently been shown that animals in a hot environment need higher levels of vitamin A. The effects of extremes of heat and cold, altitude, water supply, and other environmental factors should be studied and their relationship to the nutrition of the animal should be established.

Whether the world situation is viewed from the most pessimistic Malthusian or from the most optimistic affirmative standpoint, it is obvious that any improvement in the efficiency with which the vegetation of the Intermountain rangelands can be converted to food and fiber will be of value to society. The economic benefit can be partially estimated but the humanitarian and sociological benefits cannot. An arid region is not necessarily an unproductive region, it merely presents a greater challenge to human ingenuity. The nutritional scientists have met and are meeting that challenge.
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A basic objective of The Faculty Association of the Utah State University, in the words of its constitution, is:

to encourage intellectual growth and development of its members by sponsoring and arranging for the publication of two annual faculty research lectures in the fields, or (1) the biological and exact sciences, including engineering, called the Annual Faculty Honor Lecture in the Natural Sciences; and (2) the humanities and social sciences, including education and business administration, called the Annual Faculty Honor Lecture in the Humanities.

The administration of the University is sympathetic with these aims and shares the costs of publishing and distributing these lectures.

Lecturers are chosen by a standing committee of the Faculty Association. Among the factors considered by the committee in choosing lecturers are, in the words of the constitution:

(1) creative activity in the field of the proposed lecture; (2) publication of research through recognized channels in the field of the proposed lecture; (3) outstanding teaching over an extended period of years; (4) personal influence in developing the character of the students.

Dr. Harris was selected by the committee to deliver the Annual Faculty Honor Lecture in the Natural Sciences. On behalf of the members of the Association we are happy to present Doctor Harris' paper:

RANGE NUTRITION IN AN ARID REGION

Committee on Faculty Honor Lecture
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Sir, I am a true laborer: I earn that I eat, get that I wear, owe no man hate, envy no man's happiness, glad of other men's good, content with my harm, and the greatest of my pride is to see my ewes graze and my lambs suck.

Shakespeare — As You Like It