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To the Graduate Council:

I am submitting herewith a dissertation written by Atalla Said Mohammed entitled "A Comparison of Different Methods Which Estimate Nutritive Value of Forages." I recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Animal Science.

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# A COMPARISON OF DIFFERENT METHODS WHICH ESTIMATE NUTRITIVE VALUE OF FORAGES

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A Dissertation

Presented to

the Graduate Council of

The University of Tennessee

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In Partial Fulfillment

of the Requirements for the Degree

Doctor of Philosophy

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by

Atalla Said Mohammed

June 1966

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# CHAPTER I

## INTRODUCTION

In recent years, the demand for forages in the world has greatly increased. In developing nations, the population increase is so rapid that more of the grain is used for human consumption, while in developed nations beef consumption is rising rapidly. For profitable cattle and sheep production an abundance of good quality forages is essential. In order to differentiate good forages from poor ones, it is mandatory to have good methods of determining forage quality.

In the past, this has mainly been achieved with feeding experiments and digestibility trials. Recently, the amount of the forage that is voluntarily consumed by ruminant animals has been recognized as another important factor in determining its quality. Furthermore, several laboratory methods are becoming increasingly useful in the determination of nutritive value of forages, since they are less costly, less time-consuming, and require a smaller amount of test material. These laboratory (or *in vitro*) methods will probably not replace *in vivo* experimentation completely. They are only an estimation of the results obtained from animals, and the degree with which they estimate these animal results has to be determined carefully before they can be of general usefulness.

The major objective of this investigation, therefore, was to determine how close various laboratory methods come to estimate results

obtained directly from animals. Secondary objectives were to determine the nutritive value of three grades of alfalfa hay, to compare cattle and sheep in their ability to digest these three alfalfa hays, and to determine the relationship between the Total Digestible Nutrient (T.D.N.) and the Digestible Energy (D.E.) methods of feed evaluation, using these three alfalfa hays.

# CHAPTER II

# REVIEW OF LITERATURE

## I. DIGESTIBILITY DETERMINATIONS

Nutrients in the feces represent the greatest fraction of feed nutrients which is unavailable to the animal. Therefore, digestion data have been used extensively to evaluate the nutritive value of forages, since digestibility is calculated from feed-feces differences. However, Crampton et al. (1960) stated that the usefulness of quantitative digestibility data is limited because neither T.D.N. nor the digestibility of calories consistently describe the effective feeding value of forages as measured by the performance of animals subsisting on the forage. One reason for this might be that measurements of the extent of digestibility do not depend on or include consideration of the total intake of the feed, a factor importantly concerned with the relative feeding value of forages.

### Total Digestible Nutrients

The T.D.N. system has been in existence for a long time. During this time, it has been subjected to many modifications. Browne (1940) reports that Henneberg and Stohmann at the Weende experiment station in Germany developed this system of feed evaluation based on the content of protein, fat and two carbohydrate fractions in the year of 1863. Atwater (1890) indicated that by 1880 the German feeding standards of

formulating rations on the basis of their chemical composition had been in common use in the United States. He also cited Rubner's factors for calculating the potential energy value of nutrients (4.1 kilocalories per gram for carbohydrates, 4.1 for protein and 9.3 for fat).

Hills (1900) considered the higher calorie value of fat, and therefore multiplied fat by 2.25 and added this value to the digestible carbohydrages. The final formula,

T.D.N. = dig. protein + dig. carbohydrates + dig. fat x 2.25

resulted in 1910 (Maynard, 1953), when digestible protein was also included. Maynard reviewed the development of the T.D.N. system of feed evaluation and stated that as it is calculated now it is a better measure of feeding value than when it was first developed. However, it is still a shifting base for any calculation or comparison.

Although T.D.N. is the most popular method in the United States for evaluating the nutritive value of feeds, it is criticized by many workers. In the T.D.N. calculation, the multiplication of fat by the factor 2.25 and all nitrogen values by 6.25 is not justified. Mitchell (1942) reports that the apparent digestibility of ether extract in rations which are high in roughages is of little significance, because it contains substances which are not triglycerides and therefore have little nutritive value. Also, much of the ether extract in the feces is of metabolic origin, therefore the digestion coefficients for it are too low. Since nitrogen-free extract is not determined, it accumulates the total error in the T.D.N. determination (Maynard and Loosli, 1962).

Digestible Energy

D.E. derived from the determination of the energy content of the feed minus that of the feces in a bomb calorimeter is considered simple, time saving and accurate. The replacement of T.D.N. by D.E. was first advocated by Overman and Gains (1933). Both systems of feed evaluation are closely related. From various investigations in which both T.D.N. and D.E. had been obtained from the same digestion trials, Swift (1957a) examined 96 values and calculated the very high correlation coefficient of 0.97. This also corresponds with the work of Markley (1958) who obtained a correlation coefficient of 0.86, and with that of Barth et al. (1959a) who reported coefficients of 0.95 and 0.87 between the two methods of forage evaluation.

Lofgreen (1951) agrees with regard to the superiority of D.E. to T.D.N. He suggests the determination of D.E. and its subsequent conversion to T.D.N. values. To obtain the T.D.N. value, the digestion coefficient for energy is multiplied by this factor:

$$F = \frac{OM}{100} \times \frac{100 = (EE \times 2.25) - EE}{100}$$

where OM is the per cent organic matter in the feed and EE is the per cent ether extract in the organic matter. The factor 1,987 digestible calories per pound of T.D.N. was suggested by Maynard (1953).

Based on digestion studies with swine, Crampton et al. (1957) stated that there is a close correlation between T.D.N. and D.E. because these are merely numerical measurements of an identical biological function. They indicated that the relationship of T.D.N. and D.E.

values cannot be expressed by a single factor and presented the following equation for the calculation of the caloric value of T.D.N.:

Calories per gram of T.D.N. =

$$\left.\begin{array}{l}\% \text{ protein} \times 5.65) \\ \% \text{ fat} \times 9.3 \quad ) \\ \% \ CH_2O \times 4.3 \quad )\end{array}\right. \times (1.018 - 0.0105 \% \text{ fat})$$

Swift (1957b) obtained data from digestion trials with cattle fed either forages alone or grain with forages, and from sheep fed only forages. He calculated conversion factors of 1,998, 1,982 and 2,007 kilocalories per pound of T.D.N., respectively, and suggested a constant T.D.N.-D.E. conversion factor of 2,000 kilocalories per pound of T.D.N. for ruminants. He compared this to a conversion factor suggested by Brody et al. (1934) which was 1,814 kilocalories per pound of T.D.N. However, Barth et al. (1959b) indicated that Brody's factor expressed the caloric value of T.D.N. in terms of metabolizable energy. Therefore, this factor does not seem to be applicable to the present problem of converting T.D.N. to D.E.

Barth et al. (1959b) presented the following regression equation which predicts the caloric value of T.D.N. in forages, using per cent digestible protein as an additional variable:

Calories per gram of T.D.N. =

$$4.343 + 0.0199 \times \% \text{ digestible protein}$$

They also calculated coefficients of determination between the experimentally determined D.E. values and each of its corresponding calculated values, and reported a very high correlation (0.96). Heany and Pigden (1963) stated that D.E. is one of the most accurate and acceptable

single methods of expressing the potential nutritive value of forages. They found a very close relationship between D.E., T.D.N., Digestible Organic Matter (D.O.M.) and Digestible Dry Matter (D.D.M.) of forages. They agreed with Barth et al. (1959b) that caloric value of T.D.N. is not a constant, and that the average conversion factors now in use should be discontinued because they will not yield satisfactory estimates of D.E. from T.D.N. over a wide range of forage quality.

Comparative Nutrient Digestibility by Two Species of Ruminants

A comparison of the digestive powers between cattle and sheep has practical application. If nutrient digestibility of the two species is the same or not significantly different, then digestion coefficients obtained from one species could be applied to the other species. The existing results in this field are not in agreement.

No significant differences between the digestive power of cattle and sheep were reported by Watson et al. (1948), Forbes and Garrigus (1950) and Swift and Bratzler (1959). Baumgardt et al. (1964a) found no significant differences in nutrient digestibility between cattle and goats.

In contrast to these workers, Hamilton and Kick (1928) fed two hays and reported that steers digested nutrients better than sheep. Bartlett (1904) reported that steers had a greater capacity for digesting coarse fodders low in protein, like timothy hay and corn fodders, than sheep. Rations higher in protein were digested by sheep as well or in some cases better than by cattle. He stated that if sheep are to be

used to determine coefficients for bovines, great care should be taken to select strong animals that are good feeders and will eat coarse feeds readily, otherwise, results which are too low are likely to be obtained. Forbes et al. (1937) and Cippolloni et al. (1951) stated that greater accuracy will be obtained if digestibility data to be used for cattle are obtained with cattle and similarly for sheep.

Alexander et al. (1962) conducted a series of digestion trials with wethers and steers fed seventeen different rations. He reported highly significant correlations between sheep and cattle digestion for all components. When all rations were averaged, hay of low quality or low protein content was digested better by sheep than by cattle. This is in contrast to results reported by Bartlett (1904). However, with some feeds, cattle digested the fibrous components of low quality roughages better than sheep. Within species variations were often greater for sheep than for cattle which is in agreement with the results of Bartlett (1904) and Jordon and Staples (1951) who reported that digestion coefficients of steers showed less variation than those from lambs. Van Dyne and Lofgreen (1964) reported that sheep always digested more crude protein and less cellulose than did cattle.

Working with corn silages, Wilson (1964b) reported no statistically significant differences in dry matter digestibility between cattle and sheep. However, wethers had significantly higher average digestibility coefficients for crude fiber, ether extract and nitrogen-free extract. The digestion coefficients of crude protein were higher in the steers.

A well-controlled experiment was conducted by Vander Noot et al. (1965), in which cattle and sheep digestion coefficients of eight grass and grain silages were compared. Sheep were statistically more efficient in the digestion of dry matter, N-free extract and fiber in large-grain silages, and also in protein of both large- and small-grain silages. Differences observed for energy digestibility between steers and wethers were negligible with all silages except large grain, in which wethers were superior. High protein forages, such as legume silage, were equally well digested by cattle and sheep, except for N-free extract in which cattle were superior.

In summary, it appears that in some instances there seemed to be no differences between the digestive power of cattle and sheep. When small differences were found, the only consistent results appeared to be the superior digestion of fibrous or low-nitrogen forages by steers, and possibly a somewhat higher digestion of some nutrients in high-quality forages by sheep. Contrasting results may be attributed to differences of rations, age of animals, small numbers of animals and dissimilar environments.

## Forage Components as Predictors of Digestibility

Schneider et al. (1951) presented equations for estimating the digestion coefficients for all components in feeds, using their percentages of crude protein, crude fiber, nitrogen-free extract and ether extract as predicting factors. Sosulki and Patterson (1961) found a relationship between crude protein (P), lignin (L) and D.E. The average of two equations was D.E. = 77.3 - 4L + 1.37P.

Sullivan (1964) reported that the crude protein content of hays showed a high positive correlation with dry matter and protein digestibility. He presented the following equation to calculate the digestible protein from crude protein

$$Y = -3.52 + 0.94\ X$$

where X is the per cent of crude protein and Y is digestible protein. A high positive correlation between crude protein content and its apparent digestibility *in vitro* was also reported by Baumgardt *et al.* (1962b).

Meyer and Lofgreen (1956) conducted 152 digestion trials on 31 samples of alfalfa hay of varying quality. Nitrogen content was not as closely correlated with T.D.N. as was crude fiber or lignin content. They also obtained high correlations between crude fiber content and digestibility of organic matter. A negative correlation was also reported between the per cent crude fiber in grasses with the digestibility of crude fiber, a relationship that did not exist in alfalfa.

Norman (1935) stated that the digestibility of any normal plant material is inversely proportional to the degree of lignification or its lignin content; therefore, an essential requisite of any method for evaluating more resistant cell wall material is to consider lignin content. Crampton and Maynard (1938) proposed chemical methods for the determination of lignin and of cellulose in feeds and feces. They also indicated that this partition of the carbohydrates may have more biological significance, and hence, be of greater usefulness in predicting feeding value than the present division into crude fiber and nitrogen-free extract.

Phillips and Loughlin (1949) showed that lignin content is negatively correlated with the digestibility of energy in both timothy and alfalfa hay, and that it is an excellent basis for calculating digestibility in each of the plant species. Lignin content was also used successfully by Meyer and Lofgreen (1956) to estimate the energy of digested organic matter. Sullivan (1955, 1964) stated that the lignin content is of great value in evaluating forage. He found that the negative correlation coefficients between lignin content and dry matter or organic matter digestibility were very high. Simkins and Baumgardt (1963) evaluated six laboratory methods. They obtained a highly significant negative correlation between detergent lignin and dry matter digestibility for 30 silages. In a subsequent study conducted at the same laboratory, Baumgardt and Hi Kon Oh (1965) used samples of 59 forages and compared the following methods as estimators of in vivo dry matter digestibility: cellulose digestion in vitro, dry matter digestion in vitro, cellulose solubility in cupriethylene diamine, dry matter solubility, crude protein, acid detergent fiber, acid insoluble lignin and cell wall content. All correlations were highly significant; however, the lignin content of the forages gave the most satisfactory correlation.

From the data of 30 different forages, Van Soest (1965a) derived the following prediction equation for dry matter digestibility:

$$D.D.M. = 0.98\ S + W\ (147.3 - 78.9 \log L) - 12.9$$

where S is available cell contents, L is lignin content, which controls cell wall constituents (W) digestibility.

