A Method for Measurement of Forage Intake of Grazing Livestock Using Microdigestion Techniques[1]

G. M. VAN DYNE[2] AND J. H. MEYER

Research Nutritionist and Professor, Animal Husbandry Department, University of California, Davis, California

Knowledge of quantitative forage intake by grazing animals is basic to range management. Forage intake is measured only with difficulty, and few data are available. Two recent monographs (Agricultural Board, 1962; Joint Committee, 1962) discuss measurement of digestibility of range forage, fecal output, and utilization (i.e., disappearance) of herbage. Measurement of range forage intake requires, however, a concomitant evaluation of forage digestibility and fecal output. Range herbage disappearance may be proportional to, but is greater than forage consumption by livestock because of herbage losses such as those due to weathering and trampling, and forage consumption by insects and rodents. A review of textbooks on range management, animal nutrition, and animal production reveals only one which gives estimates of quantitative forage intake by range livestock. Stoddart and Smith (1955) quote figures of daily range forage intake by cattle, but give no data on intake by sheep.

This article presents a new technique of determining forage intake based on in vitro or in vivo microdigestion of forages and compares this method to existing methods.

Review of Literature

An ideal method for determining forage intake by grazing animals would be 1) accurate and precise, 2) applicable to individual animals, 3) applicable to all types of forage, and 4) based on easily determined chemical components. It should not depend upon dry-lot digestion trials of harvested range herbages.

Ratio Techniques

Ratio techniques, depending upon the presence of an indigestible indicator in the forage, have been used in combination with total fecal collection to measure forage intake (Agricultural Board, 1962; Joint Committee, 1962). Lignin (Garrigus, 1934; Harris et al., 1952), chromogens (Cook and Harris, 1951), and silica (Smart et al., 1960) have been the most commonly used naturally occurring indicators in range studies.

Disadvantages of the lignin ratio procedure, according to Milford (1957), are 1) lignin is not a distinct chemical entity, 2) impurities may become attached to lignin during chemical analysis, 3) methods of lignin analysis are tedious and expensive, 4) selective grazing can introduce high errors in sampling of forage actually consumed, 5) lignin may be partially digestible, and 6) changes in chemical composition of lignin may occur in the digestive tract. Furthermore, moisture in forages and high drying temperature may induce a nonenzymatic browning reaction in which products of carbohydrate degradation condense with protein (MacDougall and DeLong, 1942; Van Soest, 1962). This leads to positively biased estimates of lignin content. Conner et al. (1963) indicated range forage samples collected by ruminal fistulated cattle had a positive bias due to a nonenzymatic browning reaction. Although there are many disadvantages to the lignin ratio procedure, it has remained the most widely used method in range investigations in the United States (Cook et al. 1954, 1961, and 1962).

Chromogen has been used as a naturally occurring indicator in range forages; however, it has been found unsatisfactory by Cook and Harris (1951) with plants high in ether extract and by Van Dyne (1960) because of low and variable levels in winter range forage. Silica is another naturally occurring indicator which has been used in digestibility trials and which could be used for estimating forage intake if an accurate estimate can be made of dietary silica content. Even slight soil contamination of herbage or fecal samples causes variable and invalid results with this indicator. With the use of esophageal fistulated animals (Van Dyne and Torell, 1964), however, the silica content of the forage plus soil contaminants consumed can be accurately estimated.

One shortcoming of these indicator techniques is that estimates of forage intake usually are based on amount and composition of feces of one group of animals and the dietary composition of another group. Thus, only one valid estimate of intake is available, and there is no measure of reliability. These techniques are advantageous because they do not require harvesting of range herbages for dry-lot digestion trials and they are applicable to both cattle and sheep.

