Forage Intake by Grazing Livestock: A Review

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Highlight: A wealth of experimental data has been accumulated on quantitative intake of pen-fed livestock; such information has been widely employed to develop a keener nutritional knowledge of such animals. Data of this type are, however, distressingly lacking for grazing livestock. The procedures used for measuring intake by animals under grazing conditions have often been disappointing, and many have provided unreliable data. Forage intake measurements with grazing livestock are more commonly expressed as g DM or OM/$W_{kg}^{.75}$ or simply as a percent of body weight. Most estimates of intake for cattle and sheep grazing ranges in Western United States fall within the range of 40 to 90 g DM/$W_{kg}^{.75}$ or from 1 to 2.8% of body weight. Intake usually decreases with advancing plant maturity.

Yield of animal products from grassland areas depends on a number of associated factors. To improve forage utilization, it is necessary to measure, or at least estimate, these components. One of the most important of these components is the quantity of forage consumed by grazing livestock. Consumption and digestibility of grazed forages has been an area of interest and challenge to nutritionists, but research in this area was somewhat neglected in the United States until increased grain prices and decreased feed grain availability caused a renewed concern in forage utilization. Two reasons for the necessity of more research on this subject might be that, first, higher producing animals are likely to be those consuming most, and second, that economic returns are often limited because voluntary intake by livestock may restrict the amount of grassland products that can be utilized.

The purpose of this review was to consider methods used in estimating and expressing intake levels of grazing livestock. Moreover, much of the existing data on intake measurements was consolidat. d and expressed on a common basis.

Ways of Expressing Levels of Intake

Traditionally, most investigators have expressed forage organic matter intake (OMI) or a dry matter intake (DMI) relative to body weight (Langlands 1968), as a percent of body weight (Van Dyne and Meyer 1964), or simply in pounds or kilograms per animal per day (Streeter et al. 1974). Since intake by grazing animals must vary with some function of body weight, perhaps a better criterion for expressing intake might be its relation to maintenance in order to adjust for differences among animals (Moore and Mott 1973), although this practice does not remove variations among animals of similar weight with true metabolic differences (Arnold 1975). When differences in live weight result from differences in age, breed, or previous level of nutrition, no single relationship may be generally applicable (Langlands 1968).

The expression of intake per unit of metabolic body weight, i.e., w_{kg}^{75} (MBW) does, however seem adequate for most situations. In plotting intake against body size, Crampton et al. (1960) and Blaxter et al. (1961) both found a better fit for data when weight was coverted to MBW. Other workers have differed in opinion. Langlands (1968) calculated an exponent of 0.82 for the relationship between OMI and body weight of sheep of different breeds varying in age from one to two years. He also found that, within a breed, intake was more closely related to age than to body weight (Langlands 1968). However, the same author later reported that the mean DMI of six and 66 month-old wethers was 633 and 987 grams, respectively; but when intake of both groups was expressed on the basis of MBW, the difference in intake became negligible, i.e., 70.3 and 70.1 g/MBW, respectively (Langlands 1969).

The above expression is not routinely used by researchers in the United States, but it appears that there is an international trend to express intake on a MBW basis, although slight differences do occur. Researchers in Europe (Blaxter 1962), Australia (Minson 1973), and Canada (Heaney et al. 1968) have expressed intake in terms of g/$w_{kg}^{.734}$, g/$W_{kg}^{.73}$, and g/$W_{kg}^{.75}$, respectively. Further consideration of these relationships has been given by Pfander (1970) and Waldo (1970).

Methods for Estimating Intake

No method has been devised by which intake of grazing livestock can be accurately quantified. Thus, some type of estimation is employed where these data are desired. The types of estimations currently used are generally referred to as "indirect techniques" and basically fall into two categories, i.e., ratio techniques and index procedures. Ratio techniques involve the calculation of digestibility and fecal output data through their ratio to an "indigestible" indicator or marker. Indicators may occur naturally in the forage (internal indicator) or may be administered in known amounts (external indicator). Internal indicators are more frequently used for estimating digestibility, while external indicators are used more in fecal output estimates. Once digestibility and fecal output data are established, intake may be calculated from the simple equation:

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organic matter intake = fecal organic matter output/% organic matter indigestibility. The same procedure is used for estimating dry matter intake although most workers prefer the use of organic matter because of the relatively high ash content in range and pasture forages. Index procedures generally relate level of intake or digestibility to some component in the feces through a regression equation. The most common fecal component used to date has been nitrogen (N). Since some measure of digestibility is often required to calculate intake by grazing animals, most studies of this type have dual objectives of estimating both digestibility and intake.

Monographs detailing advantages and disadvantages of different methods utilized to arrive at estimates of fecal production, forage digestibility, and/or intake are those by Streeter (1969) and Theurer (1970). A thorough review on the properties, evaluation, and application of external and internal indicators was carried out by Kotb and Luckey (1972). Schneider et al.(1955) discussed the disadvantages of estimating intake by using agronomic measurements such as forage yield before and after grazing. Where this approach has been used, problems associated with trampling, variable forage growth, selective grazing and number of plots needed have usually been sufficient to cause somewhat questionable results. Likewise, lack of precision has seriously restricted the use of many other techniques intended to relate intake to other animal or forage characteristics, e.g., animal performance (Davis et al. 1970), number of mastications (Bjugstad et al. 1970), water consumption (Hyder et al. 1968), and fecal-excreted compounds such as iron, copper, magnesium, and silica (McManus et al. 1967).

