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LINEAR MODELS FOR ESTIMATING THE
NUTRITIVE VALUE OF SHEEP DIETS

by

Michael L. Christiansen

A thesis submitted in partial fulfillment
of the requirements for the degree

of

MASTER OF SCIENCE

in

Animal Science
(Animal Nutrition)

Approved:

UTAH STATE UNIVERSITY
Logan, Utah

1979

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This thesis is dedicated to my parents to whom I will always be grateful for teaching me the value of work.

Michael L. Christiansen

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ABSTRACT

Linear Models for Estimating the
Nutritive Value of Sheep Diets

by

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Utah State Univeristy, 1979Major Professor: Lorin E. Harris
Department: Animal Science

Digestibility data were determined in 2 replications of a 2 x 3 x 2 x 2 factorial arranged experiment to: (1) determine the effects of forage type (grass vs alfalfa), forage maturity (late vegetative vs midbloom vs fullbloom), diet ingredients (forage only vs 50:50 forage plus corn), and diet texture (coarsely chopped vs pelleted) on the digestibility of diet chemical constituents by sheep; (2) develop equations to estimate digestible energy of sheep diets from nutrient content of the diet; and (3) compare popular chemical methods used to partition feed dry matter into fibrous and soluble components. Diets were fed to growing wether lambs. Crude protein (CP) and available carbohydrates (AC) of diets were nearly 100% digestible (true digestibility) regardless of diet source. However, the apparent digestibility of CP and AC varied significantly with concentration of these components in the diet. Apparent digestibility of cellulose (CL) was significantly different between grass and alfalfa, early and late maturity stages, and coarse and pelleted diet textures. Interactions between

forage type and stage of maturity and between stage of maturity and energy level also significantly altered the apparent digestibility of all diet fibrous constituents except hemicellulose (HC). An energy level-by-diet texture interaction significantly affected the apparent digestibility of HC, CL, CW, NDF, ADF and CF. Simple (equation 1) and complex (equation 2) models were generated for estimating nutrient digestible amounts (Y_N) or diet digestible energy (DE) (Y_N) from nutrient content (X_N) of the diet. Complex models were developed to adjust the estimation of the nutrient digestible amount or DE estimations for effects due to forage type (α_i), stage of maturity (β_j), feed combination (γ_k) and texture (δ_l). Two-way interactions ($\alpha\beta_{ij}$, $\beta\gamma_k$, . . . , $\gamma\delta_{kl}$) between qualitative variables were added in the equations when significant. Interactions between qualitative variables and the quantitative variable ($\alpha_i X_{i1}$, $\beta_j X_{j1}$, $\gamma_k X_{k1}$, $\delta_l X_{l1}$, $\alpha\beta_{ij} X_{ij}$, etc) were also tried but did not significantly change the precision of the equations. Complex models gave significantly better estimates of digestible CP, AC, total lipid (TL), HC, CL, CW, NDF, ADR or CF and DE than simpler models. DE in the diets was determined by two methods: First, DE was estimated by the summation of the predicted decimal fraction of digested protein, carbohydrates, and lipids times respective caloric values (Mcal/kg) (equation 3). DE was also estimated directly from CL, CW, NDF, ADF, or CF content in the diet. Both approaches gave comparably precise estimations of diet DE when complex models were used. The CF

$$(1) Y_N = b_0 + b_1 X_N$$

$$(2) Y_N = b_0 + b_1 X_N + \alpha_i + \beta_j + \gamma_k + \delta_l + \alpha\beta_{ij} + \dots + \gamma\delta_{kl}$$

$$(3) DE = 5.65 (Y_{CP}) + 4.15 (Y_{AC} + Y_{HC} + Y_{CL}) + 9.40 (Y_{TL})$$

simple model gave poorer estimates of DE ($R^2 = .56$) than CL, CW, NDF, and ADF simple models ($R^2 = .69, .69, .71, \text{ and } .71$ respectively).

Added indicator variables compensated for differences between CF and other chemical parameters. CL, CW, NDF, ADF, and CF complex models were similar in estimation of DE (average $R^2 = .89$ for DE complex models). Complex models could be effectively used in a computer program for balancing rations for sheep. Additional experiments should be conducted to provide added information for comparison.

(122 pages)

INTRODUCTION

Chemical analysis in combination with digestion trials has been an effective way of determining the nutritive value of livestock feeds. Numerous tables have been published containing nutrient digestibility information on a variety of feeds used in animal production. Tabulated values, however, are average values only and may vary considerably from the actual digestibility value of a specific lot of feed. For this reason, researchers have sought accurate regression models as a means of rapidly estimating the digestibility of feeds. Though conducting digestion trials is the most direct and accurate way to determine feed digestibility, digestion trials are also costly and time consuming and therefore are not practical for routine feed evaluation.

Schneider et al. (1951) developed regression equations which made adjustments to average digestion coefficients within feeds according to differences in proximate chemical composition. The variation between average digestion coefficients and actual digestibility values was reduced by 25 to 45% when chemical composition differences were considered.

Schneider et al. (1952) also developed regression equations for predicting feed digestibility from proximate composition between feed types when no digestibility data were available. Considerably more variation was involved when predicting digestibility between feeds than within feeds. Schneider et al. (1950) reported that variations in the proximate composition accounted for less than half of the between-feed variance in digestibility.

Much of the variation connected with earlier regression models could be blamed on inaccuracies in chemical techniques alone. Research has shown that crude fiber procedures mispartition partially digestible and readily digestible plant carbohydrates. Plant lignin is likewise mispartitioned between partially digestible and readily digestible fractions. The extent of this mispartitioning has been shown to be highly variable between feed types.

Van Soest, in the 1960's, introduced a new approach to chemical partitioning of livestock feed by attempting to separate forage dry matter into plant cell walls and cell contents using a neutral detergent digest (Van Soest, 1963a). Digestion trials together with regression analysis indicate this approach to be more accurate than the crude fiber procedure in determining total feed fiber.

Fonnesbeck and Harris (1970a) have modified the Van Soest procedures (pre-pepsin digestion and a detergent solution at pH 3.5) so that in addition to forages, high energy feeds and protein supplements could be analyzed by detergent techniques.

Fonnesbeck (1976) has developed highly precise regression models using new chemical parameters for estimating digestible energy in sheep, swine, rabbit and rat diets.

Previous research using improved chemical methods by Fonnesbeck and Harris was conducted using experimental diets formulated to give specific cell wall and cell content values. This study was conducted to gather biological and chemical data on common livestock feeds.

The main objectives of this research were to:

Determine differences in the digestibility of diet chemical constituents due to forage type, forage maturity, associative effects, and

diet texture.

Develop regression models for estimating the nutritive value of sheep diets from chemical compositional data.

Compare chemical methods used to partition feed dry matter into fiber and soluble residues.

REVIEW OF LITERATURE

Chemical Analysis of Animal FeedsThe Proximate Analysis system

Historically, the Proximate System for separating animal feeds into components of crude fiber (CF), nitrogen-free-extract (NFE), crude protein (CP), ether extract (EE) and ash was developed by Henneberg and Stohmann in Weende, Germany, 1860. Though these early scientists are often credited for the methodology of the proximate analysis, the procedures used were actually a combination of earlier ideas of Liebig regarding division of food into carbohydrates, proteins, and fats with those of Einhoff regarding fiber as a special kind of carbohydrate (Henneberg and Stohmann, 1860, 1864). However, Henneberg and Stohmann should be recognized for perfecting known chemical methods and combining them into a system for routine feed analysis (Henneberg and Stohmann, 1860 and 1864).

Following its proposal, the proximate approach grew rapidly in popularity. In 1891, the Association of Official Agricultural Chemists adopted the Proximate Analysis as an approved scheme for partitioning feed dry matter. Early animal scientists such as Henry, author of Feeds and Feedings, were instrumental in promoting the proximate technique into extensive application soon after its adoption (Henry, 1898).

Even though the Proximate Analysis has been widely accepted throughout the world, its limitations should not be overlooked.

Theoretically, crude fiber contains the less digestible portion of the plant, namely cellulose, hemicellulose, and lignin. Nitrogen-free-extract calculated as $100 - (CF\% + CP\% + EE\% + ASH\%)$ is thought to contain the readily available carbohydrate fraction. However, animal experiments have given contradictory digestion data, where crude fiber is more digestible than NFE. Digestion coefficients calculated by Woodman (1930) for grass herbage fed to sheep, showed crude fiber having a greater digestibility than NFE and CP. A table published by Crampton and Maynard (1938) listed four feed types with the percentage of cases where the digestibilities of crude fiber were equal to or greater than those of nitrogen-free-extract: Dry feed (30%), succulent feed (20%), silage (28%), and concentrates (10%). Additional evidence showing the crude fiber and nitrogen-free-extract contradiction can be found in feed tables published by Morrison (1956). Twenty to 33% of the feeds listed show the digestibility of nitrogen-free-extract to be less than crude fiber.

The reason for the crude fiber and nitrogen-free-extract problem can be found by evaluating the effects of the acid and alkaline reagents used to determine crude fiber. Norman's (1935) study using bran, maize and bean straw revealed crude fiber to be almost exclusively of cellulose and lignin. Cellulose recovery was 60-80%, while that for lignin was highly variable, 4-67%. From comparisons of residue composition at different analytical stages, it was shown that lignin losses were brought about by the sodium hydroxide treatment. Hemicellulose was also lost due to the sulfuric acid hydrolysis. These findings were supported by Bondi and Myer (1943). They found that large percentages of pentosans (hemicellulose) and lignin were

extracted into the nitrogen-free-extract portion in both feed and feces, while most of the hexoses (cellulose) remained in the crude fiber fraction. Stallcup (1958) reported crude fiber lignin recovery for various grass and legume roughages was highly variable, a range of 18.35 - 70.98%. Cellulose recovery range was much smaller, 70.41 - 97.72%.

Grasses as a whole contain more plant cell walls and less lignin than legumes. Eighty to 86% of the hemicellulose or pentosans is soluble in weak acid or alkali, while 60-80% of the lignin is dissolved by alkali (Armstrong *et al.*, 1950; Kim *et al.*, 1967). Cereal seeds and brans have a high hemicellulose content, consequently, crude fiber recovers only 20-30% of the cell wall. Recovery in graminaceous roughages is 40-60%. Legumes are proportionately lower in hemicelluloses and lignin solubility in alkali is low, therefore, recovery of the cell wall as crude fiber is 60-80% (VanSoest, 1974).

Many other references of acid-alkali mispartitioning of important plant fiber components (hemicellulose and lignin) could be cited. However, the given examples are sufficient to demonstrate that large digestibility variations may arise between crude fiber and nitrogen-free-extract digestion coefficients.

Since it's implementation, scientists have sought alternatives to the crude fiber approach (Crampton and Maynard, 1938; Crampton and Whiting, 1943; Matrone *et al.*, 1946; Ely and Moore, 1954; Walker, 1959). However, a suitable replacement has been slow in coming. A substitute must not only be superior in partitioning of plant dry matter, but it must also be of comparable simplicity in operation. These two criteria have been difficult to meet.

Some researchers have suggested using a singular chemical entity like cellulose or lignin in hopes of reducing analytical time in isolating a fraction highly correlated with digestibility whose composition is comparable between feed types (Phillips and Smith, 1943; Sullivan, 1964). However, chemical isolation of a uniform fraction by simple laboratory techniques has also been an illusive goal to reach. Several attempts at using cellulose as a digestibility predictor have shown it no better than crude fiber (Lancaster, 1943; Walker and Hepburn, 1955; Sullivan, 1964). This is due mainly to the large digestibility variation as a result of improper removal of hemicellulose and lignin from the cellulose fraction (Norman and Jenkins, 1933; Matrone et al., 1946; Sullivan, 1955).

Lignin has shown some promise as an indicator in estimating digestibility (Lancaster, 1943; Sullivan 1955; Sullivan, 1964). However, chemical isolation of a uniform lignin fraction has also proven to be difficult. Contamination of lignin with protein and carbohydrate residues has resulted in large lignin variations within and between feed types (Norman and Jenkin, 1934; Ellis et al., 1946; Harwood, 1954; Sullivan, 1955). In addition to the analytical problem, the feed sample drying process can also contribute to lignin contamination. The nonenzymatic browning reaction produces acid insoluble artifacts in lignin at temperatures above 50° C (Van Soest, 1962).

Additional research has shown strong interactions between plant components (i.e. cellulose, hemicellulose, and lignin) suggesting that the digestion of a single chemical component is not sufficient to explain all the variability in feed digestibility (Van Soest, 1967).

Most of the literature evaluation of the proximate analysis has been directed towards the crude fiber determination. However, a critique of the proximate scheme would not be complete without mention of the ether extraction of feed lipids.

Ether extract theoretically contains the digestible lipid portion of a feed sample. A critical evaluation, however, reveals error in this thinking. Nonnutritive lipids such as waxes, sterols, pigments (i.e. chlorophyll), and essential oils are also extracted in combination with nutritive lipids by ether solvent (Fraps and Rather, 1912; Cook et al., 1952; Crampton and Harris, 1969; Roberts et al., 1963). Ethyl ether also does not extract all the digestible lipids of plants. Many lipids are bonded to proteins with water molecules involved in the union. Lipids are released from the lipoprotein molecule only if a dehydrating agent such as acetone, methanol or ethanol ruptures the linkage (Hanahan, 1960). The ratio of nondigestible lipids to digestible lipids is highly variable among feeds. When the quantity of the nutrient portion is low compared to the indigestible portion, extreme error in the calculation of ether extract digestibility occurs.

The ether extract analysis probably has not been emphasized by most researchers because the ether extract content of most feeds is relatively small compared to other feed components, i.e. carbohydrates and proteins.

Logic suggests that a chemical scheme can be a valuable tool in determining the nutrient value of feeds if it is capable of separating feed components along nutritive and nonnutritive lines. A review of the popular proximate analysis has revealed critical weaknesses in its ability to accurately partition feed dry matter. To further the

advancement towards accurately evaluating nutritional quality of all feeds, a replacement for the Weende method should be found.

Van Soest's detergent procedures

The use of detergents for extracting protein from plant cell wall constituents has proven to be an improvement over the harsher acid and alkaline treatments of the crude fiber analysis.

Foster et al. in 1950 obtained an 85-90% protein extraction from corn by using a detergent solution of alkyl benzene sodium sulfonate plus a reducing agent, bisulfite. Foster et al. (1950), however, made no mention of detergent effects on the plant fiber. In a 1956 review on hemicellulose chemistry, Williams and Benvue pointed out that detergents could be used in ridding carbohydrate fibrous residues of protein without appreciable losses in plant fiber. Benvue and Williams in 1959 published experimental results showing effective protein removal by detergents from bean and pea fiber. It was shown that non-ionic detergents were not effective for protein extraction. However, 92-95% extraction of nitrogen constituents was accomplished by using an alkylaryl sulfonate sodium sulfonate detergent solution. Only a trace of hemicellulose loss was observed. In 1963, Van Soest proposed that detergents could be used in the routine analysis of feeding stuffs (Van Soest, 1963a,b). Chemical and nutritional data has supported this proposal.

From experiments conducted using alfalfa and grass forages, Van Soest showed that a chemical digestion using a 3% buffered solution, neutral or slightly alkaline (pH 7.4 - 7.0), of sodium lauryl sulfate detergent yields a low protein fiber residue (Van Soest, 1963a;

Van Soest and Wine, 1967). Tests also have suggested that sodium sulfite be added for increased protein removal (Van Soest and Wine, 1967).

The partitioning of plant dry matter into neutral detergent fiber (NDF) and neutral detergent solubles (NDS) has been presented as an accurate separation between cell wall constituents (cellulose, hemicellulose and lignin) and the readily soluble portion contained within the plant cell (lipids, sugars, organic acids, nonprotein nitrogen, pectins, soluble proteins, etc.) (Van Soest, 1963a; Van Soest and Marcus, 1964; Van Soest and Morre, 1965; Van Soest, 1965a). The validity of this partitioning has been supported by animal digestion trials together with chemical and regression analysis (Van Soest and Moore, 1965; Van Soest, 1965b; Van Soest *et al.*, 1966). Studies involving the Lucas test (Lucas *et al.*, 1961), where NDS% content is regressed against NDS% digestible amount, have shown that the NDS fraction is chemically uniform, $R = .99$ (Van Soest and Moore, 1965; Van Soest, 1967; Fonnesebeck, 1969). The slope of the regression line also was nearly 1, giving evidence for the idea that NDS represents that part of the plant readily absorbed by the animal's digestive tract regardless of the feed type (Van Soest and Moore, 1965; Van Soest, 1967; Fonnesebeck, 1969).

In addition to the neutral detergent separation, Van Soest (1963b) has suggested that plant fiber can be prepared for a lignin determination by using an acid detergent digest (1N sulfuric acid plus 2% cetyltrimethyl ammonium bromide). The acid detergent fiber (ADF) residue is composed primarily of lignocellulose since most of the protein and hemicellulose is removed by the acidic detergent (Van

Soest, 1963b; Van Soest, 1965a; Colburn & Evans, 1967). This extraction is thought to reduce the probability of high lignin values due to protein and carbohydrate artifacts (Van Soest, 1963b; Van Soest, 1965a; Van Soest and Moore, 1965). Lignin is determined by a 72% sulfuric acid digest followed by ashing (Van Soest, 1963b; Van Soest and Moore, 1965). A potassium permanganate digest of ADF has also proven useful in calculating lignin percents (Van Soest and Wine, 1968).

The percentages of the individual carbohydrate components of the cell wall, namely cellulose and hemicellulose, can be calculated by difference (Keys and Van Soest, 1970; Van Soest and McQueens, 1973). Hemicellulose is calculated by NDF% minus ADF% and percent cellulose by ADF% minus Lignin%. However, accuracy of these calculations is varied depending upon hemicellulose and protein residue in NDF and ADF.