[1] *Acknowledgment is expressed to H. F. Heady, G. P. Lofgreen, and W. C. Weir for their interest and suggestions in this work, which was supported in part by Regional Research Project W-34—Range Livestock Nutrition. Computational time was supported in part by N.I.H. Grant FR-00009.*

[2] *Present address: Radiation Ecology Section, Health Physics Division, Oak Ridge National Laboratory, Oak Ridge, Tennessee.*

Other Methods

Fecal nitrogen index. — The fecal nitrogen index procedure originated by Lancaster (1949) has been used to determine forage intake in grazing studies in New Zealand, Australia, Africa, and Great Britain. This procedure requires that herbage be cut and fed to animals in dry-lot digestion trials to develop equations to relate fecal nitrogen content to organic matter digestibility of the forage or to the ratio of organic matter in the forage to that in the feces (Arnold and Dudzinski, 1963).

The assumptions in this technique are that 1) the pasture herbage cut and fed to the animals is similar in composition to that selected by the grazing animal, and 2) the pen-fed and grazing animals digest the pasture material to the same extent. The principal advantage of the fecal index procedure is that a qualitative estimate of the diet of the grazing animal is not required. The difficulty with this procedure under most range conditions is the impracticability of obtaining enough representative herbage with which to conduct the dry-lot digestibility trials. Although the technique is applicable to both sheep and cattle, and may be used in all seasons, separate seasonal regression equations relating fecal nitrogen to the feed-to-feces ratio are required for high accuracy (Greenhalgh and Corbett, 1960). Furthermore, the fecal nitrogen index procedure gives estimates of forage intake for groups of animals rather than for individual animals.

Nitrogen balance.—Pasture intake by grazing sheep was calculated from nitrogen balance by Beeston and Hogan (1960). These workers reasoned that a mature wether, whose weight was not varying appreciably, stored nitrogen only in the wool; therefore, nitrogen intake would be equal to the amount in the urine, feces, and wool. This method has two requirements which limit usage. It requires 1) long-term studies to overcome variations in excretion rate and 2) an assumption of nitrogen content stored in the wool.

Metabolic fecal fraction.—Dry matter intake by grazing animals can be calculated from a metabolic fecal fraction, according to Owen (1961). He found a high direct correlation between dry matter intake and a fecal fraction which dissolves in O.2N HCl in 18 hr. This procedure, not thoroughly tested, is subject to the disadvantages inherent in fecal nitrogen index techniques.

Weight balance. — Allden (1962) used animal weight balance in a 1-hour period of grazing to estimate herbage intake of sheep harnessed for collection of feces and urine. Insensible weight loss was estimated from harnessed sheep not permitted to graze. Short-term measurements of forage intake are not applicable to range conditions where the grazing activity of an animal varies widely during the day.

In summary, the above methods do not meet all the requirements for determining forage intake of grazing animals. A new method for estimating forage intake is discussed below.

Methods

Relation between digestibility and intake.—In order to illustrate how intake can be based on microdigestion of forages, it is necessary to show the relationship between digestibility and intake. Further details are given by Van Dyne (1963b).

By definition, the dry matter digestion coefficient (D_{dm}) is:

$$D_{dm} = \frac{F-E}{F} \cdot 100 \qquad (1)$$

where F is the amount of forage consumed and E is the amount of feces produced. Because an indigestible indicator occurring in the forage is quantitatively recovered in the feces then:

$$D_{dm} = 100 - 100 \cdot \frac{I_F}{I_E} \qquad (2)$$

where I_F and I_E are the concentrations of the indicator in the forage and feces, respectively. If dry matter digestibility is known, forage intake can be calculated from total excretion and digestibility of dry matter:

$$F = \frac{100 \cdot E}{100 - D_{dm}} \qquad (3)$$

Similarly, digestibility of any nutrient (D_i) can be related to the quantity of forage and feces (F and E) and to the composition of the nutrient in the forage and feces (F_i and E_i):

$$D_i = 100 - 100 \cdot \frac{E \cdot E_i}{F \cdot F_i} \qquad (4)$$

Because the ratio of excreta to forage equals the ratio of indicator concentrations in forage and feces, the digestibility of any nutrient (D_i) may be obtained without total fecal collection:

$$D_i = 100 - 100 \cdot \frac{I_F}{I_E} \cdot \frac{E_i}{F_i} \qquad (5)$$

Application of this equation is difficult because it requires a naturally occurring indigestible indicator in the forage. It will be shown in the following section how a knowledge of microdigestion may be used in lieu of assumptions about indigestibility of naturally occurring indicators.

