EVALUATION OF PASTURE FORAGE

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INTRODUCTION

Pasture has been considered the forgiveness of nature - her constant benediction. However this concept as related to the present methods of production, has been changing rapidly as man has attempted to adopt measures to derive maximum benefits from pastures. In order to keep down production costs in any livestock enterprise, it is of utmost importance to increase yields by resorting to such systems of management best suited to local conditions and other measures that bring about efficient utilization. Abundance of good pasture provides cheap feed containing most of the required nutrients for livestock and is conducive to good production. The influence of grazing management on the quality of pasture has been recognized and considered important from early times. The place that pastures occupy in the livestock industry can very well be appreciated by the estimate that grassland, hay land and forest range cover nearly 60 percent of land area of the United States.

If the results of pasture production are to find practical application, they have to be measured by the animals utilizing the pastures. It is now well recognized that the contribution that pasturage makes to the total needs of the animal is large. In spite of this, not much is known about the diet actually consumed by the grazing animal. Of the 6000 feeds studied so far, forages singularly present the greatest problem of meaningful analysis of their nutritive worth. This may be explained to a great extent by the uniqueness of pasture herbage as a feedstuff as well as to differences in utilization resulting from selective grazing and individual variability.

It is the object of this report to review the different methods employed in measuring the nutritive value of pastures with emphasis on the latest techniques developed to assess the intake and digestibility of pasture forage and evaluate them with regard to their relative usefulness. It is also intended to review the different regression equations that aid in the evaluation of forage or express the forage value in terms of energy supply to the animals. Incidentally the various systems of grazing management and some of the more important factors that affect the feeding value of pastures will be reviewed. The advantages and disadvantages of the different methods will be discussed and an attempt will be made to suggest the most useful method for evaluation of pasture forage in relation to its nutritive worth.

CRITERIA FOR FORAGE EVALUATION

Schuster (191), in a review, listed thirteen methods for evaluating pastures. Among those, hay weights, clippings, live weight gains, carrying capacity and chemical analysis were most popular. Since that time, several other criteria associated with the quality and quantity of pastures were developed that included cost of production, agronomic estimates, level of animal production, forage consumption, digestibility, balance trials to show the net availability of mineral constituents and bioassay methods (2, 12, 144 149, 155, 192).

CHEMICAL COMPOSITION

Chemical analysis is one of the oldest among the earlier methods of estimating nutritive value of feeds. Over 100 years ago workers indicated the efficacy of percentage nutrients in feed as an index of its nutritive value. Mott (155) showed the importance of organic nutrients as a simple way of expressing the nutritive value of grasses.

Cook et al. (42) indicated that, while chemical analysis of plants was not difficult, the actual composition of the grazing animal's diet was a problem since it involved the collection of representative samples, difficulty in knowing what proportion of plants was consumed and also in interpreting the nutrient content of forages. He approached the problem on the basis of analysis of vegetation before and after grazing. The difference in composition and weight served as a measure of the nutrient content of ingested forage.

Ahlgren (1), in an exhaustive review, indicated that chemical analysis, though an indirect means, was widely used to determine the nutritive value since it was easier to apply, cheaper, required less equipment, and was less cumbersome than digestion trials involving livestock. Blaser et al. (22), Scholl et al. (189), Dustman and Van Landingham (59) and Davis and Bell (53) utilized this procedure and pointed out its importance in pasture research. Bennet (20) commented that the nature of crude fiber, extent of lignification and the form in which the crude protein existed, were matters of importance in forage evaluation.

Since animal preference and grazing to random heights are limiting factors in accurate sampling in these determinations, the animal itself has been employed more recently as the collecting agent with the help of the esophageal fistula. Torrel (206) described such a fistula. This method was recommended with certain limitations by other workers in the field (18, 60, 121, 129, 222).

Weir et al. (222) pointed out that when all observations for ungrazed forage on all types of pastures and at all seasons were pooled, the protein content and silica-free ash content were very significantly greater and crude fiber very significantly less in the esophageal samples than in the hand clipped samples. This indicated selective grazing by animals as shown by data in Table 1.

Table 1. Esophageal fistula sample composition minus hand clipped sample composition of previously grazed and ungrazed areas (222).

	Ungrazed	Previously grazed
	percent	percent
Protein	4.1 ± 0.55	3.0 ± 1.1
Crude fiber	-3.5 ± 0.29	-0.9 ± 0.44
Lignin	-0.41 ± 0.30	1.53 ± 0.58
Ether extract	0.16 ± 0.05	0.21 ± 0.10
Silica-free ash	2.2 ± 0.28	2.8 ± 0.53

The relationship of chemical composition to nutritive quality of roughage was demonstrated by Hawkins (93). A positive relationship was found between the quantity consumed and the crude fiber and cellulose contents and between the digestibility of dry matter and the apparent digestibility of crude protein and crude fiber. Results showed that lignin had the most adverse effect on digestibility whereas soluble carbohydrates other than tannin affected adversely the amount of hay consumed.

MEASUREMENT OF DIGESTIBILITY

Though chemical composition affords a valuable tool in pasture evaluation, the fact that it has limited application, in that the value of a nutrient is dependent on the ability of the body to utilize it, cannot be overlooked. Since the undigested portion is useless to the body, it is reasonable to assume that digestibility should give a fair indication of the nutritive value. Although this does not give the exact picture, it does provide a most practical criterion for evaluating the diet of the grazing animal. According to Schneider (185) the earliest digestion trials were conducted at Weende Experiment Station in Goettingen, Germany. Since then, digestibility trials running to several thousands were carried on in all parts of the world. Some of the methods used are discussed in later paragraphs.

Standard Method

The digestion coefficient of a nutrient is the percentage of nutrient consumed that is digested. This method, also referred to as "Total Collection Method" or "Conventional Method" involves complete record of nutrients consumed and total collection of feces. Various devices have been developed for collecting feces and urine both for laboratory animals and also for sheep, cattle and hogs (72, 91, 218).

Indicator Methods

The time and expense involved in determining digestibility by the standard method provided the impetus for development of indirect means of estimating digestibility with the help of indicators, either naturally occurring indigestible ones (ratio technique) or those that are relatively indigestible and are nearly completely recovered (fecal-index technique) from the feces. An ideal reference substance, according to Maynard (147), "shall be totally indigestible and unabsorbable, have no pharmacological action in the digestive tract, pass through the tract at a uniform rate, be readily determined chemically and preferably a natural constituent of the feed under test."

Digestiblity can be calculated by the indicator method as follows:

$$\text{Digestibility} = 100 - \left(100 \, \frac{a.x \text{ in feces}}{b.x \text{ in forage}} \right)$$

a = conc. of indicator in forage

b = conc. of indicator in feces

x = conc. of nutrient.

For indicators recovered incompletely in feces such as chromic oxide which was recovered with 98.6 percent efficiency, Lucas (136) has suggested the following formula:

$$\text{Digestibility} = 100 - r \left(\frac{p\, c_1}{p_1 c_2} \right)$$ where

r = assumed percentage of recovery of indicator

p = percent nutrient in feces

c_1 = percent of indicator content in feed

p_1 = percent of indicator content in feces and

c_2 = percent of nutrient in feed.

Anthraquinone as Indicator. Corbin and Forbes (43) used anthraquinone as a reference substance which was administered in a gelatin capsule before each feeding. This method was based on the extraction of the dye with benzine and measurement of density with a spectrophotometer. By a concentration of density obtained with a calibrated density concentration curve, the amount of dye extracted could be measured thus:

$$\text{Digestibility} = 100 - 100 \left(\frac{x}{y} \times \frac{A}{B} \right) \text{ where}$$

x and y are percentages of nutrient in dry matter of feces and feed, respectively, and A and B are percentages of indicator in dry matter of feed and feces, respectively.

Iron Oxide as an Indicator. Bergeim (21) was among the first to use iron oxide for determining digestibility in the United States. Gallup (77) and other workers (119, 152) compared their results with the standard method but failed to obtain reliable figures, probably due to variations in the amount of iron oxide passing from the digestive tract.

Silica as an Indicator. Early workers used silica, contained naturally in hay and straw as an indicator. Digestion coefficients computed with silica ratio closely approximated the conventional trials where the error was within ten percent, according to Gallup (77). But he and his associates (79, 80) could not find this approximation later and observed that applicability of this method was limited. Knott *et al.* (119) and later Druce and Wilcox (57) pointed out that silica was not reliable due to variability in its recovery from the feces.