Tomlin et al. (1965) determined in vitro cellulose digestibility of different forages at 6, 12, 24, 30 and 48 hours of fermentation. Lignin content was negatively correlated with in vitro cellulose digestibility at the 12-hour time period for grasses and for legumes, but the regression equations for the legumes and for the grasses were significantly different from each other. This agrees with results obtained by Van Soest (1965b) who stated that alfalfa is usually eaten in larger amounts and also has a higher lignin content than grass species of comparable digestibility. This fact has provided one of the problems in using lignin to predict digestibility.

Forage Solubility as Predictor of Digestibility

Recently, various methods have been investigated which determine the solubility of forages in various solutions and attempt to relate this solubility with forage digestibility. Thus, Thurman and Wehunt (1955) reported a short laboratory method for determining Digestible Laboratory Nutrients. The procedure involved autoclaving ground samples in dilute hydrochloric acid and weighing the dried insoluble residue. However, Baumgardt et al. (1962a) and Simkins and Baumgardt (1963) reported that the value for Digestible Laboratory Nutrients was not significantly correlated with any of their digestibility data.

Another method based on solubility was developed by Dehority and Johnson (1963). This method was based on the solubility of forage cellulose in cupriethylene diamine as an estimate of forage digestibility. Solubility values obtained were significantly correlated with

*in vivo* and *in vitro* cellulose digestion, as well as with *in vivo* dry matter and energy digestibility. Using a third solubility method, Dehority and Johnson (1964) found that the dry matter solubility of forages in normal sulfuric acid was significantly correlated with their dry matter digestibility and energy digestibility *in vivo*.

Artificial Rumen Studies

Studies on the role of rumen microorganisms in the nutrition of ruminants led to the development of artificial rumen techniques. Many techniques and modifications of techniques have been developed, the primary goal of which was the determination of cellulose digestion *in vitro*.

Early artificial rumen techniques involved the use of whole rumen liquid as inoculum. Their main application appears to be in the estimation of the nutritive value of forages. Marston (1948), Louw *et al.* (1949) and Burroughs *et al.* (1950) first suggested the use of the artificial rumen techniques for measuring the feeding value. They stated that this method of forage evaluation might best be used as a screening device of important factors influencing rumen physiology from which the most promising results and actual applications can be checked in animal experimentations. Kamstra *et al.* (1955) showed that 48-hour *in vitro* and *in vivo* cellulose digestion values were of similar magnitude. Likewise, Pigden and Bell (1955), using 11 forages, obtained a close agreement of the per cent organic matter digested by sheep and the per cent anthrone carbohydrate fermented *in vitro*.

Barnett (1957) reported a similar study in which a reasonable degree of correlation was obtained between cellulose digestion *in vitro* of 27 samples of silage and their digestibility of the crude fiber *in vivo*. Hershberger *et al.* (1959) compared the cellulose digestibility of 35 hays *in vitro* and *in vivo*. Data obtained from their *in vitro* system which utilized whole rumen liquor, all-grass fermentation vessels and a 24-hour fermentation period, were compared to cellulose digestion coefficients obtained from sheep *in vivo*. They used orchard grass, Kentucky bluegrass, timothy, alfalfa and ladino clover hays as experimental rations, and found a correlation coefficient of 0.97 indicating a very close linear relationship between cellulose digestion *in vitro* and *in vivo*. They also reported a correlation coefficient of 0.92 between cellulose digestion *in vitro* and the D.E. *in vivo* of these forages.

Quicke *et al.* (1959) compared the digestibility of the cellulose of seven grass and six legume hays *in vitro* to results obtained from digestion trials with sheep. They found no significant difference between *in vitro* and *in vivo* coefficients of grass hays, but in some of the legume hays, cellulose digestibilities, as measured by two methods, were significantly different. These workers also suggested the possible use of *in vitro* techniques as tools in the evaluation of the nutritive value of forages. Based on a very extensive study in which digestibility data of 124 forages had been obtained with cattle and sheep, Reid *et al.* (1960) reported highly significant correlations between *in vitro* digestible cellulose at 36 hours and *in vivo* D.D.M. or energy.

More recently, *in vitro* dry matter digestibility has been investigated as an estimator of forage quality. Bowden and Church (1962) stated that the within trial variation of *in vitro* dry matter digestibility for all substrates digested at 48-hours was generally small while *in vitro* cellulose digestibility showed a slightly higher variability within trials. Variability of digestion coefficients between trials, estimated by including a standard alfalfa in every trial, indicated differences in the digesting capacity of rumen liquor collected from the same steer on different days. Likewise, Smith *et al.* (1965) reported that *in vitro* D.D.M. values were significantly correlated with *in vivo* digestibilities of dry matter, organic mater, energy and protein, and concluded that the *in vitro* fermentation procedure has a definite application in estimating the relative nutritional value of forages.

An alternate artificial rumen technique, regarding the type of inoculum, was developed by Cheng *et al.* (1955). Instead of using whole rumen liquid, washed suspensions of rumen microorganisms were used as inoculum. They stated that this alternate *in vitro* method is more applicable in determining requirements of rumen microorganisms such as minerals, vitamins and unidentified growth factors, in the elucidation of biochemical reactions in the rumen, and in the study of conditions necessary for maximum utilization of cellulose by rumen microorganisms. However, Van Dyne (1962) reported that inocula prepared by simply straining rumen contents through several layers of cheesecloth gave high and as uniform cellulose digestion values as did more elaborate procedures of processing the inoculum.

In reviewing *in vitro* digestibility work, Barnes (1965) stated that realistic estimates of digestibility can be obtained by *in vitro* techniques where forages are compared to each other in the same trial. However, a standard method remains to be established before reliable comparisons of *in vitro* results can be made between laboratories.

## II. VOLUNTARY INTAKE STUDIES

Recently, there has been renewed interest in determining the amount of a forage that an animal will voluntarily consume, since intake of a forage has a greater effect on animal response than its digestibility (Crampton, 1957; Byers and Ormiston, 1962; and Ingalls *et al.*, 1965). Morrison (1956) also mentioned that the magnitude of the gains made by animals on a specific ration is influenced by the quantity consumed and by the nature of the rations. There are factors which appear to be characteristic of specific roughages that limit Voluntary Intake, and this appears to be common knowledge among cattle and sheep feeders (Crampton *et al.*, 1960).

### Factors Affecting Voluntary Intake

Many factors have been suggested which influence Voluntary Intake. Crampton *et al.* (1960) are in agreement with Blaxter *et al.* (1961) and Balch and Campling (1962) in suggesting that food intake is regulated by rumen load which is a function of the rate of degradation of cellulose and hemicellulose, which in turn depends on the rate of passage of the forage. Baumgardt (1965) has recently shown that, at least with diets

consisting entirely or mainly of roughages, physical distension of the reticulo-rumen is an important factor, though probably not the only one, regulating Voluntary Intake. This is in agreement with results reported by Van Soest (1965b) and Montgomery and Baumgardt (1965) which support the hypothesis that ruminants will adjust Voluntary Intake in relation to the physiological demand for energy, if fill does not limit their intake. They indicated that with feeds of high nutritive value animals are able to consume enough dry matter to satisfy their physiological needs for energy, whereas with low nutritive value feeds, rumen load prevents the animal from consuming the amount of energy that its physiology demands.

Other factors, such as physical form, were reported to have an effect on Voluntary Intake. Buchman and Hemken (1964) determined the relative rates of voluntary consumption of chopped and ground pelleted alfalfa hay cut at different stages of maturity. Their result indicated that grinding and pelleting depressed digestibility but increased intake except for intake of the early cut hay. On the other hand, Reid et al. (1959) stated that the quality of forage depends upon the rate at which it is consumed and its energy value per unit of weight. They also emphasized that the date on which first growth forages are harvested is the major known determinant of the intake and digestibility of forages by ruminants.

Conrad et al. (1962, 1964) stated that with high roughage rations with 67 to 80 per cent dry matter digestibility, intake decreased with increasing digestibility. They concluded that physical and physiological

factors regulating feed intake change in importance with increasing digestibility. At low digestibility these factors were body weight, undigested residue per unit of body weight per day and dry matter digestibility. At higher digestibility, intake appeared to be dependent on metabolic size, production and digestibility.

Thomas et al. (1961) suggested that the dry matter content of the forage when ensiled and the resulting differences in fermentation appear to be the major determinants of the amount of dry matter consumed rather than the dry matter content of the silage per se, even though there is a positive relationship between the dry matter content of silages and their rate of consumption. Gordon et al. (1965) also observed higher dry matter intake with increasing levels of dry matter within and among alfalfa silages. However, this response was less precise at a dry matter content above 50 per cent. Ward et al. (1965) stated that the close relationship between dry matter intake and dry matter content of silage dictates that moisture content be held constant or corrected for when evaluating silages with cattle.

Miller et al. (1965) investigated if feeding two types of unlike forage in combinations would have a favorable combining effect on Voluntary Intake and cow performance. They fed three groups of six lactating dairy cows either grass-legume silage ad libitum; succulent pasture ad libitum; or a combination of silage ad libitum plus 1 hour of pasture daily. They reported that weight gains and forage consumption of the cows fed the combination of forages were significantly greater than expected, however, digestibility was not affected by the combination.

Mechanisms Regulating Voluntary Intake

Donefer et al. (1963) conducted an experiment with sheep using five completely pelleted rations consisting of the following alfalfa-barley ratios: 100:0, 85:15, 70:30, 55:45 and 40:60. As the amount of barley increased, the relative intake decreased. Their results indicated that animals consumed according to their energy needs. These workers offered a possible explanation involved in regulating food intake: with changing concentrate ratio the microbial population will be changed. Thus, the shift toward soluble carbohydrate fermentation may produce a lower rumen pH which causes inhibition of cellulolytic bacterial activity. As a result, there will be a decrease in the breakdown in fibrous portion of the feed and a decrease in consumption due to rumen capacity. Baumgardt et al. (1964b) also fed ad libitum pelleted ration consisting of the following alfalfa meal-corn ratios: 100:0, 80:20, 60:40 and 40:60. Calculations of gastrointestinal tract fill, based on rate of passage curves, suggested that distention did not limit intake.

Eng and Riewe (1964) studied the effect of varying cracked corn and chopped coastal Bermuda hay rations on Voluntary Intake. They used rations consisting of the following cracked corn-chopped coastal Bermuda hay ratios: 1:3, 1:1 and 3:1. The correlation between intake and dry matter digestibility were -.82, -.89 and -.71, respectively. Concentrate: roughage ratio and level of intake significantly affected dry matter digestibility.

In non-ruminants, it is believed that blood glucose regulates intake. However, the blood of ruminants contains less glucose and more acetate than that of non-ruminants. Since the end product of cellulose breakdown is mostly acetic acid, the possible substitute for glucose as intake regulating substance in ruminants may be acetic acid (Manning et al., 1959). Dowden and Jacobson (1960) reported that the regulation of intake in ruminants may depend on any of several metabolites. These workers indicated that one possible mechanism of regulation of intake involves the absorption of acetic acid and propionic acid into the blood stream which at certain levels would cause a chemoreceptor response and thereby inhibit intake. This was in agreement with results reported by Montgomery et al. (1963) and Baumgardt et al. (1964b). Since silages contain significant amounts of acetic and propionic acids, the above mechanism may account for the observation that dairy cattle consume less forage in form of silage than in form of hay.

The central nervous system is responsible for regulating food intake, and two areas of the hypothalamus play an important role. The ventromedial nuclei act as the "Satiety center" and the lateral hypothalamic nucleus acts as the feeding center. The animal consumes feed until a certain signal is relayed to the ventromedial nuclei. The stimulation of ventromedial nuclei results in satiety. When the food is digested thus, it causes a deactivation of the ventromedial center. As a result, some type of signal is relayed to the lateral hypothalamic nucleus, causing a stimulation of this area and producing the feeling of hunger. (Balch and Campling, 1962; Montgomery, 1965; and Conrad, 1966.)

Thermoreceptors exist in the hypothalamus, located in an area different from the lateral and ventromedial nuclei. The thermostatic regulatory mechanism is similar to that in the central nervous system. Davis and Merilan (1960) reported a considerable decrease in consumption with 90° F. and 40 per cent relative humidity or 90° F. and 50 per cent relative humidity, while animals exposed to cold tend to increase consumption. Armstrong and Blaxter (1957) stated that there is a possibility that a thermo-regulatory mechanism controls feed intake along with other mechanisms. Balch and Campling (1962) concluded that the Voluntary Intake of roughages by ruminants is related to the amount of digestion in the reticulo-rumen at certain times. However, when diets consist mainly of concentrates, Voluntary Intake is regulated by factors other than the rate at which the food disappears from the reticulo-rumen. Therefore, it seems probable that both a thermostatic and a chemostatic regulatory mechanism controls the regulation of food intake; however, direct evidence for this is inadequate.

## Prediction of Voluntary Intake

Relative intake is often predicted from short-term *in vitro* fermentation studies. Studying forages, Donefer *et al.* (1960) correlated the 12-hour *in vitro* cellulose digestion with Voluntary Intake ($r = 0.83$), whereas the 24-hour *in vitro* cellulose digestion was highly correlated to per cent *in vivo* digestibility ($r = 0.87$). Bratzler (1961) indicated that a correlation exists between intake of forage and *in vitro* coefficients obtained between 4 and 16 hours of fermentation and that

the forage species has a pronounced effect on this relationship.