The chromogen method as proposed by Reid et al. (1950) has been investigated by several workers using hand-fed cattle, but its application with grazing animals appears dubious because of large daily variations of plant chromogen concentration in feces (Reid and Kennedy 1956) and in chromogen recovery (Kennedy et al. 1959).

Lignin Ratio Technique

The lignin ratio technique has been widely used by American workers to estimate digestibility by grazing cattle and sheep (Wallace and Van Dyne 1970), in spite of many serious imperfections in the procedure (Van Dyne 1969). Sometimes it has been less reliable than the chromogen-ratio (Connor et al. 1963; Ridley et al. 1963). Occasionally, lignin has given reasonable estimates, but more frequently there have been strong indications that it yields seriously biased results (Handl and Rittenhouse 1972; Scales et al. 1974).

Analytical procedures used for determining lignin are cumbersome and complex, but one of their most negative features was shown by Wallace and Van Dyne (1970). After reviewing the apparent digestibility of lignin in various forages by different classes of animals using different analytical methods, they concluded that lignin may be digested to a large extent, particularly in immature forages.

More reliable methods for estimating digestibility under range conditions are probably the fecal nitrogen index, or a combination of in vitro techniques for estimating forage digestibility in diets selected by esophageal-fistulated animals, with either the total fecal collection method or the chromic oxide ratio for estimating fecal output (Scales et al. 1974; Lake et al. 1974; Arnold 1975).

Fecal Nitrogen Index Procedure

This method was developed partly as an alternative to methods that required sampling of forage consumed to determine digestibility. Greatest use of the method has been on improved pastures. Detailed reviews of the fecal N method have been carried out be Arnold and Dudzinski (1963), O'Donovan et al. (1967), and Streeter (1969). Van Dyne and Meyer (1964) and Langlands (1969) described different ways this technique can be used. Sources of error in fecal N regression techniques have been discussed by Greenhalgh and Corbett (1960) and Lambourne and Reardon (1963).

The foundations for this method are that fecal N is primarily of body origin and that metabolic fecal N is excreted in proportion to the quantity of dry matter consumed or digested (Blaxter and Mitchell 1948). Observations made in England (Raymond 1948) and New Zealand (Lancaster 1949) showed a positive relationship between digestibility of forage and N concentration in the feces of grazing livestock. Later, both workers developed regression equations from feeding trials which could be used to estimate digestibility by grazing animals (Lancaster 1954; Raymond et al. 1954). Wallace and Van Dyne (1970) enumerated a series of problems encountered in transposing results from conventional digestion trials to freely grazing animals, giving a simplified, hypothetical example of how the fecal N method is utilized for estimating digestibility.

Investigators following the original findings of Lancaster (1949; 1954) who were also studying intake found some application of the fecal N index approach. In the latter case, however, total fecal N excretion (rather than N concentration) and/or a feed-to-feces ratio factor (I/F) were necessary (Lancaster 1954). In these instances, total fecal collections or their estimation was required.

Errors associated with regression equations found in several studies have indicated that their application could be limited to cases where very large differences in intake or digestibility exist. Different trials have consistently shown coefficients of variability ranging from 13% (Jeffery 1971) to 9% (Lancaster 1954). Minson and Raymond (1958) regarded an error of 12% as being so large that the technique becomes useless except to measure very large differences in intake. Yet, relationships between I/F and N have been used widely (Table 1). Explorations of multiple regressions using fecal output (F), nitrogen concentration (N), and their product (FN), as independent variables, have produced relationships of different forms (e.g., quadratic, inverse, logarithmic), which have generally yielded better results than those adapting a simple form, i.e., $I=a+b\ FN$. Lambourne and Reardon (1963), working with a wide range of fresh pastures covering all seasons, obtained a curvilinear regression equation that explained variation in intake more precisely than simple linear regression equations calculated for pastures that had been divided according to season (Table 1). Likewise, using data from 35 conventional digestion trials with sheep, Arnold and Dudzinski (1963) found that results could be grouped homogeneously due to botanical or seasonal differences. Specific groups provided highly significant linear equations of the forms $I = b\ F + c\ FN$, and $I = a + b\ FN$. A quadratic expression ($I = b\ F + c\ FN + d\ FN^2$) accommodated a majority of the data but was less precise than simpler forms. A further expression: $I = a + b\ FN^2 + c\ N$, although far from being universally adequate, was generally more precise than existing formulae (Arnold and Dudzinski 1963).

It should be noted that a practical limitation of the method for determining intake might be the requirement of a total fecal collection by grazing animals, or its estimation from an external

Table 1. Observations on the use of regression analysis to predict intake from fecal nitrogen with grazing animals.