Studies show that ADF does retain residual protein and hemicellulose. The amount differing with feed type (Kim, 1967; Colburn and Evans, 1967). Some studies have shown ADF hemicellulose recovery to be around 14-16% and protein recovery from 5-16% (Colburn and Evans, 1967; Kim et al., 1967).

An evaluation of the literature has shown Van Soest's detergent procedures to be a marked improvement over the crude fiber analysis in partitioning plant dry matter of forages. Cell wall constituents are separated from soluble cell contents in forages without significant mispartitioning as has been shown between crude fiber and nitrogen-free-extract.

Improved feed analysis

Fonnesbeck and Harris (1970a,b) have proposed a revised chemical system for partitioning plant dry matter that shows certain advantages over the Van Soest system of analysis.

Neutral detergent procedures by Van Soest (1963a) have been used to dissolve forage protein while separating forage plant material into cell walls and cell contents. However, studies show NDF to retain a considerable amount of protein. Colburn and Evans (1967) have shown NDF to retain up to 30% of the sample protein. Several NDF analyses reported by Van Soest (IFI Data bank) contained over 50% of the protein. This protein residue is usually counted as NDF and could result in significantly high cell wall estimates for high protein feeds. Filtering problems during the washing of NDF for protein supplements, energy feeds, mixed diets containing these ingredients, and feces from animals eating these diets have also been observed. (Van Soest, 1966b; Martin et al., 1975; Robertson and Van Soest, 1977; P.V. Fonnesbeck, unpublished data, Rutgers University and Utah State University).

NDF obtained from samples exhibiting filtering problems usually give higher results than expected. These analysis problems as mentioned, prompted studies by Fonnesbeck and Harris (1970a) to improve chemical procedures so all classes of feed could be accurately analyzed for cell walls and cell contents by the same procedure.

Fonnesbeck and Harris (1970a) have recommended a 24 hour preliminary pepsin digest prior to the sodium lauryl sulfate reflux to rid cell walls of residual protein. Studies conducted using high protein samples of alfalfa leaf meal and alfalfa hay showed that detergent alone removes only 66% of the sample protein. The addition of the pepsin

step increased the removal of protein residue and also helped overcome filtering problems experienced in analyzing energy feeds and protein supplements. Additional forage, energy and protein supplements, and foods were analyzed by the pepsin-detergent method resulting in high protein removal (91-97%) and more precise cell wall values.

Tests were conducted by Fannesbeck and Harris (1970a) showing a sodium lauryl sulfate pH change from 7.0 to 3.5 was needed for maximum recovery of cell walls constituents. Barley straw was chosen to represent more mature cell walls and Kenturcky Blue Grass, early vegetative, was used to represent younger growing cell walls. Detergent cell wall samples were determined over a pH range of 1 to 10. Maximum cell wall recovery was shown to occur at a pH of 3 to 4. A pH of 3.5 was chosen as a compromise for the pH values determined. Additional studies on alfalfa samples using the pepsin digest plus the detergent at pH 3.5 and pH 7.0 showed effective protein removal and a higher cell wall recovery at pH 3.5.

Van Soest and Wine (1967) suggested that a 2-3% sodium lauryl sulfate detergent concentration is sufficient for proper cell wall extraction. This decision was based partly on preliminary experimental results (Van Soest, 1963a; Van Soest and Wine, 1967). Results by Fannesbeck and Harris (1970a) have supported this proposal by showing that sodium lauryl sulfate concentrations ranging from 1.5-3% are adequate for plant cell wall determinations.

Van Soest and Wine (1967) also recommended a one hour detergent reflux for NDF determinations. They observed no appreciable reduction in NDF recovery for a reflux between 30-90 minutes. A one hour

refluxing was chosen in terms of economy of time, laboratory convenience and extent of sample extraction (Van Soest and Wine, 1967).

Studies by Fannesbeck and Harris (1970a) showed that significant reductions occur in cell wall recovery with increasing reflux time. Their studies involved reflux times of 0.5, 1.0, 2.0, and 4.0 hours. A one hour reflux was chosen as a compromise between high cell wall recovery and high protein solubilization.

Further quantitative partitioning of plant cell walls into fractions of cellulose, hemicellulose, lignin, and acid insoluble ash has been suggested by Fannesbeck and Harris (1970b) and Fannesbeck (1976). They have shown that a 4% sulfuric acid reflux for one hour is effective in separating hemicellulose from the cell wall residue. The cellulose portion of cell walls is determined by difference following a 3 hour 72% sulfuric acid digest of the 4% sulfuric acid residue. The lignin component of plant cell walls is calculated by difference after the 72% sulfuric acid residue has been ashed. The recovered ash is termed acid insoluble ash. Acid insoluble ash represents that portion of the total feed ash not absorbed by the animal's digestive tract, primarily silica. The nutritive ash portion, soluble ash, is therefore calculated by subtracting acid insoluble ash from the total ash value.

Modifications to Van Soest's 72% sulfuric acid lignin techniques (top filling, draining and stirring of the residue) were introduced by Fannesbeck and Harris (1970b) to solve filtering problems when digesting and washing the 72% sulfuric acid residue. Filtering difficulties were alleviated by eliminating the stirring of the acid and residue altogether. Instead, the lignocellulose containing

crucibles were set into beakers of acid, allowing the acid to seep up slowly through the fritted disc and wet the fibrous residue.

As has been previously pointed out in discussing the proximate analysis, ethyl ether extraction of feed lipids underestimates the total lipids of feeds but overestimates the nutritive lipid of feeds due to the contaminating nonnutritive components extracted by ethyl ether. Fannesbeck and Harris (1974) have modified the Blyth and Dyer (1959) solvent system (2:1, chloroform to methanol) to extract total lipids. The lipid extraction is nearly complete and contains both nutritive and nonnutritive lipid components. The solvent extract or total lipid fraction is then washed through a silica acid column using a 1:3 ether-hexane solution. Nearly all the nutritive lipids are separated from the nonnutritive portion. Phospholipids are not included in the nutritive fraction due to the solvent concentrations. Adjustments could be made to recover them, but some nonnutritive lipids would escape to contaminate the nutritive portion; therefore, the 1:3 ether-hexane ratio is preferred.

Following the determination of total lipids, further partitioning of plant dry matter is possible by calculation only. The quantity of available carbohydrates or carbohydrates readily digested by enzymes produced by an animal's digestive tract is calculated as cell contents minus crude protein minus total lipids minus soluble ash (Fannesbeck, 1976).

Chemical procedures by Fannesbeck and Harris (1970 a,b) have shown an improvement over the NDF procedure by reducing the residual protein in cell walls and by increasing the recovery of cell wall, hemicellulose, lignin and ash. The improved procedures can also be

used in analyzing energy and protein feeds, as well as fibrous feeds without the filtering difficulties shown by the NDF method. The additional partitioning of plant material into more simplified components of cellulose hemicellulose, lignin, acid insoluble ash, soluble ash, and available carbohydrates by simplified laboratory methods has also been shown by Fannesbeck and Harris (1970a,b; 1974). However, further research is needed to determine the accuracy of these proposed empirical analytical methods.

Factors That Affect Feed Digestibility

Forage type effects

The literature contains a limited number of studies comparing in vitro or in vivo digestibility between grass and legume forages. However, a few research findings show that digestibility variation due to forage type alone may be significantly high. Consequently, this added variation could have a significant affect on the accuracy of equations used to estimate nutritive value of ruminant diets.

Tomlin et al. (1962) showed lignin to be significantly correlated to in vitro cellulose digestibility for grass and legume samples. However, separate equations were used for the forage types and were shown to be significantly different. Johnson et al. (1962) showed that the in vitro cellulose digestibility correlation with in vivo measurements was high for grasses alone ($R = .95$) but was lowered when alfalfa data were included in the analysis ($R = .86$). Additional studies by Johnson et al. (1964) compared in vitro cellulose digestibility (IVCD), solubility of cellulose in cupriethylenediamine (CED), and the solubility of dry matter in 1 N sulfuric acid (DMS) as estimators of in vivo dry

matter digestibility for grasses, legumes and mixed forages (grasses plus legumes). Correlations between laboratory methods and in vivo digestibility measurements (DMD) varied considerably depending on which class of forage and which in vitro measurement was used. The chemical predictants gave the lowest correlations when all forage classes were combined (correlation of DMD x DMS: $R = .42$; DMD x CED: $R = .66$). Regression equations were also developed using in vitro and chemical data as independent variables to predict forage digestibility. The kinds of independent variables used were extremely variable between feed classes. Again suggesting notable differences between grasses and legumes.

Correlations were also calculated by Ho et al. (1966) comparing chemical predictants CED, DMS, ADF, lignin and NDF and in vitro dry matter digestibility (IVDMD) with grass and legume in vivo dry matter digestibility. Again, a considerable amount of variation was observed among feed classes, especially for the chemical predictants (table 1). Low correlations observed when forages were combined were contributed to the higher chemical variability shown by the grasses. Correlations averaged much lower for the grasses than for the legumes.

Gaillard (1962) determined correlations between holocellulose (cellulose plus hemicellulose) and hemicellulose and the in vivo digestibility of organic matter in grasses and legumes. Low correlations for both chemical fractions were observed when no distinction was made between forage types. Significantly higher correlations, however, were calculated when forage groups were separated. Since the holocellulose contained a considerable amount of hemicellulose, Gaillard proposed that differences noted between forage types was primarily due

Table 1. Simple correlation coefficients between in vivo dry matter digestibility and predictants^a

Forage type	Predictants ^b					
	CED	DMS	ADF	Lignin	NDF	IVDMD
All Forages	.67**	.54**	-.53**	-.46**	-.47**	.88**
Grass	.69**	.60**	-.33**	-.62**	-.48**	.83**
Legumes	.69**	.76**	-.76**	-.81**	-.74**	.97**
Brome grass	.82**	.36	-.43	-.86**	-.08	.85**
Orchard grass	.72	.88*	-.80*	-.66	-.75	.98**
Reed Canary grass	.42	.49	-.68	-.95**	-.64	.84**
Timothy	.82	.60	-.43	-.80**	-.54	.84**

^aFrom Ho et al. (1966).

^bCED: Solubility of cellulose in cupriethylenediamine

DMS: Solubility of dry matter in 1 N sulfuric acid

HDF: Acid detergent fiber

Lignin: The difference between ADF and the ADF residue following a potassium permanganate treatment to dissolve lignin.

NDF: Neutral detergent fiber

IVDMD: In vitro dry matter digestibility

* $p < .05$

** $p < .01$

to digestibility differences between forage hemicellulose. Research by Sullivan (1964) showed that grasses exceeded legumes in apparent digestibilities of total dry matter and fiber fractions such as crude fiber, true cellulose, alcohol-insoluble matter and non protein alcohol insoluble matter. Van Soest (1964), Keys et al. (1969), Mowat et al. (1969), Moir (1972) and Donker et al. (1976), have also observed distinct fiber digestibility differences between grasses and legumes. This includes empirical fiber fractions of hemicellulose, cellulose, neutral detergent fiber, acid detergent fiber, and crude fiber.

Information found in the literature is not complete enough to pinpoint the source of the differences observed between grasses and legumes. However, from information given it is suggested that chemical and digestibility differences between grasses and legumes are great enough to significantly reduce the accuracy of equations for predicting forage digestibility. A separation between forage type only (grass or legume) maybe adequate to avoid a significant reduction in predictability.

Maturity effects

Maturity in forage plants has been studied intensively due to its marked effect on forage digestibility by ruminants. It has been shown that maturity factors may account for nearly 80% of the variation in forage nutritional quality (Troelsen and Cambell, 1969).

An experiment was conducted by Meyer et al. (1957) to examine maturity effects on the feeding value of oat hay. The hay was harvested at 7 different stages - 59% jointing, 16% flagleaf, 12% boot, 1% flower, 18% flower, milk, and dough stages. Holocellulose content was 35% in the jointing stage and plateaued at 52% in the milk stage. Lignin content

increased regularly to the milk stage (3.8% to 9.0%). The ratio of lignin to holocellulose increased from 10.9% to 17.3%. The added grain formation in the dough stage served to lower lignin content of the hay to 8.4%. Total digestible nutrients (TDN) decreased slowly from 68% in the jointing stage to 60% in the flower stage. However, a rapid decrease in TDN occurred to 50% in the milk stage followed by an upturn to 53% with grain formation. Sheep gains followed the TDN pattern closely. Gains were significantly larger in the jointing stage, continued at a relatively constant rate through the intermediate stages, but dropped significantly lower for both milk and dough stages. Lignin percentages were shown to be highly negatively correlated with TDN values (-.89).

Maturity effects on in vitro digestibility (IVD) of plant parts (leaves, heads, and stems) were studied by Pritchard et al. (1962) in timothy, orchard, brome, reed canary, tall fescue and mountain rye grasses. All grasses were cut at 9 separate stages of maturity. It was observed that the IVD of stems was generally lower than IVD for the leaves. Also, IVD of the stems declined more rapidly with increased maturity than did the leaves. The cutting date was shown not to be a good indicator of maturity across grass species, because a species difference in the rate of maturity was observed. A study by Johnson and White (1965) on orchard grass and rye grass also showed stem parts to be significantly lower in IVD than leaf parts. Leaves were highest in IVD followed by leaf sheath parts. It was also shown that after the head emerged, the leaf portion contributed only 11-12% of the total plant dry matter, while the stem was calculated at 50-60% of the total dry matter. Sheath and head portions contributed 20% of the dry matter. It may be concluded from the preceding data that digestibility changes in grass

stems determine to a large extent the digestibility of the entire plant. Lignification of the leaves, sheaths, and stems followed digestibility patterns in which the stems of lowest digestibility were more lignified than leaves or sheaths. Leaves contained the least amount of lignin and were the most digestible. Stems also became lignified at a faster rate than leaves or sheaths. A species variation in rate of maturity was also observed.

Ademonsum et al. (1968) ran a chemical and digestibility study on a sorghum-sudan grass hybrid at varying stages of maturity. Twelve cuts were made covering maturity stages of vegetative through more than 40% headed. Studies showed the crude protein percentage declined from 20% to about 10%, going from early to late stages. Neutral detergent, acid detergent, and cellulose increased slowly to cut 9 but increased sharply to cut 12. Lignin increases showed a similar pattern. In vivo digestibility changed very little until the fourth cut, but declined between .50 and .65 percentage units per day from then on to cut 12.

Stanely et al. (1968) determined NDF percentages in amclo clover in a study of maturity effects on hay quality. It was shown that in young vegetative forage, NDF comprised less than 40% of the total yield. During flowering it increased to 47% and at maturity to more than 50%. The forage production and cell wall data, when combined with the weather data, indicated that during wet conditions forage yields increased rather rapidly; and forage quality, as measured by cell wall percentages, will decrease more rapidly than forages under dry conditions with lower yields.

Anderson (1976) showed that a delay in cutting alfalfa brought an overall increase in total dry matter harvested. However, chemical

data showed this was due to an increase in the more fibrous parts of the plant, namely NDF and ADF. Noticeably, crude protein declined with age. The dry matter digestibility likewise declined as the forage matured. These findings by Anderson are supported by similar observations by Goering et al. (1976).

Cogswell and Kamstra (1976) studied maturity effects on the chemical composition and digestibility of range grasses (blue grama, prairie sandreed, threadleaf sedge and needle-and-thread). Data showed increased holocellulose with advances in maturity. Similarly, hemicellulose increased but not as much as ADF and cellulose. At later collections the inclusion of lignin increased the ADF fraction to a greater extent than cellulose. Lignification increased in all the species with maturity. Crude protein percent dropped continually with increasing maturity and dry matter digestibility rapidly declined with advanced maturity.

It is suggested in the research cited that digestibility variation in forages with maturity is essentially a result of quantitative changes between nondigestible, partially digestible, and readily digestible chemical constituents for all forage plants. As grasses or legumes mature, lignin and fiber quantities increase while crude protein and other non cell wall components decrease. These conclusions are in agreement with those presented in a review on chemical composition of forage plants by Van Soest (1964). Subsequently, if plant maturity differences are adequately explained by chemical composition information, the precision of equations used to predict forage digestibility from compositional data should not be affected by variations in forage maturity.

Associate effects

Associative effects may be defined as feed interaction effects which alter the digestibility of a given feed (or feeds) when combined with one or more feeds in a mixed ration. In a review on associative effects or associative digestibility Schneider and Flatt (1975) have presented the following ideas:

Digestibility differences of a feed in a mixed ration may arise because the combination of feeds may represent a higher or lower plane of nutrition than the individual feeds fed alone. For example, in ruminants cellulose digestion of a given feed in a mixed ration may be enhanced due to an adequate supply of nitrogenous substances or essential minerals that would otherwise be in a deficient quantity if the feed had been fed individually.

Apparent associative effects may arise simply due to variation connected with average digestion values found in feed tables. Digestion coefficients of rations obtained by feeding those rations in digestion experiments often differ significantly from the digestibilities calculated using table values. "Average coefficients are useful to compute rations used in practical feeding work, but they cannot be deemed accurate enough for calculating digestible nutrients in experimental rations already consumed." Difficulties may be avoided by conducting digestion trials to compute accurately the digestible nutrients for each animal for the combination of feeds used in an experiment.

Variations associated with digestion coefficients for energy feeds also may be relatively high. Energy feeds such as feed grains are generally not fed alone when fed to ruminants to determine their

digestibility values. Rather, they are fed along with high cell wall basal feed of known digestibility. The digestibility of the basal feed is assumed to remain constant when fed alone or mixed with a test feed. As a result, the variation from the combination effect as well as from errors of experimentation are attributed to the added energy feed.