Johnson et al. (1962) studied four grass hays at two stages of maturity. They reported that cellulose and dry matter digestibility after a 12-hour fermentation period was significantly correlated with relative intake. Karn et al. (1964) conducted rumen fermentation for 5, 8 and 11 hours on 65 forage samples consisting of grasses, alfalfa and mixed forage. They correlated per cent cellulose and dry matter digested in vitro with in vivo measurements of relative intakes, dry matter digestion, protein digestion and energy digestion. They found that the rates of cellulose or dry matter digestion between 5 and 8 hours were the best predictors of relative intake and Nutritive Value Index.

Chalupa and Lee (1966) determined the possibility of estimating Voluntary Intake from 6, 12 and 18 hours in vitro cellulose fermentation studies. Cellulose digestion at 18 hours was significantly correlated with relative intake ($r = 0.74$), whereas the 30 hours digestion value was significantly correlated with D.E. ($r = 0.91$), T.D.N. ($r = 0.88$) and D.D.M. ($r = 0.94$).

Van Soest (1965b) stated that one would expect a short fermentation time to correlate more highly with intake but that the optimum fermentation time for the prediction of Voluntary Intake may not be the same with different species of forage. Reid et al. (1960) fed eight hays ad libitum to mature wethers to determine Voluntary Intake and digestibility. They calculated the in vitro cellulose digestibility at intervals of 4, 8, 12, 20, 32 and 48 hours. Cellulose digestion between

24 and 48 hours was highly correlated with *in vivo* dry matter digestibility. No consistent relationship between Voluntary Intake and rate of cellulose digestion was observed. However, in a later publication, these investigators (Reid and Jung, 1965) reported a correlation coefficient of 0.90 between 12 hours *in vitro* cellulose digestion and *ad libitum* intake.

Various investigations have suggested the use of specific components in forages as predictors of Voluntary Intake. The per cent lignin content of a forage appears to be one of the most promising components. Van Soest (1964) stated that in forages where Voluntary Intake and digestibility are unrelated, chemical measures of digestibility such as fiber and lignin yield positive correlations with Voluntary Intake. As early as 1950, Forbes and Garrigus reported that data obtained in trials with steers show that for each unit increase in forage lignin content, there was a decrease of 5.8 per cent of maximum intake in total organic matter and 8.2 per cent in the D.O.M. intake. The corresponding figures obtained in trials with wethers were 6.8 per cent and 9.5 per cent, respectively.

Reid and Jung (1965) indicated that significant correlations with *ad libitum* intake were obtained with cell-wall components ($r = -.69$) and with acid insoluble lignin ($r = 0.62$), while the correlation of cell-wall components with D.D.M. was not significant. Examining 96 forages of grasses and legumes in a very extensive study, Van Soest (1965b) and Van Soest and Marcus (1964) found total correlations of -.65 and 0.73 between Voluntary Intake on one hand and

cell-wall constituents and lignin, respectively, on the other. However, they stated that there was not a significant relationship between cell-wall constituents and Voluntary Intake in forages with cell-wall contents of less than 60 per cent of dry matter. Above 60 per cent there was a marked decrease in Voluntary Intake with increasing cell-wall contents. They further stated, that the relationship between Voluntary Intake and chemical components is very high in some plant species like orchard-grass, bromegrass and sudangrass, but in other species like alfalfa, bluegrass, and perhaps timothy, this relation is confounded and yields a low correlation.

Some promising results have been obtained from the use of other chemical components as predictors of Voluntary Intake. Hawkins et al. (1964) found a positive correlation between daily intake per 100 pounds of body weight of 15 samples of coastal Bermuda grass and its crude protein and ash content. But Okamoto et al. (1964) were unsuccessful in relating silage dry matter intake to histamine concentration of the silage.

Dehority and Johnson (1963) developed a chemical method, based on the solubility of forage cellulose in cupriethylene diamine, to estimate Voluntary Intake of forages. Solubility values obtained were significantly correlated with relative intake. In a later study, Dehority and Johnson (1964) found that the dry matter solubility of a forage in normal sulfuric acid was significantly correlated with relative intake and other factors. The correlation between solubility and in vivo measurements varied considerably depending on which class of forage

and which *in vivo* measurement were being considered.

Troelsen and Bigsby (1964) carried out artificial mastication on samples of 14 hays that had been fed to sheep. The relationship between feed intake and particle size indexes was expressed by a correlation of 0.94. They illustrated how closely intake could be estimated from the particle size index and supported the theory that rate of breakdown of forage affected feed intake.

It is evident from the literature that most investigators obtain satisfactory estimates of Voluntary Intake either from short-term *in vitro* fermentation determinations, from solubility studies, or from certain chemical components of the forage. However, optimum fermentation times for prediction of Voluntary Intake might not be the same for different plant species.

In contrast, Van Soest (1964) stated that methods which are essentially measures of digestibility, such as crude fiber content and *in vitro* fermentation techniques have little hope of being adequate estimators of intake, especially in forage species which show a tendency to contain factors that inhibit intake in the immature plant.

## III. NUTRITIVE VALUE INDEX

Feeding trials are considered the most useful method to evaluate the nutritive value of feeds in terms of practical animal performance. Therefore, it is of interest to determine the relative importance of all factors known to influence animal performance. In the past, much emphasis has been placed on the importance of the digestibility of a feed and

its effect on animal performance. However, recently the extent of the Voluntary Intake of a feed is considered to be of equal or greater importance than its digestibility.

Crampton et al. (1960) reported that the relative influence of the Voluntary Intake of a forage and its energy digestibility on actual animal performance is 70 per cent and 30 per cent, respectively. This is in agreement with Byers and Ormiston (1962) who stated that the amount of forage voluntarily consumed has a greater effect on animal response than D.E.

Therefore, these investigators proposed that Nutritive Value Index, which is the product of both Voluntary Intake and energy digestibility, is the best indicator of animal performance. Correlation coefficients between animal performance and Nutritive Value Index ranged from 0.88 to 0.94. Using individual animal values, Ingalls et al. (1965) obtained the lower coefficient of 0.59.

Prediction of Nutritive Value Index

Donefer et al. (1960) conducted in vitro cellulose digestion trials using 3-, 6-, 12-, 24- and 48-hour fermentation periods. They reported that results obtained after 12 hours of fermentation were highly correlated with Nutritive Value Index, while results obtained after 24 hours of fermentation were highly correlated with energy digestibility in vivo. Therefore, they proposed that 12-hour in vitro cellulose digestibility be used as an estimator of Nutritive Value Index. Reid and Jung (1965) obtained a correlation coefficient of 0.79 between

12-hour *in vitro* cellulose digestibility and Nutritive Value Index. Chalupa and Lee (1966) reported that Nutritive Value Index could also be estimated from the product of the 18-hour cellulose digestibility *in vitro* (an estimator of Voluntary Intake) and the 30-hour cellulose digestibility *in vitro* (an estimator of total digestion).

In summary, it appears that short-term *in vitro* digestion coefficients of cellulose or dry matter alone or as their product with *in vivo* D.E. are acceptable predictors of the Nutritive Value Index. However, Van Soest (1965b) stated that Nutritive Value Index can only be predicted with some accuracy in forage species where the relation between Voluntary Intake and chemical components is high.

# CHAPTER III

## EXPERIMENTAL PROCEDURE

Three alfalfa hays of different quality were used for steer feeding and steer and wether digestibility trials. In addition, various laboratory determinations were conducted with these three alfalfa hays in an attempt to arrive at predictors of nutrient digestibility, Voluntary Intake and animal performance. For the laboratory determinations, eight silage samples were also included (Wilson, 1964a; Wilson, 1964b; and Anderson et al., 1966), which had previously been used in this laboratory in feeding and digestibility trials. The chemical composition, digestibility data and results of the feeding trials of these eight silage samples are reported in Tables I and II.

### I. ALFALFA HAYS

The hays used in this experiment were chosen to represent three distinct qualities: i.e., good, fair and poor. They were selected from different sources and locations and scored according to a hay scoring scheme developed by Burns (1965). A description of the physical characteristics of the hays is presented in Table III.

TABLE I

CHEMICAL COMPOSITION OF THE SILAGES USED IN THE VARIOUS LABORATORY METHODS

| Silage | Low Nitrated Corn Silage[a] | High Nitrated Corn Silage[a] | Corn Silage[b] | Alfalfa Silage[b] | Corn 1st Cut[c] | Corn 2nd Cut[c] | Corn 3rd Cut[c] | Corn 4th Cut[c] |
|---|---|---|---|---|---|---|---|---|
| Dry matter | 28.3 | 25.1 | 26.3 | 22.8 | 23.3 | 25.9 | 29.8 | 32.7 |
| Organic matter | 23.9 | 20.1 | 22.7 | 12.4 | 17.3 | 19.8 | 23.2 | 25.0 |
| Crude protein | 8.2 | 8.4 | 9.0 | 16.3 | 11.1 | 11.1 | 10.5 | 9.7 |
| Ether extract | 3.0 | 2.7 | 2.7 | 4.1 | 1.4 | 1.6 | 1.8 | 1.2 |
| Crude fiber | 25.3 | 23.8 | 24.0 | 30.6 | 24.7 | 23.7 | 24.1 | 27.7 |
| Nitrogen-free extract | 59.2 | 60.1 | 60.7 | 38.5 | 56.9 | 57.7 | 57.1 | 53.7 |
| Ash | 4.4 | 5.0 | 3.5 | 10.5 | 6.0 | 6.1 | 6.6 | 7.7 |
| Lignin | 3.9 | 3.7 | 4.0 | 8.9 | 3.9 | 4.0 | 3.9 | 4.7 |

[a]Wilson (1964b).

[b]Wilson (1964a).

[c]Anderson et al. (1966).

TABLE II

AVERAGE DAILY GAINS AND DIGESTIBILITY OF THE SILAGES USED IN THE VARIOUS LABORATORY METHODS

| Silage | Low Nitrated Corn Silage[a] | High Nitrated Corn Silage[a] | Corn Silage[b] | Alfalfa Silage[b] | Corn Silage 1st Cut[c] | Corn Silage 2nd Cut[c] | Corn Silage 3rd Cut[c] | Corn Silage 4th Cut[c] |
|---|---|---|---|---|---|---|---|---|
| Digestible dry matter, % | 68.2 | 69.4 | 71.1 | 59.0 | 68.9 | 68.0 | 66.4 | 66.7 |
| Digestible organic matter, % | 68.8 | 71.3 | 71.8 | 59.3 | 70.8 | 69.2 | 67.5 | 68.1 |
| Total digestible nutrients, % | 70.7 | 71.8 | 70.6 | 57.1 | 68.9 | 68.0 | 66.7 | 66.5 |
| Digestible energy, kcal./gm. | 3.12[d] | 3.17[d] | 3.15 | 2.80 | 3.11 | 3.01 | 2.91 | 2.90 |
| Average daily gain, lbs. | 1.77 | 1.75 | 1.27 | 1.08 | 1.55 | 1.67 | 1.59 | 1.23 |

[a]Wilson (1964b).

[b]Wilson (1964a).

[c]Anderson et al. (1966).

[d]Calculated according to Swift (1957b).

TABLE III

DESCRIPTION OF ALFALFA HAYS USING CRITERIA OF THE HAY SCORE SHEET

| Criterion | Maximum Points | Good Alfalfa Hay (Dairy Experiment Station) Description | Points | Fair Alfalfa Hay (Middle Tenn. Exp. Sta.) Description | Points | Poor Alfalfa Hay (Plateau Exp. Sta.) Description | Points |
|---|---|---|---|---|---|---|---|
| Stage of harvest | 30 | Very early blossom | 25 | Early blossom to mid-blossom | 21 | Seed | 15 |
| Leafiness | 30 | Very leafy | 26 | Leafy | 23 | Slightly stemmy | 20 |
| Color | 15 | Natural green color of crop | 13 | Light green | 11 | Brown | 6 |
| Odor | 15 | Very clean | 14 | Clean | 13 | Dusty | 10 |
| Softness | 10 | Soft | 8 | Soft | 7 | Slightly harsh | 6 |
| Penalties | -- | None | -- | None | -- | None | -- |
| Total Points | 100 | | 86 | | 75 | | 57 |

# II. FEEDING TRIALS

## Description of Steers

Thirty-six Hereford steers purchased in the fall of 1964 through a livestock commission firm in Middle Tennessee were used in this experiment which was conducted at the Highland Rim Experiment Station in Springfield, Tennessee. These steers graded good and averaged 570 pounds of body weight at the onset of the experiment. They were wintered under cover to gain about 1.0 pound per head per day. Their winter ration consisted of corn silage, cottonseed meal and alfalfa hay.

## Experimental Treatment

The steers were divided into six comparable lots of six animals each on the basis of weight, grade and condition. Two lots of steers were selected at random and assigned to one of the three experimental alfalfa hays. Averages of two weights taken on subsequent days were used as the beginning and ending experimental weights. The steers were weighed at 14-day intervals throughout the experiment. All steers were graded for type and condition at the end of the experiment.

The feeding trial was started on March 1, 1965, and continued for 71 days. Since the supply of poor quality hay was exhausted at this time, the trial had to be terminated. The good and fair alfalfa hays were fed ad libitum, while steers on the poor quality hay were fed an average of 2.2 pounds per head per day more than they consumed voluntarily. All steers had free access to iodized salt and water. Average daily gains and changes in condition grade were determined and subjected

to an analysis of variance (Snedecor, 1956) and a multiple range test (Duncan, 1955) to establish significant differences.