Lignin as Indicator. Maynard (146) discussing nitrogen free extract in animal nutrition, indicated that the indigestibility of lignin was a recognized fact. Furthermore, its presence tended to lower the digestibility of other constituents apparently by protecting them against the action of digestive juices. The use of this substance as an indicator, however, has yielded diverse results. Patton and Geisiker (161) considered it indigestible. Bondi and Meyer (24) did not agree with this view and stated that lignin was digested to a certain extent in all experiments.

Ellis *et al.* (61) devised a procedure for the routine determination of lignin by digesting with 72 percent sulfuric acid and drying the residue at 105°C. They concluded that the use of lignin as an indicator gave values comparable to the standard method. Cook and associates (41, 39) studied this method extensively and recommended its use.

Forbes and Garrigus (67, 69) were the first to follow the procedure of Ellis successfully. They also worked out the regression of organic matter digestibility on lignin content and found that the equations were statistically similar whether calculated from conventional or lignin ratio methods:

$Y = 95 - 4.10\,x$ for conventional calculation and

$Y = 100 - 4.53\,x$ for lignin ratio technique, where

Y = Organic matter digestibility and x = lignin content.

Sullivan (203, 204), on the other hand, indicated that lignin had considerable digestibility, exceeding ten percent in many cases. He suggested a modified and quick procedure to determine the percentage of acid insoluble lignin and related it to digestibility. The digestion coefficient of certain species of grass was apparently equal to 100 minus six times the percentage of acid insoluble lignin.

In an earlier study Kane *et al.* (111) observed that lignin in orchard grass was not as reliable an indicator as lignin in alfalfa. Smith *et al.* (196), working on digestibility of forage from burned and unburned bluestem pastures, used lignin and chromogen methods with equal success.

Methoxyl Group as an Indicator. Since measurement of lignin involved difficulties, it was thought that the methoxyl content of forages, a distinct chemical entity and feces, might serve as an indicator of digestibility. Richards and Reid (179,180) suggested that this was definitely superior to lignin. But Kane *et al.* (111) and later Ely *et al.*(62) did not favor this method since the methoxyl content of hay was greater than that in feces and this substance was digested to the extent of five percent.

In a recent study, Anthony and Reid (8) found a highly significant correlation between methoxyl content and digestibility of dry matter and hence recommended this measure for adoption as a relative index among forages differing widely in digestibility. However, the literature on this method is too meagre to warrant any definite conclusion on its value at this time.

Chromic Oxide as an Indicator. According to Schneider et al. (188), Edin first used chromic oxide as indicator in 1918. Crampton and Lloyd (45) used this substance as an indicator very successfully and a number of workers confirmed this during the last decade (9, 14, 37, 44, 51, 95, 127, 141, 143, 167, 169, 172, 190, 213).

This method of estimating chromic oxide was based on titration with sodium thiosulfate using one percent starch solution as the indicator. Later this was modified using procedures where the color density was measured by Beckman D U spectrophotometer at 375 mμ (50) and again by wet ashing the sample (23).

This method, used with pigs by Schurch et al. (190) yielded similar results to those obtained with conventional trials. The analysis of feed and feces for chromic oxide and for the proximate principles permitted calculation of respective digestion coefficients from the following formula:

Percentage digestibility of nutrient $= 100 \left(\frac{a-b}{a} \right)$ where

a $=$ nutrient per unit index material in the food and

b $=$ nutrient per unit index material in feces.

Ingested chromic oxide is completely recovered from the feces voided by several species. If the pattern of excretion followed a predictable uniformity, then total collection of feces, which involved time and expense, could be conveniently substituted by "grab" samples. Devising a specific sampling procedure is of extreme importance to circumvent certain factors affecting the chromic oxide excretion pattern. Studies in this direction indicated that there was intra-day variability in chromic oxide excretion (113, 127, 150). On the other hand, Putnam _et al_. (169), who studied the effects of feeding schedule on the excretion pattern of chromic oxide, concluded that time of administration was of primary importance in respect to the time-concentration relationship of fecal chromic oxide and that so-called diurnal effects were of little importance. The digestible dry matter as determined by total collection and indicator methods is shown in Table 2.

Table 2. Digestible dry matter as determined by total collection and indicator methods (169).

Cow No.		Total collection	Indicator	
			7-day collection	14-day collection
		%	%	%
177		66.1	65.3	63.8
196		69.3	66.2	68.1
166		70.1	67.5	68.3
279		69.3	64.2	62.5
	Average	68.3	65.9	65.8

Chromic oxide in a gelatin capsule gave lower values than the pelleted form (14). To fulfill its function as a marker, chromic oxide should be cleared from the rumen at a rate as nearly as possible equivalent to that of dry matter of the feed or any of its constituents. Howevor it was seen that chromic oxide, when administered in capsules, passed from the stomach within four hours due to quick solution of gelatin in the rumen. A mixture of chromic oxide and paper pulp fed in a gelatin capsule reduced the variation in concentrations of chromic oxide effecting a slow and uniform release in feces. This was an instance in which mode of administration affected the excretion pattern (44).

Dosing frequency was another factor which played a part and increasing the number of doses facilitated more uniformity in excretion (26, 95, 167). Other factors involved were size of dose, type of ration and position of animal - standing or lying.

As a result of experiments with grazing steers, Hardison and Reid (97) proposed that bulking of equal weights of feces obtained at 6 A.M. and 4 P.M. during periods of seven or more days would provide an accurate estimate of the total fecal output. This procedure was successfully adopted in later studies (127, 195).

Raymond and Minson (172) concluded from their studies that excretion of chromic oxide did not follow any diurnal pattern and as such a system of "grab" sampling could lead to erroneous results. They used a procedure for collecting samples which was referred to as "ring sampling" involving collection from a definite area in the sward. However, the results secured by other workers did not support the procedure adopted by these investigators (9, 44, 51, 95).

MEASUREMENT OF DIGESTIBILITY UNDER GRAZING CONDITIONS

The methods discussed thus far with the exception of lignin, could only be applied for digestion experiments conducted indoors. The problem of evaluating forages under grazing conditions presents difficulties that are not met with in the indoor trials. The animal, as a collecting agent, has a selectivity in picking up grass, thus the sample obtained for analysis seldom represents the one actually grazed. Furthermore, the grazing pattern and individual idiosyncrasies differ among animals.

Reid _et al_.(176) have observed that it was impossible except by chance to sample forage in such a way that hand chosen samples fully represented that eaten. Many other workers, working under grazing conditions, testified to this fact. Thus, all attention was directed in the last decade to overcome this problem as a result of which various indirect methods have been suggested (96, 130, 170, 176, 224).

Plant Chromogen as an Indicator

In 1950 Reid _et al_. (177) investigated naturally occurring pigments as indicators of determining digestibility of forages. This was modified subsequently for use under grazing conditions (176). These workers postulated that an essentially quantitative relationship existed between the chromogen content of consumed roughage and that of the feces voided. The greatest problem of forage sampling could be circumvented if fecal composition served as a forage sampling expedient. Furthermore, this would do away with analysis of grass for chromogen which was present in variable concentration.

Reid and coworkers (98, 176, 177, 173, 224) first established chromogen concentration values for a concentrated extract from a mixed forage, dry roughage and feces from the amount of absorbed light at 406 mμ and the following equation was arrived at:

$Y = 57.9197 - 29.0672\,x$ where

$Y =$ concentration of chromogen in units per milliliter of extract

$x =$ log of the percentage of transmitted light.

As a result of study of 18 pasture forage mixtures ranging from 51.6 to 74.0 percent dry matter digestibility these scientists worked a definite mathematical relationship between the ratio of chromogen to dry matter of feces and that of forage actually consumed which may be expressed as follows:

$Y = (0.0925\,x + 137.3 \log x) - 242.1181 \pm 1.2194$ where

$Y =$ units of chromogen per gram forage (dry basis)

$x =$ units of chromogen per gram feces (dry basis).

The coefficient of correlation between conventional trials and those computed from fecal chromogen was 0.985. The following values were plugged in to compute the digestibility:

$$\text{Percent digestibility} = 100 - 100\,\frac{\text{units chromogen/gm forage on dry basis}}{\text{units chromogen/gm feces on dry basis}}.$$

The validity of this method has been tested by Lassiter *et al*.(129) and many other workers in the field (13, 67, 112, 145, 191, 196, 202). The results obtained by Reid *et al*. in comparison to standard trials are shown in Table 3.

Table 3. A comparison of digestion coefficients estimated from the chromogen concentration of the feces with those derived from conventional trials (176).