Microdigestion and intake. — Assuming a correlation between microdigestion (digestion of a small sample in part of the digestive tract) and macrodigestion (digestion of a large sample through the entire animal) of a given nutrient, the relationship of the nutrient in the forage to that in the feces may be shown by an equation analogous to (3). The microdigestion of cellulose (c) will be used for purposes of illustration.

The amount of forage grazed (F) is easily determined if the

amount of cellulose grazed ($F \cdot F_c$) is known. The amount of cellulose grazed may be calculated from the amount of cellulose excreted ($E \cdot E_c$) if an estimate of cellulose digestion (D_c) is available:

$$F = \frac{100 \cdot E \cdot E_c}{100 \cdot F_c - F_c \cdot D_c} \quad (6)$$

Prediction of macrodigestion from microdigestion. — Digestibility values determined by 48-hour microdigestion procedures are near, but not necessarily equal to, the macrodigestion of cellulose. Thus, there are two main ways of using digestibility estimates determined by micromethods to calculate forage intake: 1) assuming the microdigestion of cellulose equals macrodigestion and 2) adjusting the microdigestion estimate for differences between micro- and macrodigestion before using it to calculate forage intake.

If microdigestion and macrodigestion are assumed equal, then equation (6) is used directly to calculate forage intake. If microdigestion and macrodigestion are not assumed to be equal, then an adjustment is necessary.

In order to equate micro- and macrodigestion, one or more standard forage samples should be included in each microdigestion trial (Van Dyne, 1963a; Tilley and Terry, 1963). This permits adjustment of microdigestion estimates of range forages in terms of the standard:

$$\text{"Adjustment ratio"} = \left(\frac{\text{microdigestion of range forage}}{\text{microdigestion of standard}}\right)_{\text{when inocula were from grazing animals}} \quad (7)$$

This ratio is then multiplied by the microdigestion value for the standard sample when it was digested by inocula from animals fed the standard forage on dry-lot:

$$\text{"Adjusted microdigestion estimate"} = \text{"Adjustment ratio"} \times \left(\text{microdigestion of standard}\right)_{\text{when inocula were from animals fed standard forage}} \quad (8)$$

A regression equation is needed to interrelate macrodigestion values of the standard forage by conventional total collection procedures (Y) and microdigestion of the standard forage (X) when inocula were from animals fed the standard forage:

$$\text{Macrodigestion of standard} = a + b\left(\text{microdigestion of standard}\right)_{\text{when inocula were from animals fed standard forage}} \quad (9)$$

where a and b are the constants of a linear regression equation. The "adjusted microdigestion estimate" is used as the X value to calculate a "predicted macrodigestion estimate":

$$\text{"Predicted macrodigestion estimate"} = a + b\left(\text{"Adjusted microdigestion estimate"}\right) \quad (10)$$

In practice, these steps are combined into one equation to calculate the predicted macrodigestion estimate which is used with equation (6) to calculate forage intake.

Results and Discussion

Numerical Example and Application

To show the application of this procedure for determining forage intake, data are taken from an experiment conducted with cattle and sheep on a mixed annual grass-forb range in a scattered-oak woodland on the Hopland Field Station in Mendocino County in northern California (Van Dyne, 1963b). In midsummer, 1961, this dry annual range had about 1220 lb/acre total herbage available. Cellulose content was determined in samples of forage collected with five esophageal fistulated steers and seven esophageal fistulated sheep over a 5-day period. Total fecal output was collected from nine ruminal fistulated steers and nine ruminal fistulated sheep during a 7-day period following a 7-day preliminary period. Cellulose content was determined in these fecal samples. The ruminal fistulated animals also provided inocula for the microdigestion estimates of cellulose by nylon bag technique (in vivo) and by artificial rumen procedure (in vitro). Both microdigestion fermentations were of 48-hour duration. The same animals were fed alfalfa in a dry-lot digestion trial during which both macrodigestion and microdigestion were determined. The alfalfa was used as the standard forage sample for microdigestion in all periods. These data are given in the upper half of Table 1. Simple linear regression equations interrelating macrodigestion and microdigestion of cellulose under dry-lot conditions are footnoted in that table.

