THE EFFECT OF GRINDING ON THE VOLUNTARY CONSUMPTION AND NUTRIENT AVAILABILITY OF EARLY VS. LATE CUT CLOVER AND TIMOTHY HAYS WHEN FED TO LAMBS.

by

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A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfilment of the requirements for the degree of Doctor of Philosophy.

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April, 1959.

ACKNOWLEDGEMENTS

The research reported in this thesis was carried out in the Department of Nutrition, Macdonald College, under the direction of Dr.E.W.Crampton and Dr.L.E.Lloyd. The author wishes to express appreciation for financial assistance received in the form of a scholarship from the Macdonald College Pasture Committee.

To Dr.E.W.Crampton, Chairman of the Department, whose constructive criticism and guidance during the planning of the experiments and in the compiling of this thesis were very much valued, the author wishes to express his sincere thanks.

To Dr.L.E.Lloyd, whose approachable nature and willingness to discuss problems arising during the experiments was a source of encouragement, the author wishes to express his sincere appreciation.

Thanks is also extended to Dr.Florence A. Farmer who arranged for the carrying out of urinary nitrogen analyses during the experiment.

Acknowledgement is made of the kindness of Dr.O.G.Bentley of the Department of Animal Science, Ohio Agricultural Experiment Station, Wooster, Ohio, who carried out the *in vitro* cellulose digestibility determinations on the forages used in this experiment.

The author wishes to thank Mrs.E.D.Catto who transcribed this thesis.

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Ph.D. Stanley Ernest Beacom Nutrition

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ABSTRACT

Voluntary consumption, as a criterion of feeding value of two forage species was further tested by determining the "within species" effect of stage of maturity and of the physical form in which these forages were fed. Chemical composition, digestibility coefficients, voluntary intake and liveweight gains were determined. Various relationships between these factors and their relationship to forage species, stage of maturity and to the physical form in which the forage was fed, were investigated.

Voluntary intake of the forages (including the effect of species, stage of maturity and physical form) was highly and significantly correlated to feeding value, whether expressed as digestible energy intake or as liveweight gain.

Feeding forages in the ground, moist condition caused a significant increase in voluntary intake. The reduction in extent of digestibility was more than offset by the increased intake of digestible nutrients, with the result that liveweight gains were markedly increased.

Suggested abbeviated title for bound copy.

Intake and utilization of chopped vs. ground forages fed to lambs.

I. GENERAL INTRODUCTION.

The production and utilization of forage crops is assuming an increasingly important role in the agricultural economy of Canada. This is particularly true of Western Canada where the shortcomings of a one crop economy are becoming more and more evident. In an attempt to bring stability to the agricultural economy and to advocate measures for the conservation of soil resources, agriculturalists are seeking to encourage the production of forage crops. This involves a three-way program. Firstly, varieties of forages must be developed which are suitable for the areas involved and which will be consumed readily by ruminant livestock. Secondly, cultural practices have to be developed to ensure optimum production levels and thirdly, pasture management and forage utilization methods must be developed by the animal husbandman and livestock nutritionist in order to ensure efficient conversion of forage materials to marketable livestock products. In order for this program to succeed the overall effect must be to increase the economic returns to the producer to the point where it competes favorably with wheat production.

Research into the utilization of forage crops by livestock, presents a great field of endeavor and a worthwhile challenge to the animal nutritionist. In conjunction with the forage crop specialist he must devise methods of estimating the feeding value of new forage varieties grown under a number of conditions and at various stages of maturity. He must also develop management practices (grazing procedures, harvesting, storing and feeding methods, etc.) which will enable a maximum utilization of a forage crop's potential feeding value without endangering subsequent production of the forage.

Forage products (pasture, silage and hay) are relatively cheap sources of nutrients and for this reason should be used to the maximum extent compatible with the production requirements of all classes of stock. While it is true that the ruminant is designed primarily for the handling of whole plant materials, nevertheless forage crops, both as pasturage and as dried, ground material have an important role to play in the feeding of swine and poultry.

In the ruminant a large portion of the energy contained in the cellulose component of the forages is made available to the animal through the action of cellulolytic bacteria. It is becoming increasingly apparent that the activity of these microorganisms is related to their state of nutrition. Thus for efficient activity of these microorganisms it is important that their nutritional needs be adequately met, either by the forage itself or by various supplements fed with the forage. It has already been demonstrated that the efficiency of utilization of poor quality roughages can be increased by adding supplemental minerals, nitrogen and other compounds.

Another means of improving the utilization of forage crops is to alter their physical condition. By grinding and, or pelleting, the density of the forage material can be increased, allowing a greater intake of feed by the animal.

The basic purpose behind both the above approaches is to increase the intake of forage material so that the proportion of nutrients available for productive purposes is increased. It is believed that by remedying certain nutrient deficiencies and, or by grinding the forage, the rate of digestion of the available nutrients is speeded up, rate of disappearance of feed material from the digestive tract is increased, and recurrence of appetite is more rapid. Some uncertainty exists as to the influence of various factors on the rate of disappearance of food and food residues from the digestive tract of the animal, however it has been demonstrated that voluntary intake of forage is related to the feeding value of a forage and to its rate of disappearance from the digestive tract.

The finding that voluntary intake was related to the feeding value of a forage resulted from a search for a reliable index of forage feeding value. The lack of correlation of chemical analysis data or even of digestibility coefficients to the actual feeding value of a forage has been known for some time. It is of fundamental importance that some measurable character of forages be found which is closely correlated to its feeding value. This characteristic, besides being a reliable criterion of feeding value, should preferably be one which can be reliably and easily determined in view of the tremendous variation which exists in the feeding value of forages. This variation, of course, means that the predicting of the feeding value of a forage, on the basis of chemical and biological properties determined for a supposedly "similar" forage, is a very unreliable procedure.

The first work in this department dealing with the relationship between voluntary intake of forages and their feeding value was conducted by Lister (1957) who fed five "forages" harvested under average farm conditions to sheep. Smith (1958) conducted a somewhat similar experiment using "ideally cured" forages. In both experiments the extent of voluntary intake of the forages was found to be closely related to their feeding value as measured in terms of liveweight gains.

The first stage of the work reported here deals with the effect of stage of maturity on the voluntary intake and feeding value of two forage species to further test the validity of voluntary intake as an index of forage feeding value. The second part of the work deals with the effect of grinding these same forages on their voluntary consumption and feeding value when fed to lambs.

II. REVIEW OF LITERATURE.

A. Methods of Assessing Forage Feeding Value, and Related Considerations.

1. INTRODUCTION.

The problem of assessing the feeding value of whole plant forages is much more complex than that of assessing the feeding value of grains. The nutritional value of grains is subject to fewer variables since only one part of the plant is involved and it is usually harvested within much narrower limits of maturity than is whole plant forage. Grains may also be mechanically "purified" to further narrow the variability in feeding value if so desired. The feeding value of grains is also less dependent on ruminal microflora than is that of forages. Morrison (1956) presents only five classifications for wheat and four for oats. However there are some twenty-two separate classifications for whole plant alfalfa products. The factors causing variability between these products are,- stage of bloom, method of curing, fertility of the soil on which they were produced, cutting (first, second or third), proportion of leaf to stem, effect of weathering, form in which fed (meal, pellets), processing method (dehydration) and purity of the stand.

When the need arises to estimate the feeding value of any particular forage crop, the difficulty in applying published data on composition and digestibility is apparent. Watson (1952) states, "The most noticeable feature of any consideration of the chemical composition of herbage is that no one set of figures can possibly represent a particular plant or association of plants." It is thus of utmost importance to devise some simple and reliable method for assessing forage feeding value.

Swift (1957) in discussing the various methods used to arrive at the nutritive evaluation of forages, points out the need for some method which can be "as meaningful as possible" and which can be carried out under conditions prevailing on most experiment stations. He emphasizes the necessity of testing forages under conditions where they constitute the entire ration in order to eliminate "associative effects" of concentrate supplementation on the utilization of the resulting ration.

2. THE RELATIONSHIP OF CHEMICAL ANALYSIS DATA TO FORAGE FEEDING VALUE.*

Chemical analysis of forages has been used in an effort to predict feeding value of forages. The most commonly reported data result from the method of proximate analysis whereby the forage is partitioned into crude protein, crude fiber, nitrogen-free extract, ether extract, ash and water. On the whole it has been found that such analytical data do not correlate with any reasonable degree of consistency with the feeding value of the forage as measured in terms of liveweight gain, milk production, etc.

Common (1954) states that, "an obvious major defect of the proximate analysis from the standpoint of the agricultural chemist is its complete failure to provide any reasonably precise direct fractionation of the carbohydrates of roughages of the many forage crops into more or less digestible fractions as far as ruminant digestion is concerned." He further believes that it is unlikely that any simple readily reproducible chemical method will ever provide an estimate of this kind. He points out that certain chemical

*Throughout this thesis "Forage Feeding Value" refers to a forage's ability to produce liveweight gains, milk, etc.

fractions (crude fiber, lignin) have been found by Lancaster (1944) to be highly correlated to the digestibility of organic matter of 17 New Zealand forages but when the prediction equations were applied to a narrower range of materials the relationships were not statistically significant. Similarly he cites the work of McMeekan (1944) in which an "r" value of -.944 was found when crude fiber content was correlated to digestibility of a wide range of forages and feedstuffs. Common comments, "One can hardly avoid the suspicion that correlation between an analytical characteristic and digestibility calculated for a wide range of different feedstuffs may include expressions of the operation of factors not operative within the more narrowly restricted population." With reference to cellulose digestibility however it is pointed out that it is far more likely to be related to lignin content in populations of one species where the anatomical disposition of cell walls are probably similar.

Crampton (1956) studying digestibility coefficients of dry and green roughages and silages fed to ruminants (197 cases) found that in 44 percent of these cases the crude fiber fraction was digested as completely as was the nitrogen-free extract. For this reason it is obvious that crude fiber content is a poor guide to the feeding value of forages as far as ruminants are concerned. Several attempts have been made to fractionate the carbohydrate portion of forages in an effort to isolate some constituent that was indicative of feeding value. Waksman and Stevens (1938), Williams and Olmstead (1935), Crampton and Maynard (1938), Crampton and Whiting (1942) and Ely et al (1953) have all devised schemes for fractionating the carbohydrate (including lignin) into more specific entities. However no fraction was isolated which was found to be consistently related to feeding value of forages.

Richards _et al_ (1958) compared methoxyl, lignin, crude fiber and crude protein content of forages and feces as indirect indicators of dry matter digestibility. They used alfalfa, sudan grass and orchard grass. They found protein content of the forages to be of no predictive value. Lignin was likewise of little value. Crude fiber compared favorably with methoxyl but was discarded as it was harder to determine. The relationship between methoxyl content and digestibility of dry matter was r = -.724 on 66 forages and r = -.725 on 98 fecal observations. Because these "r" values indicate that only some 50 percent of the variability in dry matter digestibility can be related to the methoxyl content of the forages, these workers suggest that the methoxyl content of forages could be used only in a rough way to screen or rank forages as to quality.

Crampton and Jackson (1944) state that protein level of pasturage is unlikely to limit its feeding value since protein content is usually adequate to meet the needs of the ruminant. They found a negative correlation between protein content of the forage and its digestibility. They also found that lignin content was not a reliable index of forage feeding value, (r = +.737).

Forbes and Garrigus (1950) determined the relationship between chemical composition, nutritive value and intake of forages grazed by steers and wethers. They used organic matter digestibility as the criterion of nutritive value to allow for variability in ash content between the forages studied. They found the greatest degree of correlation between organic matter digestibility and lignin content and assumed this to be a logical finding since the development of lignification physically inhibits the digestion of nutrients included within the cells. They concluded that the fact that protein content was the next best measure was probably due more to the high degree of negative correlation between lignin and protein than to any specific effect of protein itself.

Walker and Hepburn (1956) fed 24 silages to sheep and noted that a close relationship existed between the gross digestible energy contents of the silages and the lignin (method of Ellis, 1946) content. The most accurate prediction of gross digestible energy was obtained by taking into account the content of lignin (Ellis), cellulose (Crampton and Maynard, 1938) and crude protein in the silage. With hays no increase in the accuracy of predicting gross digestible energy was obtained by estimating the lignin and cellulose content rather than crude fiber alone. They found that metabolizable energy values were closely related to digestible energy values.

Meyer et al (1957) fed oat hay, harvested at seven different stages of maturity, to lambs. The lignin content of this forage gradually increased from 3.8 to 9 percent while the protein content dropped gradually from 24 to 12 percent as the forage matured. The authors concluded that the lignin content was the best indication of the total digestible nutrient content of the forages ($r = -.98$) and was also an indication of daily gain.

3. IN VITRO STUDIES.

Asplund et al (1958) studying dry matter loss and volatile fatty acid production in the artificial rumen as indices of forage quality found that coefficients between both volatile fatty acid production and dry matter loss in vitro and dry matter digestibility in vivo were of the order of .7 to .8 and either significant or highly significant. However they also found that the volatile fatty acid yields and dry matter losses were highly significantly correlated with the crude protein contents of the hays, and that values for crude protein content were as highly correlated with dry matter digestibility ($r = .91$) as were the artificial rumen assay data. They concluded that further investigation is obviously required to "appraise in what respects and to what extent, if any, assessments of the relative value of hays by artificial rumen assay may be superior or complementary to estimates based simply on relative protein levels." It is important to point out that these workers used excellent alfalfa hay (18.9% crude protein), good mixed grass alfalfa hay (12.5% crude protein) and oat straw (5.9% C.P.). As pointed out by Common (1954), such results may not be indicative of results obtained within narrower ranges of forages.

In vitro studies on the cellulose digestibility of orchard grass, alfalfa and timothy, each harvested at three stages of maturity, were carried out by Kamstra et al (1958). It was found that lignin content was correlated with the digestion of cellulose within the whole plant materials. Isolating the cellulose from the lignin greatly improved the digestion indicating the "protective" effect of lignin on cellulose during digestion.

4. LEAF TO STEM RATIO.

Crampton and Jackson (1944) suggest that leaf to stem ratio is closely related to forage digestibility. Crampton (1956) points out that leafiness reflects the protein content of the hays, leaves containing about two to two and a half times the concentration of protein found in the stems regardless of the kind of plant. Leafiness is dependent upon the stage of maturity of the plant when harvested.

Read *et al* (1958) also report on the use of leaf to stem ratio as an index of forage feeding value. They reported that with first growth forage, containing from 32 to 87 percent leaves, that leaf content was highly correlated to digestible dry matter content ($r = .95$). However with aftermath where the leaf content ranged from 55-92 percent, there was found to be little difference in the content of digestible dry matter.

5. DRY MATTER CONTENT AT TIME OF HARVEST.

Read *et al* (1958) also report that the dry matter content of a forage at harvesting time is a good index of forage quality whether first or second growth material is concerned. In 28 forages where the dry matter ranged from 15-40 percent the relationship of dry matter content to digestibility was .8. The prediction equation $Y = 87.4 - 1.042\ X$ was found to have a standard error of 4.18%. They suggest that this method requires further study.

6. EVALUATING FORAGES ON THE BASIS OF ENERGY CONTENT.

Swift (1957) considered employing net energy values as an index of forage feeding value but, "after a careful appraisal of the many years of work dedicated to the goal of making net energy determinations a satisfactory experimental procedure it is revealed that in spite of the most elaborate control of environmental conditions, departing further and further from farm practice, the desired end cannot be accomplished." The measure of nutritive value as net energy, ideal from the theoretical standpoint, is sensitive to many factors including those quite apart from the nutritive composition of the feed.

Metabolizable energy values were ruled out on the basis that the determination of the energy content of the methane and urine made it impractical as a routine procedure at most stations.

Digestible energy, determined directly from the gross energy content of the feed and the feces derived therefrom was considered to be quite satisfactory from the standpoint of ease, speed, accuracy and reproducibility of results in the hands of various investigators. Like T.D.N. it represents a feed minus feces difference but is obviously more direct and accurate and free from empirical procedures and assumptions. It was found that digestible energy and T.D.N. values when obtained on forages alone were highly correlated (r = .97) and that the caloric value of a pound of T.D.N. was about 2000 Calories (2018 Calories). The extent to which perfect correlation does not exist between digestible energy and T.D.N. values "reflects the unavoidable errors and approximations which characterize the experimental procedure of determining T.D.N."

A comparison between digestible energy and metabolizable energy revealed an even higher correlation (r =.98). The ratio of metabolizable energy to digestible energy was .79 to 1. Thus the high correlation found between digestible energy and metabolizable energy lends further support to the use of digestible energy as a "simple and meaningful measure of nutritive value." Swift also recommends that digestible protein content of forages be used as a criterion of feeding value.

Swift et al (1950) determined the metabolizable energy values of timothy, alfalfa, bromegrass, orchard grass and Kentucky bluegrass harvested at comparable stages of maturity and artificially dried. Metabolizable energy values for these forages increased in the order named. T.D.N.,digestible energy, and digestible dry matter were also determined. Bromegrass was significantly higher in metabolizable energy content than alfalfa and timothy while orchard grass was equal to bromegrass. It is important to realize that these forages were fed in equal quantities and that this method of forage evaluation places no importance on voluntary intake or on the nutrient balance of the forages.

7. VOLUNTARY INTAKE AS A MEASURE OF FORAGE FEEDING VALUE.

The use of voluntary intake data as a measure of forage feeding value is a comparatively new proposal. Huffman (1939) noted that cattle would consume more of better quality forages than of poorer quality forages and suggested that a hay of good quality would be consumed at the rate of three pounds per 100 pounds of live weight.

Crampton (1957) presented data from the literature to support the hypothesis that the protein, calcium and phosphorus content of most edible whole plant forages is adequate in relation to the energy content of those forages and that the feeding value of a forage depends primarily on the magnitude of its contribution to the daily energy need of the animal. This is reflected largely in the relative amounts in which they are consumed. It is suggested that a practical rating of feeding value would be the expressing of voluntary consumption as a percentage of a normal or expected value of three pounds (dry weight) per 100 pounds live weight.

In support of the above-mentioned hypothesis data are presented to show the relative intakes of five widely differing forages (Birdsfoot trefoil, Red Clover, Bromegrass, Timothy and Oat Straw) together with composition and digestibility data. While it is stated that there is little relationship between any of the chemical entities of forage and its voluntary intake, examination of the data reveals a high degree of relationship between protein content and daily intake ($r = .889^{xx}$ Lister, 1957). Digestibility coefficients, with the exception of protein, showed no consistent relationship to voluntary intake. The author concludes that the data lend no support to the idea that completeness (or extent) of digestion is necessarily related to the acceptability of a given forage as measured by its voluntary consumption, or by the gains of the animals fed. It is suggested that rate, rather than extent of cellulose digestion is the factor regulating voluntary intake and that the more quickly ingesta moves out of the gastric structures, the sooner hunger recurs and thus the more feed is consumed over a given period of time.

Huffman expressed a somewhat similar point of view in 1953. He stated that, "It is well known that the forestomachs of ruminants are organized to exclude the passage of coarse fibrous particles into the abomasum. It must therefore follow that a retardation of cellulose digestion will necessitate a more protracted sojourn of the feed in the rumen and a corresponding decrease in the total bulk handled within a given time."

An experiment similar to that reported by Crampton (1957) was conducted by Smith (1958) using the same forage species except that alfalfa was substituted for oat straw. All forages were artificially cured. Voluntary intake was confirmed as a useful criterion of forage feeding value. The digestibility of the non-cellulose portion of the forages was found to be more closely related to voluntary intake than was the digestibility of the dry matter, cellulose or any proximate principle. It is also of interest that undigested residues were found to move more quickly through the digestive tract under ad libitum conditions than when the quantity of feed was restricted. There was no significant reduction in the digestibility of the dry matter.

The effect of stage of maturity on the voluntary intake within one species of forage has been studied by several workers.

Meyer et al (1957) found when feeding oat hay to lambs that feed consumption increased from 2.30 lb. per lamb when fed the earliest cutting, to 2.72 lb. per lamb when fed the most mature cut. There was a drop in T.D.N. content from 68 to 53 percent. Thus, in this case, it appears that voluntary intake did not serve as a measure of feeding value.

Schneider et al (1953) fed sheep orchard grass at two stages of maturity,- bloom stage (1/2 full headed) and seed stage (all heads and seeds formed). The dry matter digestibility was 61 and 54 percent respectively, while average daily feed consumption was 937 and 773 gms. respectively.

Smith et al (1958) fed alfalfa harvested at three different stages of maturity to dairy cows during each of three years. The cuts were, one-tenth bud, full bud and one-half bloom and were fed ad libitum. The average daily production of fat-corrected milk was 30.9, 28.5 and 26.9 pounds respectively. Average daily feed consumption was 38.9, 38.1 and 36.1 pounds. Differences in production and in feed intake were highly significant for two of the three years.

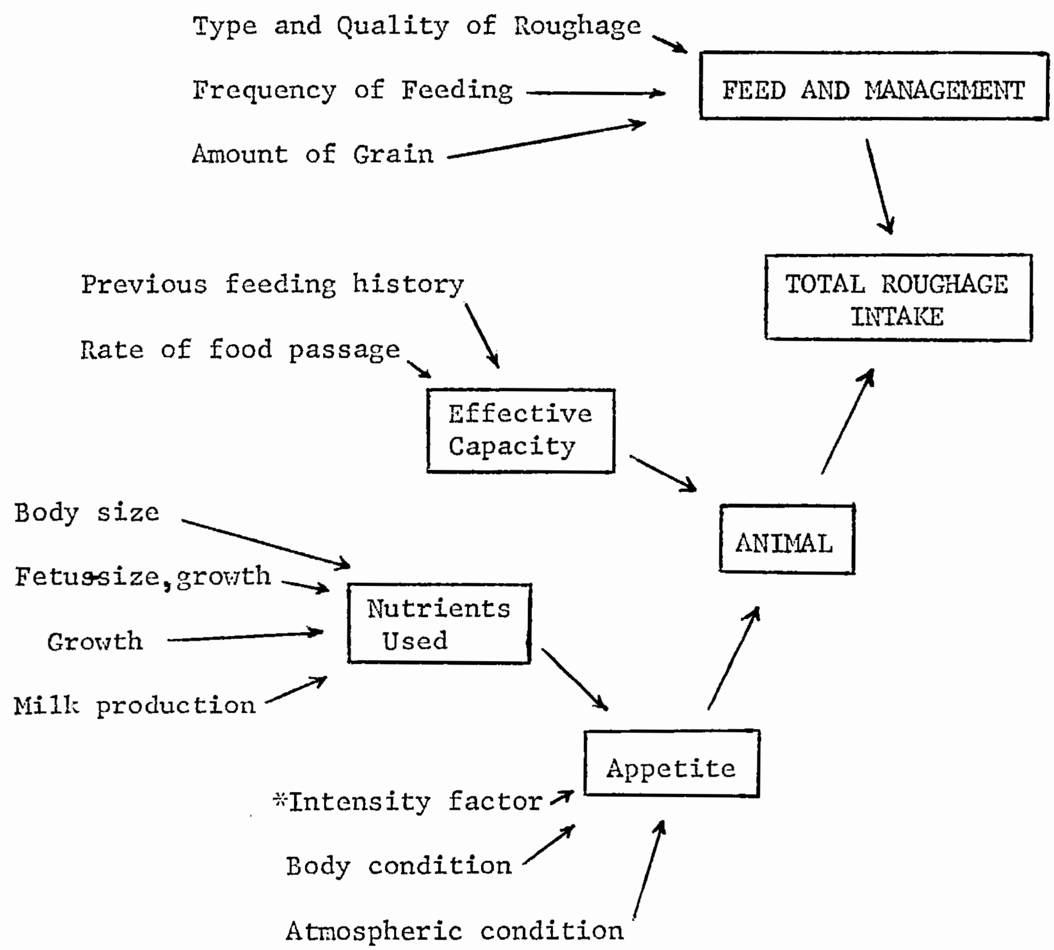
The effect of stage of maturity on the intake of forages is also reported by Reid et al (1958). In June, cows consumed 2.5 to 3.0 pounds of hay equivalent per 100 lb. of liveweight, while in mid-July the intake decreased to 1.1 to 1.7 pounds of hay equivalent per 100 lb. of liveweight. They found that, although the digestible dry matter content of forage harvested on June 10 was markedly reduced by deliberate weathering, the feeding value of the weathered forage was still appreciably higher than that of forage from the same source which was allowed to continue growth until July 8 at which time it was harvested and cured with heated air.

Forbes and Garrigus (1950) related feed consumption to forage lignin content. They found that for each percentage unit increase in forage lignin content there was a decrease of 5.8 percent of the maximum intake in the intake of total organic matter and of 8.2 percent in the digestible organic matter intake of steers. Corresponding figures were 6.8 percent and 9.5 percent for wethers.

8. FACTORS AFFECTING VOLUNTARY INTAKE.

The use of voluntary intake of forages as a measure of their relative feeding value involves some careful considerations of the factors influencing feed intake. Mather (1958) in discussing the possibilities of breeding cattle for greater forage consuming ability, outlines the following diagrammatic representation of the factors involved:

Factors Affecting Total Roughage Intake



*"Something inherent in the animal which may make her satisfied with the minimum or eat until she has to stop."

Forbes and Garrigus (1950) observed that the physical nature of the forage apart from its chemical composition is important in determining its acceptability. This was clearly shown by wether lambs on one of their tests. In two years, yearling wethers grazed on orchard grass or on Kentucky 31 fescue, apparently consumed equivalent amounts of the forages. Wether lambs, however, placed on comparable stands of the two forages, consumed significantly more orchard grass than fescue. These workers attribute this to the "relatively tender mouth" of the wether lamb in comparison with that of the yearling and to the fact that mid-summer fescue (grazed by the lambs) is much coarser, stiffer and harsher than the orchard grass that had been similarly treated and had similar chemical composition.

It is thus seen that "quality of forage", according to Mather, is only one factor affecting voluntary intake and that for strictly comparable intake data, these other factors must be held constant or otherwise taken into account when conducting tests or when comparing results between tests.

9. EFFECT OF SEASON AND STAGE OF MATURITY ON FORAGE DIGESTIBILITY.

Crampton and Jackson (1944) observed that from the first of June "digestibility of pasturage may rise, further decline or remain at the mid-summer level, apparently not depending on chemical changes, as indicated by standard feeding stuffs analysis or its modifications, but closely paralleling local climatic conditions of moisture and temperature."

Reid (1957) reported a rapid decline in the dry matter digestibility of first cutting forage with advancing maturity after a certain base date (April 30). Dry matter digestibility declined from approximately 77 percent in early May to 55 percent by mid-July. A similar decline in digestibility with advancing maturity was reported for aftermath forages although the range was narrower.

Murdock et al (1958) observed a daily decline in digestibility during the pasturing of orchard grass (73.1% April 30 to 67.3% May 6) and attributed this to selective grazing, as the choicest portions of the plant were consumed first. Consequently, on successive days the grazed forage became more stemmy and less digestible. They point out the importance of collecting fecal samples over the entire period when rotational grazing experiments are conducted. These workers found no decline in digestibility from early spring to aftermath forage. It is important to note however that the pastures were fertilized regularly and irrigated. Thus these results are in accordance with the observations of Crampton and Jackson (1944) regarding the effect of growing conditions.

Reid et al (1958) report that while 99 percent of the maximum dry matter yield is obtained around July 15 that 91 percent of the maximum yield of digestible energy is obtained when forage is harvested around June 1. Thus dry matter yield per se is not a good indication of productivity. They stress the value of early harvesting of forage crops indicating that the slight loss of digestible energy could be recouped by grazing or harvesting the regrowth.

10. CRITICISM OF T.D.N. AS A CRITERION OF FEEDING VALUE.

An assumption made by many workers is that a forage's feeding value can be determined by a knowledge of its yield of digestible nutrients. This presumes that all digestible nutrients have the same ability to meet the animal's requirements for either maintenance or production.

Swift (1957) states, "There is no scientific method for apportioning the value of a ration among its constituents. This becomes obvious when it is realized that inorganic salts or vitamins which contribute little or no energy to rations may profoundly affect the metabolism of energy." Crampton (1956) points out that with omnivora or carnivora the absence of an essential amino acid results in an increase of specific dynamic action as does lack of salt or phosphorus. In respect to amino acid metabolism a lack of a required acid means that the normal synthesis of protein is hampered and consequently a larger quota of amino acids must be deaminized. The disposal of such amino acids may be less efficient in terms of energy expenditure than is protein synthesis, and since the body must remain at constant temperature there is an increase in the heat loss."Thus possibly S.D.A. is a reflection of the degree to which the ration eaten fails exactly to meet the nutrient needs."

Watson (1952) states that a good deal more information is still needed before a final assessment can be made of the feeding value of grassland and "the animal itself is the only final and accurate yardstick." Regarding nitrogen utilization, Watson points out that to know the net absorption of nitrogen from the intestine provides no evidence that it has entered the animal as ammonia or as essential amino acids and suggests that, "at this stage of the development of the subject, practical experiments on growth, milk yield and so forth, or else thorough-going nitrogen balance experiments in which urinary nitrogen is measured seem preferable to digestibility studies."

Maynard (1957) in a review of recent developments in ruminant nutrition points out that 50 percent of carbohydrate intake is broken down to fatty acids in the rumen and that the acids formed vary in relative amounts according to conditions. There is limited evidence that these acids are not of equal value to the host. He points out that the T.D.N. system assumes that a pound of carbohydrates broken down to fatty acids has the same available energy as a pound digested to glucose. It is also pointed out that, the biological value of the amino acid mixture reaching the blood stream of the ruminant was at one time believed to be about 60 percent regardless of the biological value of the nitrogen fed to ruminants (10-13 percent protein level) (Johnson et al, 1942, 1944). However later studies by Lofgreen et al (1947) and Ellis et al (1956) show significant variation in the biological value of bacterial protein depending on the source,- urea 53.7, gelatin 57.4, casein 72.7, soybean protein 82.4 and blood fibrin 83.1 percent. It would appear that, despite the role of rumen bacteria, the nature of the nitrogen compounds as fed, is of importance from the standpoint of biological value.

Swift (1957) states that the net energy value of a ration for maintenance purposes must be definitely greater than for body increase. Experiments show that the net energy value of a ration was about 76 percent as much for body increase as for either maintenance or milk production.

It is conceivable however that the degree of nutrient imbalance in a ration could be reflected in nutrient (or forage) intake , if the imbalance were sufficiently marked to affect the digestibility of the ration (Chappel _et al_ 1955).

Despite theoretical consideration there seems to be little difference in practice in the utilization of energy for productive purposes. Hardison (1958) states, "since with the usual rations fed, relatively constant proportions of metabolizable energy are put into such functions as milk production, maintenance and body increases, a measure of digestible energy is the best practical measure of the productive value of forages that can be obtained with the facilities in all laboratories." Reid (1958) echos, "the apparent constancy with which cattle utilize metabolizable energy for maintenance, body gain and milk secretion is remarkable at least with the usual rations fed."

It is thus apparent that the assessment of the feeding value of forages is a complex matter. The markedly differing avenues by which the problem is being approached leads one to suspect that there is no simple answer to the problem. It would appear that the nutritive value of a roughage should depend upon its digestibility, the extent to which it can be eaten, and on the balance of the nutrients made available to the tissue of the animal. A measurement of the limiting factor(s) between several forages should provide a measurement of their relative feeding values.

B. <u>The Effect of Physical Form on the Intake and Utilization of Forages by Ruminants</u>.

Dry forages are usually fed in the long or uncut state. With an increasing trend towards mechanization of livestock feeding operations it is becoming increasingly apparent that forages in the chopped, ground or ground and pelleted form would, from the physical standpoint, lend themselves readily to mechanical methods of feeding and to compact storage. Before this method can be recommended to the livestock feeder, it is necessary to determine by reviewing the literature and by further experimentation where necessary, the effect of alteration of physical form on the overall feeding value of forages.