## III. DIGESTION TRIALS

### Cattle

Twelve beef steer calves of similar breeding, age, type and condition and averaging 570 pounds in body weight were used in the cattle digestion studies. They were halter-broken 2 weeks prior to the start of the trial. The steer calves were then weighed and randomly assigned to each of the three alfalfa hay treatments before being placed in the metabolism stalls, described by Hobbs et al. (1950).

A 10-day preliminary period, during which time the steers were accustomed to the metabolism stalls and necessary adjustments of the individual stalls were made, was followed by a 7-day collection period. The same hays as used in the feeding experiment were fed to the steers throughout the digestion experiment at a rate of 5 pounds per head at 8 a.m. and 5 pounds at 4:30 p.m. The animals had access to water from 8 a.m. to 5 p.m. every day. Fecal material was collected at 10 a.m. After weighing, the feces were mixed thoroughly with a shovel, and a 5 per cent aliquot was placed in a labeled wide-mouth jar. At the end of the collection period, two 500 gram representative-fecal samples were taken, placed in a weighed aluminum cake pan and dried for 3 days at 70° C.

Sheep

Digestion trials were conducted with 12 sheep of similar type, breeding and condition at the same time as the cattle digestion trials. These trials were conducted at the same time and in the same room as the steer digestion trials. The wethers were weighed and four animals were assigned to each of the three alfalfa hay treatments, before being placed in the metabolism cages designed by Briggs and Gallup (1949). A preliminary period of 10 days was followed by a collection period of 7 days. The sheep were fed twice daily 600 grams of the same hay which was used in the feeding experiment. They had access to water from 8 a.m. to 5 p.m. every day.

Fecal collections were taken at regular 24-hour intervals. The total fecal excretion was placed in paper bags and weighed, and these individual daily collections were placed in heavy plastic bags. All fecal excretions were stored in refrigeration at 35° F. until the termination of the collection period.

At the end of this period, the seven daily fecal collections were mixed thoroughly, sampled and processed in a manner similar to that employed in the cattle studies.

General

Hay and fecal samples from the cattle and sheep digestion trials were then analyzed for proximate composition according to A.O.A.C. (1960) procedures and for gross energy in a Parr oxygen bomb calorimeter.

Digestibility coefficients were calculated for each nutrient. Acid-insoluble lignin was determined in hay samples according to the Van Soest procedure (1963).

The differences of nutrient digestibility between the three hays and the differences between the digestive power of cattle and sheep were analyzed by an analysis of variance test (Snedecor, 1956). Correlation coefficients between digestion coefficients of the individual nutrients between the two species were also determined by an analysis of variance (Snedecor, 1956). A multiple range test (Duncan, 1955) was applied to the digestion coefficient means to detect statistically significant differences.

## IV. IN VITRO FERMENTATION STUDIES

Eleven forage samples were used in this study. These included the three alfalfa hays for which the feedlot and digestion trials have been described previously and eight silages for which feedlot performance and digestibility were determined by other investigators at this station (Wilson, 1964a; Wilson, 1964b; and Anderson et al., 1966). Two in vitro digestibility methods and three fermentation periods (8, 12 and 24 hours) were used to determine the per cent cellulose and the per cent dry matter digested.

The forages, cottonseed meal and a concentrate mixture used for the in vitro studies had been collected during the digestion and feedlot trials. The samples were ground through a 40-mesh screen. Four-tenths gram of the ground forage plus the appropriate amount of cottonseed meal

and/or concentrate mixture were weighed and placed into the fermentation vessels. The ratio of cottonseed meal and/or concentrate to forages was the same as in the feeding trials. Each sample was run in duplicate and three identical trials were conducted in succession.

The first *in vitro* digestibility method used was the washed cell suspension procedure described by Cheng *et al.* (1955) and Hall (1955). In the second procedure whole rumen liquor was used as inoculum. In both methods, 125 milliliter Erlenmeyer flasks were used as fermentation vessels. These flasks were fitted with a rubber stopper, through which two separate pieces of glass tubing were passed. One piece of glass tubing reached almost to the bottom of the flask. This served as the carbon dioxide inlet tube and carried carbon dioxide into the microbial suspension. The other piece of glass tubing extended just below the rubber stopper and served as an escape tube.

Before the collection of the inocula, 15 milliliters of a 1-per cent solution of sodium bicarbonate solution in distilled water were pipetted into each flask. The flasks were stoppered and placed in a shallow water bath maintained at 39.5° C. This water bath was located beneath a series of gas outlet fittings attached to a tank of carbon dioxide. A stream of carbon dioxide was started through the flasks before inoculation.

Rumen contents obtained from a fistulated steer which had been maintained on alfalfa hay were strained through four layers of cheese cloth into previously warmed thermos flasks. Approximately 5 liters of rumen juice were collected and taken to the laboratory. A washed cell

suspension was then prepared according to the method of Cheng et al. (1955).

For the whole rumen liquor method, the rumen juice was strained again through eight layers of cheese cloth. Then 15 milliliters of the whole rumen were pipetted into each digestion flask. The flasks were then returned to the water bath and reconnected to the source of carbon dioxide.

After the fermentation period, 1 milliliter of glacial acetic acid was added to the flasks of both methods to stop microbial action. The samples were dried and the per cent dry matter digested was determined. After drying, the amount of cellulose remaining in each flask was determined according to the procedure of Crampton and Maynard (1938), and the per cent cellulose digested was calculated.

This in vitro fermentation study was designed as a 2 x 2 x 3 factorial design with three replications in order to determine differences in digestibility between the two inocula and differences in rate of digestion between the forages, using both cellulose and dry matter digestion. It was analyzed statistically according to the analysis of variance test (Snedecor, 1956).

## V. SOLUBILITY OF THE FORAGES IN SULFURIC ACID

A chemical method based on the solubility of dry matter in normal sulfuric acid was carried out according to the method developed by Dehority and Johnson (1964). The three alfalfa hays used in this investigation and eight silages from previous experiments were used in

this study. A total of six-tenths of a gram of sample material was subjected to the sulfuric acid. The forages were tested either alone or in combination with grain and/or cottonseed meal in the same ratio as they were fed in the feeding trials. Then the per cent of the dry matter dissolved was calculated.

## VI. COMPARISON OF METHODS THAT EVALUATE FORAGE QUALITY

All *in vivo* and *in vitro* methods of forage evaluation which were employed in this investigation were compared in order to determine how well they express the nutritive value of forages. The main criterion of nutritive value was animal performance as expressed by the average daily gains of the steers in the feeding trial. Data obtained from the digestion trials, *in vitro* fermentation trials and sulfuric acid solubility trials, as well as the lignin content of the forages were correlated with animal performance data and with each other.

The amount of the various rations that were voluntarily consumed by the animals was obtained from the respective feeding trials. This Voluntary Intake was expressed either on the basis of the feed consumption per 100 pounds of body weight or on the basis of metabolic body size ($W_{kg.}^{0.75}$).

Nutritive Value Index was calculated in two ways. In the first, the energy digestion coefficients were multiplied by the Voluntary Intake based on metabolic body size. In the second, the dry matter digestion coefficients were multiplied by the Voluntary Intake based on metabolic body size. These Voluntary Intake and Nutritive Value Index data were

also included in the aforementioned overall correlation which was conducted according to an analysis of variance (Snedecor, 1956).

# CHAPTER IV

## RESULTS AND DISCUSSION

### I. ALFALFA HAYS

Chemical composition of the alfalfa hays is presented in Table IV. It can be observed from this table that good quality alfalfa hay contains somewhat more crude protein and less crude fiber than fair quality alfalfa hay. However, poor quality alfalfa hay contains less protein and much more crude fiber and cellulose than both the good and fair quality hays. The gross energy content of the three hays was similar.

### II. FEEDING TRIAL

Results of the feeding trial are presented in Table V. After the 71-day experiment, the average daily gains of the steers fed either good or fair quality alfalfa hay ad libitum were significantly different ($P<.01$) from the steers fed poor quality alfalfa hay ad libitum, since good and fair alfalfa hays supported average daily gains of 1.85 and 1.49 pounds per head per day, respectively, while the feeding of poor alfalfa hay caused the animals to lose weight. Even though the steers fed good quality alfalfa hay gained 0.36 pounds daily more than the steers fed fair quality alfalfa hay, this difference was not statistically significant, probably due to individual variation in animal

TABLE IV

NUTRIENT COMPOSITION OF GOOD, FAIR AND POOR ALFALFA HAYS

| | Good Quality Alfalfa Hay | Fair Quality Alfalfa Hay | Poor Quality Alfalfa Hay |
|---|---|---|---|
| Dry matter, % | 90.1 | 89.3 | 91.5 |
| Organic matter, % | 82.6 | 82.9 | 87.1 |
| Crude protein, % | 18.7 | 15.9 | 13.7 |
| Crude fiber, % | 29.4 | 35.4 | 46.7 |
| Ether extract, % | 1.9 | 1.5 | 1.1 |
| N-free extract, % | 41.7 | 40.1 | 33.7 |
| Ash, % | 7.5 | 6.4 | 4.4 |
| Cellulose, % | 26.7 | 28.6 | 38.6 |
| Lignin, % | 7.5 | 10.1 | 11.2 |
| Gross energy, kcal./gm. | 4.55 | 4.61 | 4.59 |

TABLE V

EFFECTS OF QUALITY OF ALFALFA HAY ON PERFORMANCE OF BEEF STEERS

| | Good Quality Alfalfa Hay | Fair Quality Alfalfa Hay | Poor Quality Alfalfa Hay |
|---|---|---|---|
| No. of steers/lot | 6 | 6 | 6 |
| No. of steers/treatment | 12 | 12 | 12 |
| Av. wt. and gain/head, lb. | | | |
| Initial wt. | 568 | 576 | 567 |
| Final wt. | 700 | 681 | 563 |
| Total gain | 132 | 105 | -4 |
| Daily gain | 1.85[b] | 1.49[b] | -0.06[c] |
| Av. daily feed, lb. | | | |
| Hay, fed | 17.2 | 16.5 | 13.8 |
| Hay, consumed | 17.1 | 16.5 | 11.6 |
| Salt | 0.06 | 0.09 | 0.10 |
| Av. condition grades[a] | | | |
| Initial type | 10.2 | 10.1 | 10.1 |
| Initial condition | 7.7[d] | 7.6[d] | 7.9[d] |
| Final condition | 8.3[d] | 7.9[d] | 5.3[e] |

[a]Low Standard = 6, medium Standard = 7, high Standard = 8, low Good = 9, medium Good = 10.

[b-e]Means with different superscript letters are significantly different at the 1-per cent level of probability.

performance within treatments. There was no significant difference in daily gains between the replicate lots of steers fed the same hays.

Ad libitum consumption of the steers is also reported in Table V, page 42. The steers receiving good quality alfalfa hay consumed 0.6 pound daily more than those receiving fair quality alfalfa hay which probably contributed to their higher gains (0.36 lb./day). Consumption of poor quality alfalfa hay was much less (5.5 and 4.9 pounds per head per day, respectively) than that of the good and fair alfalfa hays, which was probably the main reason for the loss of body weight by the steers fed this hay. Moreover, the good and fair quality alfalfa hays are usually higher in digestibility than poor quality alfalfa hay and hence, there is a faster rate of passage of good and fair quality hays through the digestive tract, and especially through the rumen. As a result, the animals become hungry more frequently and eat more.

The condition grades of the steers on good quality alfalfa hay were medium Standard initially and low Good at the end of the experiment, while the condition grades of the steers on fair quality alfalfa hay were medium Standard at the beginning and at the end of the trial. However, the condition grades of steers on poor quality alfalfa hays decreased during the experiment to below low Standard. The grades of steers fed the good and fair quality alfalfa hays did not change significantly during the experiment, but the grades of steers fed poor alfalfa hay decreased significantly ($P<.01$).

## III. DIGESTION TRIALS

The digestibility of the alfalfa hays by steers and by sheep is summarized in Tables VI and VII, respectively, while mean values are presented in Table VIII. There were no significant differences in the digestibility of any components between good and fair quality alfalfa hays. However, poor quality alfalfa hay had significantly ($P<.01$) lower digestion coefficients of dry matter, organic matter, crude protein, crude fiber, T.D.N. and D.E. than did good and fair quality alfalfa hays. The only exception was the digestibility of ether extract in the fair quality alfalfa hay which was significantly ($P<.01$) greater than that of ether extract in poor quality alfalfa hay, while there was no difference in the apparent digestibility of ether extract between good and poor quality alfalfa hays. This variation in ether extract digestibility might be attributed to fluctuation of the metabolic fat excretion, since Forbes et al. (1928) and Wilson (1964a) reported that the apparent digestibility of ether extract may be a highly deceptive observation, especially under conditions where the ether extract of the feces is largely of metabolic origin.

The digestibility coefficients obtained from the three alfalfa hays are in close agreement with apparent digestibilities collected by Morrison (1956) for good, fair and poor quality alfalfa hay of similar composition.