Trial No.	Dry Matter Digestibility							
	Forage 1		Forage 2		Forage 3		Forage 4	
	Conv.	Est.	Conv.	Est.	Conv.	Est.	Conv.	Est.
	%	%	%	%	%	%	%	%
1	72.8 ± 0.70	73.7 ± 0.28	72.1 ± 1.16	71.3 ± 0.54	71.6 ± 0.91	71.1 ± 0.44	72.9 ± 0.29	75.1 ± 0.25
2	66.3 ± 0.20	65.5 ± 0.38	59.3 ± 0.34	60.0 ± 0.30	63.2 ± 0.24	62.7 ± 0.10	66.3 ± 0.78	68.1 ± 0.15
3	54.4 ± 0.08	53.7 ± 0.28	53.5 ± 0.88	53.0 ± 0.05	53.8 ± 1.23	53.8 ± 0.31	58.0 ± 1.67	55.5 ± 0.30
4	54.8 ± 0.38	54.6 ± 0.56	64.1 ± 0.47	60.5 ± 0.82	60.5 ± 0.82	61.7 ± 0.31	—	—
5A	—	—	—	—	60.2 ± 0.93	60.6 ± 0.47	—	—
5	—	—	61.8 ± 0.86	61.3 ± 0.41	60.1 ± 0.62	61.2 ± 0.22		

The work was further extended to ascertain the digestibility of forage when a supplementary feed was fed and also to determine the composition of ingested forage from pastures composed largely of one plant species and to the measurement of digestibility of individual plant components such as leaves or stems. Furthermore, in order to overcome the difficulty of total feces collection, grab samples were taken and the results agreed very well with those obtained from the four-day composite samples and these determined conventionally as is shown in Table 4.

Nitrogen or Protein as an Indicator

Results of experiments in which known herbage was fed to sheep in cages by Raymond in New Zealand (170) showed the following relationship between nitrogen content of forage dry matter and oven dried feces:

Percentage N in feed = 0.795 x Percent nitrogen in ash free feces + 0.14 (t = .17).

Lancaster (124, 125) conducted 52 digestion trials covering a variety of forages ranging in protein content from 10 - 36 percent and established a relationship between the weights of forage organic matter and total nitrogen excreted. Based on this observation organic matter digestibility was calculated. He postulated that fecal nitrogen excreted per unit of organic matter was remarkably constant, the average being 0.8 ± 0.1 gm. per 100 gm. As a result, the following equation was proposed:

$$\text{Digestibility coefficient} = \frac{100\ N - .83}{N} \quad \text{where}$$

N = % of nitrogen in ash-free feces.

The figures compared well with the results of similar trials conducted by the conventional method. When this investigation was extended to include many kinds of pastures in the world the constant was found to be 0.76 ± 0.11

Table 4. Digestion coefficients derived from the analysis of partial samples of feces obtained from steers hand fed clipped, whole forage and grazing forage of the same source (176).

Date	Sampling Time	Handfed Steers			Grazing Steers		
		7	8	9	10	11	12
		%	%	%	%	%	%
8/8	P.M.	61.9	62.1	63.0	70.3	67.6	69.5
8/9	A.M.	61.0	61.3	62.8	68.2	66.6	68.0
8/9	P.M.	61.6	61.9	62.2	67.2	66.2	68.7
8/10	A.M.	61.2	62.9	63.0	67.5	65.1	68.1
8/10	P.M.	61.8	62.4	62.6	67.7	66.2	68.7
8/11	A.M.	61.6	61.5	62.0	67.6	66.4	66.4
8/11	P.M.	60.8	61.8	62.3	68.7	63.8	68.9
8/12	A.M.	61.0	61.9	61.9	67.2	64.2	67.0
Average estimate coefficient based on partial collection.		61.3 ± 0.15	61.8 ± 0.12	62.4 ± 0.18	68.1 ± 0.37	65.8 ± 0.45	68.2 ± 0.35
Estimate coefficients based on 4 day composite sample of feces.		61.4	61.7	62.8	68.3	66.1	67.9
Coefficient determined on conventional digestion trial.		60.3	62.0	63.0	—	—	—

for forages with protein percentages ranging from five to 36 percent. He divided the pasture herbage into 2 groups according to the percentage of protein thus:

Group A (103 trials) $C = 0.80 \pm 0.08$ (Protein more than 15 percent)

Group B (50 trials) $C = 0.67 \pm 0.12$ (Protein less than 15 percent) where

C = Constant indicating the relationship between the weights of forage organic matter and fecal nitrogen.

In further studies, Lancaster modified his method by relating the ratio (Y) of feed consumed to feces voided and to the fecal nitrogen content (X), the equation being $Y = 0.97 X \pm 1.02$ where Y is the reciprocal of the indigestibility ratio and therefore it may be used to determine both digestibility and intake.

At about the same time Gallup and Briggs (72) and more recently Freer (71) in Australia related fecal nitrogen, forage nitrogen and digestibility in the following equations:

Gallup and Briggs -

$Y = 51.7 + 16.2 X$ where Y = % digestibility of organic matter

X = Protein content of forage

T.D.N. = $28.0 + 4.9 X$ where X = % protein in forage.

Freer -

% digestibility of organic matter = $55.15 + 4.8136 N$ (S.E. ± 1.76) where

N = Nitrogen content of ash-free feces.

In 1950 Forbes (66) explored the possibility of utilizing the relationship between the protein content of forage and the apparent digestibility of the protein developed by Mitchell (150) in the following equation:

$Y = 42.64 (P - 5)^{0.2148}$ where

Y is the apparent digestibility of protein and P is the percentage protein.

He calculated constants for Mitchell's equation and suggested the following formula for calculation of digestibility.

$$\text{Percent digestibility} = 100 - \frac{\%\ \text{protein in feed}}{\%\ \text{protein in feces}} (100 - ax^{b}) \quad \text{where}$$

a and b are constants and x is 5 less than protein content of forage dry matter.

Table 5 contains the regression of dry matter digestibility (y) on protein content (x) of the dry matter consumed by grazing lambs (66).

Table 5. Regression of dry matter digestibility on protein content of the dry matter consumed (66).

Method	y = a + b x	Standard error of equation	Standard error of b
Lignin ratio	y = 53.3 + 0.547 x	8.0	0.188
Protein digestibility	y = 55.9 + 0.707 x	5.2	0.096

IN VITRO AND *IN VIVO* TECHNIQUES

Recently the value of the artificial rumen technique for evaluating pasture quality has been investigated (56, 120, 178, 212). Correlations were obtained between *in vitro* and *in vivo* digestibility of dry matter, cellulose, crude fiber, energy and protein. A similar relationship existed with grass cut at several stages of maturity. Digestibility *in vivo* was accurately predicted from dry matter digestibility *in vitro* of oven-dried samples. The relationships may be expressed by the following equations (178).

$y = 20.5 + 0.778x$; $r = 0.98$ where

y = dry matter digestibility *in vivo* and

x = dry matter digestibility *in vitro*.

Donefer *et al.*(56) have expressed the nutritive value indexes from *in vitro* cellulose digestion trials by the following equation:

$y = -7.8 + 1.314\,x$ where

y = index of nutritive value and

x = cellulose digestibility.

Table 6 shows the *in vitro* and *in vivo* measurements used in calculation of the *in vitro* index and effective nutritive value index (56).

METHODS OF MEASURING PASTURE YIELDS AND CONSUMPTION

In any pasture evaluation study, yield and consumption of forage are essential not only to assess the productivity but also to determine the digestibility. Intake is a useful measure since it reflects the grass nutrients consumed as well as the effects on the animal and on the pasture. The effect of plant maturity on dry matter consumption can also be studied through measurement of feed intake. It is of considerable importance also to know how closely the amount of feed eaten by different animals is related to weight gain and productive performance. As with digestibility, various methods of measurement of intake have been in vogue, each of which has certain advantages and disadvantages.

Clipping Method

This is one of the earliest methods devised to measure pasture yields and animal consumption (25, 28, 30, 54, 75, 76, 92, 117, 138, 154, 181, 205, 208). The total forage available to animals is estimated by cutting a certain strip and allowing the animals to graze in a similar experimental plot, clipping the remaining forage after grazing and crediting the difference as consumption

Table 6. _In vitro_ and _in vivo_ measurement used in calculation of _in vitro_ index and effective nutritive value index (56).