Alteration of the physical form of forages is not a new idea. Forbes <u>et al</u> (1925) fed excellent quality alfalfa hay in the ground form and found that apparent dry matter digestibility was reduced by 2.2 percentage units. The difference in digestibility of whole and ground alfalfa is explained on the basis that the ground roughage is not subjected to the same degree of soaking and fermentation in the rumen as is the whole roughage since the course of food is determined largely by its fineness of grinding, the ground roughage passing by the paunch more rapidly. Olsen (1930) fed alfalfa, sweet clover, wild hay and corn fodder and found either no difference or a definite decrease in the coefficients of apparent dry matter digestibility. These workers also observed that cows required about half as much time to consume the cut roughage ration as they did to consume the whole roughage ration. Milk and fat production was slightly increased but not enough to pay for the grinding. Mead and

Goss (1935) found that grinding lowered the digestibility of the crude fiber of hays. However grinding has not always been found to cause a reduction in the apparent digestibility of hays. Morrow and La Master (1929) found that grinding did not increase the digestibility of hays. They also noted that grinding reduced the percentage of feed refused as compared to long hays. They also pointed out that the dust associated with the grinding of the hays was a definite disadvantage. Swanson and Herman (1952) also found no significant differences in the digestibility coefficients of ground and unground hay.

Heller et al (1941) found that grinding to a powdery state confers no additional nutritive value over coarse grinding as far as sheep are concerned and may decrease palatability of the feed sufficiently to "affect adversely the development of the animal, and is itself a relatively costly process."

In many experiments forages have been ground and then pelleted. Long et al (1955) fed a mixed ration including 50 percent hay to lambs at a fixed level of intake. They found that grinding reduced the digestibility of the feed by 3-4 percentage units but that pelleting restored digestibility coefficients to the levels obtained when the ration was fed in the natural state. They noted that the ground ration was eaten in 45 minutes whereas the pelleted ration was eaten in 25 minutes.

Gardner and Akers (1955) fed alfalfa hay to dairy calves. The hay was fed in four physical forms,- long, chopped, ground, and ground and pelleted. Calf starter was also fed ad lib. The intake of hay was 1.01, 1.13, 1.36 and 2.28 lbs. per day per calf respectively.

Consumption of calf starter was reduced as hay intake increased. Grinding thus increased intake by 36 percent while pelleting more than doubled intake as compared to feeding the hay in the "long" state.

Riggs (1958) comments that grinding or chopping of good quality hays is not necessary but may be economical in the case of fodders, stovers or poorer hays because such feeds in ground form can be mixed with the ration ingredients to insure consumption without waste. When steers were fed a timothy-alfalfa mixture (Webb et al 1957) in the baled, chopped, and finely ground and pelleted forms average daily gains (lb.) and average daily feed intakes (lb.) were .63, 10.96; .62, 10.70; and 1.73, 15.69 respectively indicating a remarkable increase in feed efficiency due to grinding and pelleting combined. Pope (1958)cites the work of Neale (1955) who concluded that the feeding value of low grade alfalfa hay made into pellets was equal to or better than that of good hay fed by the usual method. Cate et al (1955) found that pelleting timothy meal increased both feed consumption and rate of gain while pelleting alfalfa resulted in no increase in gain or feed consumption. Lambs receiving pelleted timothy outgained lambs receiving alfalfa hay indicating the importance of feed intake.

Very little information appears in the literature dealing with the effect of moistening ground forages prior to feeding. Forbes (1925) stated that due to the dusty nature of the ground forages it was necessary to moisten the ground forage with an equal quantity of water. He likewise moistened the alfalfa fed in the long state. Hibbs and Conrad (1958) while giving no data, mentioned that adding an equal weight of water to a mixture of ground forage and grain resulted in a greater dry matter intake and an increase in palatability where dairy calves were concerned.

Ewing and Smith (1917) studied the effect on rate of passage of food residues on digestion coefficients. They concluded that crude fiber digestion is decreased by a more rapid passage of feed residues, although the reverse was true for the ration as a whole. They found that coarse roughages retarded rate of passage and that more finely ground feeds passed through the animal more rapidly than coarser feeds. They therefore concluded that, "the rate of passage of feed residue is influenced largely by the nature of the ration and by the quantity, the importance of the two being in the order named."

The effect of grinding on the rate of passage of ingesta has also been studied by Balch (1951). He found that when ground hay was fed with long hay to cows that the ground material was excreted much more rapidly than was the long material. Similar results were reported by Rodrique and Allan (1956) working with dairy cows and by Blaxter et al (1956) working with sheep. Blaxter's data show the effect of level of forage intake on the dry matter digestibility and rate of passage of forages fed in the long, medium ground and pelleted, and finely ground and pelleted forms. A summary of these results are as follows:

Form in which fed	Amount given daily (gms)	Apparent D.M. Digestibility (%)	Mean time spent by the food in the dig. tract (hours)	D.M. content of feces (%)
	600	80.3	103	42.3
Long	1200	79.1	72	38.6
	1500	79.4	68	37.4
Medium ground	600	76.9	74	41.6
and cubed	1200	71.5	53	39.7
(1/4" screen)	1500	69.9	42	35.4
Finely ground	600	75.9	53	41.5
and cubed	1200	68.8	39	33.7
(1/16" screen)	1500	65.4	34	31.2

Grinding and pelleting lowered digestibility indicating that as particle size decreased digestibility decreased and rate of passage increased. Increasing the level of forage intake reduced the extent of digestibility in the case of the ground and pelleted forages but not in the case of the long material. It also caused a decrease in the time spent by the forages in the digestive tract. Extent of digestibility was proportional to time spent in the digestive tract in the case of the ground and pelleted forage, but not in the case of the long forage. Feces dry matter content is related to feed intake.

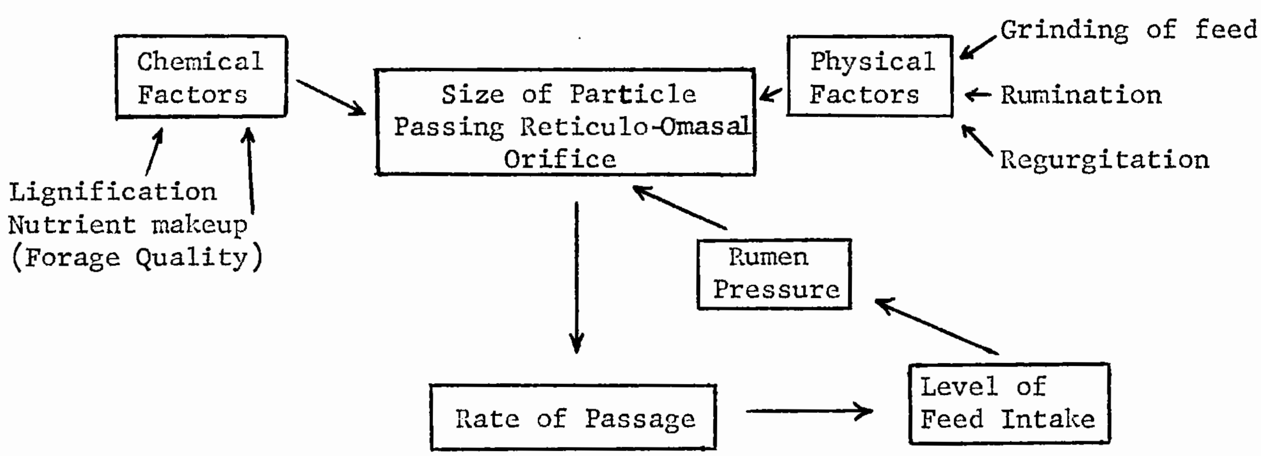
Blaxter states, "analysis of the relation between digestibility of food and its passage through the gut indicated that the former could be predicted from the latter." It was also concluded that the maximal appetite of animals for food is determined to a considerable extent by the food residues present in their digestive tracts. Method of preparation modified the rate of passage of food through the gut and this rate was the determinant of its digestibility.

These findings indicate some of the important relationships between level of feeding, digestibility and rate of passage. It would appear that the level of intake of long hay, and not ease of digestibility was the primary factor influencing the length of time the forage spent in the digestive tract. Also it is apparent that 68 hours was adequate time for attaining of maximal digestion of the dry matter of long hay.

In the case of the ground and pelleted forages it appears that particle size speeded up rate of passage as compared to the long hay. Within the ground and pelleted forages however, level of intake again appears to be the primary factor influencing time of passage. Since the inherent ease of digestibility of the forage can be assumed to be the same it is apparent that extent of digestibility depended on the level of feed intake and not vice versa. The findings of Smith (1958) and Reid (1956) that the digestibility of all roughage rations is not influenced by the level of intake is not at variance with these findings since their conclusions are based on the results of feeding forages in the unground state. We can reconcile both viewpoints if we assume, on the basis of these findings, that rate of passage is dependent on particle size and that with long or chopped forages the extent of digestibility is relatively complete by the time that particle size is reduced to the point where the digesta may leave the reticulo rumen. In the case of the ground forages the physical breakdown in particle size is much more rapid with the result that passage out of the rumen is faster. Where increased intake occurs the "rumen pressure" is even greater, further increasing the rate of passage of the ingested material. As the time of passage is reduced below the limit required for maximum extent of digestibility,

digestibility coefficients are reduced. The postulation of Crampton (1957) that forage quality affects rate of digestion and hence time of passage and thus also extent of voluntary intake can also be reconciled with the above reasoning. We may attempt to reconcile the views of most investigators as follows:

Suggested Relationships Between Factors
Influencing Rate of Passage.



Blaxter found that with one of the grasses tested, the constant describing the time course of digestion showed that about 70 percent of the digestive process was completed in 10 hours. Hale et al (1940) estimate that of the cellulose in the diet about 80 percent of the total digested disappears in the rumen, the remainder being largely digested in the large intestine. According to Gray (1947) cited by Boyne et al (1956) 60 percent of the cellulose in the feed is digested in the teticulo-rumen and 30 percent in the large intestine.

Hale *et al* (1947) studied the rate at which alfalfa hay was digested in the rumen of fistulated cows and found that 79 percent of the cellulose was broken down during the first 12 hours. During the following 12 hours very little digestion occurred. They suggest the concept of a "digestion ceiling" for alfalfa whereby rumen digestion proceeds within 12 hours to a point where lignin limits further cellulose and hemicellulose digestion. This would indicate that long forages remain in the digestive tract for an unnecessarily long period of time and that for reasons of economy grinding of forages would result in a greater return of digestible nutrients per unit of time since with the proper degree of grinding almost the same extent of digestibility can occur in the shorter time required for the passage of ground material through the digestive tract.

Blaxter *et al* (1956) calculated that immediately before they are given their next meal, sheep fed long material carry in their digestive tracts food residues equivalent to 2.6 days food intake. Sheep given the pellets made from the same material carried less than half this amount. Blaxter *et al* (1956) determined voluntary intake on the long and on the ground and pelleted hays. Appetite failed in sheep given the long material when they were consuming 1800 grams daily. With both types of cubes, much higher feed intake, up to 2400 grams daily was obtained, (a 33% increase). These findings suggest that the space-filling attributes (density) of the ration determines appetite to a considerable extent.

It should be noted at this point that the data of Blaxter *et al* (1956) offer an explanation as to why different investigators have found divergent results when comparing the digestibility of long and ground forages. Because of the effect of level of feed intake on digestibility different investigators using the same forage but feeding at different levels could obtain conflicting results.

The effect of grinding and cubing on the utilization of the energy of dried grass has been determined by Blaxter and Graham (1956). Their results showed that fecal losses of energy were considerably greater when the sheep were given cubes than when they were given chopped material. Chopped, medium ground and cubed, and finely ground and cubed grass was fed at each of two levels, 600 gms. daily and 1500 gms. daily. Fecal losses of energy were also greater when the larger ration was given. However methane production was higher when the sheep were given chopped material than when they were given cubes and fell with the increase of feeding level. There were no statistically significant differences in energy retention between the three materials within either the low or the high level of feeding. Net energy per 100 Cals of food ingested showed that higher values occurred at the lower level of feeding.

Heat losses were greater at the higher nutritional level and were considerably less for cubes than for chopped material. Digestibility studies showed that the fall in the digestibility of the structural components of the cell was the major factor causing increased fecal loss.

It is pointed out that the physical factors, which change the rate of passage of food through the gut change the rate and nature of microbial fermentation and cause variation in the mechanical work involved in prehending, masticating and cudding food, are as important as the chemical composition of the food in determining its nutritive value.

Several investigators have studied factors affecting the digestibility of long and ground hays in the rumen. Balch and Kelly (1950) found that in the rumen of cows fed hay the digesta separate into two layers, an upper layer of relatively dry, fibrous material and a lower layer of more fluid consistency. Balch (1950) showed that there was a difference in the dry matter content between the dorsal and ventral regions of as much as 10 percent. Balch and Johnson (1950) found that the breakdown of cellulose in the reticulo rumen was less rapid in the dorsal (drier) than in the ventral (moister) sections of the rumen. The time required for the breakdown of cellulose bore a positive and highly significant correlation ($r = .94^{xx}$) to the dry matter content of the surrounding rumen. They found further that the feeding of ground hay produced a higher dry matter content of the digesta in all parts of the reticulo rumen than did the feeding of unground hay and suggest that this constitutes a major factor responsible for the lower digestibility of the crude fiber of ground hay as compared to that of unground hay. These findings confirmed the earlier data of Balch (1950) suggesting that a high ratio of water to dry matter in the total intake and hence perhaps in the reticulo ruminal digesta favored the breakdown of crude fiber.

From the review of literature it is clear that no work has been carried out to determine the effect of grinding and moistening on the relative consumption and utilization of various forages (different species, and stages of maturity within species) as compared to their consumption and utilization in the chopped state. It would seem that this information should be acquired in order to further elucidate the factors influencing forage utilization.

III. OBJECT OF RESEARCH

The major objective of the research herein described is to further test the validity of the hypothesis that voluntary intake can be a criterion of forage feeding value. Specifically, the effects of stage of maturity and of the physical form in which the forages are fed, on voluntary intake, nutrient availability and liveweight gains will be investigated.

IV. EXPERIMENTAL

A. General.

The experimental work reported here was conducted under two separate projects. The object of the first was to determine the effect of stage of maturity on the voluntary consumption and utilization of two different forage species when fed to lambs. As this experiment was in progress, a fifth (and smaller) lamb was paired with one of the test lambs and fed the same forages but in the ground and moistened form. It was discovered that this "spare" lamb consumed markedly greater amounts of the forages than did its larger partner. As a result, immediately following completion of the first experiment, it was repeated using the same plan, but feeding the forages in the ground and moistened form. For purposes of this thesis the above two phases will be considered as one experiment.

The experiment may thus be considered as made up of two consecutive "4 × 4 Latin Squares" in which four lambs were each fed in different rotation four forages (viz. an early and a late cut of both Timothy and Red Clover) fed in the chopped form in Square I and in the ground, moistened form* in Square II.

B. Design of the Experiment.

The overall plan of the experiment is shown in Chart I.

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*Grinding, by means of a hammermill fitted with a 1/4" screen, resulted in a particle size varying up to maximum of 1/2" in length in the case of the Timothy and about 1/4" in the case of the Red Clover.

CHART I. Plan of Experiment

Period	Lamb No. 1	Lamb No. 2	Lamb No. 3	Lamb No. 4
I	Red Clover (early)	Red Clover (late)	Timothy (early)	Timothy (late)
II	Red Clover (late)	Timothy (late)	Red Clover (early)	Timothy (early)
III	Timothy (early)	Red Clover (early)	Timothy (late)	Red Clover (late)
IV	Timothy (late)	Timothy (early)	Red Clover (late)	Red Clover (early)

Period	Lamb No. 1	Lamb No. 2	Lamb No. 3	Lamb No. 4
V	Red Clover (early)	Red Clover (late)	Timothy (early)	Timothy (late)
VI	Red Clover (late)	Timothy (late)	Red Clover (early)	Timothy (early)
VII	Timothy (early)	Red Clover (early)	Timothy (late)	Red Clover (late)
VIII	Timothy (late)	Timothy (early)	Red Clover (late)	Red Clover (early)

C. Animals.

Five purebred Border Cheviot ewe lambs were confined to digestion stalls throughout the period of these tests. Four were used as test animals with the fifth being used as a spare for purpose of preliminary investigations (see special section under results). The four lambs used in the main project were born in March of 1957 and weighed between 46-1/2 and 52 pounds at the time of going on test, November 13, 1957. A week prior to going on test all lambs were dewormed with phenothiazine capsules and shorn.

D. Forages.

The forages used for this experiment comprised early and late cuts of both Timothy and Red Clover. The Red Clovers were harvested at the Dominion Experimental Farm at L'Assomption, Quebec, while the Timothys were harvested at Macdonald College. The Red Clover cuts were field cured for 24 hours, chopped and artificially dried under forced air at 140°F. The Timothy cuts were chopped and artificially dried the same day as cut. All forages were bagged for storage. For the second phase of the test these forages were coarsely ground in a hammermill fitted with a 1/4" screen, bagged and stored until required. The forages may be described as follows:

(1) Red Clover - cut on July 2, 1957 in the early bloom stage. Prior to feeding it would have graded lower than first grade, due to its brownish-green color.

(2) Red Clover - cut on July 25 when fully mature (seed head dead). This hay would have graded lower than (1) because of its browner color and mustier odor.

(3) Timothy - cut on July 9 in early bloom. It was fairly green and leafy and was ideally cured.

(4) Timothy - cut on July 31 at maturity. This hay was of lower grade than (3) because of its higher proportion of stem and its darker color. It was well cured.

E. Feeding Practice.

Forages were fed to lambs once daily (about 9:30 a.m.) in amounts equal to the previous day's consumption plus 10 percent to ensure *ad libitum* conditions. For the second half of the experiment the ground forages were weighed and then mixed by hand with an amount of water equal to the weight of the forage. This practice was adopted primarily to increase the palatability of the otherwise dusty feed. Pelleting was not possible with the facilities at hand and it was felt that grinding and moistening would be the next best treatment as far as encouraging consumption of forages was concerned.

Because sorting was possible during Part I of this experiment, all weigh backs for each sheep during each period were composited and sampled for analysis. During Part II no sorting was possible but owing to the fact that the feed was fed in the moistened condition weigh backs had to be dried and weighed in order to correct the consumption figures. The forages were fed for three-week periods since it had been shown by Lloyd et al (1956) that variability in digestion coefficients was of minor importance following the "standard" 10-day preliminary period. It had also been shown by Lister (1957) that voluntary consumption of most of the forages he studied did not increase significantly after the tenth day.

F. Salt and Water Consumption.

Cobalt iodized block salt was available ad lib in a special salt container designed to prevent losses due to chipping. The salt blocks were weighed each week and the daily water consumption records maintained for each lamb over the final two weeks of each feeding period. Water was available ad lib.

G. Liveweight Gains.

Each lamb was individually weighed once weekly prior to being fed. In order to minimize errors due to "fill", weight gains over the final two weeks of each period were used for purposes of treatment comparisons.

H. Digestibility and Balance Studies.

Following an 11-day preliminary period in each of the three-week periods, total feces and urine outputs were collected from each lamb daily. Aliquot samples of urine were stored under toluene in a refrigerator for subsequent nitrogen analysis, while aliquot samples of feces were taken, dried at 100°C for 24 hours, weighed to determine feces dry matter output, and composited. The 10-day composite was later ground and sub-sampled for subsequent chemical analysis.

Because this trial was conducted under *ad libitum* feeding conditions, it was arbitrarily decided to allow for a two-day lag between forage intake and feces output. Thus for purposes of calculating digestibility coefficients, the feed fed from the tenth to the nineteenth day inclusive, was assumed to correspond to the feces collected from the twelfth to the twenty-first day inclusive. It is realized that the forages, of different species and physical forms, would probably not pass through the digestive tract at the same rates, however the two-day lag should provide greater accuracy than failure to allow for any lag at all. Where feed consumption had levelled off during the period the error will, of course, be less than where consumption is fluctuating. The fact that a four lamb average is used should also tend to minimize error.

In order to correct feed composition data during Part I the feed weigh backs were sampled and analyzed.

I. Chemical Analyses.

Analyses for moisture, crude protein, crude fat, crude fiber and ash were carried out on all forage offered, chopped forages offered but uneaten, and on the feces excreted, according to the standard A.O.A.C. methods (1956) with some modifications in technique. Urine samples were analyzed for nitrogen only. Gross energy values were determined on all samples (except urine) using the Parr Oxygen Bomb calorimeter (Parr 1948) fitted with an automatic recording device, (described by Crampton 1956). Cellulose was determined on all samples (except urine) using the method of Crampton and Maynard (1938) with slight modifications (see appendix). Lignin determinations on all forage and weigh back samples were carried out using the method of Thacker (1954) slightly modified (see appendix).

J. Calculations.

1. Voluntary Intake.

For purposes of calculating digestion coefficients the voluntary intake of forages was determined by adding together the net daily feed consumption figures for the period from the tenth to the nineteenth day inclusive. However for purposes of determining the effect of grinding, species or stage of maturity on the extent of voluntary consumption the feed consumption during the final week of each period was used. This was done in order to obtain a more accurate "maximum" figure since in several cases consumption increased considerably after the tenth day.

2. Water Consumption.

Water consumption was determined daily by means of a measuring stick which had been calibrated for each water pail. By re-filling the pail to a specified mark daily, and measuring the depth of the water remaining the following morning, it was possible, by means of a chart, to convert the "depth reading" to c.c. of water consumed. During Part II the amount of water added to the ground forage was considered as part of the water consumption and added to the amount consumed from the pail. Since the water was added to the feed at the rate of 1 gram (1 c.c.) per gram of feed, the water consumed with the feed was assumed to be equal to the weight of the net air dry feed consumed. No corrections were made for evaporation losses which should have been relatively constant across the treatments within each part of the test. It is obvious however that evaporation would be higher in Part II since the evaporation from the ground feed would be a loss not occurring in Part I.

3. Salt Consumption.

Salt consumption was determined each week by weighing the individual salt licks at weekly intervals. For purposes of the experiment, only the consumption during the final week was used. To insure more accurate salt consumption data during the final two weeks, new or nearly new salt licks were used, the eroded blocks being used for the first week in each period. (Badly eroded licks were subject to chipping).

4. Digestibility Coefficients.

The "apparent digestibility coefficients," hereafter referred to as "digestibility coefficients" for reasons of brevity, were calculated as follows:

$$D.C_x = \frac{[Fo \times Cx_1] - [Fr \times Cx_2] - [Fe\ ADM \times Cx_3]}{[Fo \times Cx_1] - [Fr - Cx_2]} \times 100$$

where

$D.C_x$ = digestibility coefficient of constituent X (protein, crude fiber, cellulose, etc.)

Fo = grams of forage offered (air dry)

Cx_1 = the percentage of constituent X in the forage offered.

$Fo \times Cx_1$ therefore equals the gross amount of constituent X offered (grams)

Fr = ground forage refused (air dry)

Cx_2 = the percentage of constituent X in the refused forage

$Fr \times Cx_2$ thus equals the grams of constituent X offered but refused and $Fo \times Cx_1 - Fr - Cx_2$ = the grams of constituent X actually consumed

Fe ADM = grams of air dry feces voided

Cx_3 = the percentage of constituent X in the air dry feces

$Fe\ ADM \times Cx_3$ = the grams of constituent X voided (undigested)

Thus $Fo \times Cx1 - Fr \times Cx_2 - Fe\ ADM \times Cx_3$ = the grams of X absorbed or digested (i.e. assumed to have been absorbed).

This quantity expressed as a percentage of the amount consumed (denominator) represents the digestibility coefficient.

For the forages fed in the ground form the weigh backs were assumed to be identical in chemical composition to the feed offered hence the formula would be similar to the above except that the term $Fr \times Cx_2$ would be missing from numerator and denominator.

It might well be argued that the uneaten or "refused feed" should be considered as undigestible when calculating digestibility coefficients for chopped forages. However since we have no satisfactory way of determining what proportion of the weigh back was refused because of its unacceptability and what proportion was simply refused because it was more than the lamb was capable of consuming, we will arbitrarily express the results as here outlined. The fact that performance data of lambs fed ground forages represents the "feeding value" of the entire forage while that of lambs fed the chopped forages represents the feeding value of a slightly more acceptable portion of the forage should however be borne in mind in evaluating the results.

5. Calculation of Maintenance Requirements.

The energy requirement was determined using Brody's (1945) equation

$$X = ab\, W^n$$

where X = calories

a = activity factor

b = regression of calories per unit of metabolic size (= 70)

W = body weight in kilograms

n = .75 power.

a is equal to 2.0 for digestible calories or 1.8 for metabolizable calories where ruminants are concerned.

The formula used was thus

$$\text{Metabolizable Calories for Maintenance} = 1.8 \times 70 \times W_{kg}^{.75}$$

6. Calculation of Metabolizable Energy Values.

Metabolizable energy is that portion of the feed energy remaining after losses in feces, gas and urine have been accounted for. Swift et al (1948) showed that methane production in ruminants is proportional to the amount of carbohydrate digested and present the equation $X = \frac{2.41Y}{100} + 9.80$ where X = grams of methane produced and Y = grams of digestible carbohydrate.

Brody (1945) stated that the volume of methane and carbon dioxide produced in the rumen were approximately equal. He gives the equivalent energy loss due to CO_2 as 4 Cals per liter. The energy value of methane is 9.4 Cals/liter (Lange, 1934).

Thus one gram of methane is equivalent to 1.4 liters of methane or 13.16 Calories. Since the two gases are produced in equal volumes there is associated with this methane loss a CO_2 loss of 1.4 liters having a caloric value of 5.6 calories. Thus for every gram of methane produced there is a combined loss of 18.76 calories. To express the above equation as calorie loss we multiply by 18.76.

$$18.76 \left(\frac{2.41Y}{100} + 9.80 \right)$$

$$= 45.2116Y + 183.85$$

$$\text{or } C = .452Y + 183.85$$

where C = total estimated calories lost in gas and

Y = grams of digestible carbohydrate.

To correct for energy loss in the urine the factor 1.3 Cals/gram of digested protein (Brody 1945) was used. (See Appendix Table 7,a and b).

K. Statistical Analyses of the Data.

The analysis of variance was carried out with all data obtained. The form used is illustrated on the following page (Chart II). Owing to limited number of degrees of freedom for treatments the effect of species and stage of maturity were combined under forage.

CHART II. Analysis of Variance Form

Factor Analysed ____________________

Square I - Chopped Forages

Period	Lamb 1	Lamb 2	Lamb 3	Lamb 4	Period Totals
I	R_1	R_2	T_1	T_2	
II	R_2	T_2	R_1	T_1	
III	T_1	R_1	T_2	R_2	
IV	T_2	T_1	R_2	R_1	
Lamb Totals					

Square II - Ground Forages

Period	Lamb 1	Lamb 2	Lamb 3	Lamb 4	Period Totals
V	R_1	R_2	T_1	T_2	
VI	R_1	T_2	R_1	T_1	
VII	T_1	R_1	T_2	R_2	
VIII	T_2	T_1	R_2	R_1	

$\Sigma X =$ ______ $\Sigma X^2 =$ ______ $(\Sigma X)^2 =$ ______

$N =$ ______ $C.F. =$ ______ $C.F._{Sq_I} =$ ______

$C.F._{Sq_{II}} =$ ______

Forage Totals

Square	R_1	R_2	T_1	T_2	
II					
I					

Total S.S. ____________________

Forage S.S. ____________________

Period S.S. ____________________

Lamb S.S. ____________________

"Grinding" S.S. ____________________

"For.× Grind."S.S. ____________________

Error S.S.

Analysis of Variance

Source	D.F	S.S.	M.S.	F	.05	.01
Forage	3					
Periods	6					
Lambs	6					
Grinding	1					
For.× Gr.	3					
Error	12					
Total	31					

Results-

In most cases differences due to stage of maturity are determined by applying L.S.D's where forage differences are found to be statistically significant.

In order to determine the effect of time on the voluntary intake of forages the data of Table 1 were handled as a split-split plot.

The methods of simple regression and of correlation and of partial regression were taken from Wallace and Snedecor (1931).

V. GENERAL OBSERVATIONS.

It may be of interest to present a few observations relative to the condition of the lambs while on this test. The lambs were brought in from pasture and barn penned for about two weeks prior to going on test on November 13, 1957. They were placed in digestion stalls and remained there until May 7, 1958.

While the lambs were nervous at first they quietened down quickly and gave no trouble for the remainder of the test. The fact that only one attendant (the author) looked after them and that they received kind treatment undoubtedly had a bearing on their calm behaviour and relatively good growth performance. Also the fact that they were fed *ad libitum* contributed to their contentment.

During the period of the test the health of the lambs showed no signs of deteriorating, in fact the lambs appeared to be in better condition at the completion of the experiment than at the start.

The cages were constructed in such a way that the front feet of the lambs rested on a sandpapered area while the hind feet rested on a wire mesh floor. As a result the front hooves remained well trimmed while the hind hooves required trimming before the end of the test.

During the changeover from chopped to ground and moistened forages,considerable variability between the lambs was encountered with respect to the time required to reach a reasonable level of forage intake. About 7 to 10 dayswere required for this adjustment period, following which the intake of ground forages increased fairly rapidly.

In most cases feces were voided in the form of pellets; however, in one or two instances, especially when large amounts of ground Red Clover were fed, feces were voided in the form of soft masses.

VI. RESULTS AND DISCUSSION

A. An analysis of the factors influencing voluntary intake of the forages.

a. The effect of time on the extent of voluntary intake.

In order that the voluntary intake of forages can be used as a criterion of forage feeding value it is necessary that these forages be fed for a period of time adequate to allow for the consumption of the forages to reach a relatively constant level. Lister (1957) fed five chopped forages for a period of eight weeks each and concluded from his analysis of the data on forage intake, that voluntary consumption had reached a maximum and constant level in the case of his poorer quality forages (bromegrass, timothy and oat straw) within the first ten-day period. The consumption of Birdsfoot Trefoil increased significantly to about the thirtieth day while that of Red Clover increased gradually over the whole period of the test.

In the work discussed here, the feeding periods ran for only three weeks. A study of Figures I and II reveals that while the average voluntary intake of the chopped forages appears to have reached a maximum by the end of the third week, the intake of the ground forages does not appear to have reached a maximum, particularly in the case of the two Timothy cuts.