Ruminants may digest some fibrous feeds poorly when they are fed in rations containing a large proportion of readily digested carbohydrates. The microorganisms tend to utilize more of the soluble carbohydrates instead of attacking the cellulose or hemicellulose of feed fiber.

Finally, associative digestibility may not occur at all. Sometimes the digestion coefficients of rations are almost exactly the weighted means of those individual feeds making up the rations. Whether or not there will be an associative effect between feeds and to what extent they will affect the nutrients of the individual feeds appears to be largely unpredictable.

A few recent studies can be cited that show associative digestibility of feed nutrients may or may not occur in mixed rations.

Clemens (1968) observed associative digestibility of nitrogen-free-extract, ether extract, and crude protein in diets fed to sheep containing varying ratios of corn grain to dehydrated alfalfa meal. The digestibility of nitrogen-free-extract, ether extract, and crude protein increased curvilinearly with increasing corn in the ration. Crude fiber digestibility decreased linearly, demonstrating no associative effects on fiber digestibility.

Associative effects were observed by Vance et al. (1972) in corn grain, plus corn silage rations eaten by hereford steer calves. When net energy per kilogram of dry matter ($NE/kg\ DM$) was regressed against percentages of grain and silage, the ration net energy for maintenance (NE_M) value increased linearly with increased corn percentages. This indicated that NE_M content of each ration was constant and independent of the proportion of each feed ingredient of the ration. The ration net energy for gain (NE_g) value, however, increased curvilinearly showing that the NE_g was not constant but dependent on the feed proportions in the ration. The NE_g of corn grain decreased while that of corn silage increased as the increment of grain in the ration declined.

Feeding sheep pelleted rations of corn and alfalfa similar to rations prepared by Clemens (1968), Kromann et al. (1975) also observed interactional effects on the digestibility of nitrogen-free-extract, crude protein, and ether extract with increasing corn content. Crude fiber also showed associative digestibility. Apparent digestible energy (DE), metabolizable energy (ME), and net energy for maintenance and productivity (NE_{m+p}) showed no associative digestibility. It was postulated that the physical form of the diet may have contributed to whether or not there was an associative effect on DE, ME, and NE_{m+p} since Kromann (1967) observed an interactional effect on the same energy digestibility values for nonpelleted diets of similar ingredient composition.

Kromann et al. (1977) fed four pelleted diets consisting of varying proportions of pea scalplings and straw to wether and ewe lambs. No associative digestibility was observed for nutrient levels of nitrogen-free-extract, ether extract and dry matter. Only a

linear increase in the digestibility for these nutrients was shown as the level of pea scalping increased in the diet. Crude fiber digestibility was not affected by the diet ratios since crude fiber content was not significantly different between rations. DE and ME were shown to have a third order relationship with percent pea scalplings in the diet. NE_{m+p} showed only a linear relationship to the pea-straw ratios.

Studies by Houser et al. (1975) and Chimwano et al. (1976) showed that increasing levels of a grain supplement in ruminant rations lowered cellulose digestibility. However, a protein and energy supplement was shown to have very little affect on grass crude fiber digestibility in a digestion trial conducted by Tagari and Ben-Ghendahi (1977).

Johns and Holter (1975) fed Holstein heifers four rations containing differing ratios of urea-treated corn silage to hay crop silage. The digestibility of gross energy, crude protein, dry matter, and ether extract was greater for the 100% corn silage diet than for the 100% hay crop silage diet, the other two diets were intermediate. No positive associative effects between forages were observed.

From the information given above, it may be readily concluded that associative effects when present may add considerable variation to the availability of digestible nutrients in ruminant feeds. Unfortunately, the occurrence of associative digestibility is relatively unpredictable. Most equations used to predict feed digestibility are based upon single ingredient diets only; therefore, variation from association effects has not been a factor for consideration. However, predicting equations for a single feed diet would not be useful in most

practical feeding regimes since mixed rations are most commonly used. Further research should be conducted to study the impact associative effects may have on the predictability of regression equations and to determine the feasibility of developing equations for mixed diets.

Texture effects

The literature is quite complete with information on the effects grinding or pelleting have on feed digestibility. A thorough review of literature by Schneider and Flatt (1975) outlines the following on feed grinding and pelleting effects:

Generally, the digestibility of pelleted or ground hay is lower in digestibility than long or chopped hay. Experiments have shown that feed fiber digestibility is significantly lowered by grinding or pelleting the hay. In mixed rations where a forage is supplemented with a whole or ground, high energy feed such as corn or barley, the crude fiber digestibility again is observed to be depressed by pelleting (the hay only or the complete ration). However, the digestibility of the entire ration is often not affected or may be slightly higher than unpelleted diets. Further research not reviewed by Schneider and Flatt also supports these ideas (Campling et al., 1963; Anderson et al., 1975; Johnson et al., 1964; Waldo et al., 1971). A summary by Moore (1964), included in the review by Schneider and Flatt (1975), listed the following significant changes in ruminant digestive processes as a result of feeding ground or pelleted feeds:

1. Reduced time of prehension and mastication.
2. Probable reduced saliva secretion.
3. Decrease in rumination.

4. Increase in rate of fermentation in the rumen.
5. Increase in concentration of rumen volatile fatty acids one to four hours after feeding.
6. Decrease in ratio of acetate to propionate in rumen.
7. Decrease in rumen pH.
8. Increased rate of digestion in rumen.
9. Increased rate of passage of feed particles from the rumen.
10. Decrease in dry matter and crude fiber digestibility usually but not always observed.
11. No difference in net energy values with equalized feed intake.
12. Increased dry matter intake.
13. The fact that grinding the forage to make the pellets causes the effects of pelleting.
14. Increased palatability and acceptability of pelleted forage.
15. The finer the grinding of the forage prior to pelleting, the greater the effect.
16. Variation in the fineness of grinding probably accounts for the variable results with pellets which are obtained in digestibility experiments.

It has been adequately pointed out in the literature that the texture or physical form of a feed plays a significant role in determining its own nutritive value. Evidence shows that digestibility variation due to texture effects is due to changes in the ruminants digestive processes and is not related to feed chemical composition. Therefore, logically it may also be concluded that equations based on chemical predictants only would not be adequate for predicting feed digestibility across pelleted and nonpelleted diets.

METHOD AND PROCEDURE

Design of Experiment

Twenty-four wether lambs weighing approximately 30 kg were randomly assigned to 2 replications of a 2 x 3 x 2 x 2 factorial design digestion trial. The treatments included 2 forage types, 3 stages of forage maturity, 2 diet energy levels and 2 diet textures.

Animals given high energy diets in the first replication were re-assigned to all forage diets in the second replication. This was done to avoid possible rumen disorders due to prolonged exposure to low fiber diets.

Composition of Diets

Alfalfa and grass (40% brome grass, 60% orchard grass) were selected for the forage portion of the diets (table 2). For the study of maturity effects and to provide a wide range of cell wall percentages among diets, each forage was cut at late vegetative, midbloom and fullbloom stages. Forage was cut and crimped with a swather, suncured and harvested as baled hay. All stages of maturity were selected from the same field for each forage type except the late vegetative stage of grass. In order to have enough of the early stage of grass, a second field was selected for a few additional bales. Bales for each hay type and stage of maturity were selected at random from the field. The second cut of alfalfa was used to avoid annual weeds. The first cutting of grass was selected for mid-bloom and full-bloom stages.

Table 2. Forage harvest dates

Forage type	Date of Cutting
Alfalfa	
Alfalfa, hay, s-c, late vegetative, cut 2 (IFN 1-00-054)	July 9
Alfalfa, hay, s-c, midbloom, cut 2 (IFN 1-00-063)	July 23
Alfalfa, hay, s-c, fullbloom, cut 2 (IFN 1-00-068)	August 9
Grass	
Orchardgrass - Brome, smooth, hay, s-c, late vegetative, cut 2 (IFN 1-20-718)	July 26
Orchardgrass - Brome, smooth, hay, s-c, early bloom cut 1 (IFN 1-20-708)	June 11
Orchardgrass - Brome, smooth, hay, s-c, fullbloom, cut 1 (IFN 1-20-708)	July 26

The second cutting of grass (grass aftermath) was used for the late vegetative stage.

Energy levels in the experiment consisted of all forage diets and a 50:50 mixture of corn grain to forage.

Feed processing for pelleted diets and diets containing long hay was accomplished using the department's California pellet mill and Gehl hay chopper. Bales were selected at random from the haystack before chopping. Hay for long hay diets was chopped through a 38.1 mm (1 1/2 inch) mesh screen. A 3.18 mm (1/8 inch) mesh screen was used to prepare hay for the pelleted diets. Crushed corn grain was used in both pelleted and long hay mixed diets. Mixed diets to be pelleted were hand

mixed on the floor. Steam was used for binding pellets and pelleting was done through a 6.38 mm (1/4 inch) die.

Individual rations were weighed and sampled prior to feeding. Mixed diets of long hay and corn were mixed uniformly and then sampled. A half a percent (.5%) granulated trace mineral salt was added to all daily rations.

Digestion Trials

A 21 day digestion and balance trial was conducted consisting of a 7-10 day adjustment period for adjusting lambs to the diets followed by a 7 day preliminary period and a 7 day collection period. Feed and water were given ad libitum. During the adjustment period the ration was reduced to the amount the individual animal would completely consume.

Animals were housed in individual metabolism stalls following the adjustment period. Individual weights were taken prior to caging and at the end of each collection period.

Total collection of feces and urine was made twice daily for the full 7-day collection period. All collections were kept cool in a refrigerated room at 1° C.

Following each collection period, individual feces and urine collections were each mixed and sampled for dry matter determination and chemical analysis. Feces samples were freeze dried for chemical analysis. Urine samples were frozen.

Method of Analysis

Feed and feces samples were ground through a Wiley mill in preparation for dry matter-determination and chemical analysis. Feces

and alfalfa diets were ground through a 2 mm screen. Grass diets were ground through a 1 mm screen to obtain samples more equal to alfalfa and feces samples in particle size.

Procedures by Fannesbeck and Harris (1970a,b; 1974) and Fannesbeck (1976) were followed to chemically analyze feed and feces for percent cell walls, cellulose, hemicellulose, available carbohydrates, lignin, total lipids, acid insoluble ash, and soluble ash. Percent neutral detergent fiber was determined using procedures of Van Soest and Wine (1967) with modifications of Robertson and Van Soest (1977). Percent acid detergent fiber was determined by the method of Van Soest (1963b). Dry matter and crude protein content of feed and feces were determined using procedures outlined in Nutrition Techniques for Domestic and Wild Animals by Harris (1970). Likewise, all energy values; gross energy (GE), digestible energy (DE), and metabolizable energy (ME); were calculated following methods outlined by Harris (1970). ME values were calculated for use in research beyond this study.

Computer programs by Hurst (unpublished 1978; Utah State University, Applied Statistic Department) were used for analysis of variance and stepwise regression analysis.

RESULTS AND DISCUSSION

Chemical MethodsFiltering problems

Crucible filtering difficulties were experienced when hay-corn feed and feces samples were analyzed for neutral detergent fiber. Crucible filtering was usually too long for practicality. Completed samples gave high, wild values with low repeatability. Cell wall hay-corn feed and feces samples were moderately slow to slow in filtering through the filter stick following the 24 hour pepsin digest, but filtering time was not unreasonably long. This involved feces samples primarily. Slow filtering was usually prevented by using a coarse filtering stick. Crucible filtering in cell wall analysis of hay-corn samples (primarily feces samples) was also slow, but not excessively slow as shown in the neutral detergent procedures. Completed cell wall samples gave reasonable values with good repeatability.

Neutral detergent fiber filtering problems were prevented by the addition of an α -amylase digest as suggested by Robertson and Van Soest (1977). The grade of enzyme preparation used also contained some proteinase. All hay-corn feed and feces samples were analyzed for neutral detergent fiber using the added α -amylase procedure. The use of α -amylase was not necessary in the cell wall analysis.

A simple qualitative test was conducted to investigate the cause of the excessively slow filtering of neutral detergent fiber hay-corn samples compared to only moderately slow filtering of cell wall hay-corn samples.

Separate 1 gram samples of a commercial corn starch were boiled in 100 milliliters of water, neutral detergent, and cell wall detergent (sodium lauryl sulfate at pH 3.5) for 1 hour using a reflux apparatus. Following the 1 hour reflux, samples were filtered through glass crucibles to compare filtering ease.

Upon filtering, samples boiled in either detergent solution left behind a much larger amount of residual starch than the sample boiled in water. Residual starch from the sample boiled in water was granular in appearance. However, both detergent solutions left a starch residue having a gummy, coagulated or curded appearance. Also, the quantity of curded starch was substantially greater for the neutral detergent sample than for the cell wall detergent sample. The addition of a few milliliters of α -amylase solution recommended by Robertson and Van Soest (1976) dissolved the coagulated starch residue from both detergent solutions.

Further, 1 gram starch samples were again refluxed for 1 hour in water, neutral detergent, and cell wall detergent (sodium lauryl sulfate solution, pH 3.5). In addition to starch, 1 gram portion of ground alfalfa was added to each sample solution. The addition of the alfalfa resulted in excessively slow filtering for the neutral detergent sample and moderately slow filtering for the cell wall detergent sample. No filtering problems were experienced on the sample boiled in water.

It is concluded from the results of the simple test that excessively slow filtering on neutral detergent hay-corn samples is primarily a result of the coagulation of feed starch by the neutral detergent. The coagulated starch residue acts in combination with fibrous particles to prevent

free passage of the sample liquid. Secondly, the coagulation of feed starch also occurs in the acid cell wall detergent but to a lesser degree than in neutral detergent. Thus, only a moderate filtering problem occurs in cell wall analysis.

Neutral detergent fiber versus cell walls

Neutral detergent fiber values averaged higher than cell wall values for all diet types (tables 4 and 5). Differences ranged from .03% to 3.8% with an average of 2.4% across all diet types. Differences between neutral detergent fiber and cell wall percentages were generally lower for the hay-corn diets, an average difference of 2.8% and 1.9% for all-hay and hay-corn diets respectively. A comparison between grass and alfalfa diets showed that differences between neutral detergent fiber and cell wall residues were nearly the same for the all-hay diets, averaging 2.8% for grass and 2.7% for alfalfa. However, a greater difference was observed for the alfalfa hay-corn diets than for the grass hay-corn diets, a 2.2% and 1.6% average differences respectively.

Generally, differences between neutral detergent fiber and cell wall extractions are partly a result of a higher content of residual protein in neutral detergent fiber fractions. Neutral detergent fiber may retain up to 33% of the forage protein, while cell wall procedures, utilizing a 24 hour pepsin digestion, have been shown to reduce protein residues by 90%. Differences between neutral detergent fiber and cell wall values for this experiment equaled 27% and 15% of the total crude protein in grass and alfalfa all-hay diets respectively and 15% of the total crude protein in both the grass and alfalfa hay-corn diets.

Neutral detergent fiber to cell wall differences for the grass diets probably should have been greater than observed; however, the neutral detergent also removes silica, a significant constituent of grass dry matter. This would bring neutral detergent fiber values closer to cell wall values. Silica (acid insoluble ash) content comprised an average of 3.4% of the grass all-hay diets and 2.0% of the hay-corn diets.

Recovery of plant cell wall constituents in crude fiber

Across all diets there was 61.6% recovery of plant cell wall constituents in crude fiber. Crude fiber was 57.7% as great as neutral detergent fiber (table 3). Across forage type, the recovery of cell wall constituents in crude fiber was lowered 10% when corn comprised 50% of the diet. A 12 to 15% drop in crude fiber recovery of cell wall constituents was observed when grass instead of alfalfa comprised the forage portion of the hay-corn diets.

Data from this study is consistent with observations reported by other researchers. Substantial evidence has been reported to show that crude fiber is poor for recovering all cell wall fibrous constituents, the recovery of lignin and hemicellulose generally being considerably lower than the recovery of cellulose (Hallab and Epps, 1963; Stallcup, 1967). Van Soest (1967, 1974) has stated that crude fiber recovery of lignin and hemicellulose is significantly lower in grasses than in legumes. Crude fiber also recovers a low percentage of grain cell wall constituents (Van Soest, 1974).

Table 3. Comparison of crude fiber analyses to plant cell wall constituents

Diets	Ratio of crude fiber to other analyses	
	$\frac{CF^a}{CW}$	$\frac{CF^b}{NDF}$
Alfalfa		
All-hay	.757	.692
Hay-corn	.635	.587
Grass		
All-hay	.585	.562
Hay-corn	.485	.466
Average	.616	.577

^aPlant cell walls determined using detergent procedures by Fomesbeck and Harris (1970a).

^bNeutral detergent fiber.

Chemical Composition of Diets

To more easily see differences, compositional information (tables 4 and 5) for all-hay diets only was used in discussing differences between forage types and stages of maturity.