Forage	_In vitro_ measurements cellulose digestion			_In vivo_ measurements		
	12 hr x	24 hr =	_in vitro_ index	Relative Intake x	Digestible Energy =	Nutritive Value Index
	%	%			%	
Red Clover (early bloom)	46	54	24	98	55	54
Red Clover (full bloom)	47	53	25	92	53	49
Timothy (early bloom)	38	57	22	66	58	38
Timothy (full bloom)	27	46	12	69	50	34
Pooled standard deviation	± 3	± 2	-	± 10	± 2	± 7

by animals.

A modified agronomic method for measuring herbage production was reported by Frishknecht and Plummer (74). This was based on the assumption that the weight of herbage produced in pounds per acre was equivalent to the grams of herbage produced on a 9.6 square-foot plot. Based on degree of utilization and amount of unused forage, total production could be ascertained from Table 7.

Table 7. Total herbage produced based on degree of utilization and amount of unused forage on a 9.6 sq. ft. plot at various levels of grazing (74).

Utilization	Herbage produced calculated from different amounts of unused herbage.			
	10 gms.	25 gms.	50 gms.	75 gms.
%	(lb.)	(lb.)	(lb.)	(lb.)
0	100	250	500	750
10	111	278	555	833
25	133	333	667	1000
50	200	500	1000	1500
75	400	1000	2000	3000

Linehan (131) working on pasture output measurement, devised a formula which sought to make allowances for differences in growth of herbage during the actual grazing period and employed unrestricted growth in a protected area and that subjected to defoliation by animals during the same time. The formula may be expressed thus:

Amount of grass nutrients consumed $= C - f \dfrac{(\log d - \log f)}{(\log c - \log f)}$ where

C = quantity of grass nutrient present at the beginning of grazing

d = quantity of grass nutrient present in cages after grazing

f = quantity of grass nutrient left uneaten outfield after grazing.

Erizian Method

Erizian (63), a German investigator, worked on a method to estimate forage consumption by grazing cows. It consisted essentially of weighing animals at the beginning and end of grazing periods, collecting and weighing the total solid excreta and estimating insensible loss in body weight with the help of previously determined constants. The final weight of animal plus the weight of excreta and insensible loss minus the initial weight of animal constituted the forage consumed. While this method theoretically might be logical, time, expense and errors involved preclude the possibility of practical adoption.

Animal Requirement Method

This method takes advantage of animal performance as a criterion for evaluating forages (153, 155). Calculation of nutrients received from the pastures lacked standardization and Knott et al.(118) proposed a method for this purpose. It took into account the maintenance requirements of animals either from Morrison's standards or by calculation using the 0.73 power of body weight and allowances for production from the same standards. They suggested an allowance of 0.341 pounds total digestible nutrients per pound of 4 percent fat corrected milk and an addition of 3.53 pounds total digestible nutrients per pound gain and subtraction of 2.73 pounds total digestible nutrients for each pound loss of weight. In addition, accurate records of length of grazing period, size of pasture and number of animals were maintained which gave the actual nutrients contributed by the pasture. Any supplementary feed fed was subtracted from the total figures to arrive at pasture intake.

This method was further modified by Kidder (116). He calculated average daily maintenance from the formula $\frac{W^{.73}}{19.53}$ and used data from 32 steer feeding trials of 10 steers each to calculate 3.15 pounds with extremes of 2.47 to 4.45 pounds of total digestible nutrients per pound of gain instead of 3.53 pounds as reported by Knott (118) whose formula is as follows:

$$\text{T.D.N. from pasture} = \frac{(D \times W_1 + W_f \times R_m)}{2} + G \times R_g + (FCM \times R_{fcm}).$$

In case there was loss in weight during grazing period $-(L \times Rd)$ was substituted for $+G \times R_g$ where D is the number of days grazed, W_1 is initial weight, W_f is final weight, R_m is maintenance requirement, G is weight gain, R_g is requirement per pound gain, L is loss in weight, Rd is the sum of nutrients assumed to be available to cow in milk, FCM = fat corrected milk and R_{fcm} is nutrient requirement for production.

Hodgson et al.(102) compared the herbage obtained from clippings and this method with Knott's formula and found that the former gave yields 125 ± 10.5 percent of the latter method. They concluded that the animal requirement technique gave a truer picture of net results of grazing as is shown in Table 8.

Table 8. Comparison of T.D.N. yield of pasture as determined from clippings and from the nutrient requirement of grazing animals (102).

Grazing Period	Nutrient yield from clipping	Nutrient yield from animal requirements	Dif- ference	Yield from clippings ÷ yield from grazing
	(lb.)	(lb.)	(lb.)	%
Pasture season 1939				
1	3344.8	2255.5	1089.3	148.3
2	3266.8	2042.2	1224.6	160.0
3	1255.0	1327.1	-102.1	92.3
4	1148.4	1141.5	6.9	100.6
Total	8985.0	6766.3	2218.7	132.8
Pasture season 1940				
1	2978.5	1570.7	1407.8	189.6
2	3120.4	1204.8	1915.6	259.0
3	1507.5	1115.0	392.5	135.2
4	1198.0	1332.0	-134.0	89.9
5	544.6	832.4	287.8	65.4
Total	9348.7	6054.9	3293.8	154.4

The mean difference was highly significant.

Frick and Eaton (73) developed another method for large scale use to estimate pasture intake by dairy animals in Dairy Herd Improvement Associations. Brody's (27) dairy merit ratio formula was applied to milk production records for cows freshening in various months and estimates were made of total nutrients required by months of lactation. The following formula was used in this connection:

$$\text{Pounds of T.D.N.} = \frac{340(\text{ F.C.M.})}{1814(\text{dairy merit ratio})} - \text{ pounds of T.D.N. from barn yard.}$$

The authors themselves pointed out the limitations of this method. The dairy merit ratio might vary depending on individuality, body size, environment and age of animal.

Animal Unit and Standard Cow Days to Express Yields

The animal unit was used as a measure of carrying capacity of pastures by Vinall and Semple (207) but the expression was criticized by various workers since it did not take into consideration variations in appetite, feeding capacity, requirement for maintenance or weight change.

The Joint Committee on Pasture Research techniques (6) and Lynd (139) suggested the term "Standard Cow Days", for expressing pasture yield thus -

$$(1)\ \text{Standard Cow days per acre} = \frac{\text{T.D.N. (lb./A)}}{\text{16 lb.}}$$

$$(2)\ \text{Carrying Capacity} = \frac{\text{Standard Cow days}}{\text{No. of days grazed}}$$

The yield per acre was computed by multiplying the animal days/acre by the average daily performance of the test animals. Lucas (137) reported three statistical methods for estimating results of grazing trials of which the more striking one was the effective total digestible nutrients (ETDN). This was estimated from weights and gains of all animals. The effective total digestible nutrients of test animals was designated etdn . The test animal days was then ETDN/etdn. Daily gain was calculated from test animals only and finally gain per acre obtained as test animal days x daily gains.

Wallace (216) and Hancock (89), in analyzing the results of an experiment on intake in New Zealand, followed the method used by Brody and Proctor (27) in deriving their feeding standard for stall-fed animals. The formula for the method was:

$$\text{Digestible organic matter} = b_1\,(\text{FCM}) + b_2\,(W^{0.73}) + b_3\,(\text{W.C.})$$

The values for b_1, b_2 and b_3 were determined by multiple regression analysis and were 0.35, 0.08 and 3, respectively.

F.C.M. = 4 percent fat corrected milk

W = live weight

W.C. = Amount used for weight gain varying linearly with gain or loss

Forage Consumption: Excretion Ratio

Garrigus and Rusk (81) developed a method based on the assumption that the ratio of dry matter consumed to the fecal outgo by the grazing animal would be practically constant. The relationship between forage consumed and feces voided by the animal was determined in digestion trials. The forage consumption was then calculated by dividing the amount of dry matter defecated by the predetermined ratio between dry matter defecated and dry matter consumed. The following formula was used for the purpose:

$$\text{Dry matter consumed} = \text{weight of fecal dry matter} \times \frac{\text{weight of herbage dry matter during inside collection period}}{\text{weight of fecal dry matter during inside collection period}}$$

This ratio method was modified for use by Lancaster (126) in 22 digestion trials and referred to by Wallace (216). The equation for the factor (reciprocal of the indigestible ratio) has already appeared in this discussion. The feces output was multiplied by this factor to obtain pasture intake.

Crampton and Prudy (48, 47), Forbes and Garrigus (67) and Reid et al.(177) have all reported use of this method. While Crampton and Prudy stated that it gave an accurate picture of the intake, the latter workers found that it was not too useful due to the inherent errors involved in technique.