In order to analyse this situation statistically the feeding period was arbitrarily subdivided into four periods viz 1-5 days, 6-10 days, 11-15 days and 16-21 days and the average consumption of each forage by each sheep determined for each of these periods. The data are summarized in Table 1. Each entry represents an average consumption figure for four sheep. An analysis of variance

FIG. 1 - Trends in Timothy Consumption

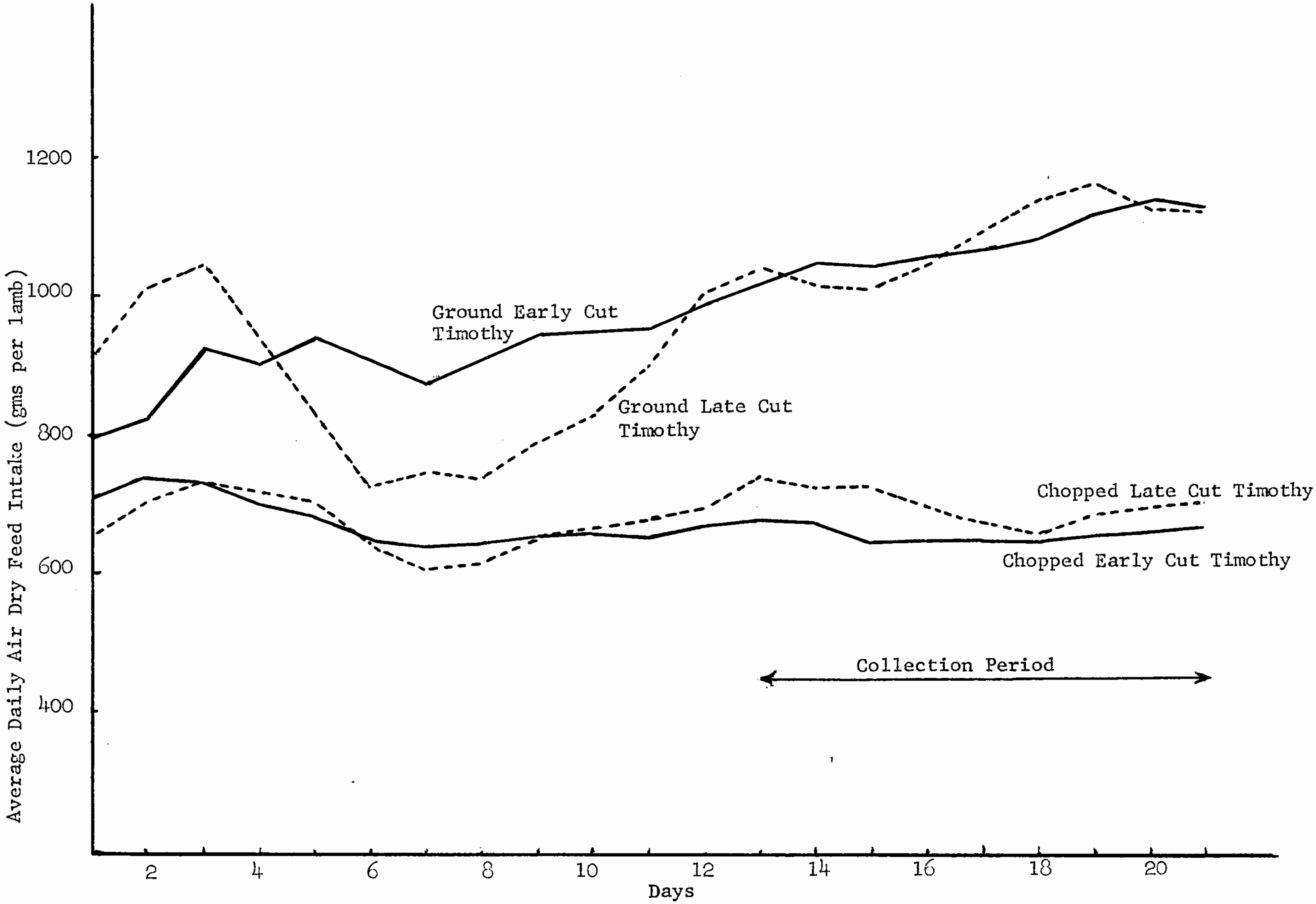

FIG. 2 - Trends in Red Clover Consumption

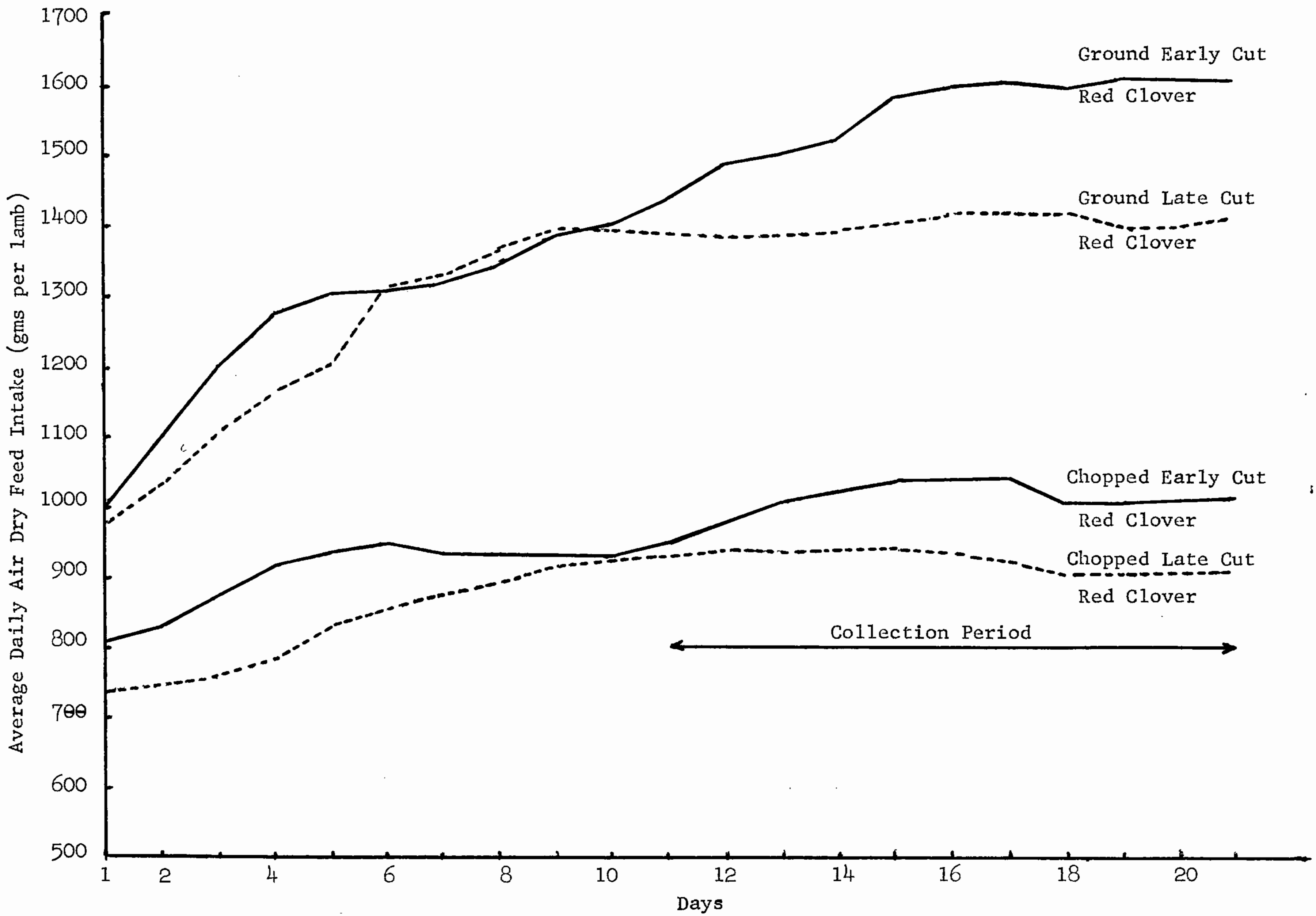

TABLE 1. Mean Voluntary Forage Intake as Influenced by Forages Species, Feeding Period and Grinding.

Forage Species	Form in which fed	Feeding Period (days) (1) 1-5	(2) 6-10	(3) 11-15	(4) 16-21	Average (W)	Overall Forage Average (X)
Red Clover (Early cut)	Chopped	872	938	1001	1022	958	1189
	Ground	1183	1362	1523	1608	1419	
Red Clover (Late cut)	Chopped	771	894	938	916	880	1099
	Ground	1095	1366	1396	1416	1318	
Timothy (Early cut)	Chopped	709	648	664	655	669	822
	Ground	874	915	1011	1102	976	
Timothy (Late cut)	Chopped	695	634	706	688	681	818
	Ground	943	761	995	1119	955	
Totals	Chopped (Z)	762	779	827	820		
	Ground (Z)	1024	1101	1231	1311		
	Overall (Y)	893	940	1029	1066		

Least Significant Differences (gms)

Between	P=.05	P=.01
a. Overall forage means (X)	69	92
b. Overall feeding period means (Y)	60	75
c. Forage treatment (species and form) means (W)	165	221
d. Overall period means within form (Z)	138	177

was carried out to determine the effect of time interval, forage (including species and stage of maturity), sheep and the effect of grinding on the voluntary intake of the forages (Table 2).

The analysis of variance reveals that there were highly significant differences in mean voluntary forage intake between periods. Reference to Table 1 shows that feed consumption was significantly less ($P < .01$) in period 1 than it was in periods 3 and 4, and that consumption in period 2 was also significantly less than in periods 3 and 4 ($P < .01$). The average difference between voluntary intake during periods 3 and 4 of 37 grams is not statistically significant. If we examine the trend within the chopped forages we find that feed intake has levelled off during the final 10 to 11 days of the feeding period. However the trend with the ground forages indicates that voluntary intake has increased during period 4 as compared to period 3. While analysis of variance indicates that the "Period × Grinding" interaction is not significant, the F value of 2.3 as compared to the P.05 F value of 2.80 cannot give one any real satisfaction that a maximum level of feed intake has been reached with the ground forages. We should therefore bear in mind that consumption figures dealing with ground forages are probably not representative of maximum possible intake levels.

The statistical significance of the other sources of variation are similar to those found in the next section and to avoid duplication will be discussed in the next section.

TABLE 2. Analysis of Variance of the Effect of Period, Sheep, Forages and Grinding on Voluntary Intakes of Forages.

Source	D.F.	S.S.	M.S.	F	P.05	P.01
Period	3	607,017	202,339	17.9^{xx}	3.86	6.99
Sheep	3	1,243,854	414,618	36.6^{xx}	3.86	6.99
Error (a)	9	101,901	11,322			
Forages	3	3,483,431	1161,144	62.8^{xx}	2.86	4.38
Forages × Period	9	314,978	34,998	1.9	2.15	2.94
Error (b)	36	665,254	18,479			
Grinding	1	4,378,210	4378,210	124.6^{xx}	4.04	7.19
Period × Grinding	3	237,131	79,044	2.3	2.80	4.22
Forages × Grinding	3	210,600	70,200	2.0	2.80	4.22
Forages × Grinding × Period	9	65,418	7,269	.2	2.08	2.80
Error (c)	48	1,687,160	35,149			
Total	127					

b. The effect of forage species, stage of maturity and of grinding on the intake of forage during the final week of each period.

If we now consider the average daily intake of forages during the final week we will obtain a more accurate idea of the differences between forages since the effect of the conditioning period is eliminated. The basic data are to be found in Appendix Table i, and the analysis of variance in Appendix Table viii.

A,"factorial" summary showing the average daily forage intake per lamb (gms) is shown as follows:

TABLE 3. Average Daily Voluntary Forage Intake (gms) - (final week).

Form in which fed	Treatment				
	Red Clover (early)	Red Clover (late)	Timothy (early)	Timothy (late)	Form* Averages
Chopped	1024	919	654	693	822
Ground	1607	1415	1095	1104	1305
Treatment Average	1315	1167	874	898	
Species Average	1241		886		
Stage Average**	1095		1033		

Analysis of variance reveals that differences due to treatment, grinding and lamb are all highly significant ($P < .01$) while differences due to period are significant ($P < .05$).

* Will be used to designate source of variation due to form in which fed (ground vs. chopped).

**Will be used to designate stage of maturity (early vs. late) - in that order.

The L.S.D's* are as follows:

X =	16	8	4
P.05	77	109	154
P.01	108	153	217

The average daily forage intake per lamb by periods is as follows:

	(Chopped (gms)		Ground (gms)
I	879	V	1112
II	815	VI	1286
III	791	VII	1370
IV	804	VIII	1451

We may conclude from this analysis that whether ground or chopped the consumption of Timothy was significantly less than the consumption of Red Clover (average 30% less). This difference was highly significant statistically.

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* In order to present L.S.D's in a compact form this method will be adopted throughout this thesis. In calculation of L.S.D's where only one error term appears in the analysis of variance the only variable is the denominator, which is numerically equal to the number of items entering into the calculation of each mean in the series of means being compared. In this experiment we have 32 individual datum for each comparison. If we are comparing any two means within the eight treatment means for example, this means that there are $\frac{32}{8} = 4$ items in each mean. If we are comparing any two of the four forage averages we have $\frac{32}{4} = 8$ items entering into the determination of each mean. If we compare the overall mean for chopped vs. ground, red clover vs. timothy or early vs. late cut forage, we have $\frac{32}{2} = 16$ items in each mean being compared. We will thus designate the number of items entering into eaoh mean as X and present the L.S.D. values at two levels of significance. Remembering, of course, that the application of these L.S.D's must be limited to comparison of a series of means in which the F test has shown significant differences to occur.

For calculation of L.S.D's and for F tests see Appendix Tables viii to xxv.

There was no significant difference between the consumption of early and late cut Timothy, in fact the consumption of late cut Timothy slightly exceeded the consumption of early cut Timothy. However, it is apparent that the late cut Red Clover was consumed to a lesser extent than was the early cut Red Clover. This difference is statistically significant when the forage is fed in the ground form and when both chopped and ground forages are averaged.

There is a 10 percent reduction in the consumption of late cut chopped Red Clover as compared to the early cut material. This, while not statistically significant, is however probably of practical significance.

Grinding of the forages significantly increased the extent of voluntary consumption of all forages ($P < .01$), the increases ranging from 54 percent in the case of the late cut Red Clover to 67 percent in the case of the early cut Timothy. An analysis of variance (Appendix Table ix) revealed that differences in the increases in voluntary consumption between forages due to grinding were not significant. Thus we may assume that the effect of grinding in increasing voluntary intake was reasonably uniform for all forages. It should be mentioned that the effect of "period" in this last analysis approached significance. The average increases due to grinding were 23, 59, 79 and 81 percent for periods V, VI, VII and VIII compared to the periods I, II, III and IV. This trend indicates that the lambs gradually became accustomed to the ground forages as time went on, increasing their consumption in each succeeding period. This trend is not only evident between periods but also within periods.

(Figures I and II). If we look at the period averages following Table 3 this trend is also noticeable. The L.S.D. (P=.05) of 154 grams reveals no differences between average forage intake during periods I to IV inclusive. However from period V to VIII inclusive there is a gradual increase in consumption, some of the period differences being statistically significant. This indicates that it is highly probable that the average increases in voluntary intake of these forages due to grinding might have been even greater had they been fed for a longer period. This plus certain other aspects (for example, effect of increased intake on the relative size of the digestive tract) requires further investigation.

B. A study of the factors affecting water consumption.

(a) Effect of Forage Treatment on water intake.

The average daily water consumption data for each lamb during the final week on each forage are presented in Appendix Table i. The analysis of variance is shown in Appendix Table xi. The factorial summary of these data is in Table 4.

TABLE 4. A Summary of the Effect of Forage and Grinding on Water Intake During the Final Week of Each Period (c.c/day/lamb).

Form in which fed	Treatment				Form Average
	Red Clover (early)	Red Clover (late)	Timothy (early)	Timothy (late)	
Chopped	2720	2528	1561	1707	2129
Ground	4850	4380	2883	3011	3781
Treatment Av.	3785	3454	2222	2359	
Species Av.	3620		2291		
Stage Av.	3004		2907		

L.S.D's (c.c.)

X =	16	8	4
P=.05	288	407	577
P=.01	404	571	809

The effect of forage and of grinding on water intake was highly significant. It is thus apparent that grinding (plus, of course, the effect of adding water to the forage) resulted in a marked increase in water intake. While the effect of stage of maturity within both species was not significant, the difference between the water consumption on Red Clover and on Timothy was highly significant. Because water intake is logically associated with dry matter intake, we might better express water consumption on the basis of a water to feed ratio. When these data are analysed statistically (Appendix

Table xii) only the effect of grinding is significant ($P < .05$). The average water to feed ratio was 2.57 for chopped forages and 2.96 for ground forages. It is possible that the greater moisture holding ability of the ground forages as compared to the chopped forages may have been responsible for this effect. However, as previously mentioned, there was undoubtedly some loss of moisture due to evaporation from the ground forages prior to their consumption which would tend to cause an overestimation of the actual water to feed ratio. The water to digestible calorie ratio (Appendix Table xiii) showed a similar relationship, averaging 1.18 c.c. per calorie for the chopped forages and 1.49 c.c. for the ground forages. There was no statistically significant difference due to forages although the Red Clovers averaged somewhat higher than the Timothys (1.38 vs. 1.29) possibly because of the higher protein and mineral content.

(b) Effect of Calorie, Protein and Mineral Intake on Water Consumption.

It is a generally accepted thumb rule that water requirements parallel calorie intake (i.e. 1 c.c. of water is required for each digestible calorie of diet). It is also known that increasing the digestible protein and mineral intake can increase water requirement due to the increased water required to dispose of urea and minerals. In order to determine the relationship between water intake and the intake of digestible calories, protein and minerals, an analysis of Partial Regression and Multiple Correlation was carried out.

The correlation coefficients between the variables involved are summarized as follows, Table 5.

TABLE 5. Summary of Correlation Coefficients (r) Involved in Determining Relationships of Factors Affecting Water Intake.

	Dig. Cals	Total Salt Consumed	Total Ash Consumed	Total Ash + Salt	Water Intake
Dig.Protein	.8443	-.1293	.9387	.8443	.7482
Intake of Dig.Calories		-.0052	.9646	.9137	.8280
Total Salt			-.4477		.4096
Total Ash					.8310
Total Salt + Ash					.9363

The results of the statistical analysis are presented in Table 6. It will be noticed from Table 5 showing the simple correlation coefficients that the relationship between salt intake and intake of feed ash is negative. It will also be noticed that when salt and ash intakes are combined the so-called "total mineral" correlates much more highly with the intake of water. Consequently another Partial Regression analysis was conducted to determine the amount of variability in water intake which could be associated with variations in intake of digestible protein, digestible calories and total minerals. The results appear in Table 7.

TABLE 6. Partial Regression and Multiple Correlation of Water Intake, (Dependent Variable) on the Intake of Digestible Protein, Digestible Calories, Total Ash, and Total Salt.

Variable (Intake of)	Partial Regression Coefficient β	Relative Beta Value (%)	Multiple Correlation Coeff. R	Coeff. of Determin. (R^2) %
Dig. Protein	.7066[xx]	19.6		
Dig. Calories	1.5032[xx]	41.6	.8024[xx]	64
Total Feed Ash	.0817	2.3		
Total Salt	1.3189[xx]	35.5		

[xx] Highly significant statistically ($P < .01$).

TABLE 7. Partial Regression and Multiple Correlation of Water Intake, (Dependent Variable) and the Intake of Digestible Protein, Digestible Calories, and Total Mineral (Feed Ash + Salt).

Variable (Intake of)	Partial Regression Coefficient β	Relative Beta Value (%)	Multiple Correlation Coeff. R	Coeff. of Determin. (R^2) %
Dig. Protein	-.1188	8.4		
Dig. Calories	-.1159	8.4	.94[xx]	89
Total Mineral	+1.1428[xx]	83.0		

[xx]Highly significant statistically.

It is rather surprising that by combining two variables (total ash intake and total salt intake) we can not only account for a much greater amount of the variability in the water intake (89%) but we can completely alter the relative importance of the effect of the variables under study. This is undoubtedly due to the negative correlation between feed ash intake and salt intake which would tend to minimize the effect of both, in the analysis of Table 6.

It is surprising that the effect of digestible calories on water intake (Table 7) now becomes insignificant statistically. It would thus appear that the high "r" value expressing the relationship of digestible calorie intake and water intake is due to the high degree of correlation between digestible calorie intake and total mineral consumed ($r = .91$).

C. Salt Consumption Data.

The average daily salt intake of the individual lambs during the final week on each of the forages is presented in Appendix Table i. A factorial summary of salt intake data by treatment is presented in Table 8.

Only differences due to grinding (and to sheep) were found to be statistically significant. Because of considerable variation in the data it is impossible to show a significant difference between the chopped and ground forms of all forages. However due to the non-significant "forage × grinding" interaction we can assume that grinding caused a significant increase in salt consumption with all forages, averaging about a 350 percent increase. Forage differences while not statistically significant are interesting. A higher salt consumption in the case of the Timothys than with the Red Clovers is indicated.

TABLE 8. Mean Salt Consumption per Treatment (gms salt consumed/ lamb/final week).

Form in which fed	Treatment				Form Averages
	Red Clover (early)	Red Clover (late)	Timothy (early)	Timothy (late)	
Chopped	21	30	23	42	29
Ground	68	88	118	129	101
Treatment Av.	45	59	71	86	
Forage Av.	52		78		
Stage Av.	58		72		

L.S.D. (gms)

X =	16	8	4
P=.05	38	-	72
P=.01	53	-	107

To eliminate the effect of forage intake on salt consumption data, the results are expressed as percent of feed consumption in Table 9. Analysis of variance (Appendix Table xiv) indicates that significant differences ($P < .05$) in percentage salt consumption were caused by grinding (and by sheep). Once again variability was such that forage differences could not be proven significant. The fact that lambs

TABLE 9. Salt Consumption Expressed as Percentage of Forage Intake.

Form in which fed	Treatment				Form Averages
	Red Clover (early)	Red Clover (late)	Timothy (early)	Timothy (late)	
Chopped	.3	.5	.5	.9	.5
Ground	.6	.9	1.9	1.8	1.3
Treatment Av.	.5	.7	1.2	1.4	
Forage Av.	.6		1.3		
Stage Av.	.8		1.0		

consumed more salt when fed Timothy than when fed Red Clover could possibly be explained by the fact that Red Clovers had a higher mineral content. The increased consumption due to grinding may be partially explained by an increased water consumption. Another factor contributing to increased salt intake when ground forages were fed could be that the lambs suffered more from boredom and hence consumed salt for something to do. No records were kept on the time spent in eating the different rations, but the ground-moistened forages would presumably be eaten with less difficulty than would the chopped forages thus allowing the lambs to "fill up" in a shorter period of time thus increasing the amount of idle time.

Nelson et al (1955) found that a high salt intake did not affect the digestibility of a ration when fed to bullocks. With wethers, however, the digestibility of organic matter and nitrogen-free extract was reduced by a high salt intake. However the salt consumption was 6 percent of the diet, at least three times that consumed by any of the lambs on this test. Cardon (1953) fed steers one pound of salt per day with no adverse affect on cellulose (alfalfa) digestion.

This increase in salt consumption indicated in Table 9 might possibly be explained on the basis of the increased water consumption occurring when the forages were fed in the ground and moistened state. On the other hand, perhaps the increased water consumption was due to the increased salt consumption. To better clarify the relationships between feed, water and salt intake the following partial regression and multiple correlation analyses were conducted using the individual intake data obtained during the final week of each period.

Independent Variables	Standard Partial Reg.Coeff. Beta	Relative Beta Values (%)	Multiple Correlation Coefficient (R)	Multiple Coeff. of Determination (R^2)%
a. The relationship of water and salt intake to forage intake (Y)				
Water intake(X_1)	.9681	76	.8877	79
Salt intake (X_2)	-.3065	24		
b. The relationship of forage and salt intake to water intake (Y)				
Forage intake(X_1)	.8122	71	.9067	82
Salt intake (X_2)	.3365	29		
c. The relationship of forage and water intake to salt intake (Y)				
Forage intake(X_1)	-.8797	43	.6262	39
Water intake(X_2)	1.1510	57		

As expected, a large proportion of the variability in water intake (82 percent) can be related to variations in feed and salt intake, feed intake being the most important factor. We can assume, on the basis of the analysis of variance in Appendix Table xii, that the effect of grinding accounts for a major portion of the remaining variability in water intake.

Only 39 percent of the variation in salt intake can be related to variations in feed and water intake. Thus we can reasonably assume that the doubling of salt intake (expressed as a percentage of the feed) due to the effect of grinding (Appendix Table xiv) was not related to any appreciable extent to the increased water consumption.

D. Liveweight Increases and Their Relation to Voluntary Forage Intake.

In any experiment dealing with the "feeding value" of forages, especially involving livestock of agricultural importance, it is desirable that feeding value be expressed in terms of some criterion having economic significance. In the final analysis it is pounds of meat, milk or wool, etc., produced which is the ultimate criterion of a forage's feeding value. There are theoretical reasons why we cannot consider all total digestible nutrients (hereafter referred to as T.D.N.) as being of equal productive value (see Review of Literature).

Since slaughter data could not be obtained in this experiment the next most practical measure of feeding value was that of liveweight gain. The weight gain data are presented in detail in Appendix Table i. A factorial summary of the data is presented in Table 10.

TABLE 10. Factorial Summary of Average Two-Week Gain (lb) per Lamb.

	Treatment				
Form in which fed	Red Clover (early)	Red Clover (late)	Timothy (early)	Timothy (late)	Form Averages
Chopped	3.6	2.1	1.9	1.3	2.2
Ground	6.9	4.0	3.5	3.9	4.6
Treatment Av.	5.3	3.1	2.7	2.6	
Species Av.	4.2		2.6		
Stage Av.	4.0		2.8		

The analysis of variance (Appendix Table x) reveals that grinding had a highly significant effect on liveweight gains and that the effect of forage treatment (species + stage of maturity) approached significance at the 5 percent level of significance. The appropriate L.S.D. values may be obtained from the following:

X =	16	8	4
P=.05	1.4	2.1	3.0
P=.01	2.0	3.0	4.2

While the variability of the data is such that the high significance (P=.01) of the effect of grinding in increasing weight gains cannot be illustrated by applying the appropriate L.S.D. (4.2 lb) to the individual forages, nevertheless the overall effect of grinding is significant at the 1 percent level (L.S.D. 2.0 lb). The interaction expressing the effect of "Grinding × Forages" is negligible indicating that the effect of grinding in increasing weight gain was not influenced by forage.

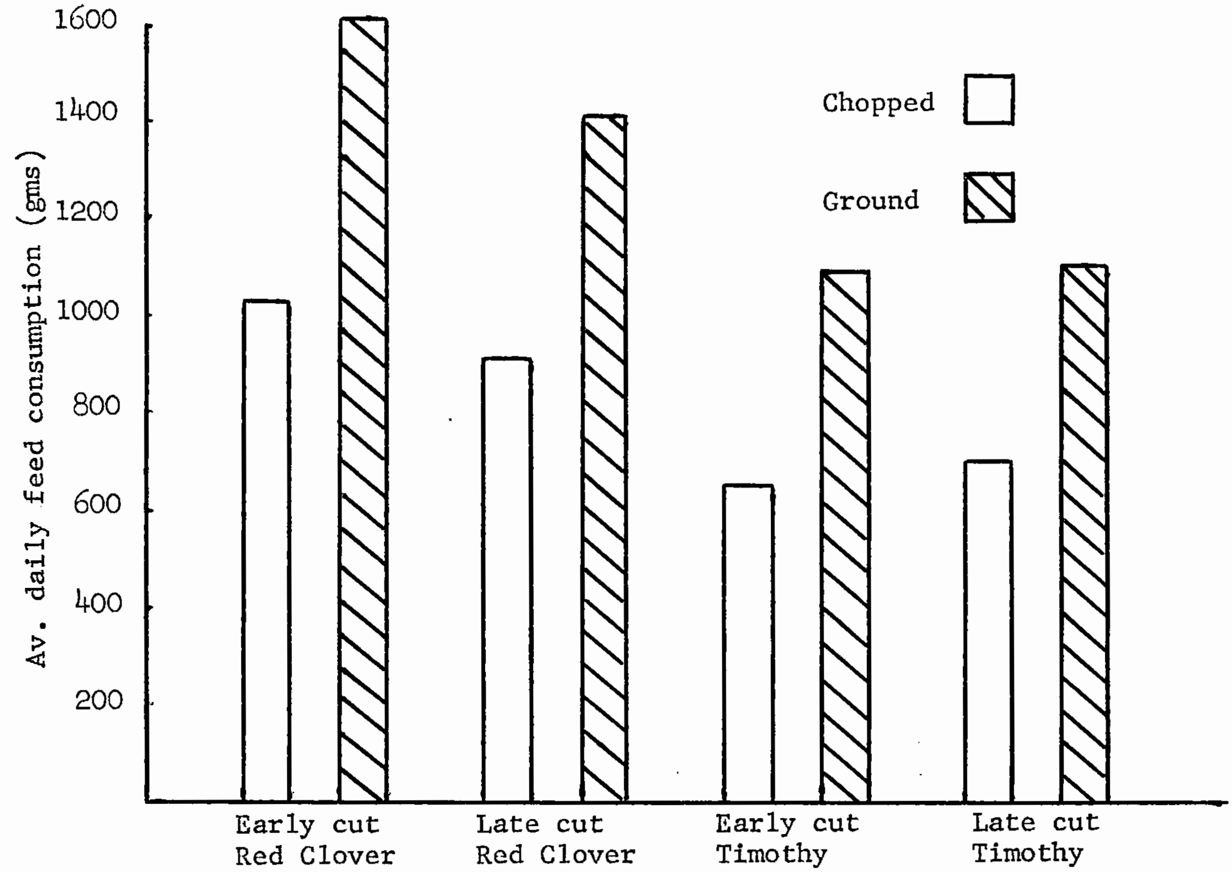
The significant effect due to forages is shown in the superiority of the gains made by the lambs fed the early cut Red Clover. The gains made by the lambs fed Timothy were not affected by stage of maturity. The differences between the gains made on the Timothy and those made by the lambs fed the late cutting of Red Clover were not statistically significant. Lambs fed late cut Red Clover gained significantly less, on the average, than did those fed the early cut Red Clover.

Figure III shows the relative voluntary intake of the forages together with the gains made on these forages. From this graphical representation it can be seen that a 60 percent increase (approximately) in forage intake due to grinding has resulted in an increase of approximately 100 per cent in the liveweight gains, indicating an apparent increase in the efficiency of forage utilization.

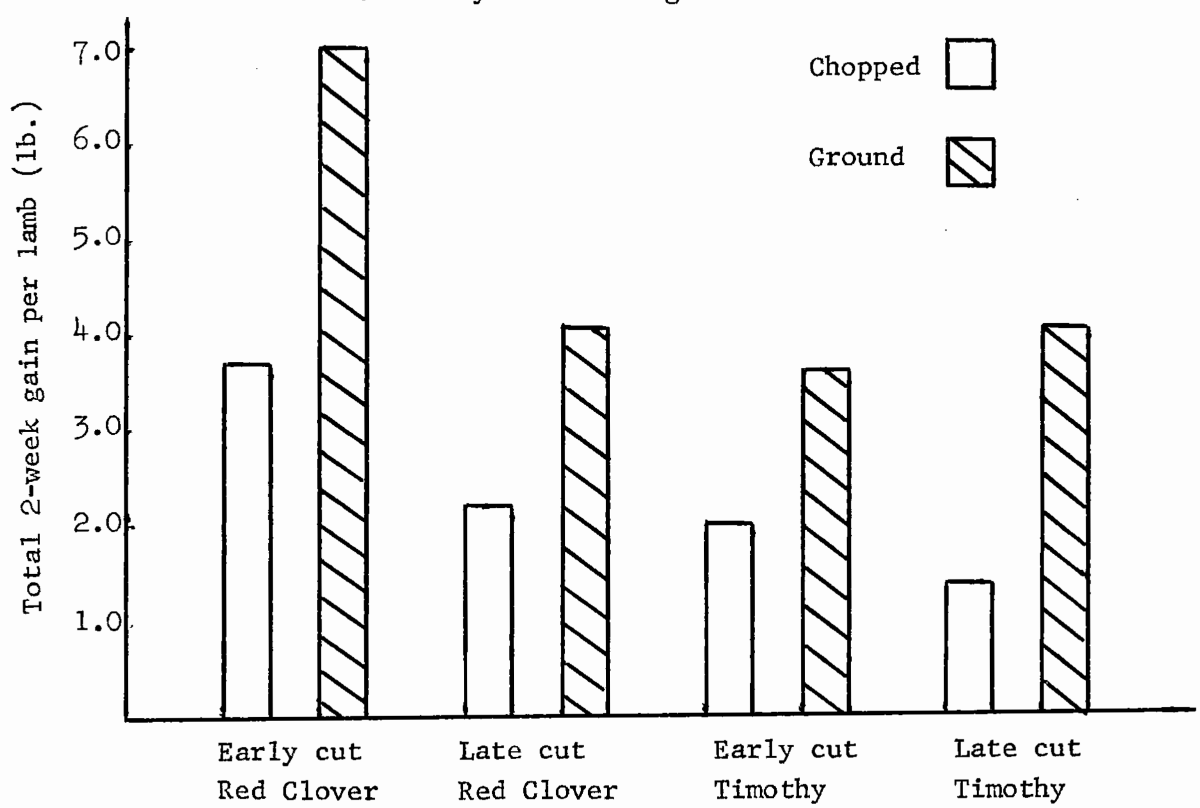
The relationship between voluntary forage intake and weight gains was determined. If individual lamb data are used in the calculation of the simple correlation coefficient the r value is $.72^{xx}$. However if average weight gains and feed consumption figures are used for each of the eight treatments the r value is $.92^{xx}$. Both these values are highly significant ($P < .01$). It is more reasonable to assume that the latter value is more truly indicative of the actual relationship between voluntary intake and weight gain because the effect of individual variation is eliminated. It does, however, indicate that when evaluating forage quality by this method it is desirable to use adequate replication. It is also obvious that in periods as short as were used in this experiment voluntary intake of any individual lamb cannot be used to predict weight gain as accurately as can corresponding data for a group of lambs.