Forage type

Grass showed much more chemical variation than did alfalfa (compare tables 4 and 5). Across maturity and texture levels, grass cell walls ranged from 49.7% to 70.2% with a mean of 60%, while alfalfa cell walls ranged from 37.5% to 42.9% with a mean of 40.6%. Grass cell wall variation was due mainly to variations in cellulose and hemicellulose content. Grass was higher in cellulose but much higher in

Table 4. Chemical composition of alfalfa diets

Treatments	Cell contents				Cell wall constituents												
	Crude protein (%)	Available carbohydrate (%)	Soluble ash (%)	Total lipids (%)	Cellulose (%)	Hemi-cellulose (%)	Lignin (%)	Acid insoluble ash (%)	Cell walls ^a (%)	Neutral detergent fiber (%)	Acid detergent fiber (%)	Crude fiber (%)	Ash (%)	Dry matter (%)	DE sheep (Mcal/kg)	ME sheep (Mcal/kg)	GE (Mcal/kg)
Alfalfa hay^b																	
Late vegetative																	
Coarse	21.2	21.4	10.8	6.1	25.7	7.9	6.7	.2	40.5	43.8	37.5	30.1	11.1	90.7	2.72	2.23	4.44
Pelleted	21.7	21.2	10.6	6.2	25.7	7.7	6.5	.4	40.3	43.3	36.3	29.9	11.1	89.8	2.45	1.94	4.47
Avg.	21.5	21.3	10.7	6.2	25.7	7.8	6.6	.6	40.4	43.6	36.9	30.0	11.1	90.3	2.59	2.09	4.46
Midbloom																	
Coarse	19.4	24.3	9.9	5.6	26.4	7.7	6.6	.1	40.8	41.5	36.6	31.6	10.0	90.6	2.81	2.30	4.48
Pelleted	19.1	28.1	9.7	5.6	23.7	7.4	6.1	.3	37.5	39.8	33.7	27.5	10.1	90.5	2.86	2.27	4.45
Avg.	19.3	26.2	9.8	5.6	25.1	7.6	6.4	.2	39.2	40.7	35.2	29.6	10.1	90.6	2.84	2.29	4.47
Fullbloom																	
Coarse	14.1	29.9	7.7	5.4	25.8	9.8	7.1	.2	42.9	47.1	35.9	31.1	7.9	90.4	2.74	2.24	4.50
Pelleted	14.3	30.4	7.3	6.5	24.5	9.8	6.9	.3	41.5	44.1	34.6	29.1	7.6	90.4	2.70	1.88	4.45
Avg.	14.2	30.2	7.5	6.0	25.2	9.8	7.0	.3	42.2	45.6	35.3	30.1	7.7	90.4	2.72	2.06	4.48
Alfalfa hay^b plus corn^c																	
Late vegetative																	
Coarse	16.6	44.9	7.2	4.2	14.8	8.0	4.1	.2	27.1	31.2	21.9	17.9	7.6	89.7	3.05	2.56	4.42
Pelleted	16.7	44.6	6.6	4.2	15.2	8.4	3.9	.4	27.9	31.1	22.9	17.0	7.1	89.5	3.04	2.74	4.46
Avg.	16.7	44.8	6.9	4.2	15.0	8.2	4.0	.3	27.5	31.2	22.4	17.5	7.4	89.6	3.05	2.65	4.44
Midbloom																	
Coarse	15.2	45.8	6.5	4.8	15.0	8.2	4.2	.3	27.7	29.3	21.5	16.6	6.8	89.6	2.94	2.43	4.43
Pelleted	14.7	48.2	5.6	4.8	13.6	9.2	3.7	.4	26.7	26.5	19.7	15.8	5.9	90.1	3.19	2.67	4.47
Avg.	15.0	47.0	6.1	4.8	14.3	8.7	4.0	.3	27.2	27.9	20.6	16.2	6.4	89.9	3.07	2.55	4.45
Fullbloom																	
Coarse	12.5	47.8	5.2	6.8	13.8	8.8	4.7	.4	27.8	30.2	23.2	18.6	5.6	89.9	3.14	2.63	4.51
Pelleted	12.8	51.5	4.7	5.9	13.9	7.0	3.9	.3	25.1	27.4	21.2	17.0	4.9	90.1	3.26	2.77	4.47
Avg.	12.7	49.7	5.0	6.4	13.9	7.9	4.3	.4	26.5	28.8	22.2	17.8	5.3	90.0	3.20	2.70	4.49

^aPlant cell walls as determined using detergent procedures by Fonesbeck and Harris (1970 a).^bAlfalfa, hay, s-c, late vegetative, cut 2 (IFN 1-00-054); Alfalfa, hay, s-c, midbloom, cut 2 (IFN 1-00-063); Alfalfa, hay, s-c, full-bloom, cut 2 (IFN 1-00-068).^cCorn dent yellow grain (IFN 4-02-935).

Table 5. Chemical composition of grass diets

Treatments	Cell contents						Cell wall constituents						Crude fiber (%)	Ash (%)	Dry matter (%)	DE sheep (Mcal/kg)	ME sheep (Mcal/kg)	DE (Mcal/kg)
	Crude protein (%)	Available carbohydrate (%)	Soluble ash (%)	Total lipids (%)	Cellulose (%)	Hemi-cellulose (%)	Lignin (%)	Acid insoluble ash (%)	Cell walls ^a (%)	Neutral detergent fiber (%)	Acid detergent fiber (%)							
Grass hay^b																		
Late vegetative																		
Coarse	11.5	23.7	7.8	5.6	25.3	16.6	6.0	3.5	51.4	55.5	36.9	27.0	11.3	92.3	2.42	1.98	4.38	
Pelleted	12.1	24.3	8.2	5.7	24.5	16.1	5.5	3.6	49.7	53.3	34.5	27.5	11.8	90.5	2.34	1.92	4.39	
Avg.	11.8	24.0	8.0	5.7	24.9	16.4	5.8	3.6	50.6	54.4	35.7	27.3	11.6	91.4	2.38	1.95	4.39	
Midbloom ^c																		
Coarse	11.8	6.2	5.8	6.0	34.9	23.4	9.0	2.9	70.2	72.7	45.3	46.7	8.7	92.1	2.33	1.89	4.40	
Pelleted	12.0	7.8	5.9	6.0	33.6	23.3	8.1	3.3	68.3	72.8	44.9	48.7	9.1	91.8	2.19	1.68	4.45	
Avg.	11.9	7.0	5.9	6.0	34.3	23.4	8.6	3.1	69.3	72.8	45.1	47.7	8.9	92.0	2.26	1.79	4.43	
Fullbloom																		
Coarse	7.6	19.3	6.5	5.5	31.4	19.4	7.0	3.3	61.1	62.8	42.3	33.1	9.8	91.8	2.16	1.74	4.30	
Pelleted	8.0	20.1	7.0	5.6	30.7	18.8	6.5	3.3	59.3	59.8	40.3	31.6	10.3	91.5	2.03	1.60	4.37	
Avg.	7.8	19.7	6.8	5.6	31.1	19.1	6.8	3.3	60.2	61.3	41.3	32.4	10.1	91.7	2.10	1.67	4.34	
Grass hay^b plus corn^d																		
Late vegetative																		
Coarse	11.4	42.0	6.2	5.3	16.0	12.9	4.1	2.1	35.1	38.5	24.5	17.3	8.3	90.7	2.75	2.31	4.36	
Pelleted	11.0	44.7	5.7	5.4	15.3	12.4	3.5	2.0	34.2	34.1	21.0	15.5	7.7	89.7	3.13	2.66	4.47	
Avg.	11.2	43.4	6.0	5.4	15.7	12.7	3.8	2.1	34.2	36.3	22.8	16.4	8.0	90.2	2.95	2.49	4.42	
Midbloom																		
Coarse	11.0	34.3	5.4	4.8	21.1	16.0	5.9	1.5	44.5	47.1	28.4	21.9	6.9	91.2	2.74	2.29	4.38	
Pelleted	12.1	35.0	4.5	4.9	20.7	15.9	4.9	2.0	43.5	45.8	27.7	20.7	6.5	90.3	2.87	2.40	4.52	
Avg.	11.6	34.7	5.0	4.9	20.9	16.0	5.4	1.8	44.0	46.5	28.1	21.3	6.7	90.8	2.81	2.35	4.45	
Fullbloom																		
Coarse	9.3	40.4	5.1	5.3	19.4	13.9	4.4	2.2	39.9	39.8	26.0	19.3	7.2	91.1	2.72	2.30	4.30	
Pelleted	9.5	39.7	5.8	5.4	18.9	14.5	4.1	2.1	39.6	40.3	26.6	19.8	7.9	90.4	2.84	2.19	4.35	
Avg.	9.4	40.1	5.5	5.4	19.2	14.2	4.3	2.2	39.8	40.1	26.3	19.6	7.6	90.8	2.79	2.25	4.33	

^a Plant cell walls as determined using detergent procedures by Fennesbeck and Harris (1970 a).

^b Orchardgrass-Brome, smooth, hay, s-c, late vegetative, cut 2 (IFN 1-20-718); Orchardgrass-Brome, smooth, hay, s-c, early bloom, cut 1 (IFN 1-20-708); Orchardgrass-Brome, smooth, hay, s-c, fullbloom, cut 1 (IFN 1-20-709).

^c Rain damage to midbloom grass hay between cutting and baling reduced water soluble constituents (available carbohydrates and ash) with a consequent increase of water insoluble constituents (protein, cell wall constituents and lipids).

^d Corn dent yellow grain (IFN 4-02-935).

hemicellulose than alfalfa. Grass cellulose content ranged from 34.9% to 24.5% with a mean of 30.1% across maturity and texture levels. Alfalfa cellulose content ranged from 26.4% to 23.7% with a mean of 25.3%. Hemicellulose content in grass ranged from 16.1% to 23.4% with a mean of 19.6% while hemicellulose content in alfalfa ranged from only 7.4% to 9.8% with a mean of 8.4%.

Alfalfa forage was shown to be slightly more lignified than grass. Averages were 6.7% and 7.1% for alfalfa and grass respectively. However, acid insoluble ash (silica) averaged considerably greater in grass (3.3%) than in alfalfa (0.4%). A large silica content is common for grasses (Jones and Handreck, 1967).

Crude protein and available carbohydrate content both showed typical trends between forage types. Crude protein averaged much higher in alfalfa (18.3%) than in grass (10.5%). Available carbohydrate also was considerably higher for alfalfa (25.9%) than for grass (16.9%).

Stage of maturity

Alfalfa showed only a slight chemical variation between stages of maturity (table 4). Midbloom alfalfa averaged the lowest in cell walls (33.2%) over texture levels. This was partly a result of a relatively large cell wall difference between texture levels. The midbloom pelleted diet appeared consistently lower than the midbloom coarse diet in cell wall, neutral detergent fiber, acid detergent fiber and crude fiber chemical residues. Therefore, it was concluded that differences in cell wall constituents between texture levels was due to an actual compositional difference of the sample rather than an error in chemical analysis.

Alfalfa hemicellulose percentages remained relatively constant for late vegetative (7.8%) and midbloom (7.6%) maturity stages, but increased approximately 2.0% for the fullbloom (9.8%) stage. Changes in hemicellulose content contributed to most of the difference between stages of maturity for alfalfa cell wall content.

Lignin content in alfalfa showed only a slight change between maturity levels. The midbloom stage appeared lowest in lignin followed by the late vegetative and fullbloom stages respectively. The differences in lignin content between midbloom texture levels resulted in making midbloom alfalfa average lowest in lignin between the three maturity levels.

Crude protein content in alfalfa followed an expected trend for maturing forages, decreasing with increasing maturity from 21.5% to 19.3% to 14.2% for late vegetative, midbloom, and fullbloom stages respectively. Available carbohydrates followed a reversed pattern to that of crude protein, increasing with increasing maturity from 21.3% to 26.2% to 30.2% for late vegetative, midbloom, and fullbloom stages respectively.

Grass chemical composition was observed to change considerably between stages of maturity (table 5). Cell wall percentages did not increase consistently with increasing maturity. Cell wall content was lowest for the late vegetative stage (50.6%) followed by the fullbloom (60.2%) and midbloom (69.3%) stages.

Midbloom grass was higher in cell wall content than the fullbloom grass mainly as a result of excessive leaching of available carbohydrates when the grass was harvested. Midbloom grass was shown to be significantly lower in available carbohydrates compared to other maturity stages. The midbloom grass was rained on while in the windrow and

still contained excessive moisture when baled. Bales were stacked loosely until dry. The loose stacking prevented molding, but did not prevent added losses of available carbohydrates. The fullbloom grass showed a lower cell wall content than expected due to vegetative regrowth at the base of the mature plant. Since stages of maturity of forage is based primarily on subjective measurements, the fullbloom grass was not cut until a substantial amount of regrowth had occurred. The regrowth added a larger portion of leaves to the mature plant contributing to an overall lower cell wall percentage in the fullbloom grass.

The leaching problem and regrowth problem as mentioned, re-emphasize the significant role stage of maturity and method of harvest play in determining hay quality.

Grass cellulose, hemicellulose, and lignin content increased in the same pattern between maturity stages as was shown by cell wall content.

Crude protein remained relatively constant between late vegetative (11.8%) and midbloom (11.9%) grass stages, but decrease markedly in the mature stage (7.8%). Crude protein content in midbloom grass was probably little affected by the moisture problem.

Grass insoluble ash was observed to decrease only slightly with increasing maturity.

Energy level

Generally, the addition of corn in the diet served to reduce cell wall constituents and in turn, significantly increase available carbohydrate and total lipid content in the diet (table 4 and 5).

Specifically, since alfalfa was relatively low in hemicellulose, the addition of corn grain with alfalfa only slightly changed hemicellulose values from those observed in alfalfa all-hay diets. However, mixing corn grain with grass lowered the hemicellulose content by 30% of values shown for grass all-hay diets, since grass all-hay diets were particularly high in hemicellulose content. Cellulose content in the diet was reduced 40% from values in all-hay diets when corn grain was mixed with either grass or alfalfa.

The addition of corn generally lowered the crude protein content of the diet from that shown in the all-hay diets for both forage types. But, since fullbloom grass was so low in crude protein (7.8%) the mixing of corn grain with the fullbloom grass increased average crude protein content to 9.4% for the hay-corn diet.

Texture level

Generally, there was no significant compositional difference observed between pelleted and coarse diets (tables 4 and 5). However, one exception was observed for the midbloom alfalfa all-hay diet. See the section on maturity differences for the discussion of this problem.

Digestibility of Diet Chemical Constituents

An analysis of variance (table 8) was used to evaluate treatment main effects and two-way interaction effects on the apparent digestibility of each feed component (tables 6 and 7). A preliminary analysis of variance showed no significant three or four-way interaction effects; therefore, the variation and degree of freedom from these effects was pooled with the error variation of the two-way interaction effects.

Table 6. Apparent digestion coefficients for chemical constituents in alfalfa diets

Treatments	Cell content				Cell wall constituents										
	Crude protein (%)	Available carbohydrate (%)	Soluble Ash (%)	Total lipids (%)	Cellulose (%)	Hemicellulose (%)	Lignin (%)	Acid insoluble ash (%)	Cell walls ^a (%)	Neutral detergent fiber (%)	Acid detergent fiber (%)	Crude fiber (%)	Ash (%)	Dry matter (%)	GE (%)
Alfalfa hay^b															
Late vegetative															
Coarse	75.4	85.9	64.7	42.0	52.5	51.0	19.6	-88.9	43.8	47.9	47.8	44.0	62.1	61.9	61.0
Pelleted	71.5	81.3	57.3	48.2	40.3	37.8	-7.4	-4.8	31.0	34.5	34.9	32.1	55.3	54.6	54.8
Midbloom															
Coarse	75.1	87.4	58.8	40.7	54.2	49.0	17.1	-10.5	46.7	45.4	50.8	48.5	56.9	63.0	62.7
Pelleted	74.9	88.2	63.9	43.5	47.1	48.5	6.7	-13.4	40.0	42.0	42.7	38.8	62.8	63.0	61.9
Fullbloom															
Coarse	66.6	91.5	50.4	42.6	44.0	56.6	-1.3	-37.7	40.2	43.9	39.3	39.0	48.8	60.5	60.7
Pelleted	63.5	90.7	47.2	40.3	28.7	47.1	-7.5	40.7	27.6	29.5	24.9	19.3	47.0	54.3	53.2
Alfalfa hay^b plus Corn^c															
Late vegetative															
Coarse	70.1	92.2	58.7	44.8	43.4	49.5	14.6	0.2	37.8	43.1	40.5	43.4	50.8	69.3	68.8
Pelleted	70.9	93.0	63.1	47.4	49.0	57.9	13.0	21.7	46.1	45.5	46.7	39.4	60.6	72.3	71.9
Midbloom															
Coarse	60.8	88.5	41.8	45.5	35.2	42.5	7.8	-40.6	31.9	26.8	31.1	30.9	37.5	63.6	66.4
Pelleted	68.6	93.4	55.5	51.1	39.4	58.1	6.0	-21.2	40.6	40.6	35.9	33.1	52.6	72.9	71.7
Fullbloom															
Coarse	66.3	92.0	46.8	74.0	34.9	54.9	17.8	29.5	36.8	38.2	40.7	38.2	38.7	70.1	69.8
Pelleted	70.5	95.1	64.1	62.5	43.3	48.3	11.5	9.8	39.1	38.6	40.0	32.3	32.3	74.4	72.8

^aPlant cell walls as determined using detergent procedures by Fommesbeck and Harris (197Ca).

^bAlfalfa, hay, s-c, late vegetative, cut 2 (IFN 1-00-054); Alfalfa, hay, s-c, midbloom, cut 2 (IFN 1-00-063); Alfalfa, hay, s-c, full-bloom, cut 2 (IFN 1-00-068).

^cCorn dent yellow grain (IFN 4-02-935).