A good quality alfalfa hay is characterized by leafiness, a bright green color, pleasant aroma, absence of foreign material such as

TABLE VI

DIGESTIBILITY BY STEERS OF GOOD, FAIR AND POOR QUALITY OF ALFALFA HAYS

| | Good Quality Alfalfa Hay | Fair Quality Alfalfa Hay | Poor Quality Alfalfa Hay |
|---|---|---|---|
| Dry matter, % | 59.5 | 59.5 | 45.0 |
| Organic matter, % | 60.1 | 59.6 | 46.8 |
| Crude protein, % | 70.9 | 69.6 | 53.9 |
| Crude fiber, % | 44.1 | 44.3 | 38.6 |
| Ether extract, % | 29.2 | 30.6 | 25.0 |
| N-free extract, % | 69.4 | 71.9 | 55.9 |
| Total digestible nutrients, % | 56.6 | 56.7 | 44.9 |
| Energy, % | 57.9 | 57.8 | 42.9 |
| Digestible energy, kcal./gm. | 2.63 | 2.67 | 1.97 |

TABLE VII

DIGESTIBILITY BY SHEEP OF GOOD, FAIR AND POOR QUALITY OF ALFALFA HAYS

| | Good Quality Alfalfa Hay | Fair Quality Alfalfa Hay | Poor Quality Alfalfa Hay |
|---|---|---|---|
| Dry matter, % | 61.5 | 59.0 | 47.7 |
| Organic matter, % | 60.4 | 59.4 | 49.6 |
| Crude protein, % | 74.5 | 75.2 | 59.7 |
| Crude fiber, % | 41.7 | 42.4 | 37.8 |
| Ether extract, % | 27.4 | 33.0 | 25.7 |
| N-free extract, % | 70.9 | 69.3 | 62.7 |
| Total digestible nutrients, % | 56.8 | 55.9 | 47.8 |
| Energy, % | 58.9 | 57.0 | 46.5 |
| Digestible energy, kcal./gm. | 2.68 | 2.63 | 2.14 |

TABLE VIII

MEAN DIGESTIBILITY BY STEERS AND SHEEP OF GOOD, FAIR AND POOR QUALITY ALFALFA HAYS

| | Good Quality Alfalfa Hay | Fair Quality Alfalfa Hay | Poor Quality Alfalfa Hay |
|---|---|---|---|
| Dry matter, % | 60.5[a] | 59.3[a] | 46.4[b] |
| Organic matter, % | 60.2[a] | 59.5[a] | 48.2[b] |
| Crude protein, % | 72.7[a] | 72.4[a] | 56.8[b] |
| Crude fiber, % | 42.9[a] | 43.4[a] | 38.2[b] |
| Ether extract, % | 28.3[a,b] | 31.8[a] | 25.4[b] |
| N-free extract, % | 70.1[a] | 70.6[a,b] | 59.3[b] |
| Total digestible nutrients, % | 56.7[a] | 56.3[a] | 46.3[b] |
| Digestible energy, kcal./gm. | 2.66[a] | 2.65[a] | 2.06[b] |

[a-b]Means in the same line with a different superscript letter are statistically significant at the 1-per cent level of probability.

fibrous stemmy weeds, and palatability. This type of hay is high in protein, minerals and vitamins. A good quality forage is one which is highly digestible and consumed in large amounts, and these two factors, digestibility and Voluntary Intake, primarily determine the magnitude of the animal's response to a forage.

Although it is not practical to feed hay alone, the results of the feeding and digestibility trials with the three hays show the importance of producing good quality alfalfa hay. Animals fed good quality alfalfa hay digested this hay better, consumed it in greater amounts and consequently made better gains. On the other hand, poor quality hay was less digestible, animals consumed less and did not even maintain their body weights.

Total Digestible Nutrient—Digestible Energy Relationship

The caloric values of T.D.N. (kcal./gm.) of good, fair and poor quality alfalfa hays were 4.65, 4.71 and 4.39, respectively, for cattle and 4.72, 4.70 and 4.48, respectively, for sheep. There seemed to be no essential difference between the values obtained from cattle and sheep. This T.D.N.-D.E. conversion factor (digestible kcal./gm. T.D.N.) was considerably lower in the poor quality alfalfa hay than in the other two hays. This agrees with results reported by Barth et al. (1959b) which were confirmed by Heaney and Pigden (1963), who stated that this conversion factor is not a constant, but increases with higher quality forages. This disagrees with results reported by Swift (1957b), who proposed the constant conversion factor of 4.1 digestible kcal./gm. T.D.N.

Lofgreen (1951) also stated that the T.D.N.-D.E. conversion factor varied from 2,057 to 2,457 digestible kcal./lb. T.D.N.

The correlation coefficient between T.D.N. and D.E. in this study was 0.98. This very close coefficient agrees with Swift (1957b), Markley (1958), Barth et al. (1959a) and Heaney and Pigden (1963) who reported coefficients of 0.97, 0.86, 0.95 and 0.97, respectively.

D.D.M. and D.O.M. were also correlated with each other and with T.D.N. and D.E. All the correlation coefficients for the four criteria with each other were 0.98. Heaney and Pigden (1963) also reported a very close correlation between these four methods of forage evaluation. Therefore, it is evident from the correlation coefficients obtained that a close relationship exists between D.E., T.D.N., D.O.M. and D.D.M. and that they can be interconverted with reasonable accuracy.

Comparative Nutrient Digestibility by Cattle and Sheep

The digestion coefficients of the three hays by steers were significantly correlated ($P<.01$) with those by the wethers. Correlation coefficients between the two species determined for the digestibility of dry matter, organic matter, crude protein, ether extract, crude fiber, nitrogen-free extract, T.D.N. and D.E. were 0.97, 0.98, 0.86, 0.95, 0.84, 0.95 and 0.97, respectively. Alexander et al. (1962) also reported highly significant correlations between cattle and sheep for dry matter (0.86), protein (0.77), crude fiber (0.95), nitrogen-free extract (0.87), ether extract (0.83), energy (0.85) and T.D.N. (0.89).

In addition, Wilson (1964a) reported significant correlations between cattle and sheep for all components of the forage with exception of crude protein. He reported correlation coefficients of 0.89 for dry matter, 0.85 for crude fiber, 0.91 for nitrogen-free extract, 0.97 for D.E. and 0.97 for T.D.N. No differences between the digestive powers of cattle and sheep had been reported by Watson et al. (1948), Forbes and Garrigus (1950) and Swift and Bratzler (1959).

It can be observed from Table IX that there were no significant species differences in the digestibility of dry matter, organic matter and ether extract of good, fair and poor quality alfalfa hay. However, crude fiber was significantly ($P<.01$) better digested by steers while crude protein was significantly ($P<.01$) better digested by sheep.

These results are in close agreement with general observations that, when species differences were found, the only consistent differences were the superior digestion of crude fiber by steers and somewhat higher digestion of protein by sheep in high quality forages.

This is in close agreement with results obtained by Bartlett (1904) and Wilson (1964a), but is in contrast with Alexander et al. (1962), who reported that low quality hay was digested better by sheep, with Wilson (1964b) who reported higher crude fiber coefficients by sheep, and with Vander Noot et al. (1965) who reported higher crude fiber coefficients by sheep in large-grain silages only. The results obtained from the present study are also in contrast with those calculated by Cipolloni et al. (1951) who reported that cattle are superior

TABLE IX

MEAN SQUARES OF DIGESTION COEFFICIENTS OF ALFALFA HAYS

| Item | Hays | Species | Hays x Species | Residual |
|---|---|---|---|---|
| Degrees of Freedom | 2 | 1 | 2 | 18 |
| Nutrient | | | | |
| Dry matter | 491.32** | 12.04 | 5.59 | 3.33 |
| Organic matter | 367.38** | 6.41 | 4.47 | 2.79 |
| Crude protein | 664.32** | 150.50** | 3.09 | 2.22 |
| Ether extract | 82.12** | 1.17 | 9.15 | 3.62 |
| Crude fiber | 64.91** | 17.85** | 1.34 | 0.95 |
| N-free extract | 260.45** | 44.83 | 71.13* | 16.07 |
| T.D.N. | 255.21** | 6.41 | 11.62* | 3.15 |
| D.E. | 0.96** | 0.02** | 0.02* | 0.01 |

**Significantly different (P<.01).

*Significantly different (P<.05).

to sheep in the digestion of all nutrients.

It appears that no or only small differences in digestibility exist between cattle and sheep. Therefore, it would seem that for most practical purposes one species might be substituted for the other in digestion trials with forages.

## IV. DATA USED FOR THE CALCULATION OF CORRELATION COEFFICIENTS

In order to determine the relationship between animal determinations and their predictors, several laboratory tests were conducted which have provided acceptable results of predicting in vivo measurements. Two types of artificial rumen methods, the whole rumen liquor method and the washed cell suspension method were utilized. Three fermentation periods (8, 12 and 24 hours) were used with each method, since data from short-term fermentation periods have been suggested as predictors of Voluntary Intake and data from long-term fermentation periods have been suggested as predictors of digestibility. These data are presented in Table X.

The second laboratory method which was used as possible predictor of either digestibility or Voluntary Intake was forage solubility in sulfuric acid. The values obtained from this determination which are presented in Table XI were also utilized in the overall determination of correlation coefficients between animal and laboratory data.

Several calculations based on the animal data had to be performed, in order to express them in a way which was suitable for the overall relationship of animal and laboratory data. Voluntary Intake data which

TABLE X

IN VITRO UTILIZATION OF THE FORAGES[a]

| Forage | Fermentation Time (Hrs.) | Whole Rumen Technique % Dry Matter Digested | Whole Rumen Technique % Cellulose Digested | Washed Cell Technique % Dry Matter Digested | Washed Cell Technique % Cellulose Digested |
|---|---|---|---|---|---|
| Good quality alfalfa hay | 8 | 47.6 | 29.2 | 42.9 | 25.3 |
| | 12 | 55.7 | 39.2 | 48.4 | 38.3 |
| | 24 | 67.7 | 51.2 | 54.5 | 49.7 |
| Fair quality alfalfa hay | 8 | 43.9 | 26.3 | 40.3 | 23.0 |
| | 12 | 53.6 | 34.1 | 45.9 | 33.0 |
| | 24 | 64.1 | 48.5 | 52.3 | 48.3 |
| Poor quality alfalfa hay | 8 | 34.9 | 18.9 | 28.8 | 17.6 |
| | 12 | 42.1 | 26.5 | 35.4 | 21.2 |
| | 24 | 54.7 | 37.8 | 39.5 | 38.6 |
| Low nitrated corn silage | 8 | 35.4 | 25.9 | 31.5 | 23.0 |
| | 12 | 43.6 | 36.5 | 36.4 | 32.5 |
| | 24 | 58.0 | 41.0 | 42.0 | 41.3 |
| High nitrated corn silage | 8 | 33.8 | 24.7 | 30.3 | 21.7 |
| | 12 | 41.9 | 32.2 | 34.7 | 30.1 |
| | 24 | 56.4 | 39.3 | 40.9 | 40.1 |
| Corn silage | 8 | 37.7 | 29.1 | 33.3 | 25.1 |
| | 12 | 46.9 | 36.1 | 40.8 | 34.9 |
| | 24 | 67.3 | 40.3 | 45.4 | 39.6 |
| Alfalfa silage | 8 | 35.3 | 26.8 | 31.4 | 22.6 |
| | 12 | 43.3 | 34.2 | 37.7 | 30.6 |
| | 24 | 57.7 | 37.3 | 41.7 | 37.0 |
| Corn silage 1st cutting[b] | 8 | 40.9 | 26.7 | 36.9 | 22.9 |
| | 12 | 51.3 | 37.3 | 41.6 | 37.7 |
| | 24 | 65.8 | 48.2 | 49.0 | 47.9 |
| Corn silage 2nd cutting[b] | 8 | 40.6 | 24.9 | 34.6 | 21.5 |
| | 12 | 49.9 | 35.8 | 38.6 | 36.3 |
| | 24 | 63.5 | 46.7 | 46.7 | 46.8 |

TABLE X (continued)

| Forage | Fermentation Time (Hrs.) | Whole Rumen Technique % Dry Matter Digested | Whole Rumen Technique % Cellulose Digested | Washed Cell Technique % Dry Matter Digested | Washed Cell Technique % Cellulose Digested |
|---|---|---|---|---|---|
| Corn silage 3rd cutting[b] | 8 | 39.8 | 24.3 | 33.5 | 21.2 |
| | 12 | 49.3 | 35.0 | 37.5 | 34.8 |
| | 24 | 63.1 | 45.9 | 45.1 | 45.3 |
| Corn silage 4th cutting[b] | 8 | 35.7 | 22.1 | 31.2 | 19.5 |
| | 12 | 42.8 | 31.7 | 35.4 | 33.0 |
| | 24 | 54.7 | 41.1 | 41.2 | 42.2 |

[a]Each value is the mean of three trials.

[b]First to fourth cutting refers to increasing degrees of maturity of corn silage.

TABLE XI

SOLUBILITY OF FORAGES IN SULFURIC ACID[a]

| Type of Forage | Forage, Alone | Forage, as Fed[b] |
|---|---|---|
| Good quality alfalfa hay | 26.9 | 26.9 |
| Fair quality alfalfa hay | 24.0 | 24.0 |
| Poor quality alfalfa hay | 15.6 | 15.6 |
| Low nitrated corn silage[c] | 23.4 | 17.1 |
| High nitrated corn silage[c] | 22.4 | 15.2 |
| Corn silage[d] | 21.0 | 20.9 |
| Alfalfa silage[d] | 25.1 | 27.0 |
| Corn silage, 1st cutting[e] | 30.4 | 31.8 |
| Corn silage, 2nd cutting[e] | 29.7 | 28.0 |
| Corn silage, 3rd cutting[e] | 29.4 | 26.9 |
| Corn silage, 4th cutting[e] | 23.4 | 23.7 |

[a]Calculated on the per cent of dry matter dissolved.