Use of Indicators for Determination of Consumption

The indicators already discussed with regard to digestibility trials could be employed also for estimation of consumption. The indicator methods also have the special advantage of eliminating total collection of feces (65, 121, 122, 134, 140, 143, 164, 175, 188).

Smith and Reid (195) postulated the mechanics of arriving at the dry matter intake by use of the following equations:

(a) Fecal Output (gm. dry matter per day)

$$= \frac{Cr_2O_3 \text{ consumed (mgm/day)}}{Cr_2O_3 \text{ concentration of feces (mgm/gm dry matter)}}$$

(b) Herbage Intake $= \dfrac{\text{Fecal output (gm. dry matter/day)}}{\text{\% Indigestible dry matter}}$

Reid _et al_.(176) suggested that an ideal method of measuring consumption would be use of a combination of indicators, chromogen in forage (to be employed as an index of indigestibility) and another added in known quantity(as an index of fecal outgo per unit of time) which would measure both digestibility and intake at the same time. Further, grab sampling would simplify the procedure.

Hardison and Reid (97) compared the dry matter intakes estimated by the combined use of chromic oxide and plant chromogen in the case of hand feeding trials to the "measured intake" and in the case of grazing trials to the intake determined from the total collection of feces and the indigestibility determined by fecal chromogen method. There was general agreement between the estimated and measured intakes. The following equation was established to represent the relationship between these two methods of measuring intake for arriving at the intake under grazing conditions.

$Y = 0.928x + 0.827$ where

Y = measured intake lbs/day

x = estimated intake lbs/day.

NUTRITIVE VALUE INDEX

The effective nutritive value of forages is dependent on the joint concept of the level of maximum voluntary intake when it alone constituted the ration and the extent of its ultimate yield of energy. To be useful as a point of general numerical index of feeding value, Crampton et al. (47) expressed observed forage consumption thus:

$$\text{Relative Intake} = \frac{\text{Observed Intake} \times 100}{80(W_{kg}^{\;0.75})}$$

The Relative Intake of forage was multiplied by the digestion coefficient of the energy to get the Nutritive Value Index.

REGRESSION EQUATIONS AS AIDS TO PASTURE EVALUATION

For some time attempts have been made to equate herbage digestibility with forage composition and other factors. It must be understood, however, that equations under one set of conditions may not be applicable in all cases since there is gradual change in composition and digestibility of the material with maturity of the forage. This situation may be avoided to a certain extent by the cold storage of fresh herbage as suggested by Raymond (171). This may not be a serious problem if the decline in nutritive value of the forage is uniform.

Kennedy (114) in his studies used the following formulas computed by different workers for estimating digestibility.

(a) Lancaster $Y = 94.04 - 2.95\,x$ (123)

(b) Allman $Y = 90.00 - 2.61\,x$ (5)

(c) Mac Meekan $Y = 92.61 - 0.06\,x$ (142)

where Y = Calculated digestibility in all cases

x = Percentage of lignin in case of (a) and (b) and percentage of crude fiber in formula (c).

Forbes and Garrigus (68) related regression of organic matter digestibility on lignin content of dry matter and the equations were:

$Y = 100 - 4.71\,x$ (steers)

$Y = 100 - 5.24\,x$ (wethers) where

Y = Organic matter digestibility

x = Lignin content.

Schneider et al. (186, 187) have suggested an equation to relate organic matter digestibility after calculating partial regression coefficients for different kinds of feed:

$Y = C + b_1x_1 + b_2x_2 + b_3x_3 + b_4\,x\,4$ where

Y = Digestibility coefficient, C = constant for the nutrient, b_1, b_2, b_3 and b_4 are partial regression coefficients and x_1, x_2, x_3 and x_4 are moisture free percentages of crude protein, crude fiber, nitrogen free extract and ether extract respectively.

The following significant rectilinear regressions of fecal nitrogen excretion in percent of dry matter intake (Y) on the crude protein content (x) of herbage were worked out by Homb and Breirem (106).

First cutting herbage $Y = 0.452 + 0.00935\,x$ $r = 0.81$

2nd. and 3rd. cutting herbage $Y = 0.264 + 0.03214\,x$ $r = 0.80$

Hallsworth (88) found the following relationship between fiber content, starch equivalent and digestibility:

Starch equivalent $=$ 73.56 - 0.62 x (fiber content)

Digestion coefficient $=$ 78.07 - 0.74 x (fiber content).

Preston et al. (168) calculated the regression of dry matter in feces on dry matter in feed (grass only) as the independent variable. The percentage digestible dry matter was found by $Y = 100 (1 - b) \pm S_b$ where Y = Digestibility percentage, S_b = Standard error of regression coefficient, b = Regression coefficient representing output of feces per unit feed ingested.

Glover et al. (82, 83, 84) studied apparent digestibility in relation to crude protein in cattle and sheep of both temperate and tropical breeds by means of trials of herbage analysis in many parts of the world and arrived at the following equation:

$Y = 70 \log x - 15$ where Y = apparent digestibility and x = crude protein content. The same authors in later studies pointed out that when exceptional feeds were encountered in which the crude fiber/crude protein relationship was abnormal, accurate results could be obtained from the following equation for ruminants:

Digestion coefficient = 5 + 60 log C.P. - 0.33 C.F. Similar equations were worked out for other animals.

Freer's formula (71) relating nitrogen to digestibility has already been described.

Phillips and associates (165), estimated the extent to which measured fermentation rates could account for the loss in weight of dry matter during digestion in Zebu Cattle and related this to dry matter digestibility thus:

$X_1 = -6.38 + 0.892\, X_2 + 0.260\, X_3$ where

$X_1 =$ Digestion coefficient, $X_2 =$ Rumen retention time,

$X_3 =$ Mean fermentation rate. The multiple correlation coefficient was 0.72.

Greenhalgh and Corbett (86, 87) suggested the following equations for dry matter digestibility (Y):

First growth trials $Y = 11_{x1} + 44.9 \pm 1.5$

Aftermath $Y = 11_{x1} + 39.4 \pm 1.5$

where $x_1 =$ % nitrogen in fecal organic matter.

For relating fecal chromogen the equations were expressed thus:

First growth $Y = 9x_2 + 54.4 \pm 1.5$

Aftermath $Y = 4x_2 + 55.4 \pm 1.5$

where $x_2 =$ units of chromogen per gram of fecal organic matter.

Later the same workers modified the equations to suit the season and level of fertilization of grasses.

Spring H (High nitrogen) $Y = 14.3\, x - 1.6\, x^2 + 48.0\ (\pm 0.85)$

Spring L (Low nitrogen) $Y = 19.3\, x - 2.3\, x^2 + 40.3\ (\pm 0.70)$

Summer H $Y = 9.8\, x - 0.2\, x^2 + 44.2\ (\pm 1.07)$

Summer L $Y = 53.0\, x - 7.9\, x^2 - 15.1\ (\pm 0.92)$

where $x =$ units of chromogen per gram of fecal organic matter

and $Y =$ Dry matter digestibility.

Meyer and Lofgreen (148) conducted 152 digestion trials and devised the following equations to relate the regression of total digestible nutrients to the lignin and fiber contents of alfalfa.

$Y = 84.57 - 3.21\, X$ where $X =$ % of lignin and

$Y = 79.7 - 0.54$ where $X =$ % of crude fiber and

$Y =$ Total digestible nutrients.

Most recently Sosulski and Patterson (200) worked out a multiple regression of digestibility of energy on lignin and protein content of forages which proved to yield the best predictions of apparent digestibility for species and general comparison which runs thus:

$Y = 77.29 - 3.99 X_1 + 1.26 X_2$ where Y = Digestibility %, X_1 = % of lignin and X_2 = % of protein.

ENERGY YIELD OF FORAGE AND ITS RELATIONSHIP TO TOTAL DIGESTIBLE NUTRIENTS

The ultimate purpose of any feed in the body is to supply energy. Quality of forage then depends on rate of consumption and energy intake per unit weight (46, 94). Assuming that other dietary conditions are adequate the following relationships could be established:

(a) Animal response (milk yield, tissue gain) plus maintenance = Energy intake

(b) Energy intake = Dry matter intake x Energy concentration, and therefore

(c) Forage energy intake = Dry matter intake of forage x Energy concentration in forage.

Total digestible nutrients do not strictly reflect biological accuracy. Still, they provide the most convenient means for adoption in animal nutrition research since the concept postulates that two feeds are of equal value when their total digestible nutrient content is the same.