Reference	Location	Animal	Type of pasture	Regression equation[a]	$S_{y.x}$ [b]
Lancaster, 1954	New Zealand	Cows	Mixed improved pastures (general)	Y=1.02+0.97N	0.39
Vercoe et al., 1961	Australia	Sheep	Improved pastures (general)	Y=0.98+0.86N	0.22
Vercoe et al., 1962	Australia	Sheep	Improved pastures (spring)	Y=1.34+0.72N	0.85
Vercoe et al., 1962	Australia	Sheep	Improved pastures (summer)	Y=1.24+0.61N	0.70
Vercoe et al., 1962	Australia	Sheep	Improved pastures (autumn)	Y=0.84+0.79N	1.07
Vercoe et al., 1962	Australia	Sheep	Improved pastures (winter)	Y=1.67+0.12N	0.92
Elliott & Fokkema, 1961	Rhodesia	Cows	Veld grassland (general)	Y=0.48+1.04N	c
Greenhalgh & Corbett, 1960	Scotland	Steers	Grasses, first growth	Y=1/(0.55−0.11N)	c
Kennedy et al., 1959	New Zealand	Cows	Improved pastures (general)	Y=−1.74+10.6 log N	0.32
Holmes et al., 1961	England	Sheep	Late ryegrass	Y=1/(0.56−0.13N)	c
Minson & Kemp, 1961	England	Sheep	November grass swand	Y=1/(0.73−0.12N)	c
Lambourne & Reardon, 1962	Australia	Sheep	Fresh pasture (entire plants)	Y=0.21+1.37N	c
Lambourne & Reardon, 1963	Australia	Sheep	Fresh pasture (all seasons)	$Y=3.66-1.39N+0.36N^2$	0.55
Lambourne & Reardon, 1963	Australia	Sheep	Fresh pasture (summer)	Y=0.83+0.88N	0.58
Lambourne & Reardon, 1963	Australia	Sheep	Fresh pasture (winter)	Y=0.12+0.86N	0.42
Arnold & Dudzinski, 1963	Australia	Cattle	Improved pastures (general) from Greenhalgh et al., 1960	$I=17.2+0.2FN+0.2FN^2-3.8N$	c
Arnold & Dudzinski, 1963	Australia	Cattle	Improved pastures (spring and summer)	$I=11.7+1.5F-1.3FN+0.4FN^2+2.7N-1.0N^2$	c
Hutton & Jury, 1964	New Zealand	Cows	Fresh pastures (general)	Y=1.35N	0.43
Arnold & Dudzinski, 1967[b]	Australia	Sheep	Improved pastures (general) from Arnold & Dudzinski, 1963	I=63.0+106.0FN	64 g
Minson & Milford, 1967	Australia	Sheep	Rhodes grass, cv. Callide	Y=6.8+179.8N	1.60
Minson & Milford, 1967	Australia	Sheep	Rhodes grass, cv. Sanford	Y=2.2+171.6N	1.40
Jeffery, 1971	Australia	Sheep	Kikuyu pastures	$I=-37.0+170.0FN-0.45F^2$	112 g
Jeffery, 1971	Australia	Sheep	Kikuyu + N fertilizer	$I=109.0+170.0FN-0.45FN^2$	112 g
Rao et al., 1973	Kansas	Steers	Bluestem pastures	I=1.13+1.75FN	c
Moran, 1976	Australia	Cattle (Zebu & Hereford)	Improved pastures (general)	$Y=2.04-0.19N^2$	c

[a] Y is feed-to-feces ratio; N=nitrogen; I=intake; F=fecal output.
[b] Standard errors given in percentage units.
[c] Data not available.

indicator. While problems observed in using bagged animals for fecal collections on open range are reviewed later, it should be pointed out that, perhaps due to its many limitations, the fecal N method is better suited for digestibility than for intake estimates (Cordova 1977). In studies with cattle grazing sandhill ranges in Colorado, fecal N was an exceptionally valid estimator of digestibility, e.g., as much as 93% of the variation in in vivo digestibility was explained by differences in fecal nitrogen (Wallace and Van Dyne 1970; Scales et al. 1974).

Total Fecal Collection.

This is the oldest method for determining intake and/or digestibility of forages by livestock, and it is commonly referred to as the "conventional" or "standard" method (Schneider et al. 1995). Under controlled conditions it involves complete records of feedstuffs consumed and total collection of feces voided to determine digestibility. When used under grazing situations the method may be inversed for estimating intake. Intake is estimated by combining determinations of digestibility of pastures grazed by animals with measurements of fecal output. Digestibility may be estimated in vitro from samples collected by esophageal-fistulated animals, or by using the fecal N method if a suitable regression equation is available (Arnold and Dudzinski 1963).