[b]Forage and/or concentrate in the same ratio as fed in the respective feeding trials.

[c]Wilson, 1964b.

[d]Wilson, 1964a.

[e]Anderson et al., 1966.

were taken from the results of the feeding trials were calculated on the basis of metabolic body size and on the basis of body weight. Nutritive Value Index (the product of Voluntary Intake based on metabolic body size and a measure of digestibility) was calculated from either dry matter digestibility or energy digestibility. These calculated data are reported in Table XII.

## V. COMPARING MEASUREMENTS OF DIGESTIBILITY

Four measurements of expressing the digestibility of the three alfalfa hays and eight silages plus concentrates (T.D.N., D.E., D.D.M. and D.O.M.) were correlated with each other. These correlation coefficients are shown in Table XIII. The correlation coefficient between T.D.N. and D.E. (0.89) in this study was highly significant. This very high coefficient agrees with Swift (1957b), Markley (1958), Barth et al. (1959a) and Heaney and Pigden (1963) who reported coefficients of 0.97, 0.86, 0.95 and 0.97, respectively.

Highly significant correlation coefficients were obtained between D.O.M. and D.D.M. (0.87) and between D.O.M. and T.D.N. or D.E. (0.77). Furthermore, there was a significant correlation coefficient of 0.67 between D.D.M. and D.E. This was in agreement with Heaney and Pigden (1963) who reported a very close correlation between these measurements of expressing digestibility. A somewhat lower and non-significant correlation (0.57) was obtained between D.D.M. and T.D.N.

TABLE XII

VOLUNTARY INTAKE AND NUTRITIVE VALUE INDEX OF THE FORAGES

| Forage | Voluntary Intake $\frac{\text{(Lb. D.M./Day)}}{\text{(100 lb. B.W.)}}$ | Voluntary Intake $\frac{\text{(Gm. D.M./Day)}}{(W_{kg.}^{0.75})}$ | Nutritive Value Index[a] | Nutritive Value Index[b] |
|---|---|---|---|---|
| Good quality alfalfa hay | 2.43 | 101.6 | 76.6 | 73.5 |
| Fair quality alfalfa hay | 2.34 | 96.3 | 71.6 | 69.7 |
| Poor quality alfalfa hay | 1.88 | 75.2 | 42.3 | 40.3 |
| Low nitrated corn silage[c] | 2.16 | 86.8 | 73.9 | 74.6[f] |
| High nitrated corn silage[c] | 2.03 | 81.4 | 70.6 | 72.6[f] |
| Corn silage[d] | 1.89 | 77.4 | 68.8 | 67.5 |
| Alfalfa silage[d] | 1.82 | 74.5 | 60.7 | 56.0 |
| Corn silage, 1st cutting[e] | 1.91 | 75.6 | 65.1 | 64.2 |
| Corn silage, 2nd cutting[e] | 1.87 | 79.6 | 67.7 | 67.4 |
| Corn silage, 3rd cutting[e] | 2.09 | 83.1 | 68.9 | 67.3 |
| Corn silage, 4th cutting[e] | 1.91 | 74.9 | 62.4 | 61.6 |

[a]Based on per cent dry matter digestion coefficient.

[b]Based on energy digestion coefficient.

[c]Wilson, 1964b. [d]Wilson, 1964a. [e]Anderson et al., 1966.

[f]Calculated from organic matter digestion coefficient.

TABLE XIII

COMPARISON OF METHODS THAT EVALUATE FORAGE QUALITY-CORRELATION COEFFICIENTS[a]

| Variable | Av. Daily Gain (lb.) | Dig. Dry Matter (%) | Dig. Organic Matter (%) | Total Dig. Nutr. (%) | Dig. Energy (kcal./gm.) | Vol. Intake $\frac{\text{(gm. D.M.)}}{(W_{kg.}^{.75})}$ | Vol. Intake $\frac{\text{(lb. D.M.)}}{\text{(100 lb. B.W.)}}$ | Nutr. Value Index (% Energy) | Nutr. Value Index (% D.M.) |
|---|---|---|---|---|---|---|---|---|---|
| Average daily gain, lb. | 1.00 | | | | | | | | |
| Digestible dry matter, % | 0.98 | 1.00 | | | | | | | |
| Digestible organic matter, % | 0.81 | 0.87 | 1.00 | | | | | | |
| Total digestible nutrients, % | 0.52 | 0.57 | 0.77 | 1.00 | | | | | |
| Digestible energy, kcal./gm. | 0.62 | 0.67 | 0.77 | 0.89 | 1.00 | | | | |
| Voluntary intake, $\frac{\text{gm. D. M.}}{W_{kg.}^{.75}}$ | 0.94 | 0.95 | 0.75 | 0.43 | 0.65 | 1.00 | | | |
| Voluntary intake, $\frac{\text{lb. D.M.}}{\text{100 lb. B.W.}}$ | 0.97 | 0.96 | 0.80 | 0.63 | 0.68 | 0.91 | 1.00 | | |
| Nutritive value index, % energy | 0.93 | 0.91 | 0.81 | 0.67 | 0.62 | 0.79 | 0.97 | 1.00 | |
| Nutritive value index, % dry matter | 0.98 | 0.98 | 0.85 | 0.63 | 0.67 | 0.91 | 0.99 | 0.96 | 1.00 |
| Lignin content, % | 0.54 | -0.57 | -0.77 | -0.99 | -0.87 | 0.44 | 0.65 | 0.70 | 0.64 |
| Solubility in sulfuric acid (forages alone), % | 0.65 | 0.70 | 0.76 | 0.75 | 0.92 | 0.74 | 0.68 | 0.58 | 0.68 |
| Solubility in sulfuric acid (forage and concentrate), % | 0.89 | 0.91 | 0.67 | 0.33 | 0.58 | 0.99 | 0.86 | 0.73 | 0.87 |

[a]Coefficients above 0.60 and below -0.60 were significant ($P<.05$) and coefficients above 0.70 and below -0.70 were highly significant ($P<.01$).

It is evident from the results that a close relationship exists between these expressions of digestibility and that one could be calculated from the other. The coefficients calculated from the eleven forage samples (hays and silages) are lower than the corresponding coefficients obtained from the three alfalfa hays alone, which were discussed previously. This agrees with the general trend of results in the literature, that higher correlation coefficients are obtained when one plant species is considered alone.

## VI. COMPARISON OF METHODS THAT EVALUATE FORAGE QUALITY

### Predictors of Digestibility

*In vitro fermentation as predictor of digestibility.* In this discussion, four measurements of expressing the digestibility of the forages (D.D.M., D.O.M., T.D.N. and D.E.) will be correlated with the various predictors of digestibility. However, the correlation of D.E. with various predictors will receive major attention. The 24-hour period of fermentation has been included in the investigation to predict forage digestibility (Table X, page 53).

The correlation coefficients between the four expressions of forage digestibility and 24-hour dry matter and cellulose digestibilities are presented in Table XIV. Coefficients between the four expressions of *in vivo* digestibility and the 24-hour dry matter and cellulose *in vitro* digestibility obtained from whole rumen liquor method were generally low and non-significant. The only exception was the coefficient between *in vivo* digestible dry matter and *in vitro* 24-hour

TABLE XIV

COMPARISON OF METHODS THAT EVALUATE FORAGE QUALITY-CORRELATION COEFFICIENTS[a]

| In Vitro Dig. (%) | Fermentation Time (Hr.) | Av. Daily Gains (Lb.) | Dig. Dry Matter (%) | Dig. Organic Matter (%) | Total Dig. Nutr. (%) | Dig. Energy (kcal./gm.) | Vol. Intake $\frac{(gm.\ D.M.)}{(W_{kg.}\ .75)}$ | Vol. Intake $\frac{(\ lb.\ D.M.\ )}{(100\ lb.\ B.W.)}$ | Nutr. Value Index (% Energy) | Nutr. Value Index (% D.M.) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Whole Rumen Liquor | | | | | |
| D.D.M. | 8 | 0.43 | 0.47 | 0.48 | 0.67 | 0.82 | 0.57 | 0.51 | 0.36 | 0.48 |
| | 12 | -0.03 | 0.08 | 0.32 | 0.50 | 0.60 | 0.17 | 0.05 | -0.06 | -0.06 |
| | 24 | -0.06 | 0.05 | 0.29 | 0.45 | 0.56 | 0.15 | 0.01 | -0.11 | -0.02 |
| Cellulose | 8 | -0.17 | 0.06 | 0.19 | 0.38 | 0.50 | 0.06 | -0.10 | -0.22 | -0.09 |
| | 12 | -0.09 | 0.02 | 0.27 | 0.55 | 0.61 | 0.09 | -0.01 | -0.08 | 0.02 |
| | 24 | 0.75 | 0.69 | 0.47 | 0.45 | 0.47 | 0.67 | 0.78 | 0.75 | 0.75 |
| | | | | | Washed Cell Suspension | | | | | |
| D.D.M. | 8 | 0.68 | 0.62 | 0.39 | 0.38 | 0.41 | 0.64 | 0.73 | 0.68 | 0.68 |
| | 12 | 0.40 | 0.44 | 0.48 | 0.69 | 0.77 | 0.50 | 0.49 | 0.38 | 0.47 |
| | 24 | 0.47 | 0.51 | 0.55 | 0.76 | 0.83 | 0.54 | 0.57 | 0.47 | 0.54 |
| Cellulose | 8 | 0.15 | 0.06 | -0.18 | 0.26 | -0.47 | -0.09 | 0.14 | 0.27 | 0.11 |
| | 12 | 0.53 | 0.60 | 0.54 | 0.45 | 0.73 | 0.69 | 0.51 | 0.33 | 0.55 |
| | 24 | 0.61 | 0.66 | 0.59 | 0.41 | 0.59 | 0.65 | 0.58 | 0.49 | 0.59 |

[a]Coefficients above 0.60 and below -0.60 were significant ($P<.05$) and coefficients above 0.70 and below -0.70 were highly significant ($P<.01$).

cellulose digestibility, which was 0.69 ($P<.05$). When the washed cell suspension method was used, however, the correlation coefficients between the four expressions of *in vivo* digestibility (D.D.M., D.O.M., T.D.N. and D.E.) and 24-hour dry matter and cellulose digestibility *in vitro* were somewhat higher than in the whole rumen liquor method. The coefficient between *in vivo* D.D.M. and *in vitro* 24-hour cellulose digestion was 0.66 ($P<.05$), while the correlation coefficients of *in vitro* D.D.M. with T.D.N. and D.E. were 0.76 and 0.83, respectively ($P<.01$).

Although the 8- and 12-hour fermentation periods were chosen as predictors of Voluntary Intake or Nutritive Value Index, their correlation coefficients with D.E. were, in some cases, as high or higher than the coefficients between D.E. and the 24-hour dry matter and cellulose digestibility *in vitro*.

Using the whole rumen liquor method, close relationships between various measures of digestibility *in vivo* on one hand, and *in vitro* cellulose digestion obtained from longer fermentation periods on the other hand were also reported by Kamstra *et al.* (1955), Pigden and Bell (1955), Barnett (1957) Hershberger *et al.* (1959), Reid *et al.* (1960, 1964), Donefer *et al.* (1960) and Chalupa and Lee (1966).

The low and non-significant correlation coefficients in this study between the 24-hour whole rumen liquor dry matter digestibility with D.D.M., D.O.M., T.D.N. and D.E. are in contrast to results obtained by Smith *et al.* (1965), whose correlation coefficients were high and significant.

In general, low and mostly non-significant correlation coefficients between the four measures of forage digestibility (D.D.M., D.O.M., T.D.N. and D.E.) and the 24-hour dry matter or cellulose *in vitro* digestibility were obtained in this study. The main reason for these low coefficients is probably the fact that the eleven forages in this study represented different plant species, hays and silages, and usually were fed in combination with other ration constituents. When values for either the three alfalfa hays or the five corn silages were plotted separately, straight line relationships were indicated. However, the few available forages of each type would not yield meaningful correlation coefficients.

There were four acceptable predictors of digestibility among the various *in vitro* determinations of the present study. In both methods (washed cell suspension and whole rumen liquor) *in vitro* cellulose digestion was significantly correlated with *in vivo* dry matter digestibility. Also, highly significant correlation coefficients were obtained between dry matter digestion *in vitro* from the washed cell suspension method and T.D.N. or D.E.

The data in this investigation indicate that some *in vitro* determinations yield usable predictors of digestibility, even when mixed rations and not forages alone were investigated. The best digestibility predictor was the *in vitro* dry matter digestibility employing the washed cell suspension method. However, a whole rumen liquor method employing a more complex fermentation medium may yield higher correlation coefficients than the values obtained in this study.

Forage solubility in sulfuric acid as predictor of digestibility. The amount of forage dissolved in normal sulfuric acid (Table XI, page 55) was used as predictor of forage digestibility (expressed as either D.D.M., D.O.M., T.D.N. or D.E.). The forages were tested either alone or in combination with grain and/or cottonseed meal in the same ratio as they were fed in the feeding trials. The correlation coefficients between the four expressions of forage digestibility and forage solubility are presented in Table XIII, page 58.