When using treatment averages the effect of body weight and of voluntary intake together account for 88 percent of the variability in liveweight gain. If X equals liveweight gain, A equals voluntary

FIG.III. (a) Effect of Grinding, Forage and Stage of Maturity on Voluntary Feed Intake (Final Week)



(b) Effect of Grinding, Forage and Stage of Maturity on Liveweight Increases



intake and B equals body weight $r_{AX} = .9200$, $r_{BX} = .7384$ and $r_{AB} = .8192$. $\beta_{XA} = .9580$ and $\beta_{XB} = -.0047$. R is thus .937 and $R^2 = 88\%$.

In view of the fact that Lister (1957) fed forages for a longer period of time (8 weeks) it may be of interest to determine how his results compared with those of this test. He fed five forages for a period of eight weeks on each of five sheep. He concluded that "there appears to be little doubt that voluntary intake is directly related to gain in weight. It can be noted that as voluntary intake doubled, gain doubled......." It should, however, be noted that his five forages were always fed in the cyclic order Red Clover, Bromegrass, Oat Straw, Birdsfoot Trefoil and Timothy, i.e. the good quality forages were preceded and followed by the poorer quality forages. In addition the gains were calculated from the beginning of the eight week period to the end of the period. Thus the weight "off" Red Clover was taken as the weight "on" Bromegrass and the weight off Oat Straw was taken as the initial weight onto Birdsfoot Trefoil. Because of differences due to fill this would exaggerate gains made on the good forages and minimize gains on the poor forages (or exaggerate losses). Table 11 shows the relationship between voluntary intake and liveweight gain of Lister's sheep as reported, and if we allow a week's adjustment period.

TABLE 11. Relationship Between Voluntary Forage Intake and Liveweight Gain (Lister 1957).

Forage	Overall 8 week period		Allowing 1 week adjustment	
	Av. daily intake (gms)	Change in weight (lbs)	Av. daily intake (gms)	Change in weight (lbs)
Birdsfoot Trefoil	1071	19.3	1137	14.8
Red Clover	971	12.5	1014	10.2
Brome grass	651	.9	653	.5
Timothy	497	-3.2	496	-4.0
Oat Straw	253	-15.4	257	-8.6
	r = .994		r = .996	

While it is interesting to note that the r values are in both instances indicative of almost perfect correlation the regression coefficients are quite different. For the eight week data $Y = .040X - 24.72$ and for the seven week data $Y = .027X - 16.62$ (where Y = the expected total gain (lbs) per lamb during the period of the test (8 and 7 weeks respectively) and X = the daily voluntary intake per lamb in grams). It is thus obvious that while voluntary intake is remarkably well correlated with liveweight gain the relationship deduced by Lister is not in accordance with his facts. From the purely biological standpoint one would expect a doubling of intake to result in a greater than double increase in liveweight gains at the near maintenance levels of this test.

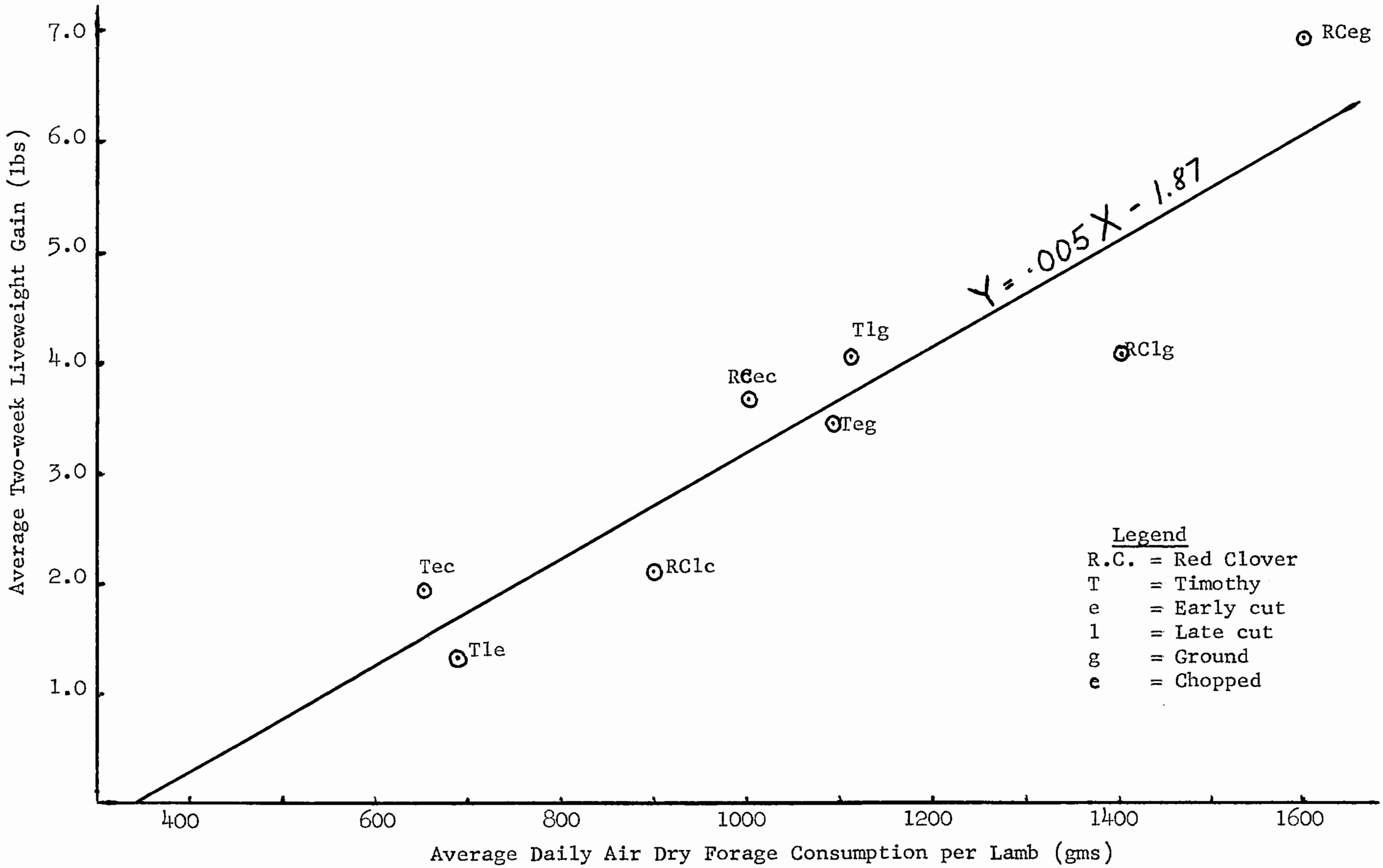
The graphical representation of the regression of liveweight gain on voluntary intake is given in Figure IV. The prediction equation Y = .005X - 1.87 is compared to that derived from Lister's 7 week data as follows:

	Daily Forage Intake (grams) 500	700	900	1100	1300	1500	
(a) Lister (1957)							
Y = .027X - 16.62 (7 week gain)	-3.12	2.28	7.68	13.08	18.48	23.88	gains = lb/lamb
Av.weekly gain	-.45	.33	1.10	1.87	2.64	3.41	
(b) Current Test							
Y = .005X - 1.87 (2 week gain)	.63	1.63	2.63	3.63	4.63	5.63	
Av.weekly gain	.32	.82	1.32	1.82	2.32	2.82	

The equations yield comparable estimates of weight gain only at the 1100 gram intake level. However since Lister was working not only with different forages but over a different consumption range (253 - 1071 gms daily) than obtained in this experiment (654 to 1603) it is not legimate to extrapolate his data beyond the upper limit of his intake figures. When it is considered that the second equation also includes the effect of feeding ground forages (which were utilized differently as compared to the chopped forages) the comparison is even less legitimate. Considering all these facts however the agreement is reasonably good.

One cannot help but comment that it is extremely hazardous to set up a prediction equation of this nature, on the basis of results obtained under any given set of conditions and expect that it will apply to another set of conditions. The numerous factors contributing

FIG.IV. Regression of Liveweight Gain (Y) on Voluntary Forage Intake (X).



to the variability not only of the forages themselves but of the animals used must be taken into consideration where such predictions are attempted. It would appear that at best, a test of this nature would give us a fairly accurate estimate of the relative feeding value of the forages used when fed under similar conditions to similar animals. This does not mean to imply that extent of voluntary intake is not a better measure of forage feeding value than is chemical analysis data or digestibility data to which these sources of variability plus other more serious shortcomings apply.

The data of this experiment indicate that voluntary intake of forages was a reliable index of the feeding value of the forages fed. This was true whether the forages were fed in the chopped or in the ground form and was as true within forage species as between forage species. (Minor discrepancies are of course to be expected since the weight gain data from such a short period are subject to considerable variation).

Having established that voluntary intake is a reliable index of feeding value, within the limits of statistical variability, the next step is to study the chemical composition of these forages to determine the relationships between composition data and voluntary forage intake.

E. Chemical Analyses Data and Their Relationship to Voluntary Intake.

(a) Chemical Composition of Forages.

A complete summary of the chemical analyses of the forages, and of the weighbacks of the chopped forages, is presented in Appendix Table ii. All figures with the exception of energy values are rounded to one decimal place. Where marked differences in the composition of the weighbacks, as compared to the offered forage, occurred, the composition of the forage as eaten is calculated. All figures are the averages of at least four duplicate analyses and the average deviation from the mean is given to provide a measure of the variability.

A study of Appendix Table iii reveals that, in general, the chopped forages were sorted to some extent as indicated by the differences in chemical composition between offered forages and their weighbacks. Weighbacks were usually lower in protein and higher in crude fiber, cellulose and lignin than was the forage "as offered", indicating that stemmy portions of the forage were being refused. The greater variability associated with the analytical data of the weighbacks reflects the differences in the sorting ability of the individual lambs. In most cases the corrected figures are within .5 percentage units of the composition of the offered forage. While these differences are slight, nevertheless the composition of the forages as eaten (Appendix Table ii) is used in the study of the effect of chemical composition on the voluntary intake of forages.

While there are one or two unexplainable (and consistent) differences in the composition of the chopped and ground forages (probably due to heterogenity of the forage) we can for practical purposes summarize the chemical composition of the forages as follows (Table 12).

TABLE 12. Summary of Composition Data of Forages as Offered.

(Data to nearest whole number except Calories).

Constituent	Timothy		Red Clover	
	Early cut	Late cut	Early cut	Late cut
Crude protein (%)	7	6	15	15
Crude fiber (%)	31	29	25	27
N-free extract (%)	48	51	43	42
Cellulose (%)	33	31	30	31
Ash (%)	6	5	8	7
Lignin (%)	9	10	10	11
Gross Cals/gm.	4.10	4.11	4.00	4.07

These analytical data do not indicate the marked differences in chemical composition between the early and late cuts that one might expect. Huffman (1953) cites numerous references showing the effect of stage of maturity on the chemical composition of various forage species including Timothy and Red Clover. In all instances, increasing maturity resulted in increases in crude cellulose, lignin and crude fiber contents.

Crude fiber as determined by the usual method of proximate analysis was originally intended to represent the undigestible portion of the feed. It is believed to contain all the original cellulose, variable portions of the hemicellulose and a small and variable proportion of the lignin (Crampton 1956). It is also stated that crude fiber is 95 percent cellulose.

The fact that the cellulose values obtained in this experiment (and also by Smith 1958) were higher than those of crude fiber may be at least partially explained by Nordfeld et al cited by Huffman (1953) who determined the composition of crude fiber of hay as follows,- cellulose 80.1, lignin 11.5, pentosans 10.9 percent and a small amount of crude protein and ash. The N.F.E. fraction contained cellulose 20.5, lignin 9.7, pentosans 29.4 percent and sugars, hexosans, organic acids, etc., 40.3 percent. Cellulose was found to be distributed as follows,- 69.3 percent in the crude fiber and 30.7 percent in the N.F.E.

Another factor, possibly explaining the discrepancy between the crude fiber and cellulose contents of the forages, is that of the method of determination. Crude fiber must survive three filtration steps, cellulose only one. It is thus possible that crude fiber is subject to greater loss than is cellulose during the determination.

(b) Correlation of Individual Chemical Constituents to Voluntary Forage Intake.

Simple correlation coefficients (r) were calculated to show the relationship between each of the chemical components and the extent of voluntary forage intake. Because grinding had a significant effect on the extent of voluntary forage intake this source of variation was removed by calculating separate r values for chopped and for ground forages. Thus each r value is calculated on the basis of 16 pairs of observations. These are presented in Table 13.

TABLE 13. Simple Correlation Coefficients (r), and Coefficients of Determination (r^2) Showing Relationship Between Voluntary Intake and Forage Composition.

Constituent	Correlation Coefficient (r)		Coefficient of Determination (r^2%)	
	Chopped	Ground	Chopped	Ground
Crude protein	$.79^{xx}$	$.73^{xx}$	62	53
Crude fiber	$-.81^{xx}$	$-.69^{xx}$	66	45
Crude fat	-.24	.07		
N-free extract	$-.63^{xx}$	$-.63^{xx}$	40	40
Cellulose	-.46	$-.61^{x}$		37
Lignin	.46	.28		
Ash	$.76^{xx}$	$.71^{xx}$	58	50
Gross energy	$-.67^{xx}$	$-.60^{x}$	41	45

^{x}Significantly different from zero $P < .05$

^{xx}Highly significantly different from zero $P < .01$

The high correlation of ash content to voluntary intake is probably due to the fact that ash content is highly correlated to protein content (r = .92). Protein content has often been regarded as being indicative of the feeding value of a forage. Whether the protein *per se* is the factor responsible for the feeding value or whether high protein content is associated with leafy, non-lignified, "palatable" forage is a matter of interest. In this test, protein content is found to be significantly correlated with voluntary forage intake. Crude fiber content is also significantly correlated, negatively, to extent of forage intake, more so that either cellulose or lignin content.

The fact that lignin is positively correlated is due to the higher lignin content of the Red Clovers as compared to the Timothys. This further emphasizes the limitation of lignin data as an index of forage feeding value when comparing different forage species. The limited data of this test indicates that within forage species lignin content *per se* is more closely associated with feeding value in the Red Clovers than in the Timothys.

(c) Partial Regression and Multiple Correlation Technique.

In order to more accurately ascertain the relative effects of various composition data on voluntary intake, a series of partial regression analyses was undertaken. These findings are summarized in Tables 14 to 16 inclusive.

TABLE 14. Partial Regression and Multiple Correlation of Voluntary Intake (Dependent Variable) on the Content of Six Forage Fractions (Independent Variables).

Independent Variables	Standard Partial Reg.Coeff. β	Relative Beta Values (%)	Multiple Correlation Coefficient (R)	Multiple Coeff. of Determination (R^2%)
a. Chopped Forages				
Crude protein	2.6	45.7		
Crude fiber	.8	14.5		
Cellulose	-.4	7.3	.88[xx]	78
N-free extract	1.4	24.6		
Ash	.2	4.1		
Lignin	-.2	3.8		
b. Ground Forages				
Crude protein	13.0[xx]	43.8		
Crude fiber	4.1[xx]	13.8		
Cellulose	.9	3.0	.96[xx]	93
N-free extract	10.1[xx]	34.0		
Ash	1.6[xx]	5.4		
Lignin	-.1	-		

[xx]Highly significant statistically ($P < .01$).

It is thus apparent that a fairly large proportion of the variability in feed intake is associated with the makeup of the forage, particularly in the case of the ground forages. It is also apparent that three of these factors, protein content, crude fiber content and nitrogen-free extract content are associated with a large portion of the variability in voluntary intake. We will now proceed to conduct further statistical analyses, eliminating some of the less important factors to determine the change in the R values.

TABLE 15. Partial Regression and Multiple Correlation of Voluntary Intake and Crude Protein, Crude Fiber, Nitrogen-free Extract and Ash Contents of the Forages.

Independent Variables	Standard Partial Reg. Coeff. β	Relative Beta Values (%)	Multiple Correlation Coefficient (R)	Multiple Coeff. of Determination (R^2%)
a. Chopped Forages				
Crude protein	2.19	54.4		
Crude fiber	.23	5.8	.86^{xx}	74
N-free extract	1.44	35.9		
Ash	.16	3.9		
b. Ground Forages				
Crude protein	9.86^{xx}	42.7		
Crude fiber	4.00^{xx}	13.3	.95^{xx}	91
N-free extract	7.57^{xx}	32.7		
Ash	1.68^{xx}	7.3		

^{xx}Significant at the 1% level.

These results show that cellulose and lignin could be eliminated with only a slight reduction in the amount of variability accounted for. While both R values are highly significant statistically, the standard partial regression coefficients are significant only in the case of the ground forages. Ash and crude fiber content of ground forages appear to be more closely asseociated with extent of voluntary intake than in the case of the chopped forages.

Table 16 shows the effect of removing ash data. There is no change in the R value as far as chopped forages are concerned. However there is a considerable lowering of the R value in the case of the ground forages. It may or may not be coincidental that the R values for chopped and ground forages are practically identical. In any case approximately 73 percent of the variability in the extent of voluntary forage intake is associated significantly ($P < .01$) with the crude protein, crude fiber and nitrogen-free extract content of the forages, whether fed in the chopped or in the ground form.

TABLE 16. Partial Regression and Multiple Correlation of Voluntary Intake and Crude Protein, Crude Fiber and Nitrogen-free Extract Content of the Forages.

Independent Variables	Standard Partial Reg.Coeff. β	Relative Beta Values (%)	Multiple Correlation Coefficient (R)	Multiple Coeff. of Determination (R^2%)
a. <u>Chopped Forages</u>				
Crude protein	2.19	59		
Crude fiber	.17	5	.86^{xx}	74
N-free extract	1.35	36		
b. <u>Ground Forages</u>				
Crude protein	5.48^{x}	51.6		
Crude fiber	1.61	15.2	.84^{xx}	71
N-free extract	3.52^{x}	33.2		

^{x} Significant at the 5% level
^{xx}Significant at the 1% level.

Other analyses were conducted, including one in which the relationship of crude protein, crude fiber and gross calorie content to voluntary intake was determined. It was found that none of these could account for as great a portion of the variability in the voluntary intake of the forages as could be accounted for by the variables shown in Tables 14, 15 and 16. In view of the similarity of the gross calorie contents of the various forages studied, it is not surprising that calorie content _per se_ was of little help in accounting for variability in forage intake.

It is also possible that the weight of the lambs may have had an influence on the amount of feed consumed. The simple correlation coefficient (r) was determined for both chopped and ground forages. It was found to be .61 and .20 respectively. Incorporating this information into a further partial regression analysis indicated that a considerable increase in the variability of forage consumption was accounted for. The results appear in Table 17.

TABLE 17. Partial Regression and Multiple Correlation of Voluntary Intake and the Crude Protein, Crude Fiber and Nitrogen-free Extract Content of the Forages together with the Effect of Lamb Weight.

Independent Variable	Standard Partial Reg.Coeff. β	Relative Beta Values (%)	Multiple Correlation Coefficient R	Multiple Coeff. of Determination (R^2%)
a. Chopped Forages				
Crude protein	1.42	56.5		
Crude fiber	-.10	4.0	.91[xx]	83
N-free extract	.69	27.5		
Lamb weight	.30	12.0		
b. Ground Forages				
Crude protein	2.22	51.0		
Crude fiber	.34	29.6	.95[xx]	90
N-free extract	1.29	7.7		
Lamb weight	.51	11.7		

[xx]Highly significant statistically ($P < .01$)

None of the partial regression coefficients was found to be statistically significant. However together they accounted for a highly significant portion of the variability in voluntary intake. Differences in weight were responsible for about 10 percent of the overall variability in forage intake. This effect of weight on intake should not be misunderstood as influencing the overall extent of forage consumption within either the "ground" or "chopped" portions of the experiment since the average weight of the lambs while on any one forage was approximately the same as on any of the other forages, (range in weight 57.6 - 59.2 on all the chopped forages and from 68.1 - 69.9 lb. on the ground forages). It is of course reasonable to assume that the heavier weights of the lambs on the "ground" test could account for some of the increased feed consumption. However since this is a legitimate expression of the effect of grinding, the above statistical analyses were conducted separately for each of the forage forms.

These findings indicate that a highly significant portion of the variability in voluntary forage intake could be associated with variations in the "chemical" constituents of those forages, particularly in the case of crude protein, nitrogen-free extract and crude fiber contents. Whether these fractions *per se* affect the voluntary intake or whether they are merely indices of the general acceptability or digestibility of the forages remains to be proven.

Estimation of Voluntary Intake from Chemical Analysis and Liveweight Data.

Using the data of Table 17 and the data on which the table is based we can derive equations with which we can attempt to predict voluntary intake of a forage on the basis of its crude protein, crude fiber and N.F.E. content and on the basis of the liveweight of the lambs consuming it. These equations are:

1. for chopped forages:

$$Y = 59.67\, X_1 - 7.80\, X_2 + 28.96\, X_3 + 18.76\, X_4 - 2066.47$$

2. for ground forages:

$$Y = 150.65\, X_1 + 38.80\, X_2 + 95.24\, X_3 + 19.94\, X_4 - 71615.00$$

Where

Y = estimated daily intake of forage per lamb in grams (air dry forage)

X_1 = crude protein content of the forage (% air dry basis)

X_2 = crude fiber content of the forage (% air dry basis)

X_3 = N.F.E. content of the forage (% air dry basis)

X_4 = Average liveweight of the lamb (lbs).

Using these equations, the average daily consumption of each of the forages per lamb (gms. of air dry forage) is as follows:

	Chopped Forages Estimated Consumption(Y)	Actual Consumption
Red Clover (early)	987	1003
Red Clover (late)	945	929
Timothy (early)	657	658
Timothy (late)	673	692

	Ground Forages Estimated Consumption	Actual Consumption
Red Clover (early)	1519	1548
Red Clover (late)	1431	1406
Timothy (early)	963	1035
Timothy (late)	1089	1026

It should be understood however that these equations yield a fairly reliable estimate of voluntary intake under the conditions of this experiment only, and do not necessarily apply to any other set of conditions.

F. A Study of Forage Digestibility and Utilization.

1. Extent of Apparent Digestibility.

One of the most commonly used criteria of a forage's feeding value is its apparent digestibility coefficient. It should be realized that the extent to which a given forage is digested is only one of the factors affecting the amount of digestible nutrients made available to the animal. The quantity of forage which can be consumed daily must also be considered. In the final analysis it is the forage's ability to provide the animal with an excess of digestible nutrients over that required for maintenance which will determine its feeding value from the economical point of view. Because it has been shown (Blaxter *et al*, 1956) that level of forage intake affects the extent of dry matter digestibility, particularly in the case of ground forages, it would seem of questionable value to attempt to relate digestibility coefficients to forage feeding value when forages are fed under *ad libitum* conditions.

The apparent digestibility coefficients of the forages used in this study are summarized in Table 18. Due to the experimental precision attainable in a digestibility study of this nature the data are presented, rounded to the nearest whole number. (The individual digestibility coefficients for each lamb in each period are to be found in Appendix Table iv.

(a) Dry matter and (b) energy digestibility.

The analysis of variance for each of these factors appears in Appendix Tables xvi and xvii respectively. Due to the close relationship between these two criteria they will be considered together ($r = .92^{xx}$). A factorial summary of the apparent digestibility coefficients is presented in Table 19.

Analyses of variance reveal that both energy and dry matter digestibility were influenced to a highly significant degree ($P < .01$) by forage treatment (including effect of species and stage of maturity) and by the effect of grinding the forages. The "grinding × treatment" interaction was not significant, indicating that within the range of statistical variability grinding caused a reduction in digestibility with all forages as far as dry matter and energy is concerned. This reduction in digestibility averaged 3 percent in the case of energy and 4 percent in the case of dry matter.

The overall species averages indicate that the energy and dry matter of Timothy was digested to about the same extent as in the case of the Red Clovers. The overall effect of stage of maturity indicates a highly significant decrease in dry matter and energy digestibility due to increasing maturity. A study of the individual

TABLE 18. The Apparent Digestibility of Forages (%) - (all figures rounded to nearest percent)

Constituent	Chopped Forages				Ground Forages				Significant Sources of Variation		L.S.D.
	Timothy		Red Clover		Timothy		Red Clover				
	Early	Late	Early	Late	Early	Late	Early	Late	Forage	Form	P = .05
Dry matter	61	53	55	55	53	51	54	51	P=.01	P<.01	4
Crude protein	57	45	58	55	47	46	57	54	P<.01	P<.05	5
Crude fiber	62	49	46	52	55	46	45	46	P<.01	P<.01	5
Ether extract	31	17	34	42	20	34	32	51	-	-	-
N-free extract	64	60	64	60	58	57	62	57	P<.05	P<.01	4
Cellulose	65	53	60	62	56	48	54	54	P<.05	P<.01	4
Energy (Cals)	58	50	55	53	52	49	54	50	P<.05	P<.01	4

TABLE 19. A Factorial Summary of the Average Apparent Digestibility Coefficients of Dry Matter and Energy.

	a. Dry Matter Digestibility Treatment					b. Energy Digestibility Treatment				
Form in which fed	Red Clover (early)	Red Clover (late)	Timothy (early)	Timothy (late)	Form Av.	Red Clover (early)	Red Clover (late)	Timothy (early)	Timothy (late)	Form Av.
Chopped	55	55	61	53	56	55	53	58	50	54
Ground	54	51	53	51	52	54	50	52	49	51
Treatment Av.	55	53	57	52		55	52	55	50	
Species Av.	54		54			53		52		
Stage Av.	56		52			55		51		

L.S.D.° values (%)

X* =	16	8	4
P.05	2	3	4
P.01	3	4	6

°Error mean squares practically identical in both analyses.

*As previously explained X = number of items entering into the calculation of each mean being compared. Since n = 32, X would = $\frac{32}{4}$ or 8 when comparing two means in a set of 4 comparable means (Treatment averages).

treatment averages, in general, bears out this finding. The fact that the extent of energy and dry matter digestibility is similar for both forage species, in spite of the differences in the feeding value of the two forages, indicates the importance of the quantitative aspects of feed intake.

(c) Crude protein digestibility.

The analysis of variance of the factors affecting protein digestibility is to be found in Appendix Table xviii. The factorial summary of the main effects is as follows (Table 20).

TABLE 20. A Factorial Summary of the Average Apparent Digestibility Coefficients of Crude Protein (%).

Form in which fed	Treatment				Form average
	Red Clover (early)	Red Clover (late)	Timothy (early)	Timothy (late)	
Chopped	58	55	57	45	54
Ground	57	54	47	46	51
Treatment Av.	58	55	52	46	
Species Av.	56		49		
Stage Av.	55		50		

The analysis of variance reveals that forage treatment, and grinding had a significant effect on protein digestibility. The "forage treatment × grinding" interaction however was significant at the 5% level indicating that grinding affected the digestibility of protein differently with the different forages. Inspection of the data indicates that grinding caused a significant reduction in the digestibility of the early cut Timothy but that its effect in the case of the other forages was negligible. By inspection of the data (if we exempt the early cut chopped Timothy) it is seen that the crude protein of Red Clover is digested to a markedly greater extent than is the crude protein of Timothy. There is also a fairly definite indication that the earlier cut forages of both species are more digestible with respect to crude protein content than are the more mature forages. This is probably due to the increase in the amount of lignin present in the plant or to a change in the nature or extent of the lignification with maturation.

The digestibility coefficients for crude protein appear to be more closely associated with forage feeding value than was either dry matter or energy digestibility data. However there are notable exceptions. Early cut, chopped Timothy was almost as digestible as was the early cut Red Clover. This same trend holds for most of the constituents whose digestibility was studied. This could possibly be explained on the basis of the combined effect of "ease of digestibility" and postulated ideas about the effect of level of forage intake on the rate of disappearance of forage materials from the digestive tract.

(d) Digestibility of crude fiber and (e) of cellulose.

Due to the similarity of these two constituents and to the fact that analyses of variance (Appendix Tables xix and xxa) reveal identical error mean squares, they will be considered together. The factorial summary is presented in Table 21.

TABLE 21. A Factorial Summary of the Average Apparent Digestibility Coefficients of Crude Fiber and Cellulose (%)

Form in which fed	a. Crude Fiber Digestibility Treatment				Form Av.	b. Cellulose Digestibility Treatment				Form Av.
	Red Clover (early)	Red Clover (late)	Timothy (early)	Timothy (late)		Red Clover (early)	Red Clover (late)	Timothy (early)	Timothy (late)	
Chopped	46	52	62	49	52	60	62	65	53	60
Ground	45	46	55	46	48	54	53	56	48	54
Treatment Av.	46	49	59	48		57	58	61	51	
Species Av.	47		53			58		56		
Stage Av.	52		48			59		54		

L.S.D.Values (%)

X^o =	16	8	4
P.05	3	4	5
P.01	4	5	7

^{o}For explanation see page 89

(r = .72^{xx} = relationship between crude fiber and cellulose digestibilities).

The analyses of variance in both instances reveal that forage treatment, and grinding both had a highly significant influence on digestibility ($P < .01$). The "forage treatment × grinding" interaction was insignificant in both cases. We thus assume that grinding caused a significant reduction in the digestibility of both crude fiber (average 4 percentage units) and of cellulose (average 6 percentage units). The overall averages of early versus late cut forages, reveal a reduction in the digestibility of crude fiber and of cellulose due to advancing maturity. However inspection of the four treatment means reveals a consistent "interaction" of "stage of maturity × forage species". It is clear that the crude fiber and cellulose of late cut Red Clover in this test was as well digested (or even slightly better digested) as was the crude fiber of the early cut Red Clover. The reduction in digestibility of the Timothy due to stage of maturity was very marked, averaging around 10 percentage units for both cellulose and crude fiber digestibility. This finding may be of some significance in view of the fact that artificial rumen work frequently uses cellulose digestibility (extent of) as a criterion of forage feeding value. Admittedly the fact that late cut Red Clover was consumed in somewhat smaller amounts than was the early cut Red Clover could conceivably influence the extent of cellulose digestion. If we refer back to the figures on energy digestibility however, we see that energy digestibility was lower in the second cut Red Clovers than in the early cut Red Clovers. It is thus obvious that the trends in crude fiber and cellulose digestibility do not correspond with the trends in energy digestibility. This casts further doubt upon the reliability of any procedure aimed at predicting forage feeding value by measuring the extent of cellulose digestion.

To test the significance of the "stage of maturity × forage" interaction the results (cellulose digestibility) were re-analysed (Appendix Table xxb). As expected the interaction was highly significant statistically. The effect of species was not significant.

It is interesting to note that the cellulose was digested to a somewhat greater extent than was the crude fiber (56 vs. 50%). The amount of lignin included in "crude fiber" could be in part responsible for this finding. The arbitrary nature of the crude fiber determination may also be partially responsible for the differences in apparent digestibility of the two fractions.

It should be noted that owing to the nature of the chemical analysis procedures for both crude fiber and cellulose (i.e. only the undigested fractions are isolated from the feces as contrasted to nitrogen analysis where NH_2, whether in amino acids or as undigested protein, is all included as undigestible) any factor interfering with the absorption of the digestion products of these two components will lead to a discrepancy between digestibility figures and the amount absorbed and will also cause a reduction in the apparent digestibility of N.F.E.

(e[1]) Digestibility of Cellulose In Vitro*

A limited amount of information was obtained on the extent of cellulose digestibility in vitro. This appears in Table 22. Data are also included on an earlier cut of Timothy (harvested June 27). On the basis of these data several interesting observations may be made. The artificial rumen technique employed was that of Bentley et al (1955) as adapted by Kamstra et al (1958).