The part of the method concerning total fecal collection is supposedly most problematic, although measurements of total fecal output under grazing conditions have been carried out extensively, particularly in western United States, e.g., Lesperance and Bohman (1961) and Connor et al. (1963) in Nevada; Van Dyne and Meyer (1964) and Wilson et al. (1974) in California; Handl and Rittenhouse (1972) and Kartchner (1975) in Oregon; Jefferies and Rice (1969) in Wyoming; Scales (1972) in Colorado; Rittenhouse et al. (1970) and Lake et al. (1974) in Nebraska; Erwin et al. (1959) in Arizona; and Cordova (1977) in New Mexico. Fecal collections with grazing animals in other geographical areas have been carried out by Holmes et al. (1961) and Minson and Kemp (1961) in England; Lancaster (1954) and Kennedy et al. (1959) in New Zealand; Arnold et al. (1964), Donelly et al. (1974), and Moran (1976) in Australia; Elliot and Fokkema (1961) in Rhodesia; and Oyenuga and Olubajo (1975) in Nigeria.

Since much time and care is spent collecting feces, the method is generally regarded as expensive, time consuming, and impractical under some situations (Corbett 1960; Brisson 1960). In a somewhat subjective way, Kartchner (1975) estimated that about 70 man-hours of field work were needed to obtain each individual fecal output measurement. This did not include preliminary preparations or sample conditioning for analysis. This figure seems high, but is logical if all details of the method are considered. Besides constant changing, weighing, and cleaning of fecal bags, other problems frequently arise. e.g., supervision and rearranging of harnesses to prevent fecal loss (Van Dyne 1969).

A negative feature related to fecal collection apparatus is its possible adverse effect on animal physiology. Such equipment has reportedly caused reductions in live weight gains, although herbage intake and digestibility were not affected (Hutchinson 1956). Brisson (1960) reported that this method precluded studies over long periods, but that statement has been contradicted by many grazing and "conventional" digestion trials in which animals have been bagged for long durations. Greenhalgh et al. (1960) bagged steers for at least 50 days and indicated they showed no discomfort, and Raymond et al. (1953) bagged sheep for 150 days with no adverse effects. Lesperance and Bohman (1961) found no problems with fecal and urine collection apparatus used under a variety of conditions in Nevada, which included 32 collections in drylot, 32 collections on improved pastures, and 17 collections on semi-desert, sagebrush ranges.

Price et al. (1964) and Phar et al. (1971) found no significant differences in individual feed consumption, nor body weight gains, between bagged and nonbagged animals. In the 1971 study, with confined 2-year-old steers, collections were made continuously for 6 days with DMI being 12.9 and 13.8 kg for the bagged and "intact" animals, respectively. Likewise, other studies have reported that harnesses did not interfere with growth and normal behavior during either indoor or field experiments. Ingleton (1971) harnessed lambs at 1 or 2 days of age until they were 6 months old and found harnessing did not interfere with normal growth in the early stages when the greatest effect might have been expected.

In view of objections raised against other methods for estimating fecal output, and eventually intake, it may be concluded that total collection may still be the procedure of choice under many situations, in spite of its relatively arduous and time consuming disadvantages.

Animal Variability and Numbers Required for Sampling

One of the major factors affecting precision of intake measurements is its high individual variability, even when expressed in metabolic units (Van Dyne and Meyer 1964; Minson and Milford 1968). The average between-animal coefficient of variation (CV) of intake by sheep has generally ranged between 10 and 16% (Blaxter et al. 1961; Minson et al 1964; Heaney et al. 1968). Almost no data are available regarding intake variability in cattle, but sheep are reportedly three to four times more variable than cattle (Van Dyne and Meyer 1964).

A direct consequence of the high variability associated with intake measurements is that, to evaluate pastures or forages, large numbers of animals must be used to detect significant differences between treatments. This was illustrated by Heaney et al. (1968) using data involving 2,427 individual sheep/period measurements which showed high individual variability, with an average CV of 16% and a mean standard deviation (SD) of 9.7 intake-units. The latter data agree closely with those obtained in other experiments. Crampton et al. (1960) and Blaxter et al. (1961) both reported a CV of 13% when three forages of varying quality were fed to five sheep. Minson et al. (1964) found a lower CV (10.5%) when several pure grass swards cut at several stages of maturity were fed to sheep. Deviations from these general averages appear in data given by Pfander (1970), who showed data with a CV of 26% for the intake of 14 forage diets, and by Butterworth (1965), who found a CV of about 7%

Several workers have shown that more animals are required for studying intake than are needed for other parameters. Obioha et al. (1970) and Lake and Clanton (1972) have shown that about three animals using 3 to 5 days of sampling would be enough for estimating forage nitrogen and digestibility. Scales (1972), however, showed that about 51, 15, and 7 steers would be needed to estimate intake within 5, 10 and 15% of a mean difference at a significant level ($P < .05$). Based on an average daily intake over 25 days for sheep and 9 days for cattle, Van Dyne and Meyer (1964) reported that about 16 sheep and two cattle would estimate intake in drylot within 10% of the mean and 90% confidence; but under grazing conditions about 26 sheep and eight steers would be needed to estimate intake with the same accuracy.