Table 7. Apparent digestion coefficients for chemical constituents in grass diets

Treatments	Cell contents				Cell wall constituents										
	Crude protein (%)	Available carbohydrate (%)	Soluble ash (%)	Total lipids (%)	Cellulose (%)	Hemicellulose (%)	Lignin (%)	Acid insoluble ash (%)	Cell walls ^a (%)	Neutral detergent fiber (%)	Acid detergent fiber (%)	Crude fiber (%)	Ash (%)	Dry matter (%)	GE (%)
Grass hay^b															
Late vegetative															
Coarse	59.7	80.2	53.0	23.5	53.8	55.9	21.1	8.4	47.8	51.8	45.7	50.6	39.3	55.0	55.0
Pelleted	62.6	75.0	52.1	38.2	53.6	55.4	14.9	15.8	47.0	43.1	40.5	47.4	41.1	55.3	53.3
Midbloom															
Coarse	58.8	20.9	48.3	42.4	62.1	65.5	35.8	9.7	57.7	61.5	55.2	69.6	35.4	54.1	52.8
Pelleted	54.5	29.7	46.6	39.0	54.2	56.1	34.1	15.1	49.8	55.1	48.6	47.2	28.6	47.8	49.2
Fullbloom															
Coarse	52.3	78.9	55.5	43.2	49.8	50.7	11.6	0.5	43.0	45.7	41.4	45.5	9.8	51.4	50.1
Pelleted	50.6	74.5	47.0	37.8	41.6	41.6	7.1	3.6	35.7	36.4	32.3	37.5	33.1	45.4	46.3
Grass hay plus Corn^c															
Late vegetative															
Coarse	56.2	81.1	44.0	44.1	58.0	57.0	30.6	3.4	51.3	50.3	50.0	48.4	34.0	63.6	63.3
Pelleted	62.3	91.4	48.6	48.6	54.8	59.2	24.1	20.6	51.2	48.8	48.0	47.1	47.0	70.5	69.9
Midbloom															
Coarse	52.7	83.9	43.2	43.2	55.5	54.6	47.3	-17.4	51.9	53.8	50.7	51.6	32.5	62.2	62.5
Pelleted	59.2	90.3	51.2	51.2	48.4	53.4	33.2	16.0	47.1	49.4	45.7	46.1	36.7	62.7	63.5
Fullbloom															
Coarse	50.9	88.2	56.7	56.7	48.6	52.0	23.3	9.2	44.8	42.2	42.0	42.4	32.9	63.5	63.1
Pelleted	59.7	90.6	23.5	23.5	53.8	55.9	21.1	8.4	47.8	35.5	34.7	32.7	38.5	60.8	60.9

^aPlant cell walls as determined using detergent procedures by Fonnebeck and Harris (1970a).

^bOrchardgrass-Brome, smooth, hay, s-c, late vegetative, cut 2 (IFN 1-20-718); Orchardgrass-Brome, smooth, hay, s-c, early bloom, fullbloom, cut 1 (IFN 1-20-708); Orchardgrass-Brome, smooth, hay, s-c, fullbloom, cut 1 (IFN 1-20-709).

^cCorn dent yellow grain (IFN 4-02-935).

Table 8. Analysis of variance: mean squares of digestion coefficients

Source	df	Cell contents				Cell wall constituents									DE (Kcal/kg)
		Crude protein (%)	Available carbohydrates (%)	Soluble ash (%)	Total lipids (%)	Cellulose (%)	Hemicellulose (%)	Lignin (%)	Acid insoluble ash (%)	Cell walls ^a (%)	Neutral detergent fiber (%)	Acid detergent fiber (%)	Ash (%)	Dry matter (%)	
Total	47	70.59	351.0	83.94	189.6	88.35	87.14	269.7	1976	75.89	79.79	69.72	136.6	66.23	.1392
Reps	1	8.944	241.6	69.24	2420.****	.1850	23.45	.2610	12230***	6.113	5.638	39.28	205.7*	3.786	.0653
Forage (F)	1	2087.***	3266.***	832.9***	357.7	875.2***	265.6	2390***	3717	873.4***	907.0***	295.2***	3294***	621.1***	1.543***
Maturity (M)	1	167.***	1071***	232.9*	319.5*	483.3*	28.58	1148***	1746	267.4**	323.6***	330.7***	214.6***	31.27	.0682
Corn (C)	1	35.67	3080***	167.7	1555***	114.0	68.00	316.4	823.6	3.045	79.70	.1387	47.58	1607***	3.379***
Texture (T)	1	34.41	30.19	49.35	16.95	276.0***	32.16	1301***	5267	139.8**	151.5*	294.8**	292.6***	2.297	.0003
FXM	2	6.195	931.7***	8.005	54.64	27.89	117.7	854.1*	1568	63.39	187.9**	78.81	29.78	43.68	.0911
FXC	1	29.36	1488.***	33.55	.0574	3.070	15.63	73.01	600.9	.1131	11.93	12.98	123.1	7.616	.0181
FXT	1	7.084	9.337	104.1	4.380	50.84	5.207	43.47	1965	22.45	20.45	6.705	75.95	7.238	.0056
MXC	2	68.99*	731.9*	39.11	204.7	138.1*	79.24	119.0	2117	115.2	111.0*	222.8***	59.10	39.70	.0459
MXT	2	1.766	22.90	24.47	199.9	24.03	42.50	110.0	419.2	24.56	58.83	25.09	1.921	14.88	.0342
CXT	1	143.8***	74.23	275.4*	9.630	166.1*	393.0*	26.82	348.8	256.5**	233.8**	219.5**	552.6***	175.7***	.3232***
Error	32	15.12	87.30	56.37	93.45	41.27	87.38	127.0	1758	38.26	30.54	34.17	38.07	13.41	.0227

^aPlant cell walls as determined using detergent procedures by Fomnesbeck and Harris.

* P < .05

** P < .01

*** P < .001

Precautions were taken in interpreting treatment effects, since apparent digestion coefficients of some chemical constituents have been shown to vary primarily as a result of changes in the percentage of the component in the diet (Van Soest, 1967; Fannesbeck, 1969). A statistical test by Lucas et al. (1961) was used to determine whether the nutritional availability or true digestibility of a given feed constituent was the same regardless of the diet source. This gave an estimate of how much of the variation associated with the apparent digestion coefficients was due to actual true digestibility differences rather than changes only in the amount of the component in the diet.

The Lucas test involves the use of the simple regression model $Y = b_0 + b_1 X_1$; where Y equals the apparent digestible amount ($\frac{\text{digestion coef.}}{100} \times \% \text{ content}$) of a given nutrient and X_1 equals the nutrient percent content in the diet (table 10). The regression coefficient (b_1) is the estimate of the nutrient true digestibility, the regression constant (b_0) estimates the nutrient endogenous excretion, and the standard deviation of the regression coefficient (S_b) together with the coefficient of determination (R^2) estimates how uniformly the nutrient was digested (true digestibility) over the diets analyzed.

Results of the Lucas test

Crude protein and available carbohydrates were shown to be highly uniform in true digestibility across all diet treatments ($R^2 = .97$, $S_b = 2.3\%$; $R^2 = .98$, $S_b = 2.1\%$ for crude protein and available carbohydrates respectively; table 10).

The estimated true digestibility for both crude protein and available carbohydrates was near 1, showing that crude protein and

available carbohydrates are nearly 100% digested by sheep for all diets considered. High crude protein and soluble carbohydrate true digestibility and nutritional uniformity across grass and legume all-hay diets has been shown by Van Soest (1967) for cattle and sheep and by Fannesbeck (1969) for horses.

Though crude protein and available carbohydrate true digestibilities were near 100%, their apparent digestibilities were shown to be much lower (tables 6 and 7). Known endogenous crude protein or metabolic fecal crude protein from secreted enzymes, sluffing tissue cells, microorganisms, etc. is responsible for differences between crude protein true and apparent digestibilities. Blaxter and Mitchell (1948) reported 2.8% metabolic fecal protein for ruminants. The Lucas model estimated endogenous crude protein to be 3.5% for this study for sheep (table 10). As a result of metabolic crude protein, crude protein apparent digestibility is shown to decrease with a decreasing crude protein content in the diet or increase with an increasing crude protein content in the diet.

The endogenous residue for available carbohydrate was estimated as 5.1% (table 10). Fannesbeck (1969) likewise estimated a 5.1% endogenous material for soluble carbohydrates using the Lucas test involving forages fed to horses. The possible source and composition of an endogenous soluble carbohydrate residue has not been adequately studied by researchers. However, since the available carbohydrate fraction is determined by difference (available carbohydrates = cell contents - (total lipids + crude protein + soluble ash)) soluble chemical components not detected by the total lipids, crude protein, and soluble ash procedures would be counted as part of the available carbohydrate fraction.

Soluble, short chained fatty acids and carbohydrates that result from microbial breakdown of feed fibers in the lower digestive tract may contribute to an available carbohydrate endogenous fraction. Soluble microbial cell components could likewise add to an endogenous available carbohydrate residue.

The Lucas models for cellulose, cell wall, neutral detergent fiber, and crude fiber showed much higher true digestibilities than their average apparent digestibilities (table 10). A significant large endogeneous value was also shown for each of these fibrous components. These deviations illustrate that the diet type did indeed have a significant affect in changing the digestibility of feed fiber. Distinct differences between forage types were observed (tables 4, 5, 6, and 7). Grass generally was higher than alfalfa in fibrous constituents (i.e., cellulose, hemicellulose, cell walls, neutral detergent fiber, acid detergent fiber, and crude fiber) and was also shown highest in fiber digestibility. Within grass, the midbloom grass was highest in cell wall constituents compared to the other grass maturity stages and also highest in the digestibility of cell wall components. These digestibility differences as mentioned, together with other fiber digestibility variation that occurred due to other treatment factors (table 7) resulted in high regression slopes and non-theoretical endogenous fiber values. Theoretically, fiber true digestibility should be close to apparent digestibility since no endogenous fiber residue is expected.

Slopes for hemicellulose and acid detergent fiber Lucas models were closer to apparent digestibility values (table 10) than was shown by other fibrous components. Hemicellulose apparent digestibility was not significantly affected by most of the treatment factors (tables

8 and 9). The hemicellulose model endogenous value was also close to zero ($b_0 = .8$). Acid detergent fiber showed a relatively high endogenous value ($b_0 = 2.0$). The affects of diet treatments on the apparent digestibility of acid detergent fiber were comparable to those shown by cellulose, cell walls, and neutral detergent fiber (table 7).

Though moderate to high R^2 values were shown for the Lucas models for all fibrous constituents, these values were still considerably less than R^2 values for the crude protein and available carbohydrate models.

Lignin was shown to have a low true digestibility ($b_1 = .16$) and an endogenous residue close to zero ($b_0 = -.02$). Yet, nutritional uniformity was extremely low ($R^2 = .05$, $S_b = 10.6$). This was a result of large variations shown in lignin apparent digestibility values within and between alfalfa and grass diets (tables 6 and 7).

Feed total lipids was also shown to be low in true digestibility and nutritional uniformity. ($b_1 = .57$; $R^2 = .19$, $S_b = 18.0$). This was expected, since the total lipid fraction contained nonnutritive as well as nutritive lipids. Total lipid apparent digestibility varied considerably between all-hay and hay-corn diets (tables 8 and 7). Total lipid apparent digestibility was affected by the addition of corn since the added corn-oil increased the nutritive portion of the total lipid fraction in the diet. Also, the total lipid apparent digestibility was affected by an increase in the total lipid content in general due to affects of a metabolic lipid residue (i.e. bile) (Schneider and Flatt, 1970). Analytical problems experienced in lipid extraction may have also contributed substantially to variation in total lipid digestibility values.

Table 9. Treatment means of apparent digestion coefficients (main effects)

Treatments	Cell content				Cell wall constituents									
	Crude protein (%)	Available carbohydrate (%)	Soluble ash (%)	Total lipids (%)	Cellulose (%)	Hemicellulose (%)	Lignin (%)	Acid insoluble ash (%)	Cell walls ^a (%)	Neutral detergent fiber (%)	Acid detergent fiber (%)	Ash (%)	Dry matter (%)	GE (%)
<u>Forage type</u>														
Grass	56.6 ^f	73.7 ^f	49.2 ^b	41.0 ^b	52.8 ^f	54.8 ^b	25.4 ^f	7.8 ^b	47.9 ^f	47.7 ^f	44.6 ^f	34.0 ^f	57.7 ^f	57.5 ^f
Alfalfa	69.5 ^g	89.9 ^g	56.0 ^b	48.6 ^b	42.7 ^g	50.1 ^b	8.2 ^g	-9.6 ^b	38.5 ^g	39.6 ^g	39.6 ^g	52.9 ^g	65.0 ^g	64.6 ^g
<u>Forage maturity</u>														
Late vegetative	66.1 ^f	85.0 ^f	56.2 ^b	42.1 ^b	50.7 ^f	53.0 ^b	13.9 ^f	-6.0 ^b	44.5 ^d	45.5 ^f	44.2 ^f	48.8 ^f	62.8 ^b	62.2 ^b
Midbloom	63.1 ^f	72.8 ^g	50.8 ^c	44.6 ^b	49.6 ^e	53.5 ^b	23.5 ^g	-7.8 ^b	45.7 ^d	46.7 ^f	45.1 ^f	42.9 ^g	61.2 ^b	61.4 ^b
Fullbloom	60.0 ^g	87.7 ^f	50.9 ^c	47.6 ^c	43.1 ^g	50.9 ^b	12.9 ^f	8.0 ^b	39.5 ^c	38.8 ^g	37.0 ^g	38.8 ^h	60.0 ^b	59.6 ^b
<u>Energy level</u>														
All hay diets	63.8 ^b	73.7 ^f	53.8 ^b	40.2 ^f	48.5 ^b	51.3 ^b	12.6 ^b	-5.15 ^b	42.5 ^b	44.7 ^b	42.0 ^b	43.4 ^b	55.5 ^f	55.1 ^f
Corn-hay diets (50:50)	62.4 ^b	90.0 ^g	51.5 ^b	49.4 ^g	47.0 ^b	53.6 ^b	20.9 ^b	3.3 ^b	43.9 ^b	42.7 ^b	42.2 ^b	43.6 ^b	67.2 ^g	67.1 ^g
<u>Texture</u>														
Coarse	62.1 ^b	80.9 ^b	50.9 ^b	45.3 ^b	59.3 ^f	53.3 ^b	20.4 ^f	-11.2 ^b	44.4 ^b	45.7 ^b	44.6 ^b	39.9 ^f	61.5 ^b	61.4 ^b
Pelleted	64.0 ^b	82.8 ^b	54.4 ^b	44.3 ^b	46.2 ^g	51.7 ^b	13.1 ^g	9.5 ^b	42.0 ^c	41.6 ^c	39.6 ^c	47.1 ^g	61.2 ^b	60.8 ^b

^aPlant cell walls as determined using detergent procedures by Fommesbeck and Harris (1970a).

^{b,c}Means of the same nutrient component and the same factor with the same superscript are not significantly different; $P < .05$

^{d,e}Means of the same nutrient component and the same factor with the same superscript are not significantly different; $P < .01$

^{f,g,h}Means of the same nutrient component and the same factor with the same superscript are not significantly different; $P < .001$

Table 10. Simple regression of apparent digestible amount with chemical content of the diet

Chemical fraction	Avg. content \bar{x}	Avg. apparent digestible amount \bar{y}	Avg. apparent digestibility	Estimated genous excretion (b_0)	Estimated true digestibility (b_1)	Standard deviation of the regression coefficient (S_{b_1})	Residual Standard deviation ($S_{\bar{y}}$)	R^2
Fibrous fraction:								
Cell wall ^a	41.7	18.2	43.2	-4.9	55.5	4.0	3.5	.808
Cellulose	22.1	10.6	47.8	-2.5	58.9	4.5	2.0	.790
Hemicellulose	12.6	6.8	52.4	-0.8	60.4	3.2	1.1	.888
Lignin	5.4	0.8	16.8	-0.02	16.0	10.6	1.0	.048
Soluble fraction:								
Available carbohydrate	32.6	28.4	81.8	-5.1	103.0	2.1	1.8	.981
Crude protein (N x 6.25)	13.6	8.6	63.1	-3.5	90.3	2.3	0.5	.971
Total lipids	5.5	2.5	44.8	-0.7	57.0	18.0	0.8	.189
Soluble ash	6.9	3.7	52.6	-1.4	72.5	4.3	0.5	.862
Other fractions:								
Neutral detergent fiber	44.1	19.9	45.1	-7.8	63.0	4.1	3.7	.837
Acid detergent fiber	31.0	13.2	42.6	-2.0	49.0	4.9	2.7	.686
Crude fiber	25.1	10.9	43.4	-5.9	67.1	5.5	3.1	.762

^aPlant cell wall residues were determined using procedures by Fonesbeck and Harris (1970a).

Feed ash was shown to be relatively uniform nutritionally ($R^2 = .86$, $S_b = 4.3$) in spite of the fact it also was composed of a nonnutritive portion, insoluble ash (silica) and a nutritive portion, soluble ash. The estimated true digestibility for ash was also high ($b_1 = .73$). The apparent digestibility of ash is also affected considerably by changes in the ash content of the diet alone as a result of a substantial ash endogenous residue (Schneider and Flatt, 1975).

Results of the analysis of variances

Forage type. Highly significant apparent digestibility differences between the forage types were observed for nearly all of the fibrous components (tables 8 and 9). Cell walls, neutral detergent fiber, acid detergent fiber and cellulose were shown to be more digestible in grass than alfalfa ($P < .001$). Hemicellulose was more digestible in grass than in alfalfa by sheep but was not significantly different in digestibility. Moir (1972), working with temporal and tropical species of grasses and legumes also fed to sheep, showed that on the average grass cell walls were 40.0% digestible versus 19.8% digestible for legume cell walls.

A considerable amount of variability was observed between lignin digestion coefficients within and between forage types (tables 6 and 7). Grass lignin was more digestible than alfalfa lignin for all maturity levels. In the all-hay diets only, the grass lignin digestibility coefficients were surprisingly high, ranging from 25.8% to 7.1% with a mean of 20.8%. No negative digestion coefficients were observed for the grass diets. However, several negative lignin digestibility coefficients were calculated for the alfalfa diets. Alfalfa lignin digestibility ranged from 17.1% to -1.3% with an average of 4.5%.