TABLE 22. In Vitro Cellulose Digestibility (%)

Forage	Ground 40 mesh 30 hours	Ground 40 mesh 48 hours	Finely Chopped** 30 hours	Finely Chopped** 48 hours
Timothy (June 27)	63.2	69.4	46.4	56.4
Timothy (July 8)	52.1	57.3	41.8	46.9
Timothy (July 31)	40.2	43.1		
Red Clover (July 2)	55.8	58.4		
Red Clover (July 25)	51.4	54.9	44.7	50.2

**Average of two experiments, each sample run in duplicate in each experiment. All other figures are average values from three experiments with duplicate samples run in each.

To facilitate comparisons between in vivo and in vitro data the following summary is presented.

		In vitro digestibility 30 hr.	In vitro digestibility 48 hr.	In vivo digestibility Chopped	In vivo digestibility Ground
Red Clover	(July 2)	56	58	60	54
	(July 25)	51	55	62	53
Timothy	(July 8)	52	57	65	56
	(July 31)	40	43	53	48

*The data presented in this section were obtained through the courtesy of Dr. O.G.Bentley of the Ohio Agricultural Experiment Station,Wooster.

While *in vitro* data indicate the relative digestibilities of the Timothys *in vivo* this does not apply in the case of the Red Clovers. Quantitatively speaking the 48 hour *in vitro* data provided a fairly accurate estimate of the extent of forage digestibility when the forages were fed in the ground state *in vivo*. It must be remembered that the *in vivo* data were obtained under *ad libitum* conditions and it is perhaps expecting too much that *in vitro* data of this type will be comparable. It is important to note that voluntary intake data within forage species cannot be explained on the basis of *extent* of cellulose digestibility, nor can the voluntary intake differences between early cut Red Clover and early cut Timothy be explained on this basis.

The *in vitro* results show the effect of certain variables on the activity of the cellulolytic microorganisms. When other factors are constant, increasing surface area of the forage by finer grinding resulted in an increase in cellulose digestibility as might be expected. This effect is apparently offset in *in vivo* trials by the increased intake and greater rate of disappearance from the digestive tract. It is apparent from these results that increasing maturity of both forage species results in a reduction in the cellulose digestibility. This may be due to increased lignification, a change in the nature of the cellulose itself or due to a decreased availability of nutritional factors required by the cellulolytic bacteria. It is difficult to assess the rate of cellulose digestibility from the meagre data available although this aspect is probably of utmost significance in determining forage feeding value. If it is assumed that the 48 hour data represents maximum cellulose digestibility then it is seen that Red Clovers attained 94-96% of this by 30 hours while the Timothys attained 91-93%. This difference seems insignificant and points to the need for further data covering the initial period in more detail before the relationship between the rate of cellulose digestibility and forage feeding value can be properly assessed.

(f) Digestibility of Crude Fat.

The low ether extract content of the forages (Appendix Table ii) coupled with the great variability, particularly in the amount of ether extractable material in the feces combined to render digestibility data of no practical or statistical value. The digestibility coefficients appear in Appendix Table iv.

(g) Digestibility of Nitrogen-Free Extract.

The detailed data on the digestibility of N.F.E. appear in Appendix Table iv. The factorial summary of the treatment averages appears in Table 23.

TABLE 23. A Factorial Summary of the Average Apparent Digestibility Coefficients of N.F.E.

Form in which fed	Treatment: Red Clover (early)	Red Clover (late)	Timothy (early)	Timothy (late)	Form Averages
Chopped	64	60	64	60	62
Ground	62	56	58	57	58
Treatment Av.	63	58	61	59	
Species A.	61		60		
Stage Av.	62		59		

L.S.D. Values (%)

X =	16	8	4
P.05	2	3	4
P.01	3	4	6

Analysis of variance (Appendix Table xxi) reveals that forage "treatment" and grinding were significant sources of variation in N.F.E. digestibility, ($P < .05$ and $P < .01$ respectively). The interaction of these two sources was not significant. Thus we may assume that grinding caused an average reduction of around 4 percentage units in the digestibility of the forages fed. The overall difference between forage species was not significant while there was an average reduction of 3 percentage units due to increasing maturity when both species are averaged.

In this experiment the digestibility (apparent) of the N.F.E. averaged about 10 percentage units higher than did that of the crude fiber.

(h) Summary and Discussion.

Under the conditions of this test, feeding of forages in the ground and moistened condition resulted in a reduction in the extent of digestibility averaging between 3 and 6 percentage units. Digestibility of protein and energy was reduced to a lesser extent than was the digestibility of crude fiber and cellulose. This could be explained on the basis of an increased rate of passage of feed and feed residues through the digestive tract which would have a greater adverse effect on the digestibility of the less easily digested nutrients.

Differences in the overall digestibility of the two forage species were slight. Dry matter, energy, cellulose and N.F.E. digestibilities being almost identical for both species. The protein of Red Clover was digested to a greater extent (7 percentage units) than was the protein of Timothy while the crude fiber of Timothy was digested to a greater extent (6 percentage units) than was that of Red Clover. The similarity in extent of dry matter and energy digestibility between the overall averages of the two forage species may be at least partially explained by the difference in level of forage intake. Morrison (1956) reports that for comparable stages of maturity the T.D.N. content of Red Clover is usually about 2 to 3 percentage units higher than that of Timothy. (It is assumed that these values were obtained under conditions of approximately equal feed intake).

In any case it is clearly evident that a forage's feeding value bears little or no relationship to the extent of dry matter or energy digestibility when fed under ad libitum conditions.

The effect of stage of maturity is shown in Table 24. It is clear that stage of maturity markedly reduced the extent of digestibility of chopped Timothy and also to a lesser extent that of ground Timothy. With Red Clover the picture is less clear cut, but the overall effect of stage of maturity is markedly less than in the case of the Timothy.

TABLE 24. Summary of Reduction (in units of percent) in Digestibility Due to Increased Maturity.

	Timothy		Red Clover	
	Chopped	Ground	Chopped	Ground
Dry matter	-8	-2	0	-3
Energy	-8	-3	-2	-4
Protein	-12	-1	-3	-3
Crude fiber	-13	-9	+6	+1
Cellulose	-12	-8	+2	0
N-free extract	-4	-1	-4	-5
Average change	-8	-4	0	-2

This explains why, despite equal intakes of early and late cut chopped Timothy, gains were less on the late cut material. This appears to be the one exception to the generally good agreement between voluntary intake data and feeding value (gains) and points to the need for further testing of the effect of stage of maturity on voluntary intake and feeding value of Timothy.

G. Quantitative Aspects of Digestible Nutrient Intake.

(a) Intake of Digestible Nutrients as Affected by Forage and Grinding.

It seems logical now to consider together the data on voluntary intake and on the digestibility coefficients in order to determine the amount of apparently digestible nutrients consumed by the lambs. Theoretically, at least, it would seem that the amount of digestible nutrients consumed in a given period of time should correlate more closely with the forage's feeding value than either its extent of digestibility or its voluntary intake.

The individual data showing the average daily intake of digestible nutrients per lamb are presented in Appendix Table vi. The data are summarized in Table 25.

It is obvious that the reduction in the extent of digestibility of nutrients due to the effect of feeding in the ground state is more than compensated for by the increase in forage intake. Grinding caused increases ranging from 54 to 67 percent in the voluntary intake of the forages tested while the digestible energy intake was increased by 40 to 50 percent. This resulted in a doubling of liveweight gains indicating an increase in the efficiency of utilization of the forages for production purposes (when efficiency is expressed as pounds of feed per pound of liveweight).

A study of Table 25 reveals that the trend toward increased intake of digestible nutrients is reasonably consistent across all nutrients (omitting ether extract).

TABLE 25. Average Daily Intake of Apparent Digestible Nutrients per Lamb (grams, except as noted)

Constituent	Chopped Forages				Ground Forages			
	Timothy		Red Clover		Timothy		Red Clover	
	Early	Late	Early	Late	Early	Late	Early	Late
Dry Matter	376	341	512	469	510	483	762	660
Crude Protein	28	20	84	82	32	30	136	115
Crude Fiber	123	96	113	125	176	138	170	176
Ether Extract	4	2	6	8	3	7	11	15
N-free Extract	205	213	288	230	286	297	408	320
Cellulose	140	111	183	181	185	149	242	232
Energy (Cals)	1574	1427	2205	2021	2183	2057	3318	2851

In order to check these results statistically, analyses of variance were conducted using the digestible energy intake data (Appendix Table xxii) and the digestible protein intake data (Appendix Table xxiii). The factorial summary of the treatment means representing digestible energy intake is presented in Table 26. Analysis of variance revealed that intake of digestible energy was significantly affected by forage and by grinding (both $P < .01$). The "forage × grinding" interaction was not significant. When the effect of maturity of individual species is considered there is found to be a decrease of 7 percent and of 12 percent in the intake of digestible calories due to the increasing maturity of the Timothy and Red Clover respectively. The reduction in digestibility of the Red Clover was statistically significant. When the overall effect of maturity, combining both species, is tested it is found to be significant ($P < .05$). Red Clovers provided 44 percent more digestible energy than did the Timothys. The difference was highly significant.

A supplementary analysis of variance in which the three degrees of freedom for forage were sub-divided into one for species, one for stage of maturity and one for "species × maturity" revealed that the effect of stage of maturity and of species were both significant ($P < .05$ and $P < .01$ respectively). The interaction was not significant.

TABLE 26. A Factorial Summary of Digestible Energy Intake. (Cals/Lamb/Day).

Form in which fed	Treatment: Red Clover (early)	Red Clover (late)	Timothy (early)	Timothy (late)	Form Average
Chopped	2205	2021	1574	1427	1807
Ground	3318	2851	2183	2057	2602
Treatment Av.	2762	2436	1879	1742	
Species Av.	2599		1810		
Stage Av.	2320		2089		

L.S.D's (Cals)

X =	16	8	4
P.05	200	290	400
P.01	280	400	570

It will be recalled that grinding reduced the digestibility of protein in the case of the early cut Timothy but not (significantly) in the case of the other forages. Table 27 reveals that this affected the net increase in the digestible protein intake. An analysis of variance (Appendix Table xxiii) was carried out to study this effect statistically. The factorial summary of the data is presented in Table 27.

TABLE 27. A Factorial Summary of Digestible Protein Intake (gms/Lamb/Day).

Form in which fed	Treatment				Form Average
	Red Clover (early)	Red Clover (late)	Timothy (early)	Timothy (late)	
Chopped	84	82	28	20	54
Ground	136	115	32	30	78
Treatment Av.	110	99	30	25	
Species Av.	98		28		
Stage Av.	70		62		

Interpretation of this data is complicated by the significant interaction betweenn grinding and forage. This is due to the reduction in protein digestibility of the early cut Timothy due to grinding which was just barely compensated for by increased feed intake. Apart from this instance, grinding resulted in an increase of approximately 50 percent in the intake of digestible protein. The overall difference between species is just significant at the 5 percent level (L.S.D. = 69 gm) according to the revised analysis necessitated by the significant interaction. The overall effect of maturity is not significant although there is a slight reduction due to increased maturity.

(b) Relationship of Digestible Nutrient Intake to Voluntary Forage Intake.

Because we have no other measure of rate of digestibility we will consider that the amount of nutrient digested daily, by the lamb, is a measure of this rate. The relationship between gross forage intake and intake of digestible nutrients is of importance. At first thought one might assume that they would be highly correlated. However it has been shown (Blaxter 1956) that as level of forage intake increase, (at least with ground forages) dry matter digestibility decreases. Thus, as level of forage intake increases, the intake of digestible nutrients might or might not keep pace, depending on the effect of level of intake on extent of digestibility. If we can find that the intake of digestible energy is highly correlated to intake of forage and that any reductions in the extent of digestibility are of minor importance, this will strengthen the hypothesis that voluntary intake is a good criterion of forage feeding value. (Assuming that feeding value is highly correlated to intake of digestible energy). The simple correlation coefficients are presented in Table 28.

TABLE 28. Relationship Between Intake of Digestible Nutrients and Gross Voluntary Intake of Forages.

"Nutrient"	Correlation Coefficient (r)	Coefficient of Determination (r^2)%
Energy (Cals)	.9801	96
Crude protein	.8072	65
Crude fiber	.8024	64
Cellulose	.9254	86
N-free extract	.9374	88

The relationships between the intakes of various digestible components of the forages and the extent of voluntary consumption are presented graphically in Figures V to IX inclusive. The eight treatment means have been plotted on each figure in order that the "goodness of fit" of the data to the regression equation can be assessed. It will be noticed that with the exception of digestible energy intake, the intake of the other digestible fractions show considerable variation in their relationship to voluntary intake. It is also noticed that there are differences in the relative distribution of the eight treatment means in the different figures. These effects are all "averaged" in the digestible energy figures with the result that the eight treatment means representing digestible energy intakes at different levels of feed intake are reasonably well "lined up" along the regression line.

We may thus conclude that, under the conditions of this experiment, there was a highly significant positive correlation between digestible energy intake and voluntary forage intake. It is thus apparent that differences in extent of energy digestibility were not sufficient to distort the relationship between voluntary intake and yield of digestible nutrients. This points out the importance of voluntary intake as a suitable criterion of forage quality. It also shows the high degree of correlation between rate of digestion and voluntary forage intake under conditions of *ad libitum* feeding. However it must be remembered that while the correlation is high there is no "proof" of a cause and effect relationship.

FIG.V - Regression of Digestible Calories Intake (Y) on Voluntary Forage Intake (X)

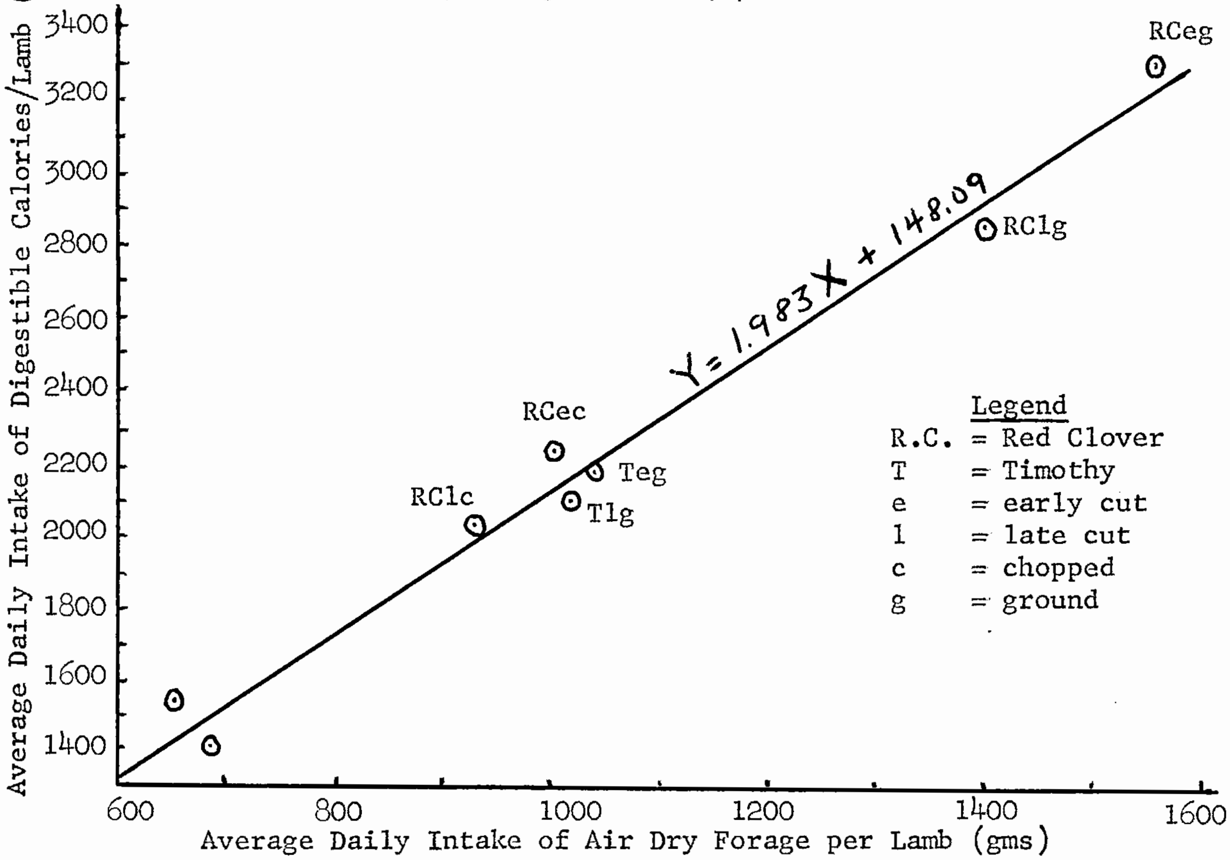


FIG. VI - Regression of Digestible Protein Intake (Y) on Voluntary Intake (X)

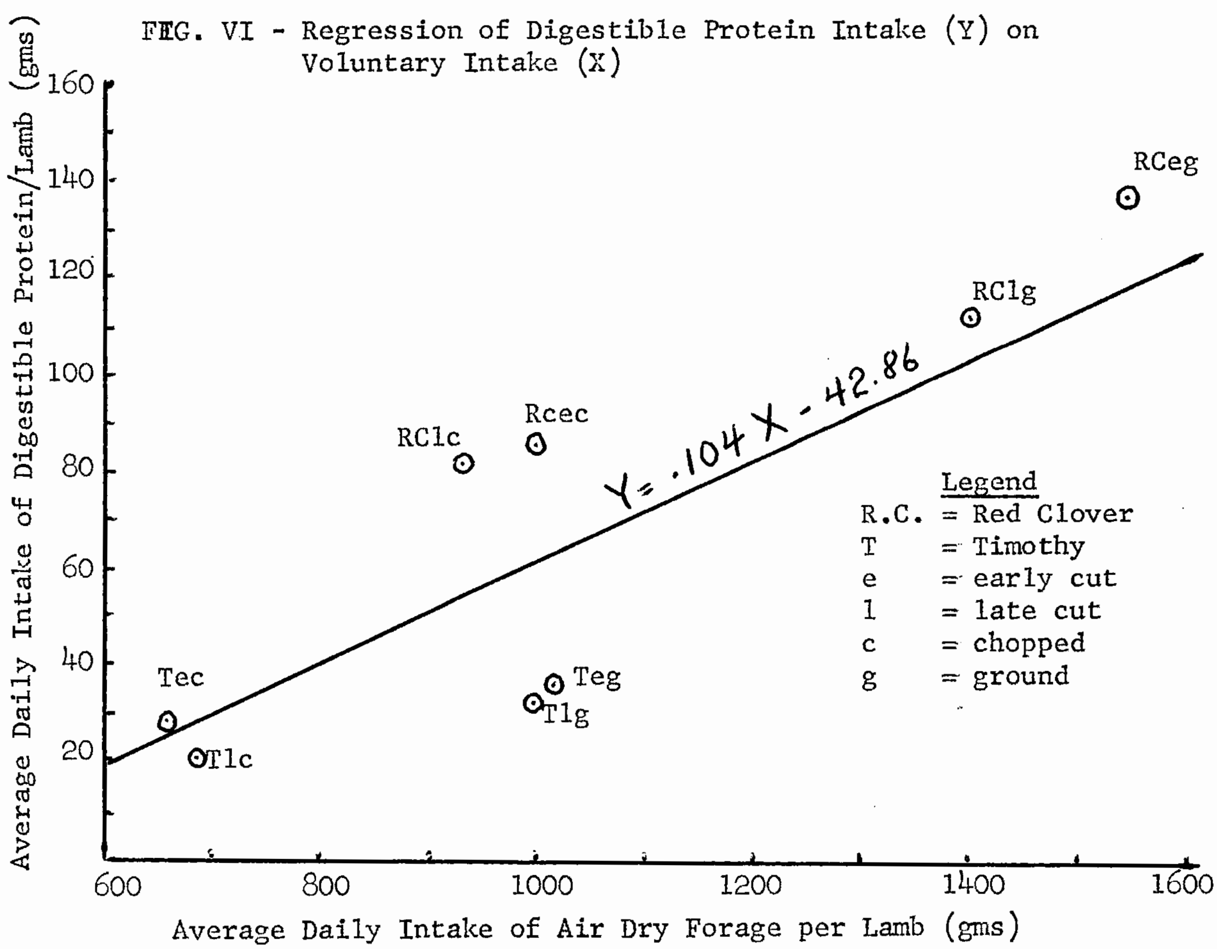


FIG.VII - Regression of Digestible Crude Fiber Intake (Y) on Voluntary Forage Intake (X)

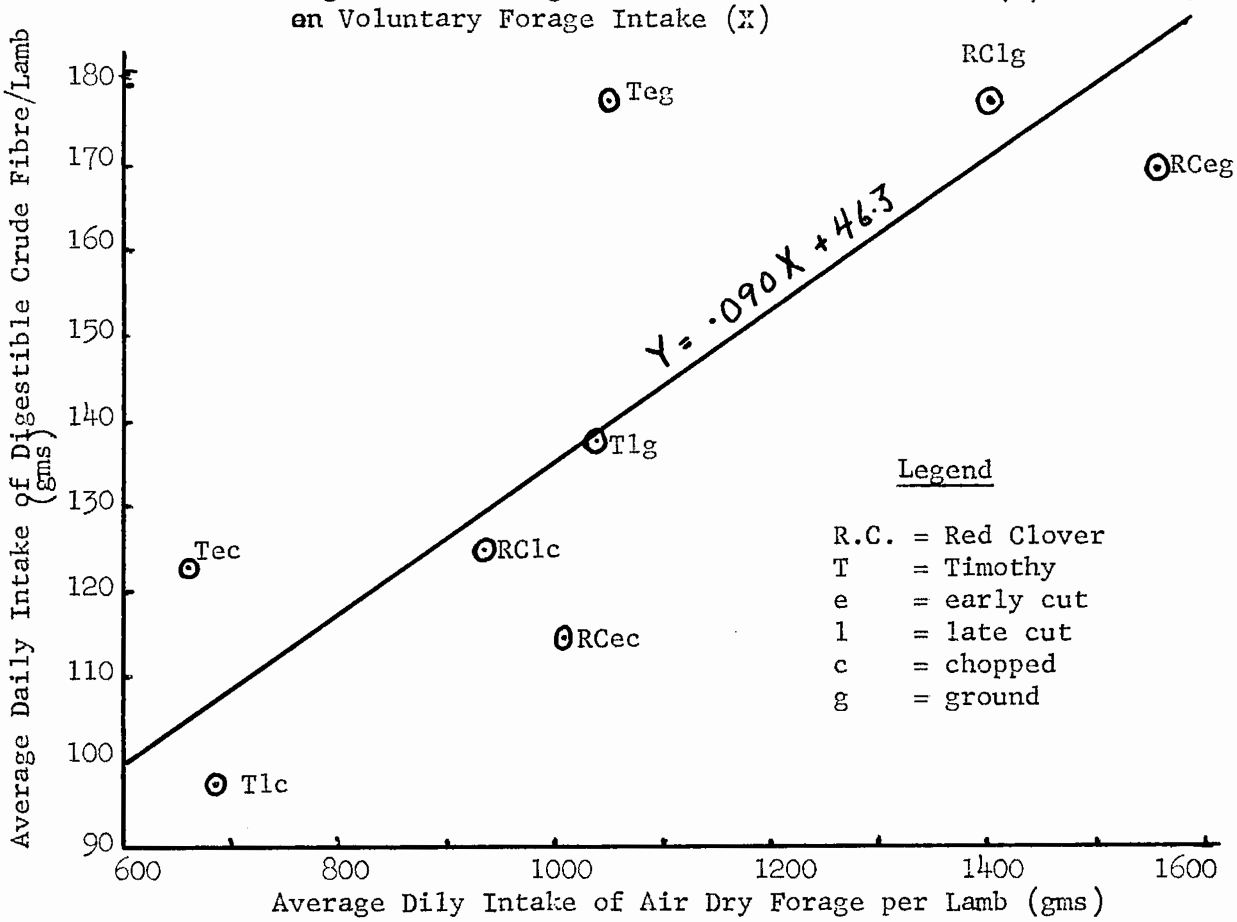


FIG. VIII - Regression of Digestible Cellulose Intake (Y) on Voluntary Forage Intake (X)

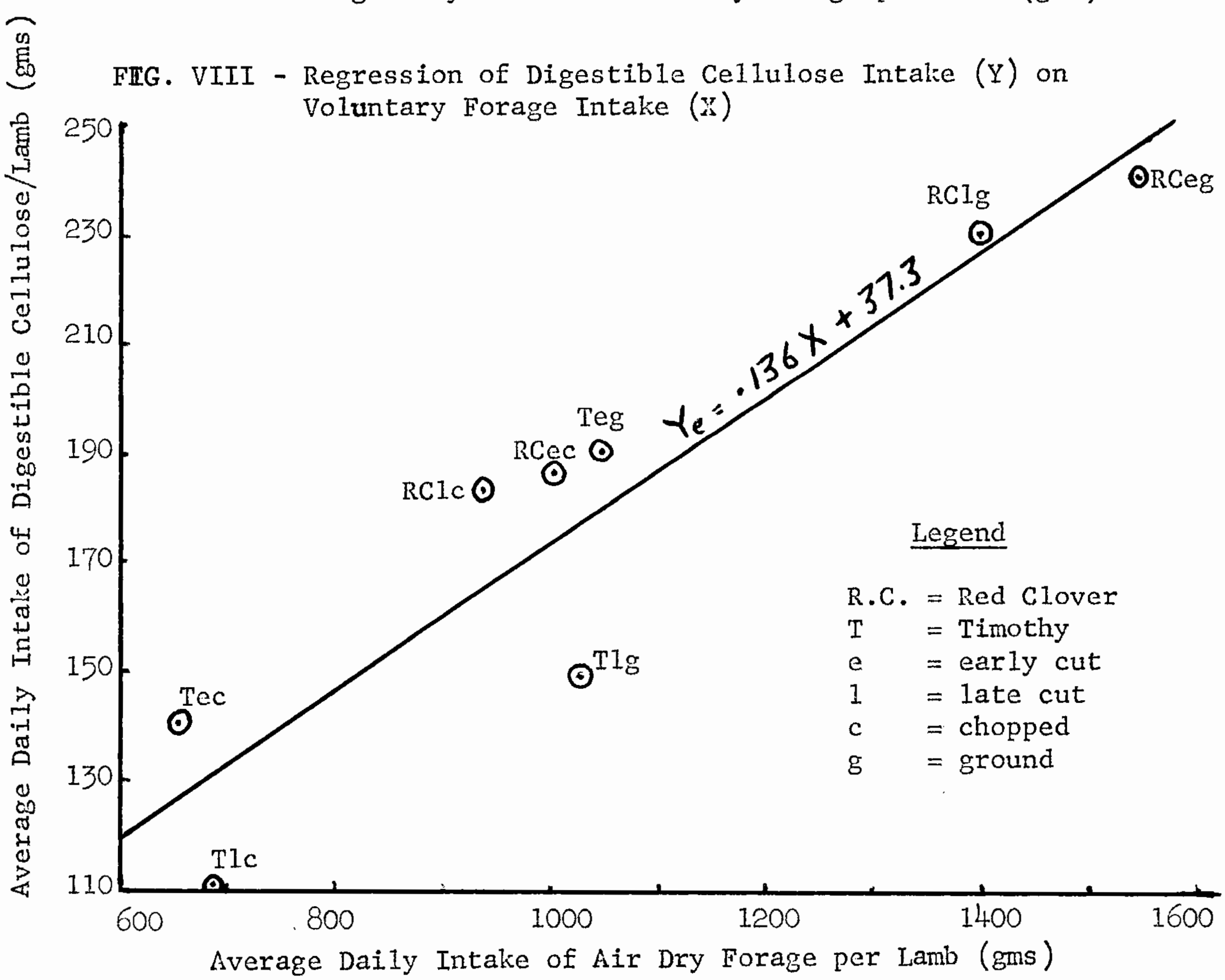
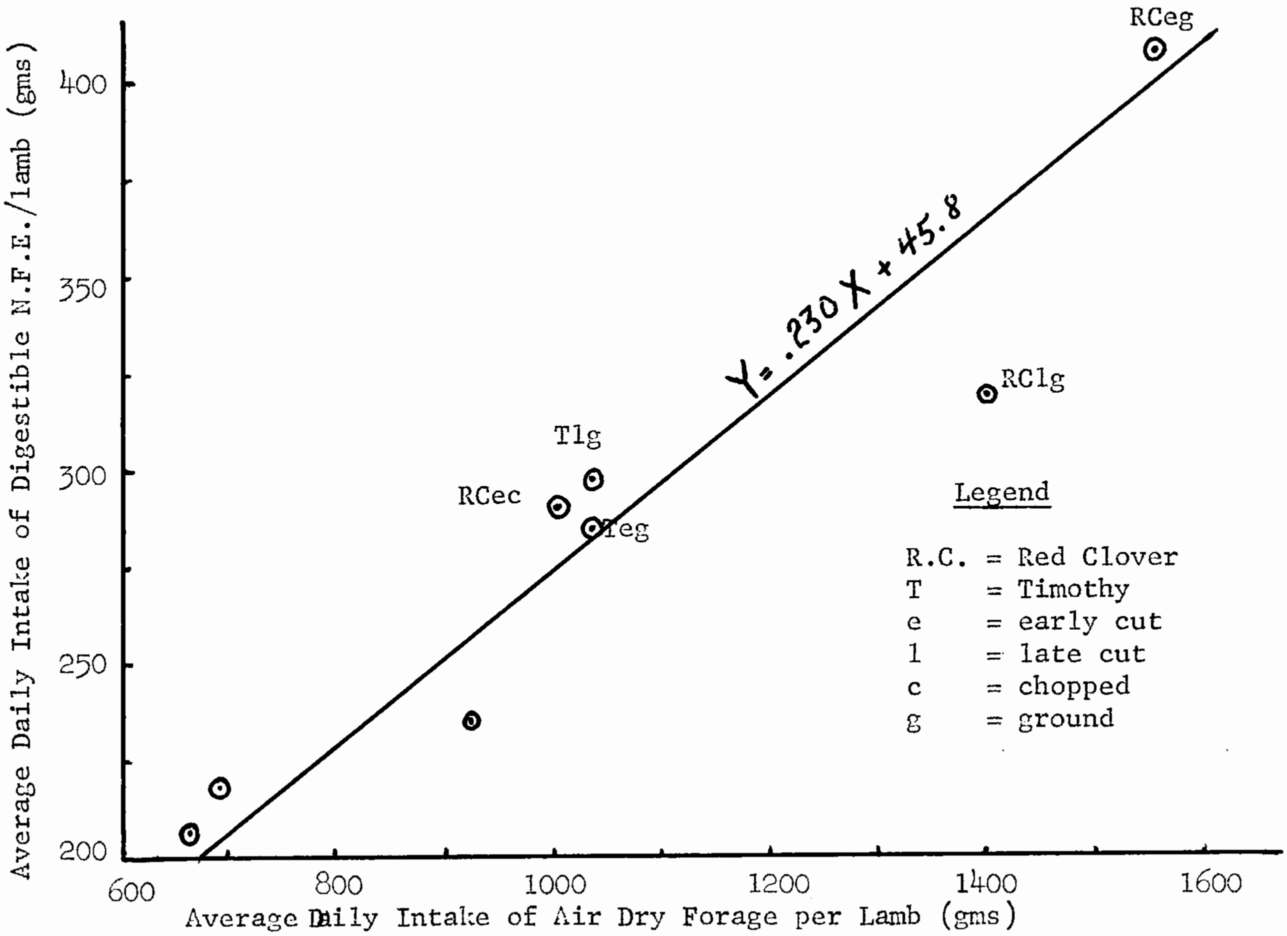


FIG. IX - Regression of Digestible N.F.E. Intake (Y) on Voluntary Forage Intake (X).