A similar phenomenon has been observed when measuring fecal output, since intake may be estimated from the ratio: fecal weight/indigestibility. Variation in intake measurements may result from differences in (1) dietary composition, (2) excretion rate, and (3) fecal composition (Van Dyne 1969). Generally there is little difference in dietary chemical composition from day to day within short periods under range conditions (Van Dyne and Heady 1965), and digestibility of intake is relatively uniform (Van Dyne 1969). Thus, variations in excretion rate and fecal composition become especially important in assessing estimates of intake under range conditions. If chemical composition of output is assumed constant, then variation in excretion rate may be considered as the main determinant of errors (Blaxter et al. 1956). Besides analytical and sampling errors, other errors caused by irregularity in excretion rate are inversely proportional to length of fecal collection period. These errors decrease rapidly as the period is lengthened (Blaxter et al. 1956).

Based on a 7-day preliminary period followed by 7 days of collection, Van Dyne (1969) considered about five steers per treatment necessary to estimate fecal output within 10% of the mean with 95% confidence. Scales (1972), sampling with six steers for six consecutive days, concluded that a minimum of six steers was required to estimate fecal excretion within 15% of the mean. Clanton (1961) found that the number of days needed to provide minimal variation in total fecal collection was about six or seven. Based on this review, more attention should be given to measurements of intake by using and combining new and different approaches, because cost and animal management problems usually make large numbers of animals impractical.

Intake Levels Measured in Grazing Livestock

According to Moore and Mott (1973), most intake trials measure differences in "relative consumption potential" (Welch and Smith 1969), or "potential intake" (Monson et al. 1972), but do not give absolute intake values. Therefore, intake values are not absolute but only indicative of relative differences in potential intake, and these differences perhaps have significance for forages only within a given experiment.

Crampton et al. (1960) suggested that a daily consumption of 80 g DM/MBW should be the intake of a "standard forage" by sheep. A comparable level in organic matter would be about 74 g OM/MBW when forage contains 8% ash (Moore and Mott 1973). In reviewing published intake data on 137 tropical forages by sheep, Jeffery and Holder (1971) concluded that the upper boundary for daily intake was about 83 g DM/MBW. Moore and Mott (1973) selected sheep intake data from hand-feeding experiments to illustrate maximum intake values as well as ranges (listing 29 examples for temperate grasses and 35 for tropical pastures). They showed that temperate grasses were consumed at levels between 30 and 94 g DM/MBW, with measurements frequently at 80 g DM/MBW or above. Tropical grasses had similar ranges (22 to 98) but levels of intake were

Table 2. Ranges in daily voluntary forage intake by grazing animals, expressed in grams per unit of metabolic body weight (MBW).