Mitchell and Wise (151) reviewed the literature extensively on digestibility in relation to energy. Lofgreen (132, 133) suggested that digestible energy could be expressed on an organic matter basis. After conducting digestion trials a conversion factor F was calculated:

$F = M(.01 + .00125 E)$ where M = Organic matter in feed and E = percent of ether extract in the organic matter.

Total digestible nutrient values were obtained by multiplying the percentage digestible energy by the factor, F, which compared very well with the conventional method (Table 9).

Table 9. Comparison of conventional and organic matter (O.M.) methods for T.D.N. determination (132).

Ration	No. of trials	Digestibility of O.M.	F	T. D. N. O.M. Method	T. D. N. Conventional Method
		%		%	%
1. Alfalfa hay	4	66.6	0.843	55.9	55.2
2. Alfalfa hay & wet beet pulp	4	71.3	0.234	16.7	16.3
3. Oat hay concentrate mixture	7	66.5	0.838	55.7	55.6
4. Flax hulls	4	42.6	0.559	36.6	36.0

Using Lofgreen's method, Walker and Hepburn (213) calculated gross digestible energy (G.D.E.) and computed starch equivalent values in which Kellner's correction for crude fiber and Woodman's addition of 20 percent were incorporated. $SE_{(GDE)}$ = (G.D.E. x F) - (CP x 0.88) + 20% where F = Conversion factor, E = percent of ether extract in organic matter and CP = percent of crude protein.

Barth and coworkers (15, 16) worked out correlation coefficients between total digestible nutrients and digestible energy which were very close. The following regression equations were established for brome and reed canary grasses, respectively.

$Y = 189.82 + 42.87\,X$

$Y = 758.43 + 32.98\,X$

where Y = Digestible energy and X = % T.D.N.

The same workers worked out a similar relationship using digestible protein as the independent variable:

Calories per gm. T.D.N. = 4.343 + 0.0199 X where X = % Digestible protein.

Walker and Hepburn (214) in a later study established the relationship between chemical composition and gross digestible energy (G.D.E.) of certain silages and also the correlation between metabolizable energy (M.E.) and G.D.E., the equations for which are as follows:

G.D.E. = 86.6 - 1.94 (lignin)

G.D.E = 59.6 - 2.34 (lignin) + 0.52 (crude protein) + 0.64 (cellulose)

M.E. = 0.884 G.D.E. - 0.58.

A comparison of 35 forages showed a correlation coefficient of +0.97 between cellulose digestion *in vitro* and *in vivo*. Cellulose digestion *in vitro* was also significantly related to digestible energy as shown in Table 10.

Table 10. Prediction equations for estimating nutritive value of forages from *in vitro* and *in vivo* techniques and forage composition data (101).

Y	X	Regression equation	S.D.	Coefficient of variation
% cellulose digested *in vivo*	% cellulose digested *in vitro*	$Y = 30.7 + 0.769\,X$	2.05	2.66
Digestible Energy	% cellulose digested *in vitro*	$Y = 1185 + 29.81\,X$	125	4.20
Digestible Energy	Axelsson - Reid - Swift formula	$Y = 4024 + 16.70\,X_1 + 49.31\,X_2$	194	6.47

X_1 = % of protein in dry matter. X_2 = % of crude fiber in dry matter.

FACTORS AFFECTING FEEDING VALUE OF PASTURES

The economic use of pasture is linked with effective utilization at the right time coupled with sound managerial decisions. Though levels of intake may not seriously affect digestibility it has been observed in several studies that heavy grazing places premiums on intake and digestibility. As intensity of grazing increases there is a corresponding decrease in protein, ether extract, gross energy and phosphorous with an increase in lignin in the feed consumed (162, 219).

Fertilization

Though nitrogen fertilization is not a sound economic proposition in range pastures, tame and cultivated pastures are very much influenced by application of fertilizers not only by way of yield but also in biological value (29, 49, 52). The effects of nitrogen application and clipping intervals on the total dry forage produced in a mixture of oats, rye grass and crimson clover mixture are detailed in Table 11.

Ward (217) in an exhaustive review of the subject, has concluded that not only yields but also nutrient levels in plants were increased by fertilization. It was further pointed out that biological assays of forages with different fertilizer treatments yielded varying results.

Broyles and Fribourg (29) pointed out that with an increase in fertilizer from 0 to 120 pounds per acre, there was a corresponding increase in dry matter and nitrogen percentages in the forage. On the other hand Wedin et al. (220) reported that heavy fertilization tended to decrease feeding value as measured by weight gain though moderate fertilization had a favorable effect.

The work was further extended to ascertain the digestibility of forage when a supplementary feed was fed and also to determine the composition of ingested forage from pastures composed largely of one plant species and to the measurement of digestibility of individual plant components such as leaves or stems. Furthermore, in order to overcome the difficulty of total feces collection, grab samples were taken and the results agreed very well with those obtained from the four-day composite samples and those determined conventionally as is shown in Table 4.

Nitrogen or Protein as an Indicator

Results of experiments in which known herbage was fed to sheep in cages by Raymond in New Zealand (170) showed the following relationship between nitrogen content of forage dry matter and oven dried feces:

Percentage N in feed = 0.795 x Percent nitrogen in ash free feces + 0.14 (t = .17).

Lancaster (124, 125) conducted 52 digestion trials covering a variety of forages ranging in protein content from 10 - 36 percent and established a relationship between the weights of forage organic matter and total nitrogen excreted. Based on this observation organic matter digestibility was calculated. He postulated that fecal nitrogen excreted per unit of organic matter was remarkably constant, the average being 0.8 ± 0.1 gm. per 100 gm. As a result, the following equation was proposed:

$$\text{Digestibility coefficient} = \frac{100\ N - .83}{N} \quad \text{where}$$

N = % of nitrogen in ash-free feces.

The figures compared well with the results of similar trials conducted by the conventional method. When this investigation was extended to include many kinds of pastures in the world the constant was found to be 0.76 ± 0.11

Table 11. Effect of nitrogen application and clipping interval on the total dry forage produced in an oats - rye grass - crimson clover mixture (49).

Clipping Interval	Dry matter production when top dressed with the following amounts of nitrogen per acre.		
	16	32	48
	(lbs/A)	(lbs/A)	(lbs/A)
2 weeks	2830	3220	3960
4 weeks	3900	4220	4850
8 weeks	5810	6075	6715

Stage of Maturity

Stage of maturity and site conditions play important roles in determining the nutrient content of grasses. The latter indirectly affect the chemical content of plants through soil and plant development, water run off and other environmental factors. Cook and Harris (40) found species differences in chemical composition. Protein content decreased with increased maturity. They postulated that nutrient content was influenced by many interdependent factors exerting additive effects.

Reid et al.(174) found that the date on which the first growth was harvested was the major determinant of intake and digestibility. With advance of growth, the lignin and cellulose contents markedly increased with a decrease in digestible dry matter value. This is an universally recognized phenomonon which needs no emphasis (10, 38, 166, 220). Kamstra et al. (110) found in in vitro trials that separating cellulose from lignin improved digestibility, indicating that the latter was responsible for this inhibitory effect.

In a very recent study Spahr *et al.*(201) demonstrated that a delay of 15 days in cutting date reduced digestibility and milk production. A species difference was also observed even at similar stages. They concluded that 65 percent of the variation associated with the stage of maturity (Table 12) could be attributed to differences in intake.

Table 12. Effect of hay on animal response by lactating cows (201).

Hay fed (a)	Average daily F.C.M. per cow (b).	Average daily changes in body weight	Average daily hay intake (c)	Average daily intake of concentrate per cow.
	(lb.)	(lb.)	(lb./cwt.)	(lb.)
1	40.4	+ 1.4	2.92 ± 0.24 (d)	9.3
2	37.1	+ 0.9	2.63 ± 0.34	9.5
3	32.8	+ 0.6	2.24 ± 0.23	8.9
4	34.3	0.0	2.29 ± 0.31	9.0
5	31.4	- 0.5	1.69 ± 0.34	9.5

(a) Hay 1. alfalfa-timothy-clover harvested 5/25
2. " " " " 6/9
3. " " " " 6/24
4. orchard grass harvested 5/25
5 " " " 6/29

(b) Adjusted for differences in production level among groups.
(c) Intake on 90 percent dry matter basis.
(d) Standard deviation.