The highly significant coefficients between the four expressions of digestibility and solubility of the forages when tested alone were 0.70, 0.76, 0.75 and 0.92 ($P<.01$), respectively. This was in agreement with results of Dehority and Johnson (1964). However, when concentrates were added to the forages, the correlation between solubility of forage and D.O.M., T.D.N. and D.E., were decreased, compared to results obtained from forage alone. In contrast, the correlation coefficient between D.D.M. and solubility of forages plus concentrates (0.91) was very high and significant ($P<.01$).

It is evident from this study that the solubility method can be used for the prediction of digestibility even if forages are not considered alone. This method is less time-consuming and less expensive than the other methods.

Lignin content as predictor of digestibility. Various components in forage as predictors of digestibility have been used in many investigations. When forages were fed alone, the lignin content seemed to be a

better predictor of digestibility than any other forage component. The correlation coefficients of lignin content with the four expressions of digestibility are presented in Table XIII, page 58.

It may be observed that a very high and statistically significant ($P<.01$) negative coefficient of -0.99 was obtained between lignin content and T.D.N. Coefficients of decreasing magnitude resulted between lignin on one hand and D.E. (-0.87), D.O.M. (-0.77) and the non-significant coefficient of D.D.M. (-0.57) on the other hand.

This high negative correlation of lignin with *in vivo* digestibility measurements agrees with results obtained by Norman (1935), Phillips and Loughlin (1949), Sullivan (1955, 1964) and Simkins and Baumgardt (1963). Since this negative correlation between digestibility and degree of lignification holds true with mixed rations also, lignin content seems to be an excellent predictor of digestibility in rations of this type.

## Predictors of Voluntary Intake

*In vitro fermentation as predictor of Voluntary Intake.* In this study, Voluntary Intake was calculated in two different ways. One based on the amount of dry matter which was consumed per unit of metabolic size (gm. D.M./$W_{kg.}$ 0.75), and the other was based on dry matter consumption per hundred pounds of body weight (lb. D.M./100 lb. B.W.). The 8-hour and 12-hour *in vitro* cellulose or dry matter digestion has been included in this investigation to predict Voluntary Intake of the forages. The correlation coefficients between the 8-hour and 12-hour

fermentation period and Voluntary Intake are presented in Table XIV, page 60.

There was no essential difference between the results obtained from the two ways of calculating Voluntary Intake. In addition, the following general observations can be made:

1. Within the 8-hour fermentation time, *in vitro* dry matter digestion was a better predictor of Voluntary Intake than *in vitro* cellulose digestion.
2. Within the 12-hour fermentation time, results of the washed cell suspension method predicted Voluntary Intake better than results from the whole rumen liquor method.
3. In 8-hour fermentation runs there were two good predictors of Voluntary Intake (dry matter digestibility *in vitro* from both the washed cell and the whole rumen liquor methods) while there was one good predictor in the 12-hour fermentation runs (cellulose digestion obtained from the washed cell method).

The correlation coefficient between the 8-hour dry matter digestion was obtained from the washed cell suspension method and Voluntary Intake based on metabolic size was 0.64 ($P<.05$). However, when Voluntary Intake was based on body weight the correlation coefficient was 0.73, and highly significant. Also, Voluntary Intake based on body weight resulted in a highly significant correlation coefficient (0.69; $P<.01$) with 12-hour cellulose digestion obtained from the washed cell suspension method. Although the 24-hour period was considered to be a predictor of digestibility, a significant correlation coefficient was

obtained between cellulose digestibility in the washed cell suspension method and Voluntary Intake based on metabolic body size.

Short-term fermentation period (up to 18 hours) have also been shown to be good predictors of Voluntary Intake by Reid et al. (1960), Van Soest (1965b) and Chalupa and Lee (1966). It should be reemphasized that in these other studies forages alone were investigated, while in the present study mixed rations (forages and concentrates) were considered. Therefore, it appears that short-term in vitro dry matter and cellulose digestibility shows promise in the prediction of Voluntary Intake even of mixed rations.

Forage solubility in sulfuric acid as predictor of Voluntary Intake. The amount of forage dissolved in normal sulfuric acid was also used as predictor of Voluntary Intake which was calculated either on the basis of body weight or metabolic body size. The results of sulfuric acid solubility of the forages either with or without concentrate are presented in Table XIII, page 58. The four correlation coefficients between Voluntary Intake and forage solubility were either significant ($P<.05$) or highly significant ($P<.01$). Results based on the more complex calculation of Voluntary Intake (metabolic body size) were superior to results based on the simpler calculation (body weight) of Voluntary Intake. Furthermore, when solubility was determined from the ration constituents in the same ratio as fed in the feeding trials, higher correlation coefficients were obtained than when the forages alone were subjected to the sulfuric acid treatment.

The very high correlation coefficient 0.99 between Voluntary Intake based on metabolic body size and the solubility of the forage-concentrate mixture indicates that solubility is an excellent method of predicting Voluntary Intake, which confirms results obtained by Dehority and Johnson (1964). This method even predicts Voluntary Intake of mixed rations.

Lignin content as predictor of Voluntary Intake. The lignin content of the forages was also considered as a possible predictor of Voluntary Intake. The resulting coefficients are presented in Table XIII, page 58. There was a significant positive correlation (0.68) between the lignin content of the forages and Voluntary Intake based on body weight, while the coefficient with Voluntary Intake based on metabolic body size was lower and non-significant.

A significant positive correlation between lignin content and Voluntary Intake was also reported by Van Soest (1964, 1965b), Hawkins et al. (1964) and Reid and Jung (1965). Therefore, it is evident that the lignin content of forages can be used in the estimation of ad libitum intake, even if forages are fed in combination with concentrates as was done in the present study.

Predictors of Nutritive Value Index

Nutritive Value Index was calculated either from energy digestibility or from dry matter digestibility. Although most investigators calculate Nutritive Value Index from digestibility and Voluntary Intake,

there are some who estimate Nutritive Value Index directly from *in vitro* digestibility. Therefore, the correlation of Nutritive Value Index with various *in vitro* results was also determined in this investigation and these results are also presented in Table XIV, page 60.

Correlation coefficients were generally low and non-significant, with the exception of significant correlation coefficients between Nutritive Value Index obtained with either the 24-hour cellulose digestion *in vitro* by the whole rumen liquor method (0.75) or from the 8-hour dry matter digestion *in vitro* by the washed cell suspension method (0.68). These results were to be expected, since these specific *in vitro* determinations were the best predictors of either *in vivo* digestibility or Voluntary Intake, from which Nutritive Value Index is calculated.

Short-term fermentation periods have also been shown to be good predictors of Nutritive Value Index by Donefer *et al.* (1960) and Reid and Jung (1965), while long-term fermentation periods have been shown to be predictors of Nutritive Value Index by Chalupa and Lee (1966). However, better estimates of Nutritive Value Index should be expected from the product of short-term *in vitro* fermentation (an estimator of Voluntary Intake) and long-term *in vitro* fermentation (an estimator of digestibility).

Animal Performance

One would expect digestibility of a ration and its *ad libitum* intake to be closely related to the body weight gains that result from

the feeding of a ration, since digestibility and intake are the primary factors which determine animal performance.

Relationship between digestibility and body weight increase. Correlation coefficients between average daily gains and the four measures of digestibility (D.D.M., D.O.M., T.D.N. and D.E.) are presented in Table XIII, page 58. It may be observed that these coefficients are quite different. A very close and highly significant relationship (0.98) existed between average daily gains and D.D.M., while a lower but still highly significant coefficient (0.81) was obtained between average daily gains and D.O.M. Still lower correlation coefficients were observed with D.E. (0.62) and T.D.N. (0.52), the latter being non-significant. Of particular interest is the low correlation of average daily gains with T.D.N., which in the past has generally been considered as the main criterion in the determination of the nutritive value of forages for animal gains.

Coefficients of determination ($r^2$) were calculated to permit an expression of the unexplained variability. The determination coefficient of average daily gains with D.D.M. was 0.96, i.e., 96 per cent of the variability of average daily gains is explained by D.D.M., and 4 per cent remains unexplained. Coefficients of determination of average daily gains were 0.66 with D.O.M., 0.38 with D.E. and only 0.27 with T.D.N. The low determination coefficient between T.D.N. and average daily gains indicates that, according to the results of this investigation, T.D.N. was a very poor predictor of animal performance. The reasons for this low coefficient are not known.

Relationship between average daily gains and Voluntary Intake. In this study, Voluntary Intake was calculated in two different ways. One was based on the amount of dry matter which was consumed per unit of metabolic size, and the other was based on dry matter consumed per hundred pounds of body weight. The correlation coefficients between average daily gain and Voluntary Intake are presented in Table XIII, page 58. There were highly significant and positive correlation coefficients between average daily gain and Voluntary Intake calculated by either method.

Coefficients of determination between average daily gains and Voluntary Intake based on metabolic weight were 0.88, and between average daily gains and Voluntary Intake based on body weight were 0.94. Therefore, according to the results in this investigation, Voluntary Intake explained more of the variability in average daily gains than did T.D.N. but somewhat less than D.D.M. The fact that ad libitum intake of a forage or in this case, a forage-concentrate mixture, has a greater effect on animal performance, than its digestibility is in agreement with reports by Crampton (1957), Byers and Ormiston (1962) and Ingalls et al. (1965).

Relationship between average daily gain and Nutritive Value Index. Average daily gains were also correlated with Nutritive Value Index which was calculated either from energy digestibility or from dry matter digestibility, and highly significant correlation coefficients ($P<.01$) of 0.93 and 0.98, respectively, were obtained (Table XIII, page 58).

This very high correlation between average daily gains and Nutritive Value Index was expected, since Crampton (1957) proposed Nutritive Value Index as the best indicator of animal performance.

# CHAPTER V

## SUMMARY

The purpose of this investigation was to determine how close various laboratory methods come to estimate results obtained directly from animal experiments. A secondary objective was the determination of the feeding value and digestibility of three qualities of alfalfa hay. Furthermore, this investigation was conducted to compare cattle and sheep in their ability to digest these alfalfa hays and to determine the relationship between the Total Digestible Nutrients and Digestible Energy methods of feed evaluation. In contrast to other studies of this type, which use forages only, the present investigation includes mixed rations also. Furthermore, in the present work Voluntary Intake was determined from the long-term feeding trials rather than being based on 7-day or 10-day short-term studies employed by other investigators.

The four methods of forage evaluation which are based on animal experimentation were average daily gains in the feedlot, in vivo digestibility, Voluntary Intake and the calculated Nutritive Value Index. The laboratory methods used to predict these values obtained from animal experimentations were two in vitro digestion techniques (whole rumen liquor and washed cell suspension), three fermentation periods (8, 12 and 24 hours) and the determination of the digestibility of two fractions (dry matter and cellulose). Other laboratory prediction methods were lignin content of the forages and forage solubility in sulfuric acid

(either forages alone or in combination with concentrates).

The determinations of average daily gains, *in vivo* digestibility and Voluntary Intake of the three qualities of alfalfa hay were a part of this study. In the feedlot study 36 steers were used, while 12 steers and 12 wethers were used in the digestion trials. For the laboratory methods, eight other forages were included from which animal data had been obtained previously in this laboratory.

The results of all animal investigations and the results of all predictors were correlated with each other. Many significant and highly significant correlations were obtained; however, only the more meaningful predictors will be summarized here.

1. *In vivo* digestibility was well predicted by results of the 24-hour *in vitro* cellulose digestibility from both the whole rumen liquor technique and the washed cell suspension technique, and also the 24-hour dry matter digestibility from the washed cell suspension technique. Good prediction of digestibility *in vivo* was also obtained from the sulfuric acid solubility determination and the very high negative correlation coefficient of -0.99 was obtained between lignin content and *in vivo* digestibility.
2. Voluntary Intake was well predicted by results from the 8-hour dry matter digestion *in vitro* from both artificial rumen methods and 12-hour cellulose digestion from the washed cell suspension technique. Voluntary Intake prediction from lignin content was fair, while results obtained from sulfuric

acid solubility indicated this to be an excellent predictor of Voluntary Intake ($r = 0.99$).

3. Nutritive Value Index, which is the product of digestibility and Voluntary Intake, is an excellent predictor of body weight gains, even when mixed rations and not forages alone are evaluated.

Results based on the feeding and digestibility trials of the three alfalfa hays are as follows:

1. Although it is not practical to feed hay alone, the results of the feeding and digestion trials with the three hays showed the importance of producing good quality alfalfa hay. The good and fair quality alfalfa hays supported average daily gains of 1.85 and 1.49 pounds per head per day, respectively, while feeding of poor alfalfa hay caused the animals to lose weight.
2. In general, there were no significant differences in the digestibility of good and fair quality alfalfa hays. However, the poor hay had significantly lower digestibility coefficients.
3. There was a very close relationship between the four measurements of digestibility and they can be interconverted with reasonable accuracy.
4. Regarding comparative digestibility of cattle and sheep, the results obtained were in close agreement with general observations that if species difference were found, the only

consistent difference was the superior digestion of crude fiber by steers and somewhat higher digestion of protein by sheep.