It is difficult to pinpoint the source of the high lignin digestibility variation, since several avenues for variation are available. High lignin digestibility variation may partly arise from inaccuracies in the chemical extraction of lignin. Earlier criticisms of the 72% sulfuric acid extraction of lignin were that the lignin residue was contaminated with protein and carbohydrate (hemicelluloses) residues (Norman and Jenkins, 1933). Lignin contamination resulted in highly variable lignin percentages between feed types. Ellis et al. (1946) introduced a pre-pepsin digest in combination with a pre 5% sulfuric acid extraction in addition to the 72% sulfuric acid procedure which serve to eliminate much of the problem of protein and carbohydrate residues contaminating the final lignin sample. Sullivan (1955), however, reported high lignin digestibility variations for lignin inspite of the improved lignin extraction procedures. Procedures by Fønnesbeck and Harris (1970) used to determine lignin composition in this study are very similar to those proposed by Ellis et al. (1946). Yet, a large lignin digestibility variation was also shown.

It may be speculated that lignin digestibility variations may also be a result of feed lignin reacting differently to the chemical extraction than lignin in the feces. Gordon (1975) has shown that the alkali recovery of lignin is significantly different between legumes and grasses and between feed and feces for the respective forage types. Of the lignin extracted with alkali, some is lost as ferulic and p-coumaric acid and some core lignin is lost in the supernatant liquor with hemicellulose. Lignin in feces and feed may likewise differ in reactivity to strong acid.

Though lignin has been theoretically dubbed an indigestible component of forage, the possibility of actual lignin digestibility must not be discounted until more accurate experimental techniques substantially prove otherwise. In this experiment, it was shown that the digestibility of cell walls in alfalfa followed the classic pattern by decreasing with increasing lignin content (table 5). However, the digestibility of grass cell walls more closely followed the digestibility pattern of lignin (table 6). The calculated digestibility of cell wall residues would not be affected by errors in the chemical extraction of lignin.

Crude protein, available carbohydrate, dry matter and gross energy were shown to be significantly more digestible in alfalfa (tables 8 and 9).

Studies by Keys et al. (1969) and Donker et al. (1976) showed no significant difference between grass and alfalfa dry matter apparent digestibilities by sheep, but showed a significantly higher apparent digestibility for alfalfa crude protein.

Since alfalfa was higher in crude protein and available carbohydrate content than grass, it naturally would follow that crude protein and available carbohydrate apparent digestibilities for alfalfa would also be higher than in grass. This is true since crude protein and available carbohydrate apparent digestibilities are highly dependent on compositional changes :

The alfalfa diet dry matter averaged 66.2% in cell contents while grass dry matter averaged 50.3% in cell contents. This showed that the alfalfa was substantially higher than grass in a rich source of energy from readily available lipids, carbohydrates, and protein and helps

explain why alfalfa was significantly higher than grass in dry matter and gross energy apparent digestibility.

Stage of maturity . Forage maturity was also shown to be a significant factor in altering apparent digestibilities for most of the feed constituents.

There was no significant difference in the apparent digestibility of cell walls between late vegetative and midbloom stages (table 9). However, the fullbloom stage was significantly lower than the late vegetative or midbloom stages in cell wall digestibility. This pattern also held true for neutral detergent fiber and acid detergent fiber apparent digestibilities as well.

Comparing maturity effects on the apparent digestibility of cellulose, hemicellulose, and lignin; no significant maturity effects were observed for hemicellulose apparent digestibility between any of the maturity levels. Maturity significantly affected the apparent digestibility of cellulose in the same manner as was shown for cell walls, neutral detergent fiber, and acid detergent fiber. Lignin apparent digestibility was significantly higher in the midbloom stage than in the late vegetative stage or fullbloom stages. No significant difference was shown between late vegetative and fullbloom stages.

A cancellation effect was observed when grass and alfalfa data were combined to determine the maturity main effects on cell walls, neutral detergent fiber, and acid detergent fiber apparent digestibilities. It is observed in the forage type-by-stage of maturity two-way tables (appendix tables 28, 30, and 32) that the apparent digestibility of cell walls, neutral detergent fiber, or acid detergent fiber in midbloom grass is much greater than in late vegetative or

fullbloom grass (a significant difference was calculated for neutral detergent fiber only). However, in alfalfa; cell walls, neutral detergent fiber, and acid detergent fiber apparent digestibility decreased with each increasing maturity stage. When grass values were added to alfalfa values, the higher fiber (cell walls, neutral detergent fiber, or acid detergent fiber) digestibility values for midbloom grass combined with the low midbloom alfalfa values to give average digestibility values acrossed forages nearly equal to those for the late vegetative stage. However, cell wall, neutral detergent fiber or acid detergent fiber digestibility for the fullbloom stage remained significantly lower than for the late vegetative stage or midbloom stages. A similar cancellation effect was also observed for cellulose.

A look at the forage type-by-stage of maturity two-way table for lignin shows that lignin in midbloom grass was unusually high in apparent digestibility (37.6%). When grass and lignin apparent digestibility values were combined to determine maturity main effects, the low lignin digestion coefficients for alfalfa combined with the higher lignin digestion coefficients for grass resulting in no significant difference in lignin digestibility between late vegetative and fullbloom stages. But, midbloom forage lignin remained significantly high in apparent digestibility due to the extremely high lignin apparent digestibility in midbloom grass (see also table 9).

Crude protein was shown to be significantly lower in apparent digestibility in diets containing fullbloom forage than in diets containing late vegetative or midbloom forage (table 9). No significant difference was shown between late vegetative and midbloom crude protein apparent digestibilities (table 9). The decrease in crude protein

content was relatively small between late vegetative and midbloom stages within alfalfa or grass diets (tables 4 and 5). However, both forage types showed a large drop in crude protein content for the fullbloom stage resulting in a significantly lower crude protein apparent digestibility in the fullbloom stage.

Available carbohydrate digestibility was shown to be significantly lower in the midbloom maturity stage than in the late vegetative or fullbloom stages (table 9). The available carbohydrate difference between late vegetative and fullbloom stages was not significant. The extremely low available carbohydrate concentration in midbloom grass was the principle cause of the significantly low available carbohydrate apparent digestibility in midbloom diets.

Dry matter and gross energy apparent digestibilities decreased with increasing maturity; however, differences were not significant.

Energy level . Significant apparent digestibility differences between all-hay and hay-corn diets were shown available carbohydrate and total lipid constituents only (table 9). Available carbohydrate and total lipid apparent digestibilities were significantly higher for the hay-corn diets.

Available carbohydrate digestibility increases for the hay-corn diets were again a result of an increase in the available carbohydrate content. The addition of corn containing large amounts of starch and other readily soluble carbohydrates significantly increased the available carbohydrate content of the diet (tables 4 and 5).

The increase in total lipid apparent digestibility for corn-hay diets was partly a result of an increase in lipid content from added corn oil. The added corn oil, however, also increased the nutritive

portion of the total lipid fraction making the total lipid fraction more digestible.

Texture level. Pelleting the diet was shown to significantly lower the apparent digestibility of cellulose, lignin, cell walls, neutral detergent fiber, and acid detergent fiber (tables 8 and 9). Hemicellulose apparent digestibility was not significantly affected by pelleting, though hemicellulose values were lower in pelleted diets.

The apparent digestibility of ash was also significantly lowered by pelleting. This was unexpected since a significant digestibility difference was not shown for the soluble ash fraction between texture levels.

Since chemical composition was not significantly different between texture levels, it may be safely concluded that differences in diet digestion coefficients between pelleted and coarse diets were due to feed processing only.

It was observed that crude protein and available carbohydrate apparent digestibilities were not significantly affected by feed pelleting. This supports the previous conclusion that crude protein and available carbohydrate apparent digestibility is primarily affected by a change in the crude protein and available carbohydrate composition of the diet only.

Forage-by-maturity interactions. A significant forage-by-maturity interaction effect on the apparent digestibility of neutral detergent fiber and lignin was observed (table 8). If the forage-by-maturity tables for cell walls, neutral detergent fiber and acid detergent fiber are examined (appendix tables 28, 30, and 32 respectively), it is shown that generally apparent digestibilities of these fibrous constituents

in alfalfa decreased with increasing maturity; however, this trend was not maintained in grass. Cell walls, neutral detergent fiber, and acid detergent fiber in midbloom grass were much more digestible than in the late vegetative and fullbloom grass stages. Forage-by-maturity interaction effects observed for cell walls and acid detergent fiber were not significant but were comparable to forage-by-maturity differences shown for neutral detergent fiber.

The forage-by-maturity table for cellulose (appendix table 23) shows that cellulose apparent digestibilities in late vegetative and midbloom grass were nearly equal. But, if cellulose digestible amounts ($\% \text{ content} \times \frac{\text{digestion coefficient}}{100}$) are calculated, cellulose in midbloom grass appears more digestible than in late vegetative and fullbloom grass. Therefore, cellulose apparent digestibility followed the same forage-by-maturity pattern as cell walls, neutral detergent fiber, and acid detergent fiber. Hemicellulose apparent digestibility also followed a like pattern.

Lignin apparent digestibility appeared to be a key factor behind the forage-by-maturity interaction effect on the apparent digestibility of fibrous constituents. In a forage-by-maturity table for lignin (appendix table 27) it is shown that lignin was much higher in apparent digestibility in midbloom grass than in late vegetative and fullbloom grass. Differences in lignin digestibility between alfalfa maturity levels were small.

The available carbohydrate content in midbloom grass was much lower than in the late vegetative and full bloom grass (table 5). This resulted in an extremely low available carbohydrate digestibility in midbloom grass (table 7). Hence, a highly significant ($P < .001$)

forage-by-maturity interaction was observed to affect available carbohydrate apparent digestibility (table 8 and appendix table 21).

Forage-by-energy level interactions. A forage-by-energy level interaction significantly affected available carbohydrate apparent digestibility only (table 8). When the forage-by-energy level table is examined a significantly large difference in available carbohydrate apparent digestibility between grass energy levels is observed, compared to the much smaller difference between the alfalfa energy levels. As was shown for the forage-by-maturity interaction, the extremely low available carbohydrate content of the midbloom grass was probably primarily responsible for the forage-by-energy level interaction effect on available carbohydrate digestibility.

Forage-by-texture interactions. No significant forage-by-texture interaction effects were observed (table 8).

Maturity-by-energy level interactions. A significant maturity-by-energy level interaction affected the apparent digestibility of crude protein, available carbohydrates, cellulose, neutral detergent fiber, and acid detergent fiber (table 8).

In the maturity-by-energy level tables for cellulose, neutral detergent fiber, and acid detergent fiber (appendix tables 24, 31, and 33) it is shown that the digestibility of these fibrous components in hay-corn diets decreased with increasing maturity. However, this digestibility pattern did not occur in the all-hay diets. The apparent digestibility of neutral detergent fiber, acid detergent fiber, and cellulose was substantially greater in the midbloom all-hay diets than in the late vegetative or fullbloom all-hay diets. Also, it is observed that, though the fibrous components in the hay-corn diets

tended to be of greater digestibility than in the all-hay diets at the late vegetative and fullbloom stages, the opposite was true at the midbloom maturity stage.

As was shown in previous sections, fibrous constituents in midbloom grass were much more digestible than in late vegetative or fullbloom grass. This condition was probably the major cause of the significant maturity-by-energy level differences among the fiber constituents.

Hemicellulose and cell wall apparent digestibilities followed a like pattern as other fibrous constituents, though differences were not significant.

The crude protein apparent digestibility pattern between all-hay and hay-corn diets was altered by an increase in crude protein content in the fullbloom hay-corn diet (table 7). The fullbloom grass was so low in crude protein that the addition of corn with fullbloom grass significantly increased the crude protein content of the diet. The crude protein maturity-by-energy level table (appendix table 20) shows a change in the crude protein digestibility trend between all-hay and hay-corn diets at the fullbloom maturity level. Crude protein became more digestible in the hay-corn diets at the mature level.

In the maturity-by-energy level table for available carbohydrates (appendix table 22) it is shown that the available carbohydrate apparent digestibility difference between the all-hay and hay-corn diets was distinctly greater at the midbloom stage than at the late vegetative or fullbloom stages. As was mentioned earlier, the extremely low available carbohydrate concentration in the midbloom grass resulted in a very low digestion coefficient for available carbohydrate in midbloom grass.

The midbloom grass coefficient was so low that the higher available carbohydrate coefficient for midbloom alfalfa was not enough to offset the low grass value when digestibility was averaged across forage types.

Maturity-by-texture interactions. No significant maturity-by-texture interaction effects were observed (table 7).

Energy level-by-texture interactions. A significantly large decrease in apparent digestibility of all fibrous constituents (cellulose, hemicellulose, cell walls, neutral detergent fiber, and hemicellulose) with pelleted diets is shown in the energy level-by-texture tables (appendix tables 24, 26, 29, 31, and 33). Significance is clearly shown in tables 8 and 9 showing texture level main effects. Pelleting forage diets increased the rate of passage of digesta through the sheep GI tract, limiting fermentation time and resulting in a lowered fiber digestibility (Blaxter *et al.*, 1956).

The energy level-by-texture tables also show clearly that combining corn with coarse hay also reduced fiber apparent digestibility considerably. However, the opposite phenomena was observed for hay-corn pelleted diets. Fiber digestibility increased going from pelleted all-hay diets to pelleted hay-corn diets. A significant lowering of fiber digestibility by combining corn with hay was not indicated in tables 8 or 9 because differences due to the energy-level-by-texture interaction cancelled one another out when digestion coefficients were averaged over coarse and pelleted diets.

An energy level-by-texture interaction also significantly affected the apparent digestibility of diet crude protein, soluble ash, ash, dry matter, and gross energy (tables 8 and 9).

Regression Analysis

Estimating nutrient digestible amount from nutrient percent content

Simple equations. Equations of the form $Y = b_0 + b_1X_1$ were generated for separate nutrient components of the experimental diets, where Y equaled the nutrient digestible amount and X equaled the nutrient percent content (table 10). This statistical model was used by Lucas et al., (1961) in estimating the true digestibility (b_1) of a given chemical component in animal feeds. For the results and discussion of these procedures see Digestibility of Diet Chemical Constituents, p 43.

Complex equations. Two types of multivariate equations were generated by using indicator or dummy variables¹ in addition to the nutrient percent content to predict nutrient digestible amount. The indicator variables were added to the model to adjust for variability due to the treatment main effects and interaction effects. The analysis of variance was used as a guide in picking the treatment factors that showed a substantial influence on the digestibility of a given feed component.

Linear models were explored first and showed such high precision in predictability that curvilinear models were not considered.

The first type (Type I) of complex model generated, contained the quantitative variable ($X =$ nutrient percent content) together with added qualitative variable (indicator variable) main effects (α_i , β_j , γ_k , and δ_l) and interactions ($\alpha\beta_{ij}$, $\alpha\delta_{ik}$, $\beta\gamma_{jk}$, $\alpha\delta_{ik}$, $\beta\delta_{jk}$, and $\gamma\delta_{lk}$).

¹Indicator variable: a quantitative indicator used in a regression model to identify the classes of a qualitative variable (Neter and Wasserman, 1974, p. 298).

Table 11. Type I regression models for estimating nutrient digestible amount (%) from nutrient content (%)

Item		Feed nutrient ¹								
		Crude protein	Available carbohydrates	Total lipids	Cellulose	Hemi-cellulose	Cell walls ²	Neutral detergent fiber	Acid detergent fiber	Crude fiber
Regression constant	b_0	-3.7504	-2.0591	-2.5379	-6.2864	-2.7957	-10.4709	-8.7188	-9.3893	-12.8850
Regression coefficient	b_1	.9251	.9359	.9218	.7624	.7585	.6882	.6498	.7172	.9508
Adjustments to regression constant for specification of diet ³										
Forage type										
Alfalfa	a_1	--	1.2951	.1607	-.2583	.7398	.2759	-.4240	-.0390	-.8822
Grass	a_2	--	-1.2951	-.1607	.2583	-.7398	-.2759	.4240	.0390	.8822
Stage of Maturity										
Early	B_1	-.0384	-.1513	-.1497	1.0519	.3946	1.2903	1.1362	.9152	1.2027
Mid	B_2	-.2557	-.5203	-.0132	.4815	.0378	1.1022	1.5118	1.0262	.6197
Late	B_3	.2941	.6716	.1629	-1.5334	-.4324	-2.3925	-2.6480	-1.9414	-1.8224
Energy level										
Hay	Y_1	-.0075	-.7739	-.4862	-1.2699	-.3893	-2.1786	-1.1302	-2.1838	-2.9492
Hay + corn	Y_2	.0075	.7739	.4862	1.2699	.3893	2.1786	1.1302	2.1838	2.9492
Texture										
Coarse	δ_1	-.0515	-.1302	-.0016	-.5788	.1191	.7850	.8403	.7356	.6227
Pelleted	δ_2	.0515	.1302	.0016	.5788	-.1191	-.7850	-.8403	-.7356	-.6227
Diet interactions										
Alfalfa x early	$a\delta_{11}$	--	--	--	-.5974	-.3575	-1.0258	-.4817	-.4689	-.6545
Alfalfa x mid	$a\delta_{12}$	--	--	--	-.1589	-.0234	-.2035	-1.1152	-.1935	-.1928
Alfalfa x late	$a\delta_{13}$	--	--	--	.4385	.3784	1.2293	1.5969	.6624	.4617
Grass x early	$a\delta_{21}$	--	--	--	-.5974	-.3575	1.0258	.4817	.4689	.6545
Grass x mid	$a\delta_{22}$	--	--	--	-.1589	-.0234	-.2035	1.1152	.1935	-.1928
Grass x late	$a\delta_{23}$	--	--	--	-.4385	-.3784	-1.2293	-1.5969	-.6624	-.4617
Early x hay	$B\gamma_{11}$	-.0961	--	--	-.1532	.0033	-.3030	-.4062	-.2892	-.1868
Mid x hay	$B\gamma_{21}$	-.1923	--	--	.7779	.3751	1.4040	1.5761	1.3163	1.0188
Late x hay	$B\gamma_{31}$	-.0962	--	--	-.6247	-.3543	-1.1010	1.1699	-1.0271	-.8320
Early x hay + corn	$B\gamma_{12}$	-.0961	--	--	-.1532	-.0033	.3030	.4062	.2892	.1868
Mid x hay + corn	$B\gamma_{22}$	-.1923	--	--	-.7779	-.3751	-1.4040	-1.5761	-1.3163	-1.0188
Late x hay + corn	$B\gamma_{32}$	.0962	--	--	.6247	.3543	1.1010	-1.1699	1.0271	.8320
Early x coarse	$\delta\delta_{11}$	--	--	-.1761	-.2429	--	--	-.1929	--	--
Mid x coarse	$\delta\delta_{21}$	--	--	-.0716	-.0879	--	--	-.5566	--	--
Late x coarse	$\delta\delta_{31}$	--	--	-.2477	-.3308	--	--	.7495	--	--
Early x pelleted	$\delta\delta_{12}$	--	--	.1761	.2429	--	--	.1929	--	--
Mid x pelleted	$\delta\delta_{22}$	--	--	.0716	.0879	--	--	.5566	--	--
Late x pelleted	$\delta\delta_{32}$	--	--	-.2477	-.3308	--	--	-.7495	--	--
Hay x coarse	$Y\delta_{11}$	.2289	.4829	-.0011	.4568	.3252	.9347	1.0286	.7410	.5994
Hay x pelleted	$Y\delta_{12}$	-.2289	-.4829	.0011	-.4568	-.3252	-.9347	-1.0286	-.7410	-.5994
Hay + corn x coarse	$Y\delta_{21}$	-.2289	-.4829	.0011	-.4568	-.3252	-.9347	-1.0286	-.7410	-.5994
Hay + corn x pelleted	$Y\delta_{22}$	.2289	.4829	-.0011	.4568	.3252	.9347	1.0286	.7410	.5994
Coefficient of determination	R^2	.981	.989	.552	.944	.936	.945	.958	.926	.955
Residual standard deviation	(%)	.5	1.5	.6	1.2	.9	2.1	2.2	1.5	1.5
Coefficient of variation	(%)	5.7	5.3	23.9	11.4	13.3	11.5	11.0	11.4	13.7