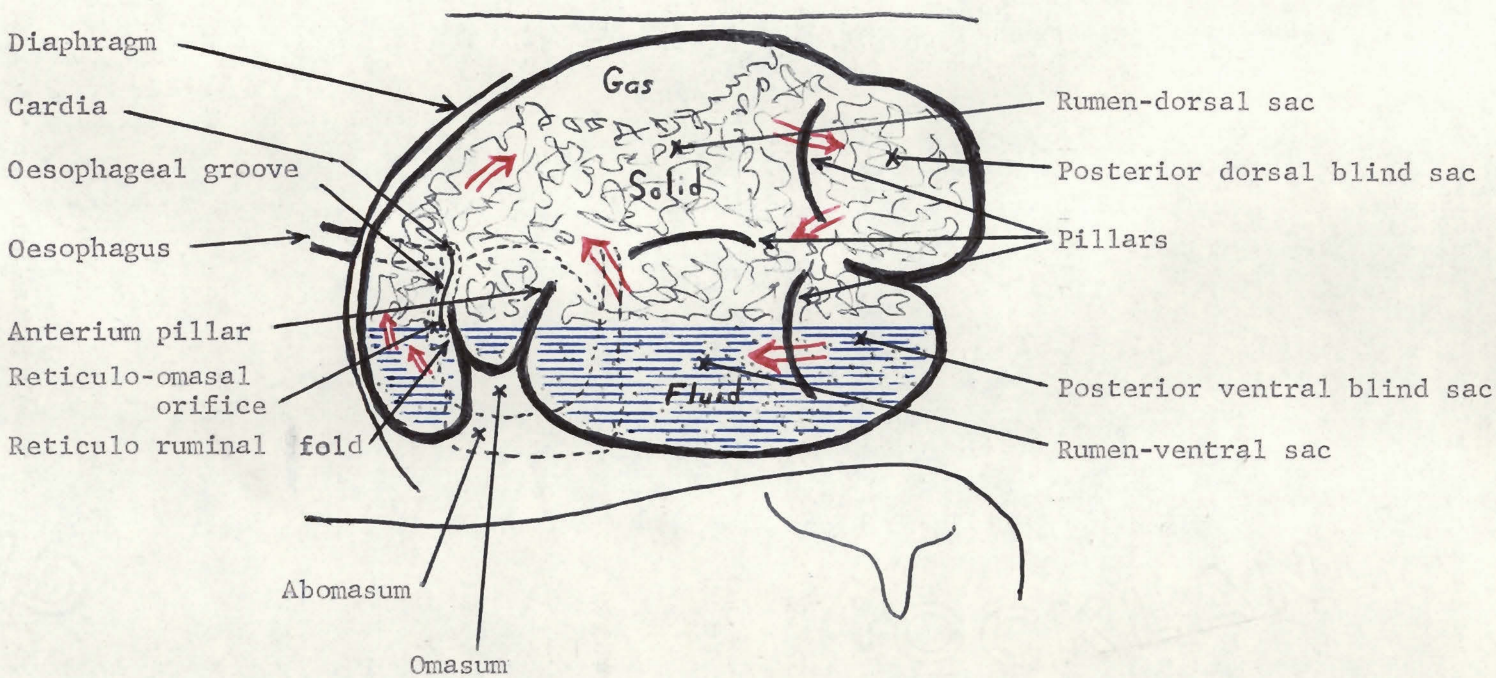


Before attempting to postulate on the factors which could influence the extent of voluntary intake of forage a brief description of the physical processes of the rumen would perhaps be in order. Figure X shows a longitudinal section through the rumen.

Balch (1958) describes the process as follows. "The food boli pass down the oesophagus and enter the rumen through the cardia, plunging among the relatively fluid digesta in the anterior region. At the end of the meal......new hay or other roughage is packed into the anterior region of the dorsal sac...... A distinct tendency also exists for any food of small particle size, or which tends to absorb water rapidly, to accumulate in the ventral regions to a greater extent than hay.... There is always, however, a mixing of recently eaten feed with residues of previous meals...... ensuring an early inoculation with rumen microorganisms."

"The basic movement of the reticulo-rumen is a cycle of contraction (.....beginning as a highly characteristic double contraction of the reticulum, followed by successive contractions of the anterior pillar, dorsal sac and ventral sac of the rumen...). The rate is always highest during eating...... The cycle of movement brings about the arrangement of digesta shown in the Fig. X, the drier and non-fibrous parts of the food tending to be found in the dorsal sacs and posterior region whereas the smaller particles and most of the fluid appear mainly in the reticulum and anterior and ventral rumen. Above the digesta there is usually a small amount of gas.

FIG. X - Logitudinal Section Through Rumen (Adapted from Balch (1958)).



"With each cycle of movement, the fluid digesta are squeezed up and back over and through the mass in the dorsal sac along the path indicated by the large arrows in Fig.X. Since packing of the mass is often very tight, the only distinct current to be seen at any one cycle is of fluids and finer particles. Even so, over a long period, the mass itself is gradually kneaded, turned, mixed and eroded. Between cycles little free fluid will be found in the dorsal sac; but, as the cycle begins, the permeating fluids can be seen first rising through the mass and then sinking into the ventral sac. By this means substances in solution and finer particles are leached from the main mass of digesta and at the conclusion of the active part of the cycle are returned to the reticulum and anterior and ventral rumen. Larger particles are less likely to follow the route until they have received further chewing.

"Rumination," (or cud-chewing)"... reduces particle size and facilitates bacterial attack, thereby increasing the chance of any given particle subsequently leaving the reticulo-rumen..... The stimulus for this reflex is the presence of fibrous foods in the reticulum and anterior rumen. Finely ground roughages lose the ability to evoke the reflex....."

"There is no general agreement about either the mechanism governing the passage of feed through the reticulo-omasal orifice or the purpose and action of the omasum......" It has been estimated.... "that in a cow consuming 20 lbs. of dry matter daily something approaching 14 lbs. of dry matter might have to pass through the orifice daily, the remainder being absorbed." (A portion of the water, volatile fatty acids, glucose, ammonia, vitamins and inorganic ions are absorbed from the rumen and go to the liver via the portal blood system).

"Considerable sieving must occur at the orifice, because of its small size, its setting in relation to the flow from the reticulum, the lining of large papillae and the mass of fibrous digesta in the omasal fundus..... Ground concentrates or ground hay tends to leave the reticulo-rumen more rapidly than unground hay eaten at the same time."

Balch (1952) found that the contraction of the reticulum is most rapid during eating and less rapid during rumination. He also suggests that it is likely that the cycle of reticulo-ruminal contraction produced more complete mixing of the digesta in the reticulo-rumen when the cows were receiving a diet in which all the hay was ground than when the diet contained long hay.

Balch (1958) observed that with the various diets he studied (including an all hay diet) that it appeared that the rate of loss of dry matter from the rumen between meals was regulated by the intake of dry matter. He also suggests that the bulkiness of the feed and the amount of digesta present initially was of importance in this regard. He found that the rate of loss of dry matter from the reticulo rumen was 2 - 3 times as great during eating as it was between meals. It was found that "at any one time the rate of passage through the reticulo-omasal orifice will be controlled by such factors as relative pressures of ingesta in the reticulum and omasum, in addition to the number of times the orifice opens and closes, the number of contractions of the orifice seems likely to be of considerable importance in effecting the accelerated passage during eating. The temporary rise during eating, in the dry matter content of the digesta lying near the orifice may also have increased the rate of passage by raising the amount of dry matter passing to the omasum during each cycle of pressure change."

Balch concludes, "from my experiments, the responsibility for control of appetite in cows cannot be given to any single factor or mechanism. It appeared probable that with hay, a cow might eat until her reticulo-rumen contained a given weight or volume of digesta, however this was not the case with cows receiving mixed diets. It seems possible that with rations containing readily digestible foods a factor other than the degree of "fill" may be involved."

It appears that as yet, the factors influencing variation in the intake of forages of different species and of different physical forms are far from being well defined. Rate, or ease of digestion, of the forage would appear to play a major role in the speed at which portions of the digestible nutrients are removed from the rumen by absorption. It should also influence the speed of breakdown of particle size and hence help to reduce rumen load by facilitating passage of undigested residues from the reticulo-rumen. If we assume that a faster reduction in rumen load will lead to a more rapid recurrence of hunger and hence increased voluntary intake we may have at least a partial explanation as to why better quality forages are consumed in greater amounts than are poorer quality forages. Forages of better quality (higher mineral content, lower degree of lignification, etc.) should be more quickly digested in the rumen because of their favorable effect on the nutrition and activity of the rumen microflora.

The reduction in particle size, by grinding, and the effect of moistening the ground feed should be expected to increase not only the ease of digestibility of the forage (due to the moist nature, greater surface area, greater availability of nutrients contained within the cells) but also increase the ease with which the feed is mixed in the rumen and with which it will pass through the reticulo-omasal orifice. The rumen capacity is also increased because of the increased density of the ground forages.

The factors concerned with forage acceptability (taste, odor, physical nature) cannot be discounted either. However their effects are difficult to assess. If one could, by means of a fistula, satisfactorily "feed" a ruminant animal more forage than it would normally consume, the importance of feed acceptability could be assessed. However to the author's knowledge, this has never been done. If ruminants consumed forages according to their relative acceptability, would the effect on yidd of digestible nutrients be different from what we would expect if we assumed that rate of digestion was the main factor influencing feed intake? It appears that close to maximal extent of digestion is normally reached long before the forage material (at least when fed in the long or coarsely chopped form) passed from the rumen. (See Review of Literature). If forage is "forced" through the rumen at faster rates because of increased acceptability (within certain physical limits, of course), would the extent of digestibility be much less than that obtained under lower levels of intake? Would there not be a greater daily "yield" of digestible nutrients? These questions cannot be answered from the results of the present study. However it appears that at this point these factors could all be involved in influencing voluntary intake.

Regardless of the cause of increased voluntary intake, the important finding as far as estimating forage feeding value is concerned, is that there is a high degree of positive correlation between voluntary intake and intake of digestible energy and that by measuring the relative voluntary forage intake we can obtain a fairly reliable estimate of the relative amount of digestible energy made available to the animal. The regression equation is:

$Ye = 1.9828X + 148.09$ where Ye = expected daily intake of digestible calories and X = the average daily intake of air dry forage (gm).

The standard error of estimate was found to be 138 Cals.

(c) A Study of Nutrient Intake as Related to Liveweight Gains.

In this section we will attempt to account for differences in liveweight gains by the effect of differences in nutrient intake. The simple correlation coefficients between a number of "intake" variables and liveweight gains are shown in Table 29. These are calculated using the means of eight treatments.

TABLE 29. The Relationship of Various Factors to Liveweight Gain.

Factor	Relationship to Liveweight Gain "r"	"t" value*
Voluntary intake (Air Dry)	.91	5.4xx
Dry matter intake	.91	5.4xx
Dig.dry matter intake	.88	4.5xx
Calorie intake	.90	5.0xx
Dig.calories intake[1]	.92	5.7xx
Met. calorie intake	.93	6.2xx
Met. energy balance	.89	4.8xx
Protein intake	.72	2.5x
Dig. protein intake	.66	2.1
Protein retention	.82	3.5x
Percent protein retention	.89	4.8xx
Total ash intake	.87	4.3xx
Salt intake	.39	1.0
Water intake	.60	1.8
Total mineral intake	.90	5.0

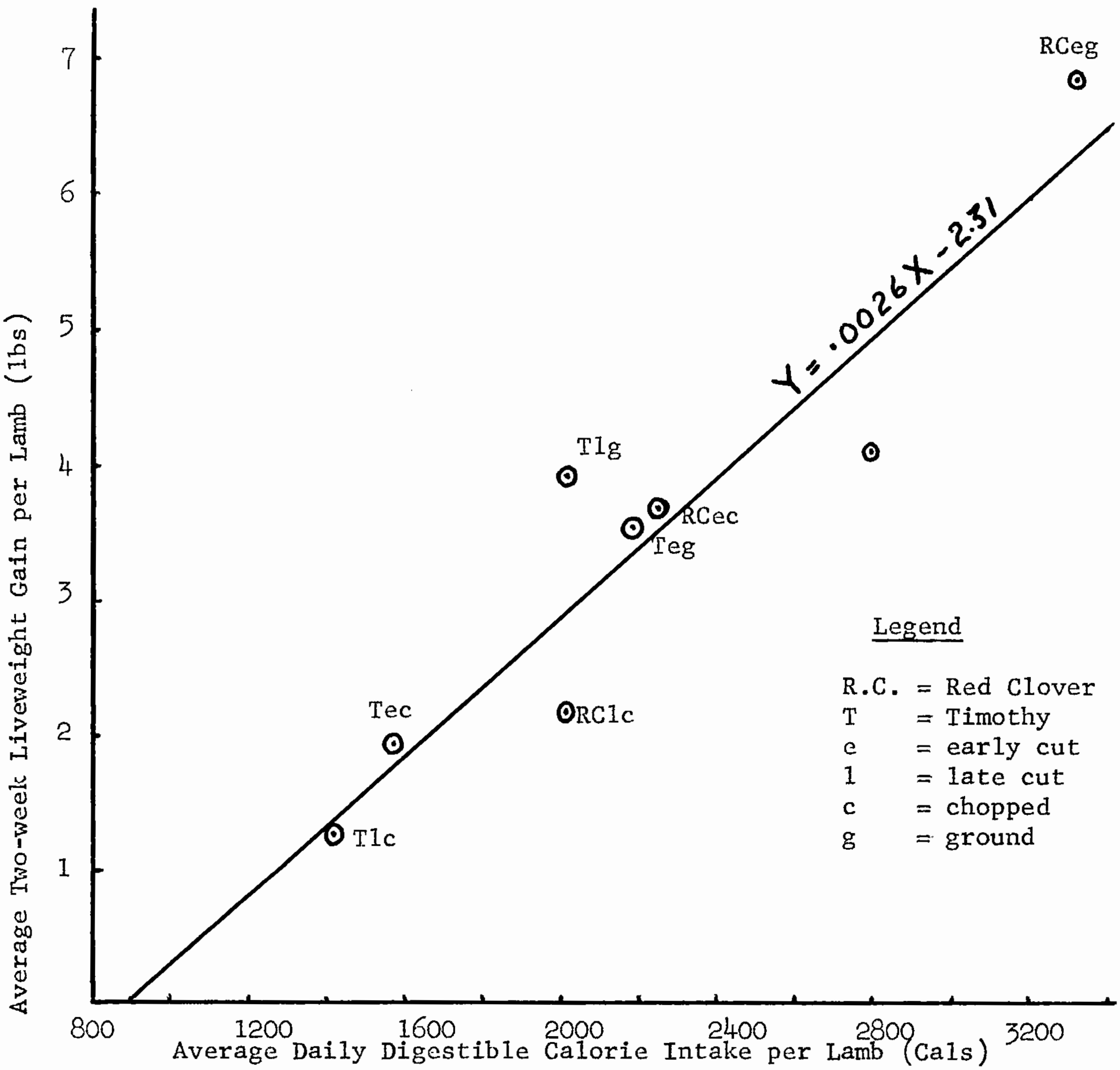
*t.05 = 2.4; t.01 = 3.7; D.F. = 6.

In selecting likely variables to include in a partial regression and multiple correlation analysis we should not select

[1] The relationship between liveweight gain and digestible calorie intake is shown graphically in Fig.11.

FIG.XI - Regression of Liveweight Gain (Y) on

Digestible Calorie Intake (X).



two variables which are obviously highly correlated with one another. Since the first seven variables are logically highly correlated with each other we will select one from this group (Dig. calorie intake). We will also select protein retention since this should logically have some effect on body gains. We will also include total ash intake and the effect of body weight.

In the regression analysis we will use the thirty-two individual values first and then carry out the analysis using the average values (Tables 30 and 31).

TABLE 30. Partial Regression and Multiple Correlation of Liveweight Gain on the Intake of Digestible Calories, Protein Retention, Ash Intake and Body Weight. (Individual Data n = 32).

Independent Variables	Standard Partial Reg.Coeff. (Beta)	Relative Beta Values (%)	Multiple Correlation Coefficient (R)	Multiple Coeff. of Determination (R^2)%
Dig.Calorie Intake	1.4958	62		
Protein retention	.0962	4	.707[xx]	50
Ash intake	.5091	21		
Body weight	.3174	13		

[xx]Highly significant statistically.

It is obvious that in this test at least individual liveweight gains cannot be predicted from the variation in the independent variables listed. This is undoubtedly due to the individual variation occurring in a test of limited duration. In an attempt to overcome this the analysis was repeated using treatment averages.

TABLE 31. Partial Regression and Multiple Correlation of Liveweight Gain on the Intake of Digestible Calories, Protein Retention, Ash Intake and Body Weight (Lot Averages n = 8).

Independent Variables	Standard Partial Reg.Coeff. (Beta)	Relative Beta Values (%)	Multiple Correlation Coefficient (R)	Multiple Coeff. of Determination (R^2)%
Dig.Calorie intake	5.5217	48		
Protein retention	.5587	5	.9813[xx]	96
Ash intake	-4.6340	40		
Body weight	-.8322	7		

[xx] $R_{.01}$ = .927

The regression equation is:

$$Ye = 18.652\ X_1 + .0059\ X_2 - .282\ X_3 - .257\ X_4 - 2.76$$

where

Ye = expected two week gain (lbs)

X_1 = average daily intake of digestible kilocalories

X_2 = grams of protein retained over the 10-day period

X_3 = total daily ash intake

X_4 = body weight in pounds (average over period).

Using this equation the calculated gains were as follows:

		Calculated Two-Week Gain		Actual
Chopped	Red Clover (early)	3.3		3.6
	Red Clover (late)	2.0		2.1
	Timothy (early)	.4		1.9
	Timothy (late)	-1.6		1.3
			(r = .99)	
Ground	Red Clover (early)	10.2		6.9
	Red Clover (late)	6.1		4.0
	Timothy (early)	3.6		3.5
	Timothy (late)	3.2		3.9
	Average	3.4		3.4

Table 32 - Analysis of Variance of Multiple Correlation

(Data of Tables 30 and 31)

Source of Variation	D.F.	S.S.	M.S.	F	Std.Error of Estimate (lbs)
(a) Using individual data (n=32)					
Due to Regression	4	76.69	19.17	6.75^{xx}	
Not accounted for	27	76.69	2.84		1.68
Total (R^2 = .500)	31	153.37	4.95		2.22
(b) Using eight pairs of treatment means (n=8)					
Due to Regression	4	20.47	5.12	19.7^{x}	
Not accounted for	3	.78	.26		.51
Total (R^2=.963)	7	21.26	3.04		1.74

^{x} $P < .05$
^{xx} $P < .01$

While none of the partial regression coefficients are statistically significant it is clear that when taken together they account for a fairly large proportion of the variability in liveweight gains. The marked difference in the proportion of the variability in liveweight gains accounted for by these variables when using individual data and when using lot averages points out the necessity of using adequate replication in tests of this nature. Longer feeding periods, over which to more accurately estimate true weight gains, are desirable.

(d) Metabolizable Energy Balance and its Relationship to Liveweight Gains.

Table 33 summarizes the energy balance data. The calculations for this table are explained in the "Experimental" section. (For the detailed calculation of the data in this table and for the calculation of metabolizable energy value of the forages see Table vii (a and b) of the Appendix). It is found that in several instances the calculated energy balance is negative. A negative energy balance should normally result in a loss in body weight. However the equation,-

$$\text{Metabolizable Cals for Maintenance} = 1.8 \times 70 \times W_{kg}^{.75}$$

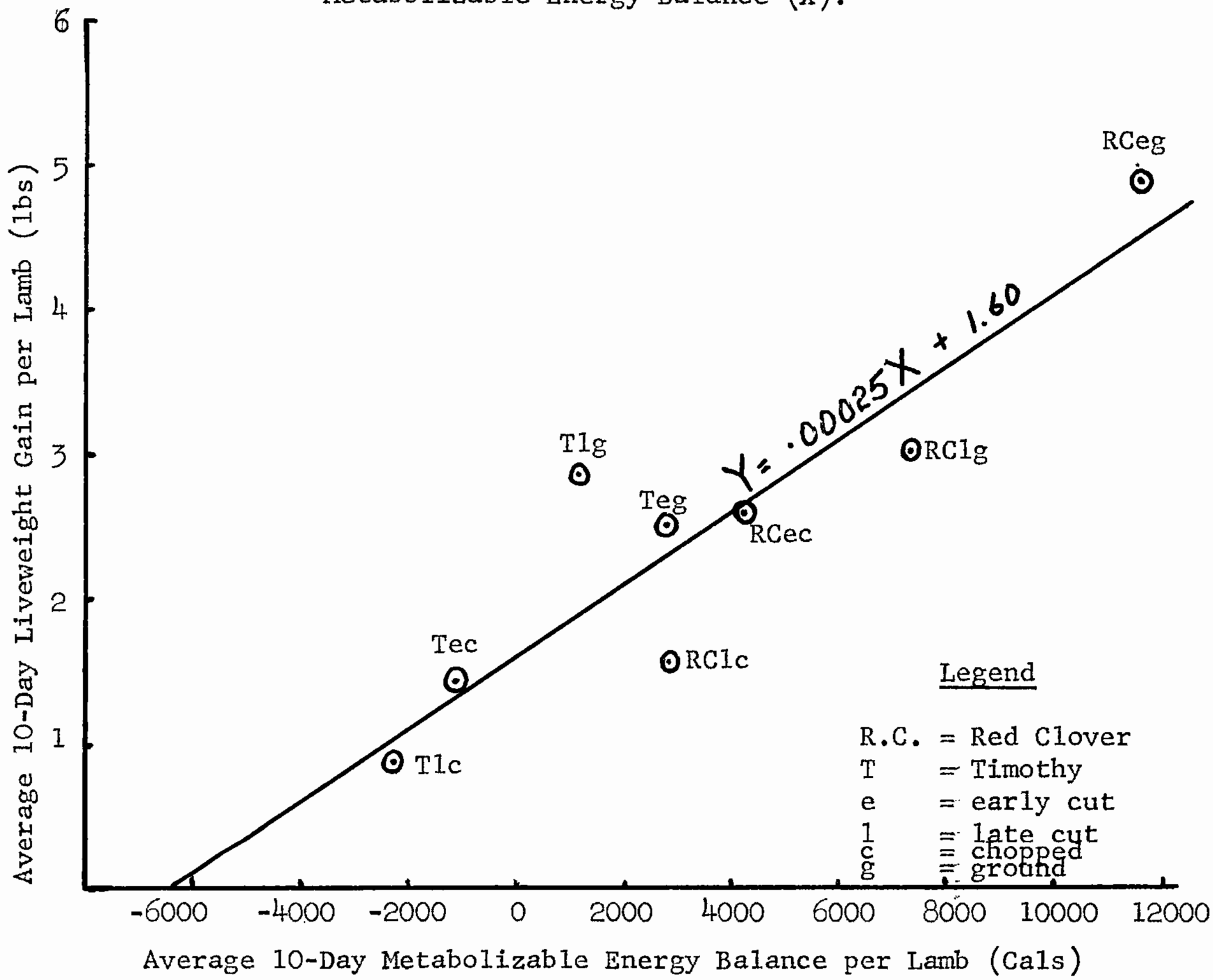
is intended to provide an average estimate of maintenance requirements and is not necessarily applicable to a specific case. In this test the lambs were closely confined in an "ideal" environment. Little energy was lost because of exercise and a minimum of body heat was lost. Figure XII shows the relationship between metabolizable energy balance and liveweight gain using the eight treatment means.

TABLE 33. Energy Balance and Liveweight Gain (10 day period).

Forage	Energy Metabolized Cals/lamb	Maintenance Requirement Met.Cals/lamb $(1.8 \times 70W_{kg}^{.75})$	Energy Balance Calories/ Lamb	Percentage of Maintenance Requirement Supplied	Index	Liveweight Gain lbs/lamb
a. <u>Chopped</u>						
Red Clover (early)	19059	14837	4222	128	149	2.6
Red Clover (late)	17380	14551	2829	119	138	1.5
Timothy (early)	13705	14814	-1109	93	108	1.4
Timothy (late)	12558	14659	-2101	86	100	.9
b. <u>Ground</u>						
Red Clover (early)	28583	16826	11758	170	198	4.9
Red Clover (late)	24479	16875	7604	145	169	2.9
Timothy (early)	19185	16495	2690	116	135	2.5
Timothy (late)	17873	16650	1223	107	124	2.8
Average	19102	15713	3389.5	120.5		

FIG. XII - Regression of Liveweight Gain (Y) on

Metabolizable Energy Balance (X).



The correlation coefficient is positive and highly significant and indicates that 80 percent of the variability in liveweight gains is associated with variation in metabolizable energy intake over "maintenance" requirements. It is interesting to note that the graph indicates an average maintenance requirement of approximately 630 metabolizable calories per day less than that calculated by the equation. This is assuming that a metabolizable energy balance of zero would coincide with maintenance of liveweight. If this is the case, the average maintenance requirement of the lambs under the conditions of this test was about 940 Metabolizable Calories daily, which would mean that their requirements could be expressed by the equation,-

$$\text{Metabolizable Calories for Maintenance} = 1.14 \times 70W_{kg}^{.75}$$

Here again the nature of our weight gain data must be considered. Obviously much more precise work would be required in order to make a reliable prediction equation.

The average metabolizable energy yielded per gram of air dry forage material fed in this test is calculated to be as follows:

	Chopped Forages	Ground Forages
Red Clover (early)	1.89	1.85
Red Clover (late)	1.88	1.75
Timothy (early)	2.08	1.86
Timothy (late)	1.82	1.77

When expressed as a percentage of digestible energy the values for metabolizable energy are,-

	Chopped Forages	Ground Forages
Red Clover (early)	86.1	86.3
Red Clover (late)	85.9	86.2
Timothy (early)	87.1	88.1
Timothy (late)	87.8	87.6

Considering that these data are calculated, it is nevertheless perhaps worthy of note that metabolizable energy values *per se* are not a reliable guide fo forage feeding value at least under *ad libitum* feeding conditions.

H. A Comparison of Methods of Assessing the Energy Value of Forages.

Regardless of which of the common methods is used to arrive at the "useful"energy content of forages there are errors involved. Table 34 presents a comparison of several of these methods based on the data of this experiment except where noted. The four methods used are as follows:

METHOD I.

Using the actual forage composition data found in the experiment we assign a calorie value of 5.6, 9.3, 4.3 and 4.3 per gram for protein, ether extract, fiber and N.F.E. respectively to arrive at the gross calorie content. We then apply the actual digestibility coefficients for these fractions and determine the yield of digestible calories. Because our composition data are in percent (air dry basis), the yield of digestible calories will be on the basis of 100 grams of the forage as fed. By dividing by 100 we thus obtain an estimate of the digestible calories per gram. Knowing the gross calories provided and the digestible calories provided we can express the digestible as a percentage of the gross.

METHOD II.

Expressing energy content in terms of T.D.N.

% T.D.N. = (% Dig.Prot.)+(% Dig.NFE)+(% Dig.Fiber)+(2.25 × % Dig.E.E.)

METHOD III.

Determination of digestible calories by measuring the calorie content of the feed and the feces obtained therefrom.

METHOD IV.

Calculating the metabolizable energy value of the forages by correcting the digestible energy content for energy lost in the urine and in gasses produced.

A study of Table 34 indicates the relationships between the results obtained by these different methods. Methods I and III are directly comparable since both are means of estimating the same thing. Despite the difference in the estimate of gross energy values the estimates of the digestible calories per gram are very close. Method II assumes an equal calorie yield from protein and carbohydrate sources, thus takes into account the energy lost in the urine from protein sources. Determination of the calorie value of T.D.N. reveals a range of from 4.1 to 4.5 calories per gram of T.D.N. (average 4.3),close to the average of 4.4 suggested by Crampton (1957). Calculated metabolizable energy values take into account the theoretical loss of energy in both the urine and the gases, hence the percentage of the gross energy is less than for any of the other methods. Metabolizable energy as calculated represents a very constant proportion of the digestible energy.

TABLE 34 - Energy Value of Forages

Forage	I Using proximate analysis and digestibility data.			II Total Dig.Nutrients		III Dig.Energy Direct Method			IV Metabolizable Energy (calc)		
	Dig.Cals per gm.	Gross Cals/gm	% Dig. of Gross	%	Dig.Cals = 1 gm.T.D.N.	Dig.Cals per gm.	Gross Cals/ gm.	% Dig. of Gross	Met.Cals per gm.	% of Gross Energy	% of Dig. Energy
a. Chopped											
Red Clover (early)	2.22	3.89	57	49.7	4.4	2.20	4.0	55	1.90	47.5	86
Red Clover (late)	2.20	3.93	56	48.8	4.5	2.18	4.1	53	1.87	45.6	86
Timothy (early)	2.43	3.95	62	55.6	4.3	2.39	4.1	58	2.08	50.7	87
Timothy (late)	2.11	3.95	53	48.3	4.3	2.06	4.1	50	1.81	44.1	88
b. Ground											
Red Clover (early)	2.16	3.93	55	47.8	4.5	2.14	4.0	54	1.85	46.3	86
Red Clover (late)	2.07	3.94	53	46.1	4.4	2.03	4.0	50	1.74	43.5	86
Timothy (early)	2.12	3.92	54	49.8	4.2	2.11	4.1	52	1.85	45.1	88
Timothy (late)	2.04	3.96	52	49.4	4.1	2.01	4.1	49	1.74	42.4	87

I. Nitrogen Balance Studies.

Under certain circumstances a study of nitrogen balance can be of some help in estimating the relative nutritional value of different proteins being fed. In this experiment however the conditions for such a comparison are not met. We have no way of knowing whether nitrogen is excreted in the urine because of its lower biological value, excessive intake or because of a reduced calorie intake. The nitrogen balance figures do however indicate the effect of increasing forage intake, due to grinding, on the nitrogen retained by the body and the relationship between nitrogen retention and liveweight gain is of interest as a possible criterion of forage feeding value. The data appear in Table 35.

The correlation coefficient expressing the relationship between protein retention and liveweight gain was found to be $r = .614^{xx}$ (D.F. = 30, $t = 4.26^{xx}$) and $r = .748^{x}$ (D.F. = 6, $t = 2.76^{x}$). This is a statistically significant relationship. However protein retention is not sufficiently well correlated to weight gains to be of any practical value, in itself, as an index of forage feeding value. The "r" value expressing the relationship between percentage protein retained and liveweight gain is $.895^{xx}$ which is highly significant despite the fact that it is based only on the eight pairs of averages in Table 35. The correlation between percent protein retention and voluntary intake is $r = .79^{x}$ which is significant at the $P = .02$ level. We can thus conclude that the percentage protein retained was a reasonably good measure of the relative feeding value of the forages fed in this experiment. The relationships are expressed graphically in Figures XIII and XIV.

TABLE 35. The Effect of Forage Treatment on Nitrogen Retention (Expressed as grams of protein retained over the 10 days corresponding to the collection period).