Effect of Cutting Interval and Height

Kennedy (112) thoroughly investigated this aspect and came to conclusions that agreed more or less with other workers (58, 159, 183, 221). Cutting herbage at an interval of six to eight weeks resulted in the best yields whereas longer or more frequent intervals decreased yield of grass mixtures. Nitrogen, ether extract and ash content of pastures decreased when the height from which herbage was cut increased above half an inch, with increases in lignin and crude fiber contents.

On the other hand, Woodman and Evans (223) noticed no deterioration due to systems of cuttings, nor did continuous cutting lead to any falling off in quality as judged from both chemical and botanical compositions.

Season, temperature and humidity are all factors which influence the nutritive value but these again are interdependent on stage of growth (156, 159, 160).

SYSTEMS OF GRAZING MANAGEMENT

The most practical way of harvesting grasses and legumes at the peak of their nutritive value is pasturage. Livestock are wasteful in their grazing habits. Proper stocking rate and restriction of grazing to small areas to control selection, with judicious management, are factors imperative to increase efficiency of forage utilization.

Three main pasture management systems are continuous, rotational and soiling systems. Recently a more intensive type, strip grazing, which is an intense modification of rotational grazing, has come into prominence.

Though rotational grazing was practiced in England and Germany from the early 19th century, it did not receive due attention until after the World War I. It was Professor Warmbold of Germany, who popularized it, designating it as the Hohenheim system. It involved systematic rotation of animals on pasture and particularly heavy annual dressings of commercial fertilizers. Rotation has been favorably received where it is practiced by farmers since it not only increased capacity and produced more meat and milk, but it also provided for extension of the pasture season and speeded plant recuperation (3, 4, 19, 64, 100, 109, 158, 159, 7).

Rotation *versus* Continuous Grazing

Rotational grazing, also called paddock grazing, consists of confining livestock in an enclosure so small that they are compelled to utilize forage more uniformly and efficiently in a given time. The plots are grazed in succession and any excess forage harvested and utilized. Animals are turned out for a prolonged period on large areas for continuous grazing.

These two systems have been compared by a number of workers (31, 55, 90, 151, 193, 198). Brundage and Peterson (31) concluded that the rotational system yielded nearly three times as much total digestible nutrients as did the continuous system. The results of their findings are given in Table 13.

Table 13. T.D.N. production under two management systems (31).

Source of T. D. N.	Total T.D.N.		T. D. N. per acre	
	Continuous	Rotation	Continuous (b)	Rotation (c)
	(lb.)	(lb.)	(lb.)	(lb.)
Grazing	5680.9	5929.8 (5649.2) a	1183.5	3138.4
Hay	---	8312.0	---	2968.2
Total	5680.9	14241.8	1183.5	3096.2

(a) 1.8 acres of rotational pastures supplied the nutrients in parenthesis. The remainder was supplied by 6 day grazing on that part of the pasture which also produced hay and is not included in the calculations to determine T.D.N. production per acre.

(b) 4.8 acres.

(c) 4.6 acres.

While a majority of workers confirmed the advantages of the rotational system with regard to utilization and productive ability, Lassiter et al. (128), in a 13-year study of bluegrass pastures did not find any advantage under conditions of his experiment. Davis and Pratt (55) pointed out the disadvantages of the rotational system - its high cost, more management required and the necessity to graze more mature forage at certain times.

Soilage System

This system, also designated zero grazing, involves mechanical cutting and hauling forage to livestock kept in dry lot. It requires fewer acres. The land is saved from trampling and droppings and less energy is spent by animals. Both leaves and stems are utilized. However, the high cost of equipment and labor are disadvantages.

While there are conflicting reports about its efficacy, (17, 100, 107, 108, 182, 197) Myers (157) felt that soilage was best adapted to conditions where land resources are limited and labor is cheap. According to Hoglund (103), dairy farmers could decrease the pasture acreage as much as 25 to 30 per cent by using zero grazing, but one should consider whether the additional cost would yield sufficient return to offset the investment.

Rotation *versus* Strip Grazing Systems

Strip grazing, also known as break grazing, daily rotational grazing or close folding, is one-day rotational grazing. It is popular in New Zealand, England and lately in the United States.

The relative merits of each system are debatable. Wallace (215) pointed out that strip grazing enabled limited supplies of pasture to be rationed and fed off in an efficient manner over an extended period. It proved extremely useful in autumn and winter during periods of slower growth.

Holmes *et al.* (104, 105) and other investigators in England 11, 36, 70, 194, 209, 210, 211) made extensive studies comparing these two systems. They succeeded in demonstrating an appreciable increase in yield with the strip system. In one experiment this system yielded 215 and 201 cow days per acre whereas rotational system yielded 181 and 136 cow days per acre in two successive years. Similar increases in milk yield and body gains were recorded. Under the strip system the average intake was 24 pounds of dry matter compared to 28 pounds per day for the other systems were necessary for identical yields.

Brundage and coworkers (32, 33, 34, 35) stated that it was possible to compare differences in production during different grazings and differences in production from each pair of paddocks during any particular grazing as well as pertinent interactions. Strip grazing yielded decidedly better results in their studies (Table 14).

Table 14. Comparison of two systems of pasture grazing (32).

Particulars	Rotational	Strip
No. of cows	4	4
Acres	3.6	3.45
Days on pasture	75	75
Average daily production per cow		
4% F.C.M. (lb.)	28.10	33.18
Weight gain (lb.)	0.33	0.14
Average daily grain ration (lb.)	5.1	5.1
Production per acre from pasture		
T.D.N. (lb.)	1622	2061
Standard cow days	101	129

Under reasonably lenient management a given quantity of pasture yielded much the same in both systems (215) whereas under heavy grazing conditions strip system was superior. Lucas (135) postulated that stocking rate played a major role during the period of heavy growth. However, at other times, grazing management assumed a greater importance. Neither stocking rate nor management system affected milk yield, but strip grazed cows showed four to five percent lower feed intake and better gross efficiency. U.S.D.A. workers (85), comparing both the systems, found that neither total digestible nutrient yield nor animal production was significantly affected by either method. New Zealand and other American workers had expressed much the same opinion (99, 108, 115, 135, 197).

In a recent experiment Brundage (30) found that daily herbage digestibility was cyclic in rotational grazing whereas in strip grazing daily variations were greatly reduced. That the uniformity in intake was not at the expense of quality was indicated by the greater digestibility of forage in the strip system.

Multiple regression equations were computed using variables as shown below which were found to reduce significantly the variance of milk production.

Rotational grazing $Y = -.200\,T + .470\,D - .019\,W + 27.51 \pm 2.81$

Strip grazing $Y = -.057\,T - .094\,W + 133.13 \pm 2.55$

where Y = Daily F.C.M. in pounds, T = Time in days from initiation of grazing, D = Daily herbage digestibility percent and W = Daily weight in pounds.

DISCUSSION

Since it is the object of this report to suggest a method, beyond reproach, of evaluating forage under grazing conditions, it is worth while to look in retrospect. The use of the plant chromogen method for estimating digestibility is well suited to meet the needs of the situation. One of the main criticisms levelled against this method, was that it was not suited for winter forages as less chromogen was recovered in feces probably because of metabolization of chromogens in the presence of essential oils found in these forages (39). Even this could not be confirmed since it was not known whether chromogens absorbing light at 406 mμ could be metabolized.

The lignin method was frought with difficulties in sampling representative forage. Furthermore, lignin digestibility has been established beyond doubt. Saltonstall (184) had to face this problem in his experiment. He indicated that careful handpicking of similar material eaten by the animal as it grazed did not give reliable figures. Kane et al.(109) in their comparative study of different methods found that the lignin or the corrected lignin technique using total collection of feces gave significantly lower figures than the standard collection technique. On the other hand, the chromogen method with partial collection technique compared very well with the standard method.

While the fecal nitrogen method has been tested for its validity, the main objection to it was that variable proportions of metabolic nitrogen formed part of the fecal nitrogen. Furthermore, obtaining representative samples of forage was a serious limiting factor. The procedure of Reid (176) whereby the concentration of chromogen in forage was computed by a predetermined formula circumvented forage sampling, allowing estimation of digestibility under conditions simulating grazing.

A step which would save labor and time was random (grab) sampling of feces for chromogen estimation. That this could be done successfully was demonstrated by Reid. Soni _et_ _al_. (190) reported no diurnal variations in digestibility. Hardison _et_ _al_.(95) suggested fecal sampling at 6 A.M., 12 noon and 12 midnight. Estimated figures with this procedure did not significantly differ from those obtained from standard trials.