Reference	Location	Type of animal	Type of pasture	Intake (animal/day) originally expressed	grams/MBW	Basis of measure[a]
			Dry matter intake			
Cook & Harris, 1951	Utah	Sheep	Winter desert range	2.2 - 3.4 lb/100 lb	57.1- 88.2	LR/TC
Fels et al., 1959	Australia	Sheep		1.4 lb/100 lb	36.3	
Elliott & Fokkema, 1961	Rhodesia	Africander cows	Summer veld grassland	1.5 - 1.9 lb/100 lb	38.9-49.3	LR/TC
Holmes et al., 1961	England	Cattle	Ryegrass-clover pastures	1.8 lb/100 lb	46.7	FN
Pearce & Vercoe, 1961	Australia	Sheep	Mature *Lolium rigidum*	1.7 lb/100 lb	44.1	FN
Cook et al., 1962	Utah	Sheep	Poor and good desert ranges	2.53-3.21 lb	65.7-83.3	LR
Connor et al., 1963	N. Nevada	Hereford steers	Sagebrush-grass range	8.4-10.4 lb	69.4-85.9	CR/TC
Connor et al., 1963	S. Nevada	Hereford steers	Desert shrub range	5.1 - 9.0 lb	42.1-74.4	CR/TC
Van Dyne & Meyer, 1964[b]	California	Sheep	Dry annual summer range	1.7 - 2.2 lb	43.5-58.0	LR/TC
Van Dyne & Meyer, 1964	California	2-yr steers	Dry annual summer range	10.6-13.1 lb	64.0-78.2	LR/TC
Streeter et al., 1968	Nebraska	Hereford steers	Sandhill range (1964)	1.8 - 2.5 lb/100 lb	48.0-64.9	LR/CrO
Streeter et al., 1968	Nebraska	Hereford steers	Sandhill range (1965)	1.4-1.7 lb/100 lb	37.6-44.1	LR/CrO
Smith et al., 1968	S. Nevada	Mature steers	Desert shrub range	5.3-10.2 kg	46.7-89.8	LR/CrO
Hyder et al., 1968	Colorado	Hereford steers	Summer blue grama range	16.5-33.5 lb	135.6-204.2	Water/int.
Jefferies & Rice, 1969	Wyoming	Hereford steers	Shortgrass range (1966)	1.7-2.8 kg/100 kg	53.8-88.5	IVDMD/TC
Jefferies & Rice, 1969	Wyoming	Hereford steers	Shortgrass range (1967)	1.9 - 2.4 kg/100 kg	60.1-75.9	IVDMD/TC
Rittenhouse et al., 1970	Nebraska	330-kg heifers	Winter sandhill range	50.0-58.0 g/MBW	50.0-58.0	LR/TC
Handl & Rittenhouse, 1972	Oregon	275-kg steers	Crested wheatgrass pasture	5.4-7.2 kg	80.0-108.1	IVDMD/TC
Scales, 1972	Colorado	Hereford steers	Sandhill range (May to Nov)	2.9-6.1 kg	41.3-86.6	IVDMD/TC
Streeter et al., 1974	Colorado	Mature Hereford cows	Native meadow forage	9.5-11.8 kg	97 -121[c]	IVCWC/CrO
Lake et al., 1974	Nebraska	Yearling steers	Irrigated pastures	7.97 kg	116.1	IVDMD/TC
Orcasberro, 1974	New Mexico	Sheep	Irrigated alfalfa	1.0 lb/100 lb	26.0	LR/TC
Kartchner, 1975	Oregon	Lactating cows	Crested wheatgrass pasture	8.2-17.9 kg	75 -145[c]	IVDMD/TC
			Organic matter intake			
Arnold et al., 1964	Australia	Sheep	Perennial and annual pastures (diff. stocking rates)	0.62-1.42 kg	39.7-78.3	FN/TC
Arnold & Dudzinski, 1967	Australia	Ewes (diff. physiol. status)	*Phalaris* and *Trifolium* pastures	0.87--1.96 kg	48.5-109.2	VN/CrO
Hills, 1968	New Mexico	Hereford and Sta. Gertrudis cows	Semidesert grassland	7.2-14.5 kg	75.4-151.1	LR/CrO
Scales, 1972	Colorado	Hereford steers	Sandhill range	36.7-75.7 g/MBW	36.7-75.7	IVOMD/TC
Langlands & Bowles, 1974	Australia	Sheep	Native pastures	0.95-1.25 kg	63.3-78.6	IVOMD/CrO
Donnely et al., 1974	Australia	3-yr sheep (33 kg)	*Trifolium* pastures	0.65-0.92 kg	49.8-70.5	IVOMD/TC
Oyenuga & Olubajo, 1975	Nigeria	260-kg steers	Tropical-pasture mixtures	4.44-8.18 kg	82.3-95.2	FN/Cro
			Digestible organic matter intake			
Langlands, 1968	Australia	Sheep (different ages and breeds)	Improved pastures	0.62-1.11 kg	39.3-52.4	FN/CrO
Wilson et al., 1971	California	Sheep	Native annual grassland	0.93-1.10 kg	53.2-62.9[c]	IVCWC/TC
Wilson et al., 1971	California	Sheep	Improved annual and native grasses	0.74-1.04 kg	42.3-59.5[c]	IVCWC/TC
Scales, 1972	Colorado	Hereford steers	Sandhill blue grama range	23.1-46.2 g/MBW	23.1-46.2	IVOMD/TC
Langlands & Bowles, 1974	Australia	Sheep	Native pastures	0.50-0.70 kg	31.4-46.7	IVOMD/CrO
Young & Newton, 1974	England	Lactating sheep (diff. breeds)	Perennial ryegrass	0.50-2.12 kg	24.3- 94.5	IVOMD/CrO
Oyenuga & Olubajo, 1975	Nigeria	260-kg steers	Tropical-pasture mixtures	2.85-5.54 kg	52.3-64.5	FN/CrO
Arnold, 1975	Australia	Sheep (diff. breeds)	*Phalaris* and *Trifolium* pastures	0.60-0.98 kg	34.3-56.1	FN/TC
Bishop et al., 1975	Argentina	2-yr-old wethers	Semiarid sandhill grassland	6.7-13.2 g/kg W	17.5-34.7	IVOMD/TC
Moran, 1976	Australia	Brahman cattle	Improved pastures	1.95-5.80 kg	31.2-83.2	FN/CrO
Moran, 1976	Australia	Hereford cattle	Improved pastures	2.40-6.80 kg	42.7-101.7	FN/CrO

[a] LR=lignin ratio; TC=total collection; FN=fecal nitrogen; Cr=chromogen ratio; CrO=chromic oxide ratio; IVDMD or IVOMD=in vitro digestibility; CWC=cell wall constituents.
[b] Van Dyne and Meyer (1964) also used silica and cellulose microdigestion for estimating intake.
[c] Approximated values because no body weights are given.

above 80 g DM/MBW less frequently than those for temperate grasses (Moore and Mott 1973). Intake values for 14 forage diets selected by Pfander (1970) agree closely with the former reports as he obtained a range between 51 and 119, with a mean OMI of 75.9 g/MBW.

Compared to hand-fed forages, intake data for grazing animals is quite limited (Table 2). Since intake values were expressed in varying terminology, particularly those by American workers, an effort was made to convert them to metabolic units. Recognition is made that intake was not always expressed as a function of body weight probably because different physiological status of animals within a given experiement produced no meaningful relationships between intake and body size (Young and Newton 1974; Arnold 1975).