Treatment	Protein consumed (gms)	Protein lost in feces (gms)	(%)	Protein lost in urine (gms)	(%)	Protein Retained (gms)	(%)	Liveweight gain (lb) (10 days)
a. Chopped								
Red Clover (early)	1445	601	42	637	44	207	14	2.6
Red Clover (late)	1477	660	45	612	41	205	14	1.5
Timothy (early)	494	215	44	222	45	57	11	1.4
Timothy (late)	443	243	55	176	40	24	5	.9
b. Ground								
Red Clover (early)	2377	1024	43	843	35	510	22	4.9
Red Clover (late)	2143	992	46	753	35	398	19	2.9
Timothy (early)	683	364	53	211	31	108	16	2.5
Timothy (late)	642	347	54	186	29	109	17	2.8

FIG. XIII - Regression of Liveweight Gain (Y) on Percent Protein Retention (X)

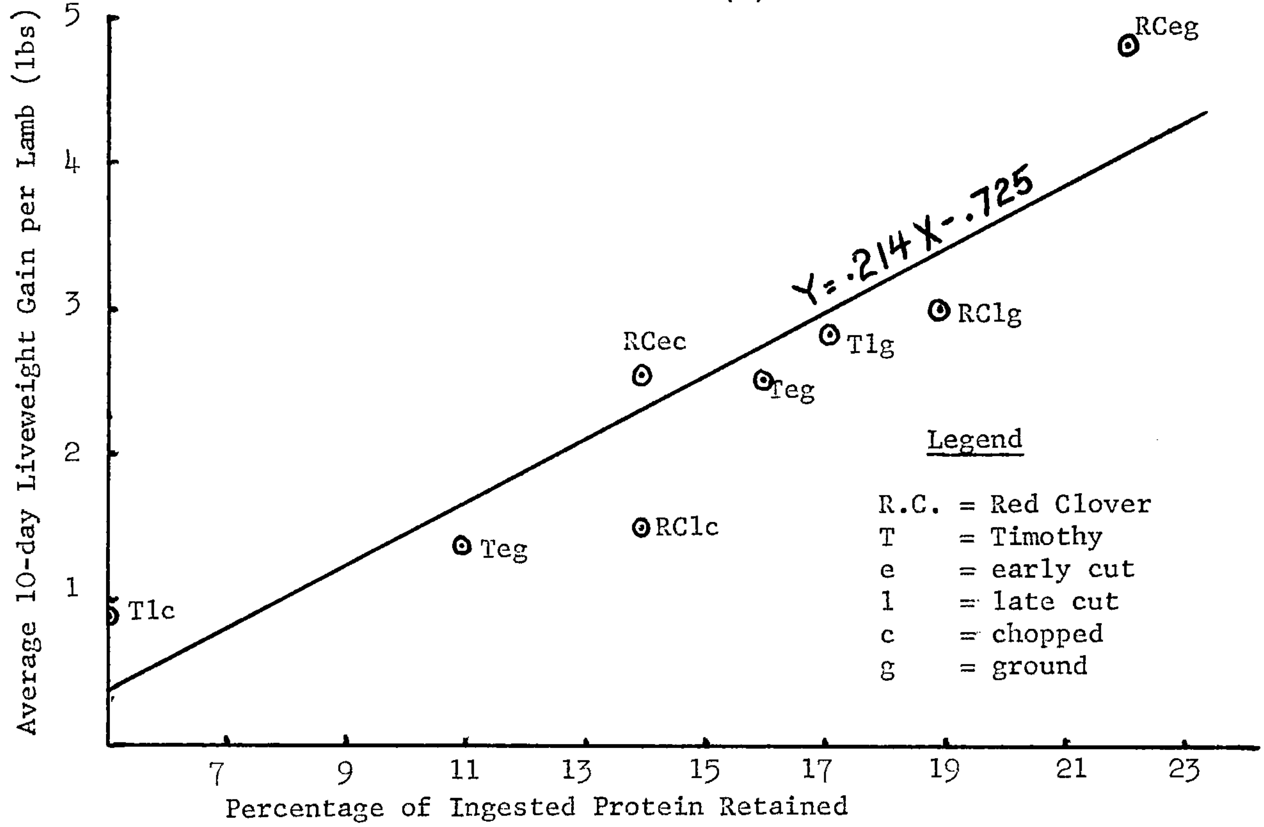
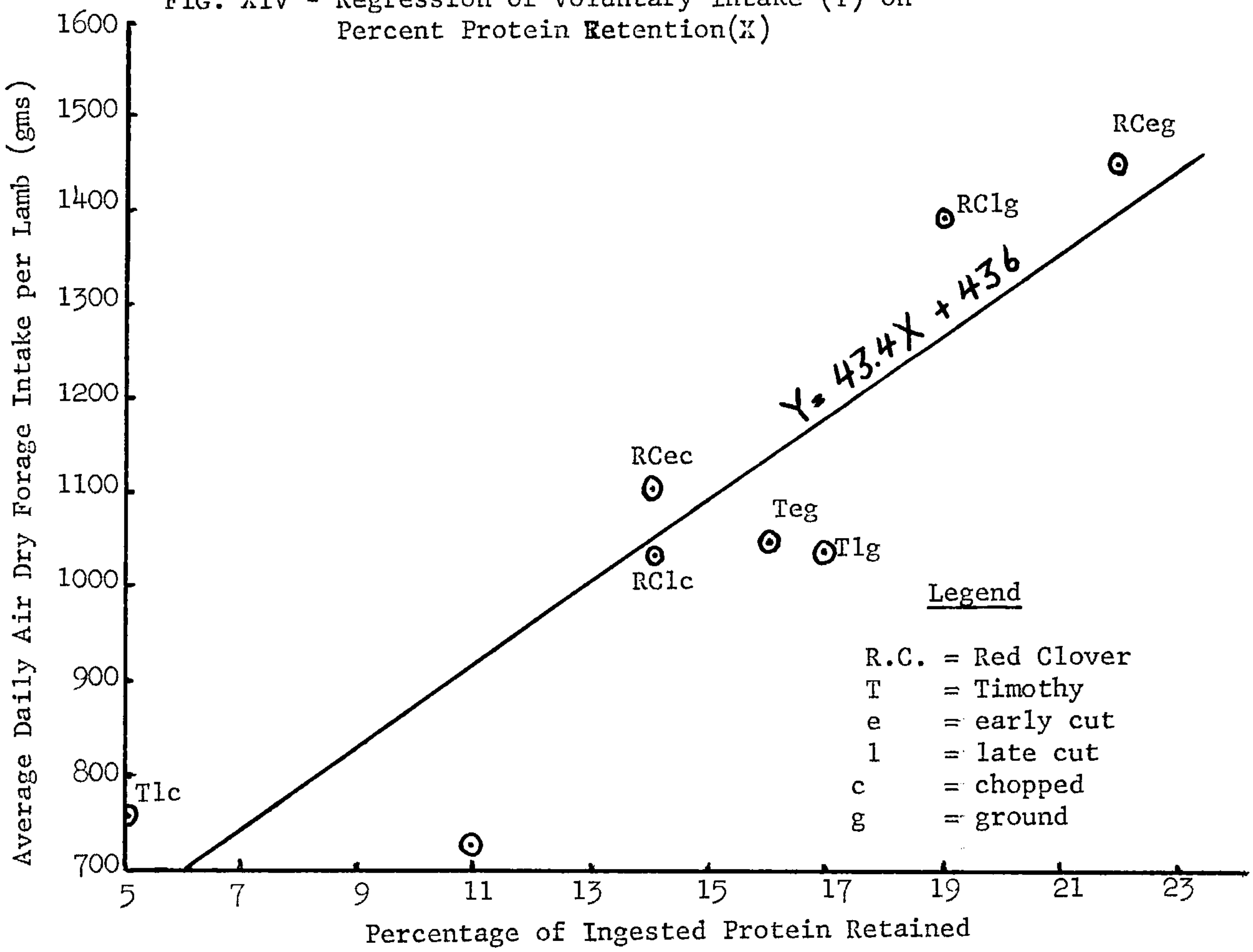


FIG. XIV - Regression of Voluntary Intake (Y) on Percent Protein Retention(X)



The analysis of variance of the nitrogen retention data is presented in Appendix Table xxiv. A highly significant interaction between forage and grinding complicates the picture. While the data of Table 35 indicate that there was approximately a doubling of protein retention due to grinding, the numerical increases on the four forages varied considerably, which probably explains the reason for the interaction. Regardless of the analysis of variance it is quite obvious that both "grinding" and "forage" had a large influence on the amount of protein retained.

J. Miscellaneous Observations.

1. The Relationship Between Feces Moisture Content and Voluntary Intake.

Ewing *et al* (1917) suggest that in cattle, the dry matter content of the feces could be used as an index of the rate of passage of the feed, the moister the feces, the faster the rate of passage. Leitch and Thompson (1944) observed that milking cows produced feces containing 5 percent more water than those produced from dry cows and steers. They did not suggest a reason however. Castle (1956) found a significant relationship ($r = .51$, $P < .05$) between the dry matter content of the feces and the time of 5 percent excretion. (i.e. the higher the dry matter content the longer the time required for 5% excretion). Balch (1950) also suggests that the water content of the feces may indicate the rate of passage through the digestive tract posterior to the reticulo rumen.

In view of the relationship between voluntary intake and rate of passage found in Blaxter's work (see Review of Literature) and the effect on feces moisture content, it was decided to determine the relationship between feces moisture content and voluntary intake using the data of this experiment.

An analysis of variance (Appendix Table xv) to determine the effect of forage and of grinding on the feces moisture content, revealed that both these factors had a highly significant effect ($P < .01$). A factorial summary of the data is presented in Table 36.

TABLE 36 - The Effect of Forage and of Grinding on the Water Content of Feces (%).

Form in which fed	Treatment: Red Clover (early)	Red Clover (late)	Timothy (early)	Timothy (late)	Form Average
Chopped	67.4	68.2	62.2	63.4	65.3
Ground	73.9	72.4	66.5	66.4	69.8
Treatment Av.	70.7	70.3	64.3	64.9	
Species Av.	70.5		64.6		
Stage Av.	67.5		67.6		

L.S.D.'s (%)

X =	16	8	4
P=.05	1.9	2.6	3.7
P=.01	2.6	3.7	5.3

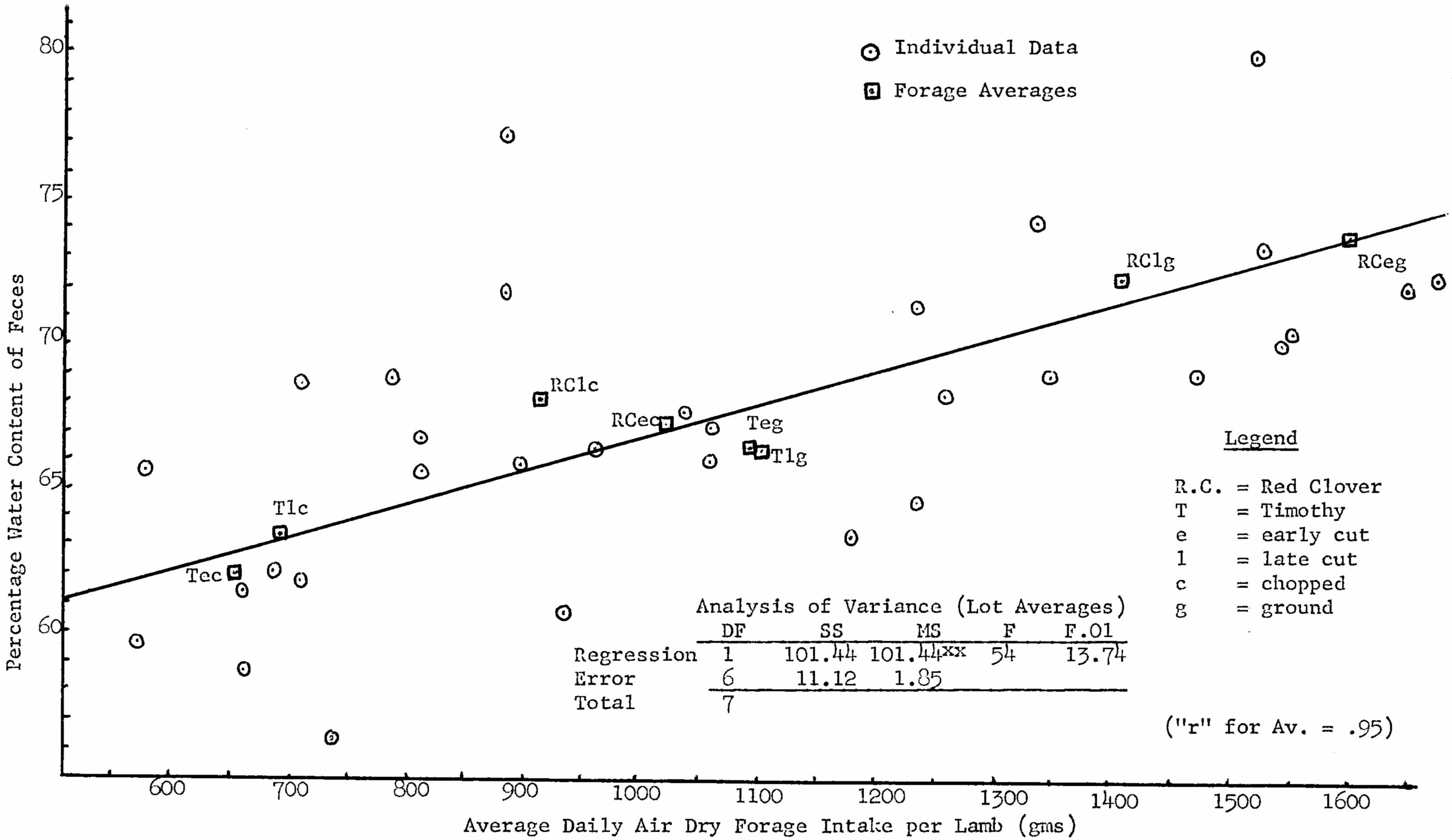
It is thus seen that feces produced by lambs consuming Red Clover are higher in moisture content than those produced by lambs fed Timothy and that feces produced on ground forages contain more moisture than feces produced on chopped forages. It is therefore probable that feces moisture content is related to voluntary intake. This relationship was determined and is shown graphically in Figure XV. The correlation coefficient for the eight pairs of means is highly significant and positive ($r = .95^{xx}$).

The regression of feces moisture content on voluntary intake is expressed by the equation,-

$Ye = .0116\ X + 55.21$, where Ye = percent moisture content of feces, and X = average daily feed intake per lamb (gms).

Because of the high degree of relationship between voluntary intake and feces moisture content it is not inconceivable that this could provide the basis for estimating forage consumption on pasture. While considerable work will be required before the accuracy of this method can be assessed under pasture conditions, the problem of estimating pasture consumption is of such importance that no possibility should be overlooked. The scatter diagram (Fig.XV) indicates the desirability of using lot averages rather than individual data when relating feces moisture content to voluntary intake data and vice versa.

FIG:XV - Regression of Feces Moisture Content (Y) on Forage Intake (X)



Analysis of Variance (Lot Averages)

	DF	SS	MS	F	F.01
Regression	1	101.44	101.44xx	54	13.74
Error	6	11.12	1.85		
Total	7				

2. Summary and Results Obtained in Pilot Trials.

A pilot trial was conducted to determine the effect of grinding and moistening on the voluntary intake and utilization of the four forages under study. The spare lamb was "paired" with one of the lambs fed in Part A of the major experiment and received the same forages (in the same order and at the same time) only in the ground and moistened form. The data are summarized in Table 37.

At the start of the experiment the spare lamb weighed 40 lbs. while the "mate" weighed 53 lbs. The forages were fed in the order T_1 R_1 T_2 R_2 which in the light of subsequent findings explains certain "discrepancies" in the consumption figures.

Nevertheless this pilot trial provided a lot of useful information even considering the statistical (and biological) shortcomings of the trial. The following results later substantiated were as follows:

(1) Grinding and moistening increased forage intake considerably.

(2) Grinding and moistening caused a reduction in extent of digestibility of all feed components.

(3) Grinding and moistening caused an approximate doubling of protein retention.

(4) Grinding and moistening resulted in a marked increase in salt consumption.

TABLE 37 - The Effect of Grinding and Moistening on the Voluntary Intake and Utilization of Forages (Pilot Trial).

	Spare lamb (ground forages)				Test mate (chopped forages)			
Forage Designation*	R_1	R_2	T_1	T_2	R_1	R_2	T_1	T_2
Av. daily consumption (gms)	1190	1199	794	844	964	875	662	564
Two week gain (lbs)	5.5	2.0	3.0	1.0	4.0	2.0	3.5	-1.5
Digestibility Data (%)								
Dry Matter	57	50	50	45	60	53	64	54
Energy	57	50	46	42	59	52	59	49
Protein	59	51	52	40	60	52	59	43
Fiber	45	45	48	39	52	55	67	53
Cellulose	60	55	52	41	65	63	71	55
N.F.E.	67	56	53	52	67	58	66	58
Ether Extract	64	55	0	41	69	45	0	54
Protein balance (gms)	422	410	176	74	225	238	82	-17
Salt consumption/week (gms)	59	64	46	162	22	64	11	74

*R = Red Clover, T = Timothy, 1 = early cut, 2 = late cut

VII - SUMMARY AND CONCLUSIONS

The conclusions which we may draw on the basis of the findings in this experiment may be summarized as follows:

1. Red Clovers were consumed to a significantly greater extent ($P < .01$) than were the Timothys. Stage of maturity of the Timothys had no effect on voluntary intake whereas the more mature Red Clover was consumed to a lesser extent (11% less, P approx. = .01) than was the early cut Red Clover.

2. Feeding the forages in the ground, moistened form caused a highly significant increase in the voluntary intake of all four forages studied, the average increase being 60 percent over that consumed when fed in the chopped form. There were no statistically significant differences between forages as far as percentage increase in consumption due to grinding was concerned.

3. Voluntary intake of forages (including the effect of species, stage of maturity and form in which fed) was highly correlated ($P < .01$) to feeding value, whether feeding value was expressed as intake of digestible energy or as liveweight gain.

4. Variability in crude protein, nitrogen-free extract, crude fiber and ash content of the forages accounted for 91 percent of the variability in voluntary intake of ground forages and 74 percent of the variability in the intake of chopped forages. Ash and crude fiber content appeared to have a greater influence on the intake of ground forages than of chopped forages.

5. Grinding and moistening forages, resulted in a reduction in the digestibility of most of the feed nutrients (averaging 3 to 6 percentage units). Because of increased feed intake however, there was a greater amount of digestible nutrients made available to the animal with the result that liveweight gains were doubled.

6. Increasing maturity markedly reduced the digestibility of chopped Timothy (dry matter and energy digestibility reduced by 8 percentage units) and to a lesser extent that of ground Timothy. Its effect on the digestibility of Red Clover was variable but generally less marked than with the Timothys.

7. Intake of digestible calories or energy balance were found to provide no better relationship to liveweight gain than did voluntary (air dry) intake data.

8. The digestible calorie equivalent of a gram of T.D.N. was found to vary between 4.1 and 4.5 Calories, the average being 4.3. The digestible energy per gram of air dry forage, calculated from proximate analysis data, closely paralleled the values obtained by direct determination, overestimating the latter by an average of one percent.

9. The percent nitrogen retained was found to be more closely related to forage intake (r^2 = .80) than was the amount of protein retained (r^2 =.56).

10. Water intake, relative to forage intake, was increased when the forages were fed in the ground moistened form. Approximately 90 percent of the variability in gross water consumption could be associated with variation in the intake of digestible protein, digestible calories and total minerals (feed ash plus salt). Of these, total mineral intake was by far the most important factor.

11. Feeding forages in the ground-moistened condition resulted in a doubling of salt intake (expressed as a percentage of forage intake). This increase could not be attributed to the increased water intake.

12. Feces moisture content was found to be highly correlated to voluntary intake ($r = .95^{xx}$ using eight treatment means).

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APPENDIX

APPENDIX

Cellulose Determination (Modified method of Crampton and Maynard, 1938).

1. Weigh 1 g sample into a 90 ml test tube. Extract colored material with benzene. Centrifuge, pour off benzene.
2. Add 20 ml of 80% acetic acid and 2 ml of conc. HNO_3.
3. Mix with glass stirring rod. Leave rod in tube during digestion period.
4. Place tube in boiling water bath for 30 minutes. Stir every 10 minutes. (Feces samples will tend to foam during first few minutes, stirring won't prevent it. Lift rack of tubes partially from boiling water to counteract foaming and gradually immerse as foaming ceases.)
5. Add 25 ml of 95% ethanol.
6. Filter through a Selas crucible (coarse porosity).
7. Wash tube out with ethanol (95%).
8. Wash residue in crucible with 5 ml acetone.
9. Dry in vacuum oven at 95°C and 27 inches of Hg for at least 4 hours.
10. Weigh.
11. Ash in muffle furnace at 600°C.
12. Weigh. Loss in weight is taken as the cellulose present in original sample.

Lignin Determination. (Modified method of Thacker, 1954).

1. Weigh out 1 g sample directly into a 250 c.c. Erlenmeyer flask.
2. Cover the sample with 20-30 c.c. of an ethanol-benzene mixture and let stand overnight if possible.
3. Filter (using filter sticks), repeat the above treatment until no more pigment is extracted. Leave filter stick in Erlenmeyer.
4. Wash with alcohol, then with ether. Remove ether by suction.
5. Add 40 c.c. of a 1% pepsin solution in 0.1NHCl. Incubate overnight at 40°C.
6. Filter off the pepsin solution, wash with hot water.
7. Add 150 ml of 5% (1N) H_2SO_4 and boil on a hot plate for one hour maintaining volume of solution by adding distilled water.
8. Filter and wash with alcohol, then with ether. Remove ether.
9. Add 20 ml of 72% (23.4N) H_2SO_4. Digest for two hours at room temperature (20-23°C).
10. Dilute, filter and wash. (It was found almost impossible to filter without first placing a layer of oven-ashed "Hyflo Super-Cel" over the filter. This was applied by placing the filter stick under suction intp a water suspension of "Super-Cel.")
11. Add 150 ml of 3% (.6N) H_2SO_4. Boil on hot plate for 1 hour maintaining volume.
12. Filter into a Gooch crucible. Wash free of acid.
13. Dry in vacuum oven and weigh. (4 hours at a vacuum pressure of 27 inches of mercury).
14. Ignite in muffle furnace, (600°C overnight) and weigh. Loss in weight is considered as lignin.

Reagents.

Ethanol-benzene -2:1 by volume. (95% alcohol is used here).

Alcohol 95%.

Ether.

Pepsin solution - 8.17 c.c. conc. HCl + 10 gm pepsin and make up to 1000 c.c. with water.

H_2SO_4 a - 3% - 31 c.c. of 96% H_2SO_4 in 1 liter of soln.

b - 5% - 52 c.c. of " " " " " "

c - 72% - 750 c.c." " " " " " "

APPENDIX TABLE i - Feed Consumption, Water and Salt Intake and Liveweight Gains of Individual Lambs by Period.

Forage Species	Lamb No.	Average Daily Feed Consumption (gms. A.D.forage/lamb) Final 2 weeks	Coll. Period	Final week	Av.Daily Water Intake (cc./lamb) Final week	Av.Daily Salt Intake (gms/lamb) Final week	Liveweight Gain (lbs/lamb) Final 2 weeks	Coll. Period
(a) Chopped Red Clover (early)	1	1175	1185	1178	2717	1.86	2.0	1.4
	2	1019	1026	1058	3417	6.71	4.0	2.9
	3	953	960	964	2276	3.14	4.0	2.9
	4	842	842	895	2470	.01	4.5	3.2
	Mean	997	1003	1024	2720	2.9	3.6	2.6
Red Clover (late)	1	1060	1063	1040	2414	4.00	2.5	1.8
	2	951	957	938	2649	3.72	3.0	2.1
	3	866	866	879	3031	9.14	2.0	1.4
	4	815	830	817	2019	.14	1.0	.7
	Mean	923	929	919	2528	4.3	2.1	1.5
Timothy (early)	1	718	715	710	1737	3.72	1.5	1.1
	2	678	678	661	1971	7.71	.5	.4
	3	645	649	666	1371	1.57	3.5	2.5
	4	592	591	577	1164	.14	2.0	1.4
	Mean	658	658	654	1561	3.3	1.9	1.4
Timothy (late)	1	771	771	782	2011	9.00	1.0	.7
	2	713	715	679	1865	4.00	1.5	1.1
	3	530	535	579	1679	10.57	-1.5	-1.1
	4	734	745	733	1272	.57	4.0	2.9
	Mean	687	692	693	1707	6.0	1.3	.9

/Table i continued
on following page.

APPENDIX TABLE i (continued)

Forage Species	Lamb No.	Average Daily Feed Consumption (gms. S.D. forage/lamb) Final 2 weeks	Coll. Period	Final week	Av. Daily Water Intake (cc./lamb) Final week	Av. Daily Salt Intake (gms/lamb) Final week	Liveweight Gain (lbs/lamb) Final 2 weeks	Coll. Period
(b) Ground Red Clover (early)	1	1602	1622	1688	5252	9.29	8.5	6.1
	2	1453	1470	1556	4688	21.57	7.0	5.0
	3	1599	1628	1656	4568	5.71	6.0	4.3
	4	1464	1471	1526	4893	2.14	6.0	4.3
	Mean	1530	1548	1607	4850	9.7	6.9	4.9
Red Clover (late)	1	1534	1535	1531	4467	7.57	2.0	1.4
	2	1237	1253	1241	5638	33.42	3.0	2.1
	3	1538	1530	1550	3975	7.14	7.0	5.0
	4	1302	1304	1338	3440	2.00	4.0	2.9
	Mean	1403	1406	1415	4380	12.5	4.0	2.9
Timothy (early)	1	1281	1280	1351	3154	9.29	6.0	4.3
	2	1207	1200	1257	3013	18.00	2.5	1.8
	3	643	644	712	3035	38.85	1.0	.7
	4	1002	1014	1058	2328	1.43	4.5	3.2
	Mean	1033	1035	1095	2883	16.9	3.5	2.5
Timothy (late)	1	1360	1380	1472	3172	5.86	2.5	1.8
	2	774	805	900	3568	38.28	3.5	2.5
	3	1150	1167	1236	2940	28.42	6.5	4.6
	4	723	750	806	2362	1.00	3.0	2.1
	Mean	1002	1026	1104	3011	18.4	3.9	2.8

APPENDIX TABLE ii - Chemical Composition of Forages as Consumed by Individual Lambs.

Forage Species	Lamb No.	Crude Protein %	Crude Fiber %	N-free Extract %	Ether* Extract %	Ash %	Cellulose %	Lignin %	Gross Energy Cals/gm.	Dry* Matter
(a) Chopped Red Clover (early)	1	14.12	24.75	44.41	1.22	7.48	30.31	9.32	3.99	92.06
	2	14.67	23.70	45.54	1.02	8.18	30.06	9.88	4.04	93.01
	3	14.22	23.68	44.94	2.10	7.42	30.20	11.42	4.00	92.33
	4	14.52	26.60	42.08	1.32	7.27	31.29	8.90	4.02	91.72
	Mean	14.4	24.7	44.2	1.4	7.6	30.5	9.9	4.0	92.3
Red Clover (late)	1	16.29	25.44	41.17	1.70	7.68	30.59	12.00	4.02	92.26
	2	15.88	25.52	41.30	2.18	7.69	30.79	12.00	4.06	92.64
	3	15.89	26.90	39.63	1.86	7.41	31.39	11.49	4.14	91.80
	4	15.53	26.57	41.87	1.18	7.03	32.35	11.36	4.16	92.08
	Mean	15.9	26.1	41.0	1.7	7.5	31.3	11.7	4.1	92.2
Timothy (early)	1	7.15	28.82	50.28	1.20	6.16	31.73	8.25	4.17	93.57
	2	7.04	31.31	47.56	2.38	5.93	33.24	8.81	4.08	94.18
	3	8.75	30.62	46.27	1.19	6.94	33.73	8.70	4.12	93.75
	4	7.23	29.03	49.95	1.98	5.83	31.64	9.41	4.12	94.02
	Mean	7.5	29.9	48.5	1.7	6.2	32.6	8.8	4.1	93.9
Timothy (late)	1	6.01	29.53	51.80	1.41	5.00	30.76	9.92	4.18	93.66
	2	6.48	27.85	51.65	1.46	5.77	30.25	9.55	4.10	93.20
	3	6.59	28.10	50.49	2.14	5.78	30.36	10.08	4.11	93.24
	4	6.49	28.56	51.87	1.42	5.46	30.76	8.73	4.11	93.69
	Mean	6.4	28.5	51.5	1.6	5.5	30.5	9.6	4.1	93.5

/Table ii continued on following page.

APPENDIX TABLE ii (continued)

Forage Species	Lamb No.	Crude Protein %	Crude Fiber %	N-free Extract %	Ether* Extract %	Ash %	Cellulose %	Lignin %	Gross Energy Cals/gm.	Dry* Matter
(b) Ground Red Clover (early)	1	14.54	25.04	42.75	1.70	7.77	29.90	9.13	3.92	91.80
	2	15.44	24.80	42.18	1.74	7.84	28.92	9.65	4.01	92.00
	3	15.51	23.84	42.41	2.09	7.97	29.05	9.54	4.05	91.82
	4	16.01	23.32	42.44	2.80	7.71	28.39	9.88	4.02	92.28
	Mean	15.4	24.3	42.4	2.1	7.8	29.1	9.6	4.0	92.0
Red Clover (late)	1	15.29	27.56	39.86	1.63	7.31	31.27	13.48	4.05	91.65
	2	14.70	28.01	39.92	1.72	7.03	31.56	12.76	4.01	91.38
	3	15.79	26.83	41.44	1.23	7.05	29.82	14.66	4.05	92.34
	4	15.10	26.78	40.35	2.87	7.32	30.70	14.34	4.05	92.42
	Mean	15.2	27.3	40.4	1.9	7.2	30.8	13.8	4.0	92.0
Timothy (early)	1	6.39	31.84	48.71	1.12	5.64	32.58	10.18	4.13	93.70
	2	6.69	31.05	47.36	2.00	5.95	31.61	9.95	4.04	93.05
	3	6.68	30.80	47.55	1.75	6.26	32.48	9.39	4.05	93.04
	4	6.71	30.38	48.56	1.54	6.46	32.48	9.90	4.13	93.65
	Mean	6.6	31.0	48.0	1.6	6.1	32.3	9.9	4.1	93.4
Timothy (late)	1	6.16	30.10	50.69	1.53	5.50	30.56	10.43	4.07	93.98
	2	6.02	30.57	49.56	1.61	5.12	31.55	9.92	4.16	92.88
	3	6.08	28.04	51.49	2.48	5.35	29.62	9.82	4.01	93.44
	4	6.99	29.21	49.55	1.87	5.31	30.87	9.90	4.15	92.93
	Mean	6.3	29.5	50.3	1.9	5.3	30.7	10.0	4.1	93.3

*Feed as fed basis.

All individual data represent the average of duplicate samples checking within 5% of each other.

APPENDIX TABLE iii - Chemical Analyses of Forages and Weighbacks (Air Dry Basis).

Constituent	Chopped Forages												Ground Forages			
	Timothy						Red Clover						Timothy		Red Clover	
	Early			Late			Early			Late						
	As Offered	W.B.	As Eaten	As Offered	W.B.	As Eaten	As Offered	W.B.	As Eaten	As Offered	W.B.	As Eaten	Early	Late	Early	Late
Dry Matter %	93.9			93.5			92.3			92.2			93.4	93.3	92.0	92.0
M.D.*	(.2)			(.3)			(.3)			(.3)			(.3)	(.4)	(.2)	(.4)
Crude Protein %	7.2	4.1	7.5	6.1	3.3	6.4	13.9	8.2	14.4	15.4	[illegible]	15.9	6.6	6.3	15.4	15.2
M.D.	(.6)	(.3)		(.2)	(.2)		(.3)	(1.3)		(.2)	[illegible]		(.1)	(.3)	(.4)	(.3)
Crude Fiber %	30.3	34.3	29.9	28.9	33.4	28.5	25.3	31.7	24.7	26.9	34.4	26.1	31.0	29.5	24.3	27.3
M.D.	(1.0)	(1.5)		(.5)	(.5)		(.9)	(3.0)		(.3)	(6.4)		(.4)	(.8)	(.7)	(.5)
Ether Extract %	1.7	1.1		1.6	1.1		1.4	1.3		1.7	1.6		1.6	1.9	2.1	1.9
M.D.	(.5)	(.2)		(.2)	(.3)		(.3)	(.4)		(.3)	(.4)		(.4)	(.4)	(.4)	(.5)
Ash %	6.3	6.5	6.2	5.4	3.9	5.5	7.6	8.2	7.6	7.4	6.4	7.5	6.1	5.3	7.8	7.2
M.D.	(.3)	(.7)		(.3)	(.2)		(.2)	(1.6)		(.1)	(1.3)		(.4)	(.1)	(.1)	(.1)
N-free Extract %	48.4	47.0	48.5	51.4	51.1	51.5	44.1	42.7	44.2	40.9	39.4	41.0	48.0	50.3	42.4	40.4
M.D.	(1.3)	(1.1)		(.4)	(1.4)		(1.0)	(.7)		(.6)	(2.5)		(.6)	(.7)	(.2)	(.5)
Cellulose %	32.8	35.3	32.6	30.8	33.7	30.5	30.8	34.5	30.5	31.9	37.5	31.3	32.3	30.7	29.1	30.8
M.D.	(.8)	(1.5)		(.2)	(.9)		(.3)	(2.1)		(.1)	(5.0)		(.3)	(.6)	(.4)	(.6)
Lignin %	8.9	9.9	8.8	9.6	10.0	9.6	9.9	9.6	9.9	11.9	13.8	11.7	9.9	10.0	9.6	13.8
M.D.	(.5)	(.2)		(.4)	(.2)		(.7)	(.2)		(.2)	(.7)		(.2)	(.2)	(.2)	(.7)
Energy Cals/gm.	4.11	3.99	4.12	4.12	4.08	4.13	4.00	3.89	4.01	4.09	4.05	4.10	4.09	4.10	4.00	4.04
M.D.	(.03)	(.04)		(.02)	(.02)		(.02)	(.06)		(.05)	(.04)		).04)	(.06)	(.04)	(.02)

*Average deviation of 4 values

APPENDIX TABLE iv - Apparent Digestibility Coefficients for Individual Lambs.