Predicted macrodigestion estimates were calculated with use of equations (7) through (10). An example of the calculations for sheep with artificial rumen technique follows:

$$\text{Predicted macrodigestion} = 59.6\% - 0.11\left(\frac{39.8\%}{52.5\%}\right) \bullet (58.8\%) = 53.5\%$$

This predicted estimate was used in equation (6) to predict forage intake:

$$\text{Predicted forage intake} = \frac{(37.35\%) \bullet (1.05 \text{ lb/24 hr}) \bullet (100)}{(100) \bullet (41.03\%) - (41.03\%) \bullet (53.5\%)} = 2.05 \text{ lb/24 hr}$$

A comparison is made of estimates of forage intake calculated by various procedures in Table 2. Lignin ratio estimates of forage intake are by the usual procedures (Agricultural Board, 1962). Forage and fecal lignin contents are footnoted in Table 2. Predicted macrodigestion estimates of forage intake are taken from and explained in Table 1. Microdigestion per se was used with equation (6) to calculate intake. Further and more detailed comparisons of estimates of intake are given by Van Dyne and Meyer (1964).

All estimates of forage intake calculated from microdigestion, adjusted or nonadjusted, were slightly greater for both sheep and cattle than were estimates of forage intake calculated from lignin ratio. In many instances there was little difference between the predicted macrodigestion estimate and the forage estimate determined from microdigestion per se. But in other instances, e.g., cattle by artificial rumen technique, there was ap-

Table 1. Example of calculation of forage intake from microdigestion data, forage and fecal composition, and fecal output.

Item	Units	Sheep	Cattle
	— — — Required information — — —		
Forage cellulose	% organic matter	41.03	42.64
Fecal cellulose	% organic matter	37.33	34.37
Fecal output	lb/24 hr, organic matter	1.05	6.66
Microdigestion of range forage, range diet			
Cellulose by nylon bag method	%	56.2	52.0
Cellulose by artificial rumen	%	54.8	61.4
Microdigestion of standard forage, range diet			
Cellulose by nylon bag method	%	58.8	56.3
Cellulose by artificial rumen	%	57.9	58.5
Microdigestion of standard, standard diet			
Cellulose by nylon bag method	%	61.8	59.9
Cellulose by artificial rumen	%	58.8	54.5
	— — — Calculated results — — —		
"Adjusted microdigestion" of range forage			
Cellulose by nylon bag method	%	59.1	55.3
Cellulose by artificial rumen	%	55.7	57.2
"Predicted macrodigestion" of range forage[1]			
Cellulose by nylon bag method	%	53.8	54.6
Cellulose by artificial rumen	%	53.5	53.3
Predicted forage intake			
from nylon bag data	lb/24 hr, organic matter	2.07	11.82
from artificial rumen	lb/24 hr, organic matter	2.05	11.50

[1]The regression equations used to predict macrodigestion (Y) of cellulose from microdigestion (X) were developed under dry-lot trials with the standard forage; they were, for nylon bag and artificial rumen technique respectively, Y=66.2–0.21X and Y=59.6–0.11X.

preciable difference between the nonadjusted and adjusted values.

These data are given primarily to show that estimates of forage intake calculated from microdigestion are within expected limits for forage intake by livestock on these dry annual ranges. The 24-hr shrunk weight of the sheep averaged about 98 lb and the shrunk weight of the cattle averaged about 710 lb during this sampling period. Thus, the average of estimates of forage intake, calculated from microdigestion of cellulose, were about 2.18 and 1.64 lb forage daily/cwt body weight, respectively, for sheep and cattle.

Critique of New Procedure

This procedure holds special promise for calculating the forage intake by individual animals. Estimates of forage composition, fecal output and composition, and microdigestion can be obtained individually from bifistulated animals (as illustrated by Van Dyne and Torell, 1964). Thus, forage intake estimates can be made on an individual rather than on a group basis, as is done usually in lignin ratio or fecal nitrogen index procedures.