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# APPENDIX

TABLE XV

EFFECTS OF QUALITY OF ALFALFA HAY ON THE BODY WEIGHT INCREASE OF INDIVIDUAL BEEF STEERS (POUNDS PER DAY--71-DAY FEEDING PERIOD)

| Animal No. | Lot No. | Good Quality Alfalfa Hay | Animal No. | Lot No. | Fair Quality Alfalfa Hay | Animal No. | Lot No. | Poor Quality Alfalfa Hay |
|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 1.90 | 13 | 3 | 1.55 | 25 | 5 | 0.23 |
| 2 | | 2.00 | 14 | | 1.23 | 26 | | 0.56 |
| 3 | | 2.01 | 15 | | 1.69 | 27 | | -0.68 |
| 4 | | 2.07 | 16 | | 1.34 | 28 | | 0.39 |
| 5 | | 1.76 | 17 | | 1.10 | 29 | | -0.70 |
| 6 | | 1.76 | 18 | | 1.48 | 30 | | -0.20 |
| 7 | 2 | 1.73 | 19 | 4 | 1.30 | 31 | 6 | -0.07 |
| 8 | | 1.93 | 20 | | 2.03 | 32 | | -0.49 |
| 9 | | 2.11 | 21 | | 1.80 | 33 | | 0.23 |
| 10 | | 1.46 | 22 | | 1.41 | 34 | | -0.23 |
| 11 | | 1.55 | 23 | | 1.48 | 35 | | 0.38 |
| 12 | | 1.93 | 24 | | 1.44 | 36 | | -0.14 |

TABLE XVI

DIGESTIBILITY OF ALFALFA HAYS BY STEERS

| Nutrient | Good Quality Alfalfa Hay Animal Number | | | | Fair Quality Alfalfa Hay Animal Number | | | | Poor Quality Alfalfa Hay Animal Number | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| Dry matter, % | 59.9 | 57.8 | 61.6 | 58.8 | 59.3 | 58.9 | 60.7 | 59.0 | 45.6 | 45.4 | 43.4 | 45.4 |
| Organic matter, % | 60.6 | 58.5 | 62.2 | 59.0 | 59.4 | 58.9 | 60.8 | 59.2 | 49.8 | 46.2 | 44.9 | 46.4 |
| Crude protein, % | 70.0 | 69.4 | 73.6 | 70.7 | 70.4 | 68.9 | 70.4 | 68.9 | 51.2 | 56.0 | 54.5 | 53.8 |
| Ether extract, % | 30.3 | 28.6 | 29.4 | 28.6 | 29.8 | 31.9 | 34.0 | 26.6 | 25.0 | 25.0 | 24.6 | 25.5 |
| Crude fiber, % | 45.1 | 42.9 | 44.5 | 43.8 | 44.6 | 44.3 | 44.5 | 44.1 | 39.1 | 39.5 | 36.5 | 39.4 |
| N-free extract, % | 70.5 | 67.9 | 71.1 | 68.0 | 70.8 | 71.2 | 73.3 | 72.2 | 58.6 | 55.3 | 53.8 | 55.9 |
| T.D.N., % | 57.3 | 55.3 | 58.0 | 55.9 | 56.3 | 56.6 | 54.5 | 56.4 | 45.6 | 45.4 | 43.2 | 45.2 |
| Energy digested, % | 59.1 | 56.8 | 59.3 | 56.3 | 57.9 | 57.5 | 58.6 | 54.5 | 42.1 | 43.7 | 41.7 | 44.0 |
| Digestible energy, kcal./gm. | 2.69 | 2.58 | 2.70 | 2.56 | 2.67 | 2.65 | 2.70 | 2.65 | 1.93 | 2.00 | 1.92 | 2.02 |
| Caloric value of T.D.N., kcal./lb. | 2,131 | 2,120 | 2,112 | 2,082 | 2,150 | 2,124 | 2,133 | 2,133 | 1,893 | 2,013 | 2,010 | 2,024 |

TABLE XVII

DIGESTIBILITY OF ALFALFA HAYS BY SHEEP

| Nutrient | Good Quality Alfalfa Hay Animal Number | | | | Fair Quality Alfalfa Hay Animal Number | | | | Poor Quality Alfalfa Hay Animal Number | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 |
| Dry matter, % | 64.2 | 63.5 | 61.9 | 56.2 | 58.7 | 58.7 | 60.0 | 58.7 | 46.1 | 48.8 | 47.0 | 49.0 |
| Organic matter, % | 61.2 | 60.5 | 62.9 | 57.0 | 59.1 | 59.7 | 60.6 | 59.1 | 47.7 | 50.3 | 49.0 | 51.2 |
| Crude protein, % | 74.8 | 76.1 | 74.8 | 72.3 | 75.7 | 75.7 | 76.1 | 73.4 | 59.9 | 61.1 | 58.6 | 59.1 |
| Ether extract, % | 29.0 | 29.0 | 25.8 | 25.8 | 36.0 | 32.0 | 32.0 | 32.0 | 23.5 | 26.7 | 27.8 | 25.0 |
| Crude fiber, % | 41.9 | 42.7 | 41.9 | 40.1 | 42.3 | 43.0 | 42.6 | 41.8 | 36.9 | 38.7 | 36.8 | 38.8 |
| N-free extract, % | 70.1 | 76.0 | 74.0 | 63.5 | 68.4 | 68.1 | 71.0 | 69.8 | 58.6 | 63.0 | 62.9 | 66.5 |
| T.D.N., % | 56.7 | 59.6 | 58.2 | 52.7 | 55.6 | 55.6 | 56.7 | 55.5 | 46.7 | 48.3 | 47.0 | 49.2 |
| Energy digested, % | 58.6 | 61.7 | 60.4 | 55.0 | 57.0 | 56.6 | 57.8 | 56.7 | 46.7 | 46.5 | 45.6 | 47.2 |
| Digestible energy, kcal./gm. | 2.66 | 2.81 | 2.75 | 2.50 | 2.63 | 2.61 | 2.67 | 2.61 | 2.14 | 2.14 | 2.10 | 2.17 |
| Caloric value of T.D.N., kcal./lb. | 2,136 | 2,139 | 2,146 | 2,154 | 2,145 | 2,130 | 2,135 | 2,139 | 2,184 | 2,011 | 2,024 | 1,879 |

TABLE XVIII

IN VITRO DRY MATTER DIGESTION OF FORAGES (PER CENT)

| Trial No. | Ferm. Time (Hr.) | Good Quality Alfalfa Hay | Fair Quality Alfalfa Hay | Poor Quality Alfalfa Hay | Low Nitrated Corn Silage | High Nitrated Corn Silage | Corn Silage | Alfalfa Silage | Corn Silage, 1st Cut. | Corn Silage, 2nd Cut. | Corn Silage, 3rd Cut. | Corn Silage, 4th Cut. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Whole Rumen Liquor Method | | | | | | | |
| 1 | 8 | 50.2 | 43.0 | 35.3 | 34.1 | 33.9 | 39.2 | 36.2 | 41.3 | 40.9 | 40.0 | 35.7 |
| | 12 | 60.8 | 58.8 | 41.3 | 42.2 | 40.6 | 48.6 | 44.2 | 49.0 | 48.2 | 46.6 | 40.2 |
| | 24 | 69.9 | 67.1 | 58.1 | 60.1 | 58.6 | 67.1 | 65.1 | 71.1 | 68.7 | 68.9 | 64.2 |
| 2 | 8 | 48.0 | 46.1 | 35.0 | 35.1 | 32.4 | 34.3 | 33.1 | 39.6 | 39.5 | 38.5 | 34.9 |
| | 12 | 53.7 | 51.2 | 42.3 | 43.9 | 41.7 | 44.3 | 41.0 | 51.6 | 50.2 | 49.7 | 42.9 |
| | 24 | 66.4 | 62.0 | 52.4 | 55.2 | 54.5 | 60.4 | 53.0 | 63.2 | 61.1 | 60.3 | 56.1 |
| 3 | 8 | 44.6 | 42.6 | 34.5 | 37.0 | 35.1 | 39.8 | 36.7 | 41.6 | 41.3 | 40.8 | 36.4 |
| | 12 | 52.7 | 50.8 | 42.7 | 44.7 | 43.4 | 47.9 | 44.6 | 53.4 | 51.4 | 51.7 | 45.2 |
| | 24 | 66.7 | 63.4 | 53.5 | 58.8 | 56.0 | 65.3 | 55.0 | 63.1 | 60.8 | 60.3 | 53.9 |
| | | | | | Washed Cell Suspension Method | | | | | | | |
| 1 | 8 | 43.9 | 39.9 | 28.1 | 31.3 | 29.8 | 34.7 | 33.2 | 35.4 | 33.9 | 31.6 | 30.0 |
| | 12 | 48.6 | 48.0 | 35.8 | 37.4 | 34.8 | 41.5 | 37.6 | 41.6 | 38.1 | 37.2 | 35.1 |
| | 24 | 56.7 | 54.0 | 40.1 | 41.7 | 39.8 | 46.5 | 43.7 | 49.7 | 47.3 | 46.8 | 42.5 |
| 2 | 8 | 42.8 | 40.7 | 29.1 | 30.8 | 29.9 | 31.3 | 29.6 | 36.7 | 33.7 | 33.5 | 30.9 |
| | 12 | 47.5 | 45.0 | 34.2 | 35.6 | 34.1 | 41.7 | 37.2 | 40.9 | 37.6 | 36.1 | 34.1 |
| | 24 | 53.1 | 51.4 | 39.4 | 41.3 | 40.5 | 45.3 | 41.0 | 48.5 | 46.4 | 44.5 | 40.9 |
| 3 | 8 | 41.8 | 40.2 | 29.2 | 32.3 | 31.3 | 33.9 | 31.4 | 38.6 | 36.2 | 35.4 | 32.9 |
| | 12 | 49.4 | 44.7 | 36.1 | 36.1 | 34.9 | 40.9 | 38.3 | 42.1 | 39.9 | 39.1 | 36.9 |
| | 24 | 53.8 | 51.5 | 39.1 | 43.1 | 42.3 | 44.5 | 40.4 | 48.9 | 46.5 | 44.0 | 40.2 |

TABLE XIX

IN VITRO CELLULOSE DIGESTION OF FORAGES (PER CENT)

| Trial No. | Ferm. Time (Hr.) | Good Quality Alfalfa Hay | Fair Quality Alfalfa Hay | Poor Quality Alfalfa Hay | Low Nitrated Corn Silage | High Nitrated Corn Silage | Corn Silage | Alfalfa Silage | Corn Silage, 1st Cut. | Corn Silage, 2nd Cut. | Corn Silage, 3rd Cut. | Corn Silage, 4th Cut. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Whole Rumen Liquor Method | | | | | | |
| 1 | 8 | 29.1 | 26.2 | 20.6 | 27.7 | 27.2 | 30.8 | 26.4 | 27.8 | 25.8 | 25.8 | 23.6 |
| | 12 | 39.8 | 34.2 | 26.7 | 37.3 | 31.4 | 37.4 | 32.3 | 38.3 | 34.8 | 35.5 | 31.7 |
| | 24 | 52.8 | 49.7 | 39.6 | 44.5 | 40.4 | 41.4 | 37.5 | 49.0 | 48.3 | 47.0 | 43.2 |
| 2 | 8 | 27.9 | 26.0 | 17.5 | 24.8 | 23.3 | 27.9 | 26.7 | 25.8 | 23.4 | 22.6 | 21.5 |
| | 12 | 38.0 | 33.7 | 27.4 | 36.6 | 33.1 | 34.5 | 31.7 | 37.0 | 35.8 | 34.5 | 21.5 |
| | 24 | 50.9 | 49.3 | 37.7 | 39.1 | 38.8 | 39.7 | 37.9 | 47.1 | 45.6 | 45.2 | 40.4 |
| 3 | 8 | 30.6 | 27.6 | 18.7 | 25.2 | 23.6 | 28.7 | 27.4 | 26.1 | 25.6 | 24.4 | 21.3 |
| | 12 | 39.9 | 34.5 | 25.6 | 35.5 | 32.3 | 36.4 | 34.4 | 36.7 | 36.7 | 35.0 | 32.1 |
| | 24 | 49.9 | 46.5 | 36.0 | 39.3 | 38.7 | 39.8 | 36.6 | 47.4 | 46.2 | 45.4 | 39.5 |
| | | | | | | Washed Cell Suspension Method | | | | | | |
| 1 | 8 | 25.6 | 22.6 | 17.7 | 22.7 | 21.4 | 26.0 | 21.9 | 22.8 | 22.5 | 22.4 | 19.7 |
| | 12 | 38.6 | 31.3 | 21.3 | 31.2 | 28.2 | 36.0 | 31.2 | 38.3 | 36.5 | 35.4 | 32.8 |
| | 24 | 50.0 | 49.1 | 38.1 | 42.5 | 40.8 | 40.5 | 37.5 | 47.3 | 48.2 | 47.0 | 43.0 |
| 2 | 8 | 24.7 | 23.3 | 16.9 | 22.7 | 21.4 | 23.8 | 22.4 | 22.8 | 21.0 | 20.4 | 19.2 |
| | 12 | 37.6 | 33.6 | 20.9 | 32.6 | 30.5 | 33.8 | 29.9 | 37.2 | 36.0 | 34.3 | 32.8 |
| | 24 | 49.3 | 47.5 | 38.8 | 40.5 | 39.6 | 38.8 | 36.3 | 47.6 | 45.5 | 44.0 | 41.8 |
| 3 | 8 | 25.6 | 23.3 | 18.3 | 23.5 | 22.2 | 25.5 | 23.4 | 23.0 | 21.1 | 20.8 | 19.6 |
| | 12 | 38.6 | 34.3 | 21.5 | 33.8 | 31.6 | 34.9 | 30.6 | 37.7 | 36.4 | 34.8 | 33.3 |
| | 24 | 49.6 | 48.2 | 38.8 | 40.8 | 39.9 | 39.4 | 37.3 | 48.6 | 46.5 | 45.1 | 42.0 |