Forage Species	Lamb No.	Crude Protein %	Crude Fiber %	Cellu-lose %	N-free Extract %	Ether Extract %	Gross Energy %	Dry Matter %
(a) Chopped R.Clover (early)	1	56.18	40.11	58.12	64.84	49.45	53.45	53.51
	2	64.83	50.00	64.54	69.37	20.90	59.49	60.74
	3	60.45	52.21	64.64	67.21	69.57	58.92	59.68
	4	50.79	41.96	52.57	55.01	16.98	47.28	46.05
	Mean	58.1	46.1	60.0	64.1	34.3	54.8	55.0
R.Clover (late)	1	57.35	54.18	63.96	61.72	45.38	54.48	56.89
	2	54.93	49.94	59.95	59.85	57.68	52.07	54.41
	3	51.53	54.94	63.16	57.96	45.49	52.14	53.13
	4	57.28	47.61	62.23	61.95	18.99	54.13	54.20
	Mean	55.3	51.7	62.3	60.4	41.9	53.2	54.7
Timothy (early)	1	53.36	59.62	61.23	63.19	14.73	57.61	58.78
	2	56.00	61.23	65.17	63.91	56.90	57.71	60.50
	3	59.23	67.39	70.78	66.04	0.00	59.12	63.96
	4	58.36	60.19	63.88	63.98	54.16	57.41	60.02
	Mean	56.7	62.11	65.3	64.3	31.4	58.0	60.8
Timothy (late)	1	39.47	50.39	52.71	59.87	0.00	51.66	52.57
	2	48.05	45.08	49.74	59.82	1.62	48.26	52.03
	3	42.77	52.65	55.41	58.28	54.45	49.40	53.59
	4	48.88	46.33	53.04	61.21	9.71	50.74	52.99
	Mean	44.8	48.6	52.7	59.8	16.5	50.0	52.8
(b) Ground R.Clover (early)	1	54.97	45.95	53.57	62.14	60.89	54.1	54.19
	2	59.30	43.52	52.67	61.53	2.56	53.3	53.12
	3	55.81	44.88	53.42	62.59	0.00	52.8	52.50
	4	57.68	46.62	55.10	62.36	66.31	54.0	54.31
	Mean	56.9	45.2	53.7	62.2	32.4	53.6	53.5
R.Clover (late)	1	54.73	44.79	53.28	54.89	74.37	49.2	50.38
	2	52.92	52.14	58.17	58.43	48.12	53.0	53.57
	3	52.61	44.32	50.14	56.26	0.00	47.4	49.59
	4	54.63	43.22	52.93	56.27	80.30	51.3	51.26
	Mean	53.7	46.1	53.6	56.5	50.7	50.2	51.2
Timothy (early)	1	44.78	55.79	57.07	58.41	0.00	52.1	53.27
	2	47.22	54.25	53.67	56.09	41.70	50.3	52.39
	3	46.57	59.77	58.85	58.49	17.87	52.8	55.04
	4	48.27	50.77	53.36	56.97	18.24	51.1	51.37
	Mean	46.7	55.12	55.7	57.5	19.5	51.6	53.0
Timothy (late)	1	45.35	47.60	46.77	56.57	3.66	48.0	50.41
	2	41.89	45.51	49.60	56.45	29.02	49.2	49.59
	3	44.30	41.61	45.26	58.26	56.22	46.6	50.77
	4	53.05	48.26	50.21	57.89	48.43	52.5	51.57
	Mean	46.2	45.8	48.0	57.3	34.3	49.1	50.6

APPENDIX TABLE v - Digestible Nutrient Content of Forages by Periods.

Forage Species	Lamb No.	Protein %	Crude Fiber %	N-free Extract %	Ether Extract %	Total Dig. Nutrients %	Energy Cals/100 gm. A.D.	T.D.N. Caloric Equiv.	Dig. Cellulose %
(a) Chopped Red Clover (early)	1	7.93	9.93	28.80	.60	48.01	213.3	4.4	17.62
	2	9.51	11.85	31.59	.21	54.26	240.3	4.4	19.40
	3	8.60	12.36	30.20	1.46	54.44	235.7	4.3	19.52
	4	7.37	11.16	23.15	.22	42.18	190.1	4.5	16.45
	Mean	8.4	11.3	28.4	.6	49.7	219.9	4.4	18.2
Red Clover (late)	1	9.34	13.78	25.41	.77	50.26	219.0	4.4	19.57
	2	8.72	12.74	24.72	1.26	49.02	211.4	4.3	18.46
	3	8.19	14.78	22.97	.85	47.85	215.9	4.5	19.83
	4	8.90	12.65	25.94	.22	47.99	225.2	4.7	20.13
	Mean	8.8	13.5	24.8	.8	48.8	217.9	4.5	19.5
Timothy (early)	1	3.82	17.18	31.77	.18	53.18	240.2	4.5	19.43
	2	3.94	19.17	30.40	1.35	56.55	235.5	4.2	21.66
	3	5.18	20.63	30.56	0	56.37	243.6	4.3	23.87
	4	4.22	17.47	31.96	1.12	56.17	236.5	4.2	20.21
	Mean	4.3	18.6	31.2	.7	55.6	239.0	4.3	21.3
Timothy (late)	1	2.37	14.88	31.01	0	48.26	215.9	4.5	16.21
	2	3.11	12.55	30.90	.02	46.61	197.9	4.2	15.05
	3	2.82	14.79	29.43	1.17	49.67	203.0	4.1	16.82
	4	3.17	13.23	31.75	.14	48.47	208.5	4.3	16.32
	Mean	2.9	13.9	30.8	.3	48.3	206.3	4.3	16.1

/Table v continued on following page.

APPENDIX TABLE v (continued)

Forage Species	Lamb No.	Protein %	Crude Fiber %	N-free Extract %	Ether Extract %	Total Dig. Nutrients %	Energy Cals/100 gm.A.D.	T.D.N. Caloric Equiv.	Dig. Cellulose %
(b) Ground Red Clover (early)	1	7.99	11.51	26.56	1.04	48.40	212.1	4.4	16.02
	2	9.16	10.79	25.95	.04	45.99	213.7	4.6	15.23
	3	8.66	10.70	26.54	Θ	45.90	213.8	4.7	15.52
	4	9.23	10.87	26.47	1.86	50.76	217.1	4.3	15.64
	Mean	8.8	11.0	26.4	.7	47.8	214.2	4.5	15.6
Red Clover (late)	1	8.37	12.34	21.88	1.21	45.31	199.3	4.4	16.66
	2	7.78	14.60	23.33	.83	47.58	212.5	4.5	18.36
	3	8.31	11.89	23.31	Θ	43.51	192.0	4.4	14.95
	4	8.25	11.57	22.70	2.41	47.94	207.8	4.3	16.25
	Mean	8.2	12.6	22.8	1.11	46.1	202.9	4.4	16.6
Timothy (early)	1	2.86	17.76	28.45	Θ	49.07	215.2	4.4	18.59
	2	3.16	16.84	26.56	1.30	49.49	203.1	4.1	16.97
	3	3.11	18.41	27.81	1.12	51.85	213.8	4.1	19.11
	4	3.24	15.42	27.66	1.18	48.98	211.0	4.3	17.33
	Mean	3.1	17.1	27.6	.9	49.8	210.8	4.2	18.0
Timothy (late)	1	2.79	14.33	28.68	.20	46.25	195.4	4.2	14.29
	2	2.52	13.91	27.98	1.49	47.76	204.7	4.3	15.65
	3	2.69	11.67	30.00	3.01	51.13	186.9	3.7	13.41
	4	3.71	14.10	28.68	2.57	52.27	217.9	4.2	15.50
	Mean	2.9	13.5	28.8	1.8	49.4	201.2	4.1	14.7

APPENDIX TABLE vi - Daily Intake of Digestible Nutrients for Individual Lambs by Period.

Forage Species	Lamb No.	Crude Protein gm.	Crude Fiber gm.	Cellulose gm.	N-free Extract gm.	Ether Extract gm.	Gross Energy K.Cals	Total Ash gm.	Dry Matter gm.
(a) Chopped Red Clover (early)	1	94	117.7	208.8	341.3	7.2	2.53	88.7	583.9
	2	98	121.6	199.1	324.1	2.2	2.47	83.9	579.8
	3	83	118.7	187.4	290.0	14.5	2.26	70.5	529.1
	4	62	94.0	138.5	194.9	1.8	1.60	61.2	355.8
	Mean	84	113	183	288	6	2.22	76	512
Red Clover (late)	1	99	146.5	208.0	270.1	8.0	2.33	81.7	557.8
	2	83	122.0	176.7	236.5	12.6	2.03	73.6	482.3
	3	71	128.0	171.7	198.9	7.6	1.87	64.2	422.2
	4	74	105.0	167.1	215.3	1.8	1.87	58.3	414.1
	Mean	82	125	181	230	8	2.03	69	469
Timothy (early)	1	27	122.9	138.9	227.2	1.3	1.72	44.0	393.0
	2	27	130.0	146.9	206.1	9.8	1.60	40.2	386.5
	3	34	133.9	154.9	198.3	-	1.58	45.1	389.1
	4	25	103.3	119.4	188.9	6.7	1.40	34.4	333.5
	Mean	28	123	140	205	4	1.58	41	376
Timothy (late)	1	18	114.7	125.0	239.2	-.9	1.66	38.6	379.5
	2	22	89.8	107.6	220.9	.2	1.42	41.3	346.6
	3	15	79.2	90.0	154.4	6.6	1.09	30.9	267.2
	4	24	98.6	121.5	236.5	1.0	1.55	40.7	370.1
	Mean	20	96	111	213	2	1.43	38.	341

/Appendix Table vi continued on following page.

APPENDIX TABLE vi (continued)

Forage Species	Lamb No.	Crude Protein gm.	Crude Fiber gm.	Cellulose gm.	N-free Extract gm.	Ether Extract gm.	Gross Energy K.Cals	Total Ash gm.	Dry Matter gm.
(b) Ground Red Clover (early)	1	130	186.7	259.8	431.0	16.8	3.44	126.0	807.1
	2	135	158.6	223.9	381.4	.7	3.14	115.2	718.3
	3	141	174.1	252.6	432.0	-2.9	3.48	129.7	784.5
	4	136	159.9	230.1	389.3	27.3	3.19	113.4	737.1
	Mean	136	170	242	408	11	3.31	121	762
Red Clover (late)	1	128	189.5	255.7	335.9	18.6	3.06	112.2	708.9
	2	97	183.0	230.1	292.3	10.4	2.66	88.1	613.5
	3	127	181.9	228.8	356.7	-1.0	2.94	107.9	700.6
	4	108	150.9	211.8	295.9	30.0	2.71	95.4	617.6
	Mean	115	176	232	320	15	2.84	101	660
Timothy (early)	1	37	227.3	237.9	364.0	-1.0	2.75	72.2	638.6
	2	38	202.1	203.6	318.8	10.0	2.44	71.4	585.0
	3	20	118.5	123.1	179.0	2.0	1.38	40.3	329.7
	4	33	156.3	175.7	280.4	2.8	2.14	65.5	487.6
	Mean	32	176	185	286	3	2.18	62	510
Timothy (late)	1	39	197.7	197.2	395.7	.8	2.70	75.9	653.8
	2	20	112.0	126.0	225.3	3.8	1.65	41.2	370.9
	3	31	136.1	156.4	350.0	16.3	2.18	62.4	553.5
	4	28	105.8	116.3	215.2	6.8	1.63	39.8	354.7
	Mean	30	138	149	297	7	2.04	55	483

APPENDIX TABLE viia - Calculation of Metabolizable Energy Values and Energy Balance for Individual Lambs - Chopped Forages (10 day basis)

Forage Species	Lamb No.	Av.Weight (lb) (over final 2 weeks)	Metab. Wt. (kg)	Maintenance* Requirement Met.Cals/lamb (10 days)	Total 10-Day Intake Data: Air Dry Feed (gms)	Dig. Calories (X)	Dig. Fiber (gm)	Dif. NFE (gm)	Total Dig. CHO (Y)	Total Dig. Protein (Z)	Energy lost in: Gas C=.452(Y) +183.85 (U)	Urine C=1.3(Z) (V)	Metab. Energy X-(U+V)	Metab. Energy per gm. A.D. forage	Energy Balance Met.Cals/Lamb/10 days
Red Clover (early)	1	59.5	11.85	14931	11854	25287	1176	3412	4588	940	2249	1222	21816	1.84	6885
	2	61.0	12.09	15237	10263	24673	1216	3241	4457	975	2190	1268	21215	2.07	5978
	3	57.0	11.48	14463	9602	22604	1186	2900	4086	825	2023	1073	19508	2.03	5045
	4	58.3	11.68	14715	8424	15985	940	1949	2889	620	1484	806	13695	1.63	-1020
	Mean	59.0		14837		22137							19059	1.89	4222
Red Clover (late)	1	61.3	12.13	15282	10628	23295	1466	2702	4168	993	2060	1291	19944	1.88	4662
	2	55.0	11.18	14085	9567	20253	1220	2365	3585	834	1797	1084	17372	1.82	3287
	3	56.5	11.41	14373	8655	18679	1279	1989	3268	709	1655	922	16102	1.86	1729
	4	57.0	11.48	14463	8298	18675	1051	2153	3204	738	1626	959	16090	1.94	1627
	Mean	57.5		14551		20226							17380	1.88	2829
Timothy (early)	1	60.8	12.05	15183	7146	17182	1229	2272	3501	272	1769	354	15059	2.11	-124
	2	62.8	12.35	15561	6784	15978	1300	2061	3361	267	1696	347	13935	2.05	-1626
	3	54.8	11.15	14049	6489	15792	1339	1983	3322	336	1679	437	13676	2.11	-373
	4	57.0	11.48	14463	5909	13972	1033	1889	2922	249	1499	324	12149	2.06	-2314
	Mean	58.9		14814		15731							13705	2.08	-1109
Timothy (late)	1	62.0	12.23	15408	7708	16642	1147	2391	3538	182	1611	237	14794	1.92	-614
	2	57.3	11.53	14526	7148	14152	898	2210	3108	222	1583	289	12280	1.72	-2246
	3	55.8	11.30	14238	5348	10866	791	1574	2365	150	1248	195	9618	1.80	-4620
	4	57.0	11.48	14463	7454	15541	986	2365	3351	237	1692	308	13541	1.82	-922
	Mean	58.0		14659		14300							12558	1.82	-2101

Met.Cals for maintenance $C = 1.8 \times 70 \times Wt_{kg}^{.75}$

APPENDIX TABLE viib - Calculation of Metabolizable Energy Values and Energy Balance for Individual Lambs - Ground Forages (10 day basis)

Forage Species	Lamb No.	Av.Weight (lb) (over final 2 weeks)	Metab. Wt. (kg)	Maintenance* Requirement Met.Cals/lamb (10 days)	Total 10-Day Intake Data: Air Dry Feed (gms)	Dig. Cals. (X)	Dig. Fiber (gm)	Dig. NFE (gm)	Total Dig. CHO (Y)	Total Dig. Protein (Z)	Energy lost in: Gas C=.452(Y) +183.85 (U)	Urine C=1.3(Z) (V)	Metab. Energy X-(U+V)	Metab. Energy per gm. A.D. forage	Energy Balance Met.Cals/ Lamb/10 days
Red Clover (early)	1	70.8	32.18	17019	16222	34395	1867	4310	6177	1297	2964	1686	29745	1.83	12726
	2	69.5	31.59	16785	14697	31398	1586	3814	5400	1345	2614	1749	27035	1.84	10250
	3	64.5	29.32	16245	16276	34801	1741	4321	6062	1408	2911	1830	30060	1.85	13815
	4	72.0	32.73	17253	14710	31915	1599	3893	5492	1358	2655	1765	27495	1.87	10242
	Mean	69.2		16808		33127							28583	1.85	11758
Red Clover (late)	1	77.5	35.23	18216	15351	30561	1895	3359	5254	1285	2548	1671	26342	1.72	8126
	2	66.5	30.23	16245	12533	26643	1830	2923	4753	975	2323	1268	23052	1.84	6807
	3	70.5	32.05	16974	15300	29363	1919	3567	5486	1271	2653	1652	25058	1.64	8084
	4	65.5	29.77	16065	13035	27057	1509	2960	4469	1075	2195	1398	23464	1.80	7399
	Mean	70.0		16875		28406							24479	1.75	7604
Timothy (early)	1	80.5	36.59	18747	12795	27542	2273	3640	5913	367	2845	477	24820	1.89	5473
	2	75.3	34.23	17838	12000	24380	2021	3187	5208	379	2528	493	21359	1.78	3521
	3	53.0	24.09	13734	6438	13764	1185	1790	2975	200	1523	260	11981	1.86	-1753
	4	63.3	28.77	15660	10136	21385	1563	2804	4367	328	1781	426	19178	1.89	3518
	Mean	68.0		16495		21768							19185	1.86	2690
Timothy (late)	1	84.3	38.32	19404	13800	26963	1978	3957	5935	385	2855	501	23607	1.71	4203
	2	65.3	29.68	16308	8052	16486	1121	2253	3374	203	1702	264	14520	1.80	-1788
	3	65.3	29.68	16029	11668	21786	1362	3500	4862	314	2372	408	19006	1.63	2977
	4	59.0	2682	14859	7402	16347	1057	2152	3209	278	1628	361	14358	1.94	-501
	Mean	68.5		16650		20396							17873	1.77	1223

*Met.Cals for maintenance $C = 1.8 \times 70 \times Wt_{kg}^{.75}$

ANALYSIS OF VARIANCE TABLES viii to xxv

TABLE viii - Voluntary Intake of Forages (gms/lamb/final week).

Source of Variation	D.F.	S.S.	M.S.	F	P.05	P.01
Forages	3	1097218	365739	36.4xx	3.49	5.95
Periods	6	271557	45260	4.5x	3.00	4.82
Lambs	6	321000	53500	5.3xx	3.00	4.82
Grinding	1	1863415	1863415	185.3xx	4.75	9.33
Grinding × Forage	3	34376	11459	1.14		
Error	12	120644	10054			
Total	31					

L.S.D. gms =

$= t \times \sqrt{\frac{2 \times 10054}{X}}$

$t_{.05} = 2.179 \quad t_{.01} = 3.055$

X =	16	8	4
P.05	77	109	154
P.01	108	153	217

X = number of items used to calculate each mean in the sets being compared.

TABLE ix - Increase in Feed Intake Due to Grinding (%)

Source of Variation	D.F.	S.S.	M.S.	F	P.05	P.01
Forages	3	349.8	116.6			
Periods	3	8653.4	2884.4	4.13	4.76	
Lambs	3	809.76	269.9	-		
Error	6	4182.5	697			
Total	15					

Nothing statistically significant.

TABLE x - Liveweight Gain (Average Two Week Gain - lbs.)

Source of Variation	D.F.	S.S.	M.S.	F	P.05	P.01
Forages	3	37.96	12.65	3.37*	3.49	5.95
Periods	6	17.60	2.93	.78	3.00	4.82
Lambs	6	5.60	.93	.25	3.00	4.82
Grinding	1	43.95	43.95	11.72xx	4.75	9.33
Grinding × Forage	3	3.27	1.09	.29	3.49	5.95
Error	12	44.99	3.75			
Total	31					

L.S.D. (lbs) =

$t \times \sqrt{\frac{2 \times 3.75}{X}}$

X =	16	8	4
P=.05	1.41	2.11	2.98
P=.01	1.98	2.96	4.18

* Approaches significance.

TABLE xi - Water Consumption (c.c. consumed daily/lamb during final week.

Source of Variation	D.F.	S.S.	M.S.	F	P.05	P.01
Forages	3	14653881	4884627	34.8xx	3.49	5.92
Periods	6	1037175	172863	1.23	3.00	4.82
Lambs	6	3354523	559087	3.98	3.00	4.82
Grinding	1	21829527	21829527	155.5xx	4.75	9.33
Grinding × Forage	3	997934	332645	2.37	3.49	5.95
Error	12	1684515	140376			
Total	31					

L.S.D. (c.c.) =

$$t\sqrt{\frac{2 \times 140376}{X}}$$

X =	16	8	4
P=.05	289	407	577
P=.01	405	571	810

t.05 = 2.179 t.01 =3.055

TABLE xii - Water:Feed Ratio (c.c./gms - final week of each period).

Source of Variation	D.F.	S.S.	M.S.	F	P.05	P.01
Forages	3	.64	.21	1.0		
Periods	6	4.68	.78	3.5x	3.00	4.82
Lambs	6	2.84	.47	2.1		
Grinding	1	1.24	1.24	5.6x	4.75	9.33
Grinding × Forage	3	.01	.003			
Error	12	2.68	.22			
Total	31					

[1] L.S.D. for comparing effect of grinding within each forage)5% level .72
)1% level 1.01
[2] L.S.D. " " overall effect of ")5% level .36
)1% level .51

L.S.D. $t\sqrt{\frac{2 \times .22}{X}}$ (where X = 4[1] or 16[2] respectively)

t.05 = 2.179 t.01 = 3.055

TABLE xiii - Water:Dig. Cals Ratio (c.c./Cal - 10 day collection period)

Source of Variation	D.F.	S.S.	M.S.	F	P.05	P.01
Forages	3	.2020	.067	.89		
Periods	6	1.0731	.179	2.36		
Lambs	6	.6771	.113	1.49		
Grinding	1	.7781	.778	10.28xx	4.75	9.33
Grinding × Forage	3	.0524	.018			
Error	12	.9083	.076			
Total	31					

L.S.D. for comparing effect of grinding within each forage)5% level .42
)1% level .59

L.S.D. for comparing overall effect of grinding; 5% level =.21; 1% level =.30

TABLE xiv - Salt Consumption as percent of Feed Consumption.

Source of Variation	D.F.	S.S.	M.S.	F	P.05	P.01
Forages	3	4.27	1.42	1.5	3.49	
Periods	6	6.43	1.07	1.1	3.00	
Lambs	6	18.90	3.15	3.3^{x}	3.00	4.82
Grinding	1	4.84	4.84	5.1^{x}	4.75	9.33
Grinding × Forage	3	1.47	.49	.5	3.49	
Error	12	11.38	.95			
Total	31					

L.S.D. for comparing effect of grinding	P.05
-with in each forage	1.50%
overall average	.75%

TABLE xv - Water Content of Feces.

Source of Variation	D.F.	S.S.	M.S.	F	P.05	P.01
Forages	3	274.7	91.6	15.5^{xx}	3.49	5.95
Periods	6	253.3	42.2	7.2^{xx}	3.00	4.82
Lambs	6	105.2	17.5	3.0^{x}	3.00	4.82
Grinding	1	159.9	159.9	27.1^{xx}	4.75	9.33
Grinding × Forage	3	12.9	4.3	.7		
Error	12	70.2	5.9			
Total	31					

$$\text{L.S.D.}(\%) = t\sqrt{\frac{2 \times 5.9}{X}}$$

t.05 = 2.179   t.01 = 3.055

X =	16	8	4
P.05	1.87	2.65	3.74
P.01	2.62	3.71	5.25

TABLE xvi - Digestibility of Dry Matter (%)

Source of Variation	D.F.	S.S.	M.S.	F	P.05	P.01
Forages	3	120.3	40.1	5.94^{xx}	3.49	5.95
Periods	6	56.7	9.5	1.40	3.00	4.82
Lambs	6	42.9	7.2	1.06	3.00	4.82
Grinding	1	111.0	111.0	16.46^{xx}	4.75	9.33
Grinding × Forage	3	48.2	16.1	2.38	3.49	5.95
Error	12	80.9	6.7			
Total	31					

$$\text{L.S.D. }\% = t \times \sqrt{\frac{2 \times 6.74}{X}}$$

t.05 = 2.179   t.01 = 3.055

X =	16	8	4
P.05	2.0	2.8	4.0
P.01	2.8	4.0	5.6

TABLE xvii - Digestibility of Energy (%).

Source of Variation	D.F.	S.S.	M.S.	F.	P.05	P.01
Forages	3	139.6	46.5	6.8xx	3.49	5.95
Periods	6	43.6	7.3	1.1	3.00	4.82
Lambs	6	26.3	4.4	.6	3.00	4.82
Grinding	1	66.7	66.7	9.8xx	4.75	9.33
Grinding × Forage	3	35.5	11.8	1.7	3.49	5.95
Error	12	82.0	6.8			
Total	31					

$$L.S.D.\% = t\sqrt{\frac{2\times 6.8}{X}}$$

$t.05 = 2.179 \quad t.01 = 3.055$

X =	16	8	4
P.05	2.0	2.8	4.0
P.01	2.8	4.0	5.6

TABLE xviii - Digestibility of Crude Protein (%).

Source of Variation	D.F.	S.S.	M.S.	F	P.05	P.01
Forages	3	628.1	309.4	30.8	3.49	5.95
Periods	6	109.5	18.3			
Lambs	6	72.6	12.1			
Grinding	1	64.7	64.7	6.44x	4.75	9.33
Grinding × Forage	3	147.5	49.2	4.92x	3.49	5.95
Error	12	120.5	10.0			
Total	31					

The interaction "Grinding × Forage" is significant. Hence we must re-analyse using the M.S. for interaction as our error term to test the effect of forage and grinding.

	D.F.	M.S.	F	P.05 (3 D.F.)
Forage	3	309.4	6.29	9.28
Grinding	1	64.7		
For × Gr.	3	49.2		

Thus neither Forage or Grinding in themselves are significant sources of variation.

TABLE xix. Digestibility of Crude Fiber (%)

Source of Variation	D.F.	S.S.	M.S.	F	P.05	P.01
Forages	3	820.5	373.5	26.1xx	3.49	5.95
Periods	6	83.9	14.0	1.3	3.00	
Lambs	6	132.5	22.1	2.1	3.00	
Grinding	1	130.8	130.8	12.5xx	4.75	9.33
Grinding × Forage	3	44.6	14.9	1.4	3.49	
Error	12	125.5	10.5			
Total	31					

$$L.S.D.\% = t\sqrt{\frac{2 \times 10.5}{X}}$$

X =	16	8	4
P.05	2.5	3.5	5.0
P.01	3.5	4.9	7.0

t.05 = 2.179   t.01 = 3.055

TABLE xxa - Digestibility of Cellulose (%).

Source of Variation	D.F.	S.S.	M.S.	F	P.05	P.01
Forages	3	451.8	150.6	14.5xx	3.49	5.95
Periods	6	75.6	12.6	1.2	3.00	
Lambs	6	48.9	8.1	.8	3.00	
Grinding	1	426.3	426.3	41.0xx	4.75	9.33
Grinding × Forage	3	29.2	9.7	.9	3.49	
Error	12	124.3	10.4			
Total	31					

$$L.S.D.\% = t\sqrt{\frac{2 \times 10.4}{X}}$$

X =	16	8	4
P.05	2.5	3.5	5.0
P.01	3.5	4.9	7.0

t.05 = 2.179   t.01 = 3.055

TABLE xxb - Recalculation of Analysis of Variance of Factors Influencing Cellulose Digestibility in which the D.F. for Forage are Split to Determine Effect of Species and Stage of Maturity.

Source of Variation	D.F.	S.S.	M.S.	F.	P.05	P.01
Species	1	35.2	35.2	3.4	4.75	9.33
Stage of Maturity	1	166.9	166.9	16.0xx	4.75	9.33
"Species × Stage"	1	249.7	249.7	24.0xx	4.75	9.33

Ditto as above
Table xxa   Using error of Table xxa

TABLE xxi - Digestibility of Nitrogen-free Extract (%).

Source of Variation	D.F.	S.S.	M.S.	F	P.05	P.01
Forages	3	118.4	39.5	5.74x	3.49	5.95
Periods	6	53.1	8.9	1.29	3.00	
Lambs	6	17.6	2.9	.4	3.00	
Grinding	1	114.4	114.4	18.8xx	4.75	9.33
Grinding × Forage	3	28.1	9.4	1.4	3.49	
Error	12	82.6	6.9			
Total	31					

$$\text{L.S.D.\%} = t\sqrt{\frac{2 \times 6.9}{X}}$$

t.05 = 2.179 t.01 = 3.055

X =	16	8	4
P.05	2.0	2.9	4.0
P.01	2.8	4.0	5.7

TABLE xxii - Intake of Digestible Calories (K.Cals / day).

Source of Variation	D.F.	S.S.	M.S.	F	P.05	P.01
Forages	3	5.548	1.85	26.8xx	3.49	5.95
Periods	6	.767	.13	1.9	3.00	
Lambs	6	1.329	.22	3.1x	3.00	4.82
Grinding	1	4.891	4.89	70.9xx	4.75	9.33
Grinding × Forage	3	.325	.11	1.6	3.49	5.95
Error	12	.831	.07			
Total	31					

$$\text{L.S.D.(KCals)} = t\sqrt{\frac{2 \times .07}{X}}$$

t.05 = 2.179 t.01 = 3.055

X =	16	8	4
P.05	.20	.29	.40
P.01	.28	.40	.57

TABLE xxiii - Intake of Digestible Protein (gms/lamb/day).

Source of Variation	D.F.	S.S.	M.S.	F	P.05	P.01
Forages	3	47774	15925	265		5.95
Periods	6	1054	176	3x	3.0	
Lambs	6	715	119	2	3.0	
Grinding	1	4802	4802	80	4.75	9.33
Grinding × Forage	3	2880	960	16xx	3.49	5.95
Error	12	721	60			
Total	31					

	D.F.	M.S.	F	P.05	P.01
Forages	3	15925	16.6x	9.28	29.41
Grinding	1	4802	5.0		
Gr × For.	3	960			

$$\text{L.S.D.} \quad t.05(3.182)\sqrt{\frac{2 \times 960}{4}} = \underline{\underline{69}} \text{ gms/day}$$

TABLE xxiv - Nitrogen Retention (Expressed as grams protein retained daily per lamb).

Source of Variation	D.F.	S.S.	M.S.	F	P.05	P.01
Forages	3	5314	1771	59^{xx}		5.95
Periods	6	347	58	2		
Lambs	6	365	61	2		
Grinding	1	2002	2002	67^{xx}		9.33
Forage × Grinding	3	798	266	9^{xx}		5.95
Error	12	354	30			
Total	31					

	D.F.	M.S.	F	P.05
Forage	3	1771	6.66	9.3
Grinding	1	2002	7.53	10.1
Gr × For.	3	266		

TABLE xxv - Analysis of Variance in Partial Regression and Multiple Correlation,- the relationship of voluntary intake to the crude protein, crude fiber and N.F.E. composition, and the effect of lambs weight.

Source of Variation	D.F.	S.S.	M.S.	F	P.05	P.01
(a) Chopped Forages						
Regression	4	405805	101451	13.4^{xx}	3.06	4.89
Deviation from Reg.	11	83116	7556			
Total	15	488922				
$R = .91$ $R^2 = .83$						
(b) Ground Forages						
Regression	4	1304271	326068	24^{xx}	3.06	4.89
Deviation from Reg.	11	144919	13174			
Total	15	1449190				
$R = .95$ $R^2 = .90$						

^{xx}Highly significant ($P < .01$).

NOTE: Total S.S. = Sum of Squares for Voluntary Intake ($\sum x^2$)

Regression S.S. = $R^2(\sum x^2)$

Dev. from Reg. S.S. = $1 - R^2 (\sum x^2)$