Another factor which had to be recognized is that fecal chromogen is light labile as reported by the authors themselves and confirmed by other workers who felt precautions could be taken to overcome this difficulty. The fact was pointed out by Reid that complete recovery of ingested chromogen was not essential in the computation of digestibility, provided the rate of recovery was constant for all forages. The suggestion of Raymond (171) that cold storage offered a convenient method of studying many problems of pasture nutrition might be sound in principle, but even this did not take into account the changes occurring as a result of selective grazing.

Garrigus and Rusk (81) listed several sources of error in the "clipping" technique. The lack of agreement in clipping and grazing heights biased the results. The use of yield of an adjacent plot to estimate the quantity of forage offered in the experimental plot introduced errors necessitating repetition to secure accuracy. They felt the consumption-excretion ratio could be usefully employed for estimating dry matter consumption in grazing trials.

The total animal requirement method, no doubt, was a distinct improvement over those already discussed. But even here, such factors as differences in fill, energy used in grazing, temperamental changes and environmental factors biased the results. In spite of this, it would be reasonable to argue in favor of its soundness in contrast to the clipping method which is purely empirical.

Turning to the latest methods developed, evidence adduced tilted the balance to the logical preference of the chromic oxide method. The various implications of the chromic oxide excretion pattern were discussed thoroughly. It was conclusively understood that neither intra-day variation of chromic oxide excretion, effect of time and mode of administration, nor dosage presented any serious problem in partial sampling of feces. Simultaneous estimation of digestibility and rate of consumption could then be successfully accomplished by the use of a combination of indicators - chromogen and chromic oxide. This would not only eliminate forage sampling but also total fecal collection.

It is evident from a review of literature on grazing systems that it is difficult to pinpoint which system is best. The advantages and disadvantages of any system are not static and no single system seems to fit in all farming situations. While English workers felt optimistic about the strip system in regard to increases in milk yield and weight gain, there was lack of unanimity among United States and New Zealand workers on this point.

Cornell workers (115) believed that both the systems were similar in so far as daily milk yield was concerned. Still they felt that the strip system was superior inasmuch as the herbage was more efficiently utilized. The cows on the rotational system spent considerable time moving up and down the fence line and appeared to be hungry. This gave rise to a point that if milk production was the criterion, heavy stocking rates had to be used.

On the other hand U.S.D.A. workers (85) felt that under conditions of their experiment, conventional rotational grazing offered a better solution. The similarity of efficiency in both the systems was explained on the basis of identical quantities of forage wasted, since the amounts initially available were essentially the same. The mere existence of this or that system had little bearing on the extent of grazing waste since overstocking or understocking was not necessarily eliminated by either. It was unlikely that any waste could occur from understocking in the strip system since the area is fixed on a daily basis. These workers recognized that strip grazing reduced wastes resulting from conventional rotation grazing of tall and mature crops.

Smith and Keyes (197) examined the economics of rotational and strip systems and found the average cost of producing 100 pounds of milk was $1.19 and $1.29, respectively. The factors that might have contributed to this situation were that the forages in their experiments were largely unfertilized grasses. It seems obvious that more intensive systems of management are feasible only with heavy yielding crops.

SUMMARY

Research in pasture forage has lagged mainly for want of precise measurement techniques. Chemical composition provides some index of its nutritive value. The nature of crude fiber, extent of lignification and percentage of other constituents no doubt give some indication of its nutritive worth. However, they do not reflect the true picture. Such factors as species, soil fertility, stage of growth, and other environmental conditions affect the composition of forages.

The ultimate test of pasture quality is the ability of the animal to utilize it. The greatest problems that confronted research workers were selectivity and animal variation. While the latter problem is not an insurmountable one, the challenge was successfully tackled by the use of chromogen technique. The definite mathematical relationship that existed between chromogen dry matter of feces and that of consumed forage eliminated the problem of sampling.

Measurement of forage consumption is important in the determination of pasture yields and digestibility. The clipping method, the dry matter consumption-excretion ratio method and the animal requirement methods have inherent errors and hence do not merit recommendation. The combined use of two indicators (chromogen as an index of indigestibility) and chromic oxide (as a measure of fecal outgo) hold much promise for simultaneous measurement of both intake and digestibility.

The numerous regression equations which relate chemical composition to digestibility were reviewed. The greatest limitation for adopting these is their applicability in all sets of conditions. The in vitro and in vivo techniques lately developed require further research before adoption. The primary value of any feed is to supply energy and any procedure that aids in estimating the available energy in a forage will be of much benefit. Lofgreen's conversion factor very well may be adopted for this purpose.

Efficient utilization of pasture is indispensable for maximum animal production. No particular system seems to fit in all farming situations and there is no general agreement on the advantages and disadvantages of each. Rotational grazing is acclaimed to be superior to the continuous system with regard to efficiency of utilization. Strip grazing which is a modification of rotational system provides for better utilization of growth when pastures are slowing down but moving fences and better management are charges to be reckoned with. Soiling has the disadvantage of cost of cutting and hauling herbage. Under certain conditions where labor is cheap and where land is expensive, it may be resorted to with advantage to provide feed for a large herd.

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EVALUATION OF PASTURE FORAGE

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Pastures are the least expensive sources of wholesome and nourishing feed for ruminant animals. The evaluation of the feeding value of pasture has not kept pace with that for other kinds of feeds due to inherent difficulties involved. Selective grazing and animal variation are the most serious problems that confront research workers attempting to meet this challenge. This report consists of a review of the different methods developed for forage evaluation. Literature concerning the important factors affecting the feeding value of pastures and different systems of grazing management has been critically reviewed.

Chemical composition, though a valuable indicator of the nutritive value of any feed, does not reflect the true picture since the nutrients in a feed are not utilized by the body in their entirety. Animal preference and grazing to random heights prevent accurate estimation of actual consumption since representative sampling of grazed forage is difficult to accomplish. Samples obtained from an esophageal fistula may solve this problem to a certain extent.

Measurement of digestibility, in spite of its limitations, has been generally accepted to be the most reliable criterion for evaluating feeds. Both the direct and indirect methods of estimating digestibility were reviewed and discussed. External indicators which are relatively indigestible and are nearly completely recoverable and internal indicators, naturally occurring and indigestible, can be usefully employed in digestibility measurements. Not all methods, however, are applicable under conditions simulating grazing since animals vary in their grazing behaviour as well as in their selectivity. The techniques developed, using a definite mathematical relationship between chromogen concentration in feces dry matter and consumed forage, afford the best answer to the problem under most conditions. The greatest impediment to forage sampling is overcome by this method.

Measurement of forage consumption is an important step in pasture evaluation. Several methods of measuring forage yield including clipping, animal requirement, estimation from correcting animal weight before and after grazing, animal-unit days, forage consumption, excretion ratio method and indicator method were reviewed. The combined use of two indicators, chromogen in forage employed as an index of indigestibility and chromic oxide as an index of fecal outgo, facilitates simultaneous measurement of digestibility and rate of herbage intake.

Regression of digestibility on some of the chemical constituents of pasture herbage has been established by a number of workers. Equations suitable under different conditions have been worked out. They can be usefully employed to express the nutritive values, but caution is necessary in their application, since it is doubtful that they will fit in all situations.

Recently the value of artificial rumen techniques in evaluating pastures has been investigated. Correlations between in vitro and in vivo digestibility have been established which compared favorably. They need further development to merit definite recommendation.

Total digestible nutrients, no doubt, offer a convenient means of expressing the feeding value in nutrition research though they do not strictly represent biological accuracy. Efforts were directed to find factors for converting energy values into total digestible nutrients. Lofgreen's conversion factor which was arrived at after conducting a series of digestion trials may be adopted for this purpose.

Several factors such as fertility, stage of maturity, site, soil conditions, cutting height, and other environmental factors such as season, temperature and humidity affect the feeding value of pasture fofage. The more recent literature concerning these was reviewed and discussed.

In order to realize the maximum production from pastures, it is imperative that they should be efficiently utilized. Since livestock are wasteful in their grazing habits a system of grazing management which will yield maximum results should be adopted. Different systems of grazing management such as continuous, rotational, strip and soilage systems and their relative merits were discussed. No particular system fits in all situations and there is no general agreement on the advantages and disadvantages of each. Proper stocking rate with sound management is essential for maximum exploitation of pastures. However, a majority of workers have pointed out the superiority of strip grazing over the rotational system for good pastures. Under certain circumstances, when labor is cheap and land is limited, the soilage system may be adopted to advantage.