Most intake estimates for grazing livestock appear to vary more with techniques used and researchers involved than with forages and environmental conditions tested. Dry matter intake by cattle grazing sandhill pastures in Nebraska during 1964 ranged from 48 to 65 g/MBW, whereas in 1965, a year of higher precipitation, DMI varied from 37 to 44 g/MBW (Streeter et al. 1968). The lower intake in 1965 was attributed to increased moisture content of forage consumed; however, according to Lake et al. (1974), the amount of water ingested with grasses does not affect intake. Rittenhouse et al. (1970) reported intake values ranging from 50 to 58 g/MBW for winter pastures in the same location. Using similar pastures in Colorado, Scales (1972) found an average DMI by cattle of 63 g/MBW and a range of 41 to 87 g/MBW, although the lowest value was estimated during November, while the lowest values reported by Streeter et al. (1968) were in June and August, for 1964 and 1965, respectively. Since Rittenhouse et al. (1970) and Streeter al. (1968) used the lignin-ratio method for estimating digestibility, the technique may have worked differently on pastures at different stages of maturity. Wallace and Van Dyne (1970) demonstrated that lignin digestibility varies with types of pasture and degree of plant maturity, whereas others have shown both erratic and unrealistic digestibility values when the lignin-ratio technique has been used on forages containing 5% or less lignin (Scales et al. 1974).

Cattle grazing Western United States ranges usually consume quantities of forage dry matter ranging from 1 to 3% of body weight (Table 2). Some actual values were 0.9 to 2.2% in Nevada (Connor et al. 1963); 1.4 to 2.6% in Nebraska (Rittenhouse et al. 1970; Lake et al. 1974); 1.0 to 2.4% in Colorado (Scales 1972); 1.6 to 3.6% in Oregon (Handl and Rittenhouse 1972; Kartchner 1975); and 1.7 to 2.8% in Wyoming (Jefferies and Rice 1969). A high estimation of intake was reported by Hyder et al. (1968), using the water-intake method to calculate forage intake ranging from 16.5 to 33.5 lb/day for 463- to 690-lb yearling Hereford steers, respectively. This represents an intake figure ranging from 7.5 to 15.2 kg DM/day, which is 3.6 to 4.9% of body weight, or 135 to 204 g/DM/MBW.

Intake estimates for grazing cattle in the United States are comparable to those of Elliot and Fokkema (1961), who found Africander and Mashona cows grazed, respectively, 1.9 and 1.5% body weight from summer Veld grassland in Rhodesia. Oyenuga and Olubajo (1975) found intakes of 2.3% in 1967 and 2.5% in 1968 for tropical pasture mixtures in Nigeria; whereas, Holmes et al. (1961) estimated DMI by cows to be about 1.8% on pastures in England.

Effect of Plant Maturity

In general, both intake and digestibility of a given plant species decline with advancing maturity. It is possible, however that a good correlation between intake and digestibility as plants mature may be coincidental rather than a cause-and-effect relationship. Moore and Mott (1973) prepared an extensive list of comparisons between intake and digestibility and showed that within species, correlation coefficients of 0.9 or better were observed only by Minson (1972). In most other cases, correlation coefficients were too low to suggest that digestibility per se is the only or even the primary factor controlling forage intake.

Variation of forage intake with increasing maturity is probably highly species-oriented. In most cases intake decreases with plant growth, but rate of decline has not been consistent. Furthermore, with some plant species, intake remained fairly constant over a considerable period, e.g., Milford and Minson (1968) noticed that intake of Rhodes grass remained constant up to 170 days. Similarly, DMI of *Phaseolus atropurpureus* var. *Siratro* remained at a very high level up to 260 days, at which stage the foliage was completely dead (Milford and Minson 1965). Heaney et al. (1966) found that S-50 timothy had a constant intake over a wide range of maturity. However, it should be noted that all these data were obtained from indoor feeding experiments and may not necessarily be applicable to grazing conditions.

Limited data have been published regarding changes in DMI with advancing maturity under grazing conditions. There is, however, considerable evidence that intake decreases as the grazing season progresses. Only in one of nine experiments reviewed, i.e., Streeter et al. (1968), were irregular patterns in forage consumption found which could not be explained in terms of plant maturity. In most other trials, intake reached a peak with the new growth, after the rainy season started, and declined thereafter. More detailed observations on changes in forage intake with advancing maturity are listed in Table 3.

Effect of Nitrogen Fertilization

Evidence for the influence of fertilization on forage intak ruminants is meager. Mahoney and Poulton (1962) observed no differences in intake by sheep of timothy fertilized at 45 or at 134 kg of N/ha. Holmes and Lang (1963) found that intake by steers was the same on grass fertilized with either high or low levels of nitrogen. Reid and Jung (1965) noted that fertilization of tall fescue had no effect on DMI by sheep and later Reid et al. (1966) reported that neither level nor source of N fertilizer had a significant effect on level of orchardgrass intake by sheep. On the other hand, Odhuba et al. (1965) noted a significant increase in the intake by sheep grazing tall fescue fertilized with high levels of N. Similar results were found by Kelsey et al. (1973) with sheep fed blue grama hay. Higher responses to N fertilization have been found in topical pastures, where intake was increased as much as 78% (Minson 1973). The most likely reason for this difference in response was the low levels of less than 1% N in control diets.