¹Equations are of the form $Y = b_0 + b_1X_1 + a_1 + B_3 + Y_k + \delta_k + a\delta_{1j} + B\gamma_{jk} + \delta\delta_{jk} + Y\delta_{kk}$; where Y is the predicted digestible amount, and X_1 is the percent nutrient content with the respective regression constant (b_0) and regression coefficient (b_1). The regression constant is further adjusted by qualitative indicators ($a_1, B_3, Y_k, \dots, Y\delta_{kk}$) according to the description of the ingredient or diet. All indicators must be used as they apply. For example, if the diet was alfalfa hay (a_1), late maturity (B_3), fed alone (Y_1), and pelleted (δ_2); the calculation for percent digestible CL for a feed containing 20% CL would be: $Y = b_0 + (b_1X_1) + a_1 + B_3 + Y_1 + \delta_2 + a\delta_{31} + B\gamma_{31} + \delta\delta_{32} + Y\delta_{12} = -6.286 + [(1.762)(20)] + .258 - 1.533 - 1.270 - .579 + .439 - .625 - .131 + .457 = 4.3\%$.

²Plant cell walls as determined using procedures by Fornesbeck and Harris (1970a).

only. A type I equation was generated for each nutrient that contributed to the energy value of a given diet and was of the form: $Y = b_0 + b_1X_n + \alpha_i + \beta_j + \gamma_k + \delta_l + \alpha\gamma_{ij} + \beta\delta_{jl} + \alpha\delta_{il} + \beta\delta_{jl} + \gamma\delta_{lk}$.

A stepwise regression process was used to select the combination of indicator variables (main effects and interactions) that accounted for the most variation in predictability.

An adjustment to the regression constant (b_0) was brought about by the added indicator variables (see footnote a of table 11).

The second type of (Type II) complex models differed from Type I models in that they contained interactions between the quantitative and qualitative variables (α_iX_1, β_jX_1 , etc.) in addition to the variables already shown for Type I equations. Type II equations were of the form: $Y = b_0 + b_1X_1 + \alpha_i + \beta_j + \gamma_k + \delta_l + \alpha\beta_{ij} + \dots + \gamma\delta_{kl} + \alpha_iX_1 + \beta_jX_1 + \gamma_kX_1 + \delta_lX_1 + \alpha\beta_{ij}X_1 + \dots + \gamma\delta_{kl}X_1$.

The added qualitative-by-quantitative variable interactions affected the predictability of the equation by making adjustments to the regression coefficient (b_1) (see footnote a of table 12). A stepwise regression process was also used to select the combination of variables that accounted for the most variation in prediction.

All Type I equations showed a significant improvement over the simple equations in estimating the digestible amount of each nutrient in question (compare tables 10 and 11). All Type I equations showed higher coefficients of determination (R^2) than those shown by the simple equations (crude protein, .98 vs .97; available carbohydrate, .99 vs .98, total lipids, .55 vs .19; hemicellulose, .94 vs .89; cellulose, .94 vs .79; cell walls, .95 vs .81; neutral detergent fiber, .96 vs .84; acid detergent fiber, .93 vs .69; crude fiber, .94 vs .76).

Table 12. Type II regression models for estimating digestible amount (%) from nutrient content (%)

Item		Feed nutrient ^a						
		Crude protein	Cellulose	Hemi-cellulose	Cell Walls ^b	Neutral detergent fiber	Acid detergent fiber	Crude fiber
Regression constant	b_0	-3.9441	2.1611	-6.3469	-27.0561	28.3977	-11.5693	-15.5339
Regression coefficient	b_1	.9382	.4688	1.0490	1.0716	-.2471	.7993	1.0541
Adjustments to regression constant (b_0) for specification of diet ^b								
Forage type								
Alfalfa	a_1	--	-.2654	2.1133	3.7873	-8.6064	.0925	1.2900
Grass	a_2	--	.2564	-2.1133	-3.7873	8.6064	-.0925	-1.2900
Stage of maturity								
Early	β_1	.0124	14.2851	2.4706	1.6760	-12.8500	.7461	2.0065
Mid	β_2	-.3535	-7.3318	-8.140	-.1535	43.9395	1.9309	1.5760
Late	β_3	.3411	-6.9533	-1.6566	-1.5226	-31.0895	-2.6770	-3.5825
Energy level								
Hay	γ_1	.3052	9.9419	1.5251	-4.7457	-8.5685	-2.5655	-3.6474
Hay + corn	γ_2	-.3052	-9.9419	-1.5251	4.7457	8.5685	2.5655	3.6474
Texture								
Coarse	δ_1	--	-1.5635	-.6490	-1.4071	1.5298	1.4205	-1.6289
Pelleted	δ_2	--	1.5635	.6490	1.4071	-1.5298	-1.4205	1.6289
Diet interactions								
Alfalfa x early	$\alpha\beta_{11}$	--	--	-6.8831	-14.0684	5.2902	-.6172	-.9695
Alfalfa x mid	$\alpha\beta_{12}$	--	--	1.4088	17.0324	-5.1219	-.1022	.4615
Alfalfa x late	$\alpha\beta_{13}$	--	--	5.4743	-2.9640	-1.6583	.7194	.5080
Grass x early	$\alpha\beta_{21}$	--	--	6.8831	14.0684	-5.2902	.6172	.9695
Grass x mid	$\alpha\beta_{22}$	--	--	-1.4088	17.0324	5.1219	.1022	-.4615
Grass x late	$\alpha\beta_{23}$	--	--	-5.4743	-2.9640	1.6583	-.7194	-.5080
Early x hay	$\beta\gamma_{11}$	.2258	24.8169	-1.4994	-15.5917	-2.7986	-1.4593	1.7301
Mid x hay	$\beta\gamma_{12}$	-1.3993	-9.5070	-.3396	18.5059	9.4927	5.6044	5.8289
Late x hay	$\beta\gamma_{13}$	1.1735	-15.3099	1.8386	-2.9142	-6.6941	-4.1451	-7.5590
Early x hay + corn	$\beta\gamma_{12}$	-.2258	-24.8169	1.4994	15.5917	2.7986	1.4593	-1.7301
Mid x hay + corn	$\beta\gamma_{22}$	1.3993	9.5070	.3396	-18.5059	-9.4927	-5.6044	-5.8289
Late x hay + corn	$\beta\gamma_{32}$	-1.1735	15.3099	-1.8386	2.9142	6.6941	4.1451	7.5590
Early x coarse	$\beta\delta_{11}$	--	--	--	--	--	--	.0719
Mid x coarse	$\beta\delta_{12}$	--	--	--	--	--	--	-.4974
Late x coarse	$\beta\delta_{13}$	--	--	--	--	--	--	.4255
Early x pelleted	$\beta\delta_{21}$	--	--	--	--	--	--	-.0719
Mid x pelleted	$\beta\delta_{22}$	--	--	--	--	--	--	.4974
Late x pelleted	$\beta\delta_{23}$	--	--	--	--	--	--	-.4255
Hay x coarse	$\gamma\delta_{11}$	--	2.1669	--	3.1469	.5692	4.0431	--
Hay x pelleted	$\gamma\delta_{12}$	--	-2.1669	--	-3.1469	-.5692	-4.0431	--
Hay + corn x coarse	$\gamma\delta_{21}$	--	-2.1669	--	-3.1469	-.5692	-4.0431	--
Hay + corn x pelleted	$\gamma\delta_{22}$	--	2.1669	--	3.1469	.5692	4.0431	--
Adjustments to regression coefficient (b_1) for specification of diet ^b								
CP x hay	$\gamma_1 X_1$	-.0329	--	--	--	--	--	--
CP x hay + corn	$\gamma_2 X_1$	.0329	--	--	--	--	--	--
CP x (early x hay)	$\beta\gamma_{11} X_1$	-.0099	--	--	--	--	--	--
CP x (mid x hay)	$\beta\gamma_{21} X_1$	.1205	--	--	--	--	--	--
CP x (late x hay)	$\beta\gamma_{31} X_1$	-.1106	--	--	--	--	--	--
CP x (early x hay + corn)	$\beta\gamma_{12} X_1$	.0099	--	--	--	--	--	--
CP x (mid x hay + corn)	$\beta\gamma_{22} X_1$	-.1205	--	--	--	--	--	--
CP x (late x hay + corn)	$\beta\gamma_{32} X_1$	.1106	--	--	--	--	--	--

TABLE 12 (Continued)

Item	Feed nutrient ^a						
	Crude protein	Cellulose	Hemi-cellulose	Cell Walls ^b	Neutral detergent fiber	Acid detergent fiber	Crude fiber
CL x early	B ₁ X ₁	--	-.3778	--	--	--	--
CL x mid	B ₂ X ₁	--	.2723	--	--	--	--
CL x late	B ₃ X ₁	--	.1055	--	--	--	--
CL x hay	Y ₁ X ₁	--	-.4804	--	--	--	--
CL x hay + corn	Y ₂ X ₁	--	.4804	--	--	--	--
CL x coarse	G ₁ X ₁	--	.1264	--	--	--	--
CL x pelleted	G ₂ X ₁	--	-.1264	--	--	--	--
CL x (early x hay)	B _{Y1} X ₁	--	-1.1323	--	--	--	--
CL x (mid x hay)	B _{Y2} X ₁	--	.4484	--	--	--	--
CL x (late x hay)	B _{Y3} X ₁	--	.6839	--	--	--	--
CL x (early x hay + corn)	B _{Y12} X ₁	--	1.1323	--	--	--	--
CL x (mid x hay + corn)	B _{Y22} X ₁	--	-.4484	--	--	--	--
CL x (late x hay + corn)	B _{Y32} X ₁	--	-.6839	--	--	--	--
CL x (hay x coarse)	Y _{G1} X ₁	--	-.1062	--	--	--	--
CL x (hay x pelleted)	Y _{G2} X ₁	--	.1062	--	--	--	--
CL x (hay + corn x coarse)	Y _{G3} X ₁	--	.1062	--	--	--	--
CL x (hay + corn x pelleted)	Y _{G22} X ₁	--	-.1062	--	--	--	--
HC x hay	Y ₁ X ₁	--	-.1769	--	--	--	--
HC x hay + corn	Y ₂ X ₁	--	.1769	--	--	--	--
HC x coarse	Y ₁ X ₁	--	.0626	--	--	--	--
HC x pelleted	G ₁ X ₁	--	-.0626	--	--	--	--
HC x (alfalfa x early)	O _{B1} X ₁	--	.5446	--	--	--	--
HC x (alfalfa x mid)	O _{B2} X ₁	--	-.1019	--	--	--	--
HC x (alfalfa x late)	O _{B3} X ₁	--	-.4427	--	--	--	--
HC x (grass x early)	O _{G1} X ₁	--	-.5446	--	--	--	--
HC x (grass x mid)	O _{G2} X ₁	--	.1019	--	--	--	--
HC x (grass x late)	O _{G3} X ₁	--	.4427	--	--	--	--
HC x (early x hay)	B _{Y1} X ₁	--	.1704	--	--	--	--
HC x (mid x hay)	B _{Y2} X ₁	--	.0414	--	--	--	--
HC x (late x hay)	B _{Y3} X ₁	--	-.2118	--	--	--	--
HC x (early x hay + corn)	B _{Y12} X ₁	--	-.1704	--	--	--	--
HC x (mid x hay + corn)	B _{Y22} X ₁	--	-.0414	--	--	--	--
HC x (late x hay + corn)	B _{Y32} X ₁	--	.2118	--	--	--	--
CW x coarse	G ₁ X ₁	--	--	.0625	--	--	--
CW x pelleted	G ₂ X ₁	--	--	-.0625	--	--	--
CW x (alfalfa x early)	O _{B1} X ₁	--	--	.3064	--	--	--
CW x (alfalfa x mid)	O _{B2} X ₁	--	--	-.3940	--	--	--
CW x (alfalfa x late)	O _{B3} X ₁	--	--	.0876	--	--	--
CW x (grass x early)	O _{G1} X ₁	--	--	-.3064	--	--	--
CW x (grass x mid)	O _{G2} X ₁	--	--	.3940	--	--	--
CW x (grass x late)	O _{G3} X ₁	--	--	-.0876	--	--	--
CW x (early x hay)	B _{Y1} X ₁	--	--	.4062	--	--	--
CW x (mid x hay)	B _{Y2} X ₁	--	--	-.4324	--	--	--
CW x (late x hay)	B _{Y3} X ₁	--	--	.0262	--	--	--
CW x (early x hay + corn)	B _{Y12} X ₁	--	--	-.4062	--	--	--
CW x (mid x hay + corn)	B _{Y22} X ₁	--	--	.4324	--	--	--
CW x (late x hay + corn)	B _{Y32} X ₁	--	--	-.0262	--	--	--
CW x (hay x coarse)	Y _{G1} X ₁	--	--	-.0653	--	--	--
CW x (hay x pelleted)	Y _{G2} X ₁	--	--	.0653	--	--	--
CW x (hay + corn x coarse)	Y _{G12} X ₁	--	--	.0653	--	--	--

Table 12. (Continued)

Item		Feed nutrient ^a						
		Crude protein	Cellulose	Hemi-cellulose	Cell Walls ^b	Neutral detergent fiber	Acid detergent fiber	Crude fiber
CH x (hay + corn x pelleted)	$\gamma_{22}^6 X_1$	--	--	--	-0.0653	--	--	--
NDF x early	$\beta_{11}^6 X_1$	--	--	--	--	.2735	--	--
NDF x mid	$\beta_{21}^6 X_1$	--	--	--	--	-9.268	--	--
NDF x late	$\beta_{31}^6 X_1$	--	--	--	--	.6533	--	--
NDF x hay	$\gamma_{11}^6 X_1$	--	--	--	--	.3530	--	--
NDF x hay + corn	$\gamma_{21}^6 X_1$	--	--	--	--	-3.530	--	--
NDF x (alfalfa x early)	$\alpha_{11}^6 X_1$	--	--	--	--	-0.102	--	--
NDF x (alfalfa x mid)	$\alpha_{21}^6 X_1$	--	--	--	--	-2.082	--	--
NDF x (alfalfa x late)	$\alpha_{31}^6 X_1$	--	--	--	--	.1980	--	--
NDF x (grass x early)	$\alpha_{21}^6 X_1$	--	--	--	--	-0.102	--	--
NDF x (grass x mid)	$\alpha_{22}^6 X_1$	--	--	--	--	.2082	--	--
NDF x (grass x late)	$\alpha_{23}^6 X_1$	--	--	--	--	-1.980	--	--
ADF x (early x hay)	$\beta_{11}^{11} X_1$	--	--	--	--	--	.0386	--
ADF x (mid x hay)	$\beta_{21}^{11} X_1$	--	--	--	--	--	-1.365	--
ADF x (late x hay)	$\beta_{31}^{11} X_1$	--	--	--	--	--	.0949	--
ADF x (early x corn + hay)	$\beta_{12}^{11} X_1$	--	--	--	--	--	-0.386	--
ADF x (mid x corn + hay)	$\beta_{22}^{11} X_1$	--	--	--	--	--	.1365	--
ADF x (late x corn + hay)	$\beta_{32}^{11} X_1$	--	--	--	--	--	-0.979	--
ADF x (early x coarse)	$\beta_{11}^{11} X_1$	--	--	--	--	--	-0.359	--
ADF x (mid x coarse)	$\beta_{21}^{11} X_1$	--	--	--	--	--	.0429	--
ADF x (late x coarse)	$\beta_{31}^{11} X_1$	--	--	--	--	--	.0070	--
ADF x (early x pelleted)	$\beta_{12}^{11} X_1$	--	--	--	--	--	.0359	--
ADF x (mid x pelleted)	$\beta_{22}^{11} X_1$	--	--	--	--	--	-0.0429	--
ADF x (late x pelleted)	$\beta_{32}^{11} X_1$	--	--	--	--	--	-0.0070	--
ADF x (hay x coarse)	$\gamma_{11}^{11} X_1$	--	--	--	--	--	-1.072	--
ADF x (hay x pelleted)	$\gamma_{12}^{11} X_1$	--	--	--	--	--	.1072	--
ADF x (hay + corn x coarse)	$\gamma_{21}^{11} X_1$	--	--	--	--	--	-1.072	--
ADF x (hay + corn x pelleted)	$\gamma_{22}^{11} X_1$	--	--	--	--	--	-1.072	--
CF x alfalfa	$\alpha_1^9 X_1$	--	--	--	--	--	--	-0.0843
CF x grass	$\alpha_2^9 X_1$	--	--	--	--	--	--	.0843
CF x coarse	$\gamma_1^9 X_1$	--	--	--	--	--	--	-0.0878
CF x pelleted	$\gamma_2^9 X_1$	--	--	--	--	--	--	-0.0878
CF x (early x hay)	$\beta_{11}^{11} X_1$	--	--	--	--	--	--	-0.0771
CF x (mid x hay)	$\beta_{21}^{11} X_1$	--	--	--	--	--	--	-1.929
CF x (late x hay)	$\beta_{31}^{11} X_1$	--	--	--	--	--	--	.2700
CF x (early x hay + corn)	$\beta_{12}^{11} X_1$	--	--	--	--	--	--	.0771
CF x (mid x hay + corn)	$\beta_{22}^{11} X_1$	--	--	--	--	--	--	.1929
CF x (late x hay + corn)	$\beta_{32}^{11} X_1$	--	--	--	--	--	--	-2.700
Coefficient of determination	R^2	.982	.962	.958	.958	.973	.940	.971
Residual standard deviation	(%)	.5	1.0	.8	2.01	1.8	1.5	1.3
Coefficient of variation	(%)	6.1	9.5	11.8	11.0	9.0	11.4	11.9