Forage intake, calculated from microdigestion, is based on accurately analyzed constituents, such as cellulose in forage and feces. This procedure does not require assumptions about indigestibility of naturally occurring indicators and does not require harvesting of range forages for dry-lot digestion trials. The procedure is applicable to both cattle and sheep. It is useable on all types of ranges in all seasons, since microdigestion estimates may be obtained easily by nylon bag or artificial rumen technique under range conditions (Van Dyne, 1962 and 1963a).

Table 2. Comparison of estimates of daily forage intake calculated from lignin ratio, predicted macrodigestion, and microdigestion per se.

Technique	Sheep	Cattle
	lb. organic matter intake per head	
Lignin ratio[1]	1.83	11.24
Predicted macrodig.		
nylon bag	2.07	11.82
artificial rumen	2.05	11.50
Microdig. per se		
nylon bag	2.18	11.18
artificial rumen	2.16	13.91

[1]Sheep and cattle diets contained 13.7 and 14.1% lignin, respectively, on organic matter basis. Feces contained 23.9 and 23.8%, respectively.

Determining forage intake from microdigestion requires more effort than the chromogen or the lignin ratio techniques, but less effort than the fecal nitrogen index procedure. In comparison to the lignin ratio technique, the procedure is especially valuable under conditions wherein lignin may be partially digested, e.g., in immature forages or in browse by game animals (Smith et al., 1956). Similar to the lignin, chromogen, or silica ratio procedures, the new method requires an accurate sample of the forage grazed.

Summary and Conclusions

Existing methods for determining forage intake are reviewed with regard to their applicability under range conditions.

A new procedure for determining forage intake by grazing animals is described. This procedure involves: 1) determination of the digestion value of range forage and standard forage samples using micromethods with inocula from grazing animals; 2) prediction, by use of a regression equation, of macrodigestion from microdigestion of range forage,

adjusted to microdigestion of a standard sample; and 3) use of the predicted macrodigestion estimate, composition of range forage, and composition and amount of feces to calculate forage intake.

The new procedure, based on microdigestion, eliminates the necessity of assuming indigestibility of naturally occurring indicators, e.g., lignin or chromogens. The new procedure also obviates harvesting range herbages for dry-lot digestion trials, as is required in the fecal nitrogen index technique.

LITERATURE CITED

ALLDEN, W. G. 1962. Rate of herbage intake and grazing time in relation to herbage availability. Proc. Australian Soc. Animal Prod. 4:163-166.

AGRICULTURAL BOARD — NATL. ACAD. SCI., NATL. RES. COUNCIL, AND AMER. SOC. RANGE MANGT. 1962. Basic problems and techniques in range research. Natl. Res. Council Publ. 890. 341 pp.

ARNOLD, G. W. AND M. L. DUDZINSKI. 1963. The use of fecal nitrogen as an index for estimating for the consumption of herbage by grazing animals. Jour. Agr. Sci. 61:33-43.

BEESTON, J. W. U., AND J. P. HOGAN. 1960. The estimation of pasture intake by the grazing sheep. Proc. Australian Soc. Animal Prod. 3: 79-82.

CONNER, J. M., V. R. BOHMAN, A. L. LESPERANCE, AND F. E. KINSINGER. 1963. Nutritive evaluation of summer range forage with cattle. Jour. Animal Sci. 22:961-969.

COOK, C. W. AND L. E. HARRIS. 1951. A comparison of the lignin ratio technique and the chromogen method of determining digestibility and forage consumption of desert range plants by sheep. Jour. Animal Sci. 10:565-573.

COOK, C. W., J. E. MATTOX, AND L. E. HARRIS. 1961. Comparative daily consumption and digestibility of summer range forage by wet and dry ewes. Jour. Animal Sci. 20: 866-870.

COOK, C. W., L. A. STODDART, AND L. E. HARRIS. 1954. The nutritive value of winter range plants. Utah Agr. Exp. Sta. Bul. 372.