Summary

Present methods for estimating intake by grazing livestock lack precision and are often tedious, expensive, and time consuming. In this respect, some techniques may be superior to others, but many appear to yield results which may be seriously biased. The modern use of multiple regression analysis and computational capabilities for obtaining prediction equations may increase the possibility of obtaining more precise estimates of forage intake. However, such predictive functions cannot be

Table 3. Changes in forage intake with advancing maturity in pastures grazed by esophageal-fistulated animals.

Reference	Location	Vegetation type	Sampling dates	Daily intake	Units/day	Basis of measure[a]
Connor et al., 1963	Nevada (N)	Sagebrush-grassland	Jun, Jul, Aug 1960	4.7 3.8 3.9	kg DM	CR/TC 1
Connor et al., 1963	Nevada (S)	Desert shrub range	Jul, Aug, Sep 1960	3.3 4.1 2.3	kg DM	CR/TC 1
Van Dyne and Myer, 1964	California	Annual dry foothill	Jul, Aug, Sep 1961	6.2 5.8 6.1	kg DM	NB/TC 1
Van Dyne and Meyer, 1964	California	Annual dry foothill	Jul, Aug, Sep 1961	0.9 1.0 0.9	kg DM	NB/TC 3
Streeter et al., 1968	Nebraska	Sandhill native range	6/9, 6/21, 7/3 7/21, 8/11, 9/11, 1964	1.9 1.8 1.9 2.1 2.2 2.5	kg DM/ 100 kg	LR/CrO 1
Streeter et al., 1968	Nebraska	Sandhill native range	6/9, 6/22, 7/8 7/28, 8/24, 1965	1.5 1.6 1.7 1.6 1.7	kg DM/ 100 kg	LR/CrO 1
Wilson et al., 1971	California	Native annual grasses	Apr, Jun, Aug 1968	1.1 0.9 1.0	kg DOM	IVC/TC 3
Wilson et al., 1971	California	Improved annual pastures	Apr, Jun, Aug 1968	0.9 0.7 1.0	kg DOM	IVC/TC 3
Scales, 1972	Colorado	Sandhill blue grama	5/1, 5/26, 6/22, 7/23, 9/1, 11/2, 1970	49.7 63.6 58.7 75.7 54.4 36.7	g $OM/W^{.75}$	IVD/CDT 1
Langlands and Bowles, 1974	Australia	Native pastures	Jan (NG), May, Aug (M), Oct (NG)	1.1 1.1 1.0 1.2	kg OM	IVD/CrO 3
Streeter et al., 1974	Colorado	Native mountain meadow	6/16, 7/26, 9/8, 10/18, 1970	11.8 10.2 9.5 9.8	kg DM	IVD/CrO 2
Kartchner, 1975	Oregon	Crested wheatgrass	4/29, 5/20, 6/10, 7/29, 1974	12.4 16.5 10.0 9.0	kg DM	IVD/TC 2
Bishop et al., 1975	Argentina	Semiarid native sandhill grassland	Jan to Dec 1968	9.7 12.7 13.2 8.5 10.3 8.6 6.7 8.7 9.5 k9.0 9.8 10.6	g $DOM/W^{.75}$	IVD/TC 3
Smith et al., 1968	Nevada (N)	Desert shrub range	Jan, Jun, Sep	5.3 7.4 10.2	kg DM	LR/CrO 1
Handl and Rittenhouse, 1972	Oregon	Crested wheatgrass	Apr/70, Jun/70, Apr/71	7.2 6.7 6.5	kg DM	IVD/TC1

[a] Basis of measurement: X/Y; X=digestibility est.; Y=fecal output est.; CR=Chromogen ratio; LR=Lignin ratio; NB=Nylon bag; TC=Total fecal collction; IVD=Digestibility in vitro; IVC=in vitro cell walls; CDT=continuous dig. trial; M=Mature; NG=New growth; 1=steers; 2=cows; 3=sheep.

applied under all circumstances. Irrespective of the technique used, investigators must verify or determine, under their experimental conditions, the proper predictive function to be used.

The trend in expressing intake estimates with grazing livestock is in terms of g/DM or $OM/W_{kg}^{.75}$ although some researchers prefer simpler forms. Among methods used to estimate intake it would appear that the most reliable data have been provided where fecal output was determined by total collection and digestibility measured by in vitro analysis of grazed forage samples. The fecal N method appears quite adequate for estimating digestibility under certain grazing conditions but has not proven very accurate in the direct estimation of intake by grazing animals. The lignin ratio method has very limited value in estimating digestibility and, consequently, intake under grazing conditions.

Intake estimates for grazing livestock have been highly variable but those considered most valid in this review showed a range of 40 to 90 g $DM/W_{kg}^{.75}$. From several studies conducted with grazing cattle and sheep in western United States, intake estimates have generally ranged from about 1 to 2.8% of body weight. Ranges found in both of the above cases were associated with a decline in intake with advancing plant maturity on grazing areas. The relationship between intake and forage maturity is apparently more variable than that between digestibility and forage maturity.

The effect of nitrogen fertilization on forage intake is inconsistent although large increases in intake have sometimes been observed particularly on tropical pastures.

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