COOK, C. W., K. TAYLOR, AND L. E. HARRIS. 1962. The effect of range condition and intensity of grazing upon daily intake and nutritive value of the diet on desert ranges. Jour. Range Mangt. 15:1-6.

GARRIGUS, W. P. 1934. The forage consumption of grazing steers. Proc. Amer. Soc. Animal Prod. pp. 66-69.

GREENHALGH, J. F. D. AND J. L. CORBETT. 1960. The indirect estimation of the digestibility of pasture herbage: I. Nitrogen and chromogen as faecal index substances. Jour. Agr. Sci. 55:371-376.

HARRIS, L. E., C. W. COOK, AND L. A. STODDART. 1952. Range nutrition techniques. Jour. Animal Sci. 11: 181-190.

JOINT COMMITTEE — AMER. SOC. AGRON., AMER. DAIRY SCI. ASSOC., AMER. SOC. OF ANIMAL PROD., AND AMER. SOC. RANGE MANGT. 1962. Pasture and range research techniques. Comstock Publ. Assoc., Ithaca, New York. 242 pp.

LANCASTER, R. J. 1949. The measurement of feed intake by grazing cattle and sheep: I. A method of calculating the digestibility of pasture based on the nitrogen content of faeces derived from the pasture. New Zealand Jour. Sci. Tech. 36: 15-20.

MACDOUGALL, D. AND W. A. DELONG. 1942. Effect of initial drying temperature on the apparent lignin content of plant tissues. Canad. Jour. Res. (B) 20:40-48.

MILFORD, R. 1957. The usefulness of lignin as an index of forage consumed by ruminants. p. 79-85. *IN:* Ligninfication of plants in relation to ruminant nutrition. Proc. Symp. in Canberra, Australia. Div. Plant Ind. CSIRO. 108 pp.

OWEN, J. B. 1961. A new method of estimating the dry matter intake of grazing sheep from their faecal output. Nature 192(4797):92.

SMART, W. W. G., JR., G. MATRONE, W. O. SHEPHERD, R. H. HUGHES, AND F. E. KNOX. 1960. The study of the comparative composition and digestibility of cane forage (*Arundinaria* spp.). N. Car. Agr. Exp. Sta. Tech. Bul. 140.

SMITH, A. D., R. B. TURNER, AND G. HARRIS. 1956. The apparent digestibility of lignin by mule deer. Jour. Range Mangt. 9:142-145.

STODDART, L. A. AND A. D. SMITH. 1955. Range management. McGraw-Hill Book Co., Inc., New York. 2nd Ed. 433 pp.

TILLEY, J. M. A. AND R. A. TERRY. 1963. A two-stage technique for the *in vitro* digestion of forage crops. Jour. Brit. Grassland Soc. 18:104-111.

VAN DYNE, G. M. 1960. Range investigations. *IN:* Annual Prog. Rep. West. Reg. Res. Proj. W-34, Mont. Agr. Exp. Sta. pp. 9-60.

VAN DYNE, G. M. 1962. Micro-methods for nutritive evaluation of range forages. Jour. Range Mangt. 15:303-314.

VAN DYNE, G. M. 1963a. An artificial rumen system for range nutrition studies. Jour. Range Mangt. 16: 146-147.

VAN DYNE, G. M. 1963b. Forage intake and digestion by cattle and sheep on a common dry foothill annual range. Ph.D. Dissertation. Univ. Calif., Davis, 399 pp.

VAN DYNE, G. M. AND J. H. MEYER. 1964. Forage intake by cattle and sheep on dry annual range. Jour. Animal Sci. (manuscript submitted).

VAN DYNE, G. M. AND D. T. TORELL. 1964. Development and use of the esophageal fistula: a review. Jour. Range Mangt. 17:7-19.

VAN SOEST, P. J. 1962. The estimation of forage protein digestibility and determination of the effects of heat-drying upon forages by means of the nitrogen content of acid-detergent fiber. Agr. Res. Serv. Mimeo. 16 pp.