^aEquations are of the form $Y = b_0 + b_1 X_1 + a_1 + \beta_1 + \gamma_1 + \delta_1 + \alpha_{11} + \alpha_{12} + \alpha_{13} + \alpha_{14} + \alpha_{15} + \alpha_{16} + \alpha_{17} + \alpha_{18} + \alpha_{19} + \alpha_{20} + \alpha_{21} + \alpha_{22} + \alpha_{23} + \alpha_{24} + \alpha_{25} + \alpha_{26} + \alpha_{27} + \alpha_{28} + \alpha_{29} + \alpha_{30} + \alpha_{31} + \alpha_{32} + \alpha_{33} + \alpha_{34} + \alpha_{35} + \alpha_{36} + \alpha_{37} + \alpha_{38} + \alpha_{39} + \alpha_{40} + \alpha_{41} + \alpha_{42} + \alpha_{43} + \alpha_{44} + \alpha_{45} + \alpha_{46} + \alpha_{47} + \alpha_{48} + \alpha_{49} + \alpha_{50} + \alpha_{51} + \alpha_{52} + \alpha_{53} + \alpha_{54} + \alpha_{55} + \alpha_{56} + \alpha_{57} + \alpha_{58} + \alpha_{59} + \alpha_{60} + \alpha_{61} + \alpha_{62} + \alpha_{63} + \alpha_{64} + \alpha_{65} + \alpha_{66} + \alpha_{67} + \alpha_{68} + \alpha_{69} + \alpha_{70} + \alpha_{71} + \alpha_{72} + \alpha_{73} + \alpha_{74} + \alpha_{75} + \alpha_{76} + \alpha_{77} + \alpha_{78} + \alpha_{79} + \alpha_{80} + \alpha_{81} + \alpha_{82} + \alpha_{83} + \alpha_{84} + \alpha_{85} + \alpha_{86} + \alpha_{87} + \alpha_{88} + \alpha_{89} + \alpha_{90} + \alpha_{91} + \alpha_{92} + \alpha_{93} + \alpha_{94} + \alpha_{95} + \alpha_{96} + \alpha_{97} + \alpha_{98} + \alpha_{99} + \alpha_{100} + \alpha_{101} + \alpha_{102} + \alpha_{103} + \alpha_{104} + \alpha_{105} + \alpha_{106} + \alpha_{107} + \alpha_{108} + \alpha_{109} + \alpha_{110} + \alpha_{111} + \alpha_{112} + \alpha_{113} + \alpha_{114} + \alpha_{115} + \alpha_{116} + \alpha_{117} + \alpha_{118} + \alpha_{119} + \alpha_{120}$; where Y is the predicted digestible amount, and X_1 is the nutrient content with the respective regression constant (b_0) and regression coefficient (b_1). The regression constant is adjusted by qualitative variables ($\alpha_1, \alpha_2, \dots, \alpha_{120}$) according to the description of the ingredient or diet. The regression coefficient is also adjusted by qualitative-quantitative variable interactions. ($\beta_1, \beta_2, \dots, \beta_{120}$) according to the description of the ingredient or diet and the specific feed nutrient in question. All indicators must be used as they apply. For example, if the diet was alfalfa hay (α_1), late maturity (β_2), fed alone (γ_1), and pelleted (δ_2), the calculation for percent digestible CL for a feed containing 20% CL would be: $Y = (b_0 + a_1 + \beta_3 + \gamma_1 + \delta_2 + \beta_{31} + \gamma_{12}^6) + (b_1 + \beta_3 X_1 + \gamma_1 X_1 + \delta_2 X_1 + \beta_{31} X_1 + \gamma_{12}^6 X_1) X_1 = (2.161 - .256 - 6.953 + 9.942 + 1.564 - 15.310 - 2.167) + (1.469 + .106 - .480 - .126 + .684 + .106) 20 = 4.2\%$

^bPlant cell walls as determined using detergent procedures by Fornesbeck and Harris (1970a).

The improvement of the Type I equations was further substantiated by an observed decrease in the error variations between Simple and Type I models. An F test comparing the error-sum-of-squares (SSE) between the Simple and Type I models revealed a significant reduction in the unexplained or residual variation when qualitative factors were added to the linear model (table 13). Even the Type I equations for crude protein and available carbohydrate showed a significant reduction in the error variation though only a slight improvement was shown in the R^2 values.

Type II equations for hemicellulose, cellulose, cell walls, neutral detergent fiber, acid detergent fiber, and crude fiber showed only a slight increase in the R^2 value from that shown by the Type I equations (hemicellulose, .96 vs .94; cellulose, .96 vs .94; cell walls, .96 vs .95; neutral detergent fiber, .97 vs .96; acid detergent fiber, .94 vs .93; and crude fiber, .97 vs .96). The F test between the error sum-of-squares showed a very small but statistically significant reduction in the unexplained variation for hemicellulose, cellulose, neutral detergent fiber, and crude fiber Type II equations only (table 13). The type II crude protein equation showed no improvement in the R^2 value and very little reduction in the error term over the Type I model. In developing a Type II equation for available carbohydrates and total lipids, all quantitative-by-qualitative interactions were eliminated in the stepwise regression process without showing an improvement over the Type I equations. Therefore, no available carbohydrate or total lipid Type II equations were generated.

Generally, it was shown that the complex equations, Type I and II, for the fibrous constituents contained dummy variable main effects and

Table 13. Statistical comparison between the error sum-of-squares (SSE) of Simple (A), Type I (B), and Type II (C) Models for estimating apparent digestible amounts

Item		Feed nutrient								
		Crude protein	Available carbohydrates	Total lipids	Cellulose	Hemicellulose	Cell walls ^a	Neutral detergent fiber	Acid detergent fiber	Crude fiber
(A)	df _A	46	46	46	46	46	46	46	46	46
	SSE _A	17.43	152.62	28.65	56.72	183.92	559.34	622.41	336.04	448.05
(B)	df _B	39	40	38	36	34	36	34	36	36
	SSE _B	11.56	84.52	15.84	32.31	48.98	159.98	158.29	79.08	84.51
(C)	df _C	38	-	33	31	31	30	31	29	31
	SSE _C	10.83	-	16.01	21.42	33.50	121.33	101.06	64.22	55.06
B versus A	F ^b	2.83	5.37	3.84	2.72	7.81	8.99	8.31	11.70	15.48
	P <	.025	.001	.001	.01	.001	.001	.001	.001	.001
C versus B	F ^c	2.56	-	-	3.15	4.77	1.59	5.85	0.96	3.32
	P <	NS	-	-	.025	.025	NS	.005	NS	.025

^aPlant cell walls determined using detergent procedures by Fonnesbeck and Harris (1970 a).

$$^b F = \frac{(SSE_A - SSE_B) / d.f._A - d.f._B}{SSE_B / d.f._B}$$

$$^c F = \frac{(SSE_B - SSE_C) / d.f._B - d.f._C}{SSE_C / d.f._C}$$

interactions corresponding to the treatment effects, as shown by the analysis of variance, having relatively high mean squares, though mean squares were not always significantly high.

The improved precision of the complex equations (type I and II) was also shown by calculating DE from the estimated digestible amounts of crude protein, available carbohydrates, total lipids, cellulose, and hemicellulose using the Simple, Type I and II equations. DE was calculated using the equation $DE = 5.65 (Y_{CP}) + 4.15 (Y_{AC} + Y_{CL} + Y_{HC}) + 9.40 Y_{TL}$; where Y_N equals the decimal fraction of the estimated nutrient digestible amount. The 5.64, 4.15 and 9.40 were assigned caloric values (Mcal/kg) for feed protein, carbohydrates, and lipids respectively (see appendix tables 38, 39, and 40 for estimated nutrient digestible amounts, estimated DE and observed DE).

From the regression of the observed DE (Y) against the estimated DE (X), it was shown that DE estimated using Type I equations was nearer to observed DE than DE estimated using simple equations (table 14). Also, since it was shown in table 13 that hemicellulose and cellulose Type II equations had a significantly lower residual sum-of-square than corresponding Type I equations, DE was also estimated using hemicellulose and cellulose digestible amounts from Type II equations. However, no advantage was shown for using hemicellulose and cellulose Type II equations when estimating DE from estimated digestible amounts (table 14).

Generally, it must be considered that though most of the Type II equations showed a significant reduction in the unexplained variation (SSE) compared to the Type I equations, this reduction was very small. Also, only a very slight improvement in the R^2 value was shown by the

Table 14. DE (Mcal/kg) estimated indirectly^a; using Simple, Type I and Type II equations; regressed against DE (Mcal/kg) observed

Equation type	Coefficient of determination	Residual standard deviation (Mcal/kg)	Coefficient of variation %
Simple ^b	.71	.20	7.5
Type I ^c	.82	.16	5.9
Type I ^d and Type II ^d	.82	.16	5.9

^aDE was estimated using the equation: $DE = 5.65 (Y_{CP}) + 4.15 (Y_{AC} + Y_{CL} + Y_{HC}) + 9.40 Y_{TL}$; where Y_N equals the decimal fraction (CP - crude protein, AC - available carbohydrate, CL = cellulose, HC = hemicellulose, or TL = total lipids) of the nutrient digestible amount as predicted from Simple, Type I or Type II models. The 5.65, 4.15, and 9.40 are assigned caloric values for protein, carbohydrates, and lipids (Lloyd et al., 1978).

^bCP, AC, CL, HC and TL digestible amounts predicted with Simple equations.

^cCP, AC, CL, HC and TL digestible amounts predicted with Type I equations.

^dCP, AC, and TL digestible amounts predicted with Type I equations and CL and HC digestible amounts predicted with Type II equations.

Type II equations. Therefore, from a practical standpoint, the use of the more complex Type II equation over the Type I model may not be justified from the data of this experiment.

Estimating digestible energy from nutrient percent content

Simple equations. Equations of the form $Y = b_0 + b_1 X_1$, were also used to estimate DE directly for sheep diets; where Y equaled estimated DE and X_1 equaled the diet percent content of available carbohydrate, cellulose, cell walls, neutral detergent fiber, acid detergent fiber or crude fiber (table 15). Van Soest (1965) proposed the use of the

Table 15. Simple regression models^a for estimating DE (Mcal/kg) directly from nutrient content (%)

Item		Feed Nutrient						A ^c
		Available carbo- hydrate	Cellulose	Cell walls ^b	Neutral detergent fiber	Acid detergent fiber	Crude fiber	
Regression constant	b ₀	1.928	3.754	3.719	3.762	3.887	3.552	-.974
Regression coefficient	b ₁	.0235	-.0475	-.0244	-.0240	-.0382	-.0339	.0041
Coefficient of determination	R ²	.614	.689	.696	.709	.680	.558	.500
Residual standard deviation	(Mcal/kg)	.23	.21	.21	.20	.21	.25	.27
Coefficient of variation	(%)	8.7	7.8	7.8	7.5	7.9	9.3	9.9

^aEquations are of the form $Y = b_0 + b_1X_1$; where Y is the predicted digestible energy (Mcal/kg), and X₁ is the nutrient content (%) of the diet.

^bPlant cell walls determined using detergent procedures by Fannesbeck and Harris (1970 a).

^cA = 100 - (100 L/S), where L equals the percent lignin content (%) of a given diet and S equals percent neutral detergent solubles (% cell contents).

predictant A (%); $A = 100 - (100 L/S)$, where L equals the percent (%) lignin content of the diet and S equals the percent (%) neutral detergent solubles (cell contents). A Simple model utilizing the predictant A (%) was also generated for comparison (table 15).

Overall, the precision of the Simple models was shown to be average to poor in estimating DE (table 15). R^2 values ranged from .71 to .50 with residual standard deviations ranging from .27 Mcal/kg to .20 Mcal/kg. It appeared that cellulose, cell walls, neutral detergent fiber and acid detergent fiber were quite comparable as DE predictants, though the chemical composition between these separate fractions was notably different. Neutral detergent fiber was shown to be the most accurate as a predictant. Available carbohydrate, crude fiber, and A models were markedly lower in precision for estimating DE than cellulose, cell wall, neutral detergent fiber, and acid detergent fiber models.

The extra low available carbohydrate values for midbloom grass may account for much of the variation associated with the available carbohydrate model. Variation connected with the crude fiber was expected to be high since it has been adequately shown in the literature and in the chemical analysis section of this study that crude fiber recovery of cell wall fiber is highly variable between diet types.

Van Soest's proposed equation utilizing the predictant A is based on the theory that lignin is a nonnutritive component of forage cell walls and is the primary factor limiting the digestibility of cell wall carbohydrates (Van Soest and Moore, 1965). It is further stated that, since lignification is negatively related to forage digestibility and the cell contents are positively related to digestibility, the ratio of L/S would be a good indicator of indigestibility. However, in the present study

it was shown that fiber digestibility in the grass diets did not follow the hypothetical pattern. Lignin was apparently substantially digestible in grass. Midbloom grass was highest in cell wall contents and also highest in lignin digestibility. This deviation from the hypothesis by Van Soest would account for much of the variation shown for the Van Soest model. The extra low available carbohydrate values for midbloom grass also may have added substantial variation to the model.

Complex equations. Type I and II multivariant models were developed for estimating DE directly using the diet percent content of cellulose, cell walls, neutral detergent fiber, acid detergent fiber, or crude fiber as the only quantitative independent variable in the equation.

Type I equations for each predictant mentioned were shown to be significantly better in DE predictability than corresponding Simple models (compare tables 15 and 16). This was shown by a distinct increase in R^2 values (cellulose, .88 vs .69; cell walls, .88 vs .70; neutral detergent fiber, .90 vs .71; acid detergent fiber, .88 vs .68; and crude fiber, .90 vs .56) and a decrease in the residual standard deviation of regression (cellulose, .15 Mcal/kg vs .21 Mcal/kg; cell walls, .15 Mcal/kg vs .21 Mcal/kg; neutral detergent fiber, .14 Mcal/kg vs .20 Mcal/kg, acid detergent fiber, .15 Mcal/kg vs .21 Mcal/kg; and crude fiber, .14 Mcal/kg vs .25 Mcal/kg). An F test comparing the unexplained variation (SSE) in estimating DE using simple and complex models showed that the Type I complex models significantly reduced the SSE (table 18).

Type I models also estimated closer DE values to observed DE than simple models (table 19 and appendix tables 41 and 42). DE predicted

Table 16. Type I regression models for estimating DE (Mcal/kg) directly from nutrient content (%)

Item		Feed nutrient ^a				
		Cellulose	Cell walls ^b	Neutral detergent fiber	Acid detergent fiber	Crude fiber
Regression constant	b ₀	3.3991	3.2774	3.6618	3.6412	3.4240
Regression coefficient	b ₁	-.0315	-.0138	.0217	-.0302	-.0287
Adjustments to the regression constant for specification of diet ^a .						
Forage type						
Alfalfa	a ₁	.1097	.0694	.0094	.1107	.1347
Grass	a ₂	-.1097	-.0694	-.0094	-.1107	-.1347
Stage of maturity						
Early	β ₁	-.0031	.0025	-.0074	.0084	-.0142
Mid	β ₂	.0692	.0652	.0842	.0581	.0904
Late	β ₃	-.0661	-.0677	-.0768	-.0665	-.0762
Energy Level						
Hay	γ ₁	-.0897	-.1486	-.0705	-.0472	-.0654
Hay + corn	γ ₂	.0897	.1486	.0705	.0472	.0654
Texture						
Coarse	δ ₁	.0130	.0182	.0212	.0220	.0276
Pelleted	δ ₂	-.0130	-.0182	-.0212	-.0220	-.0276
Diet Interactions						
Alfalfa x early	αβ ₁₁	-.0110	-.0318	.0006	-.0119	-.0107
Alfalfa x mid	αβ ₁₂	-.0385	-.0358	-.0892	-.0455	-.0707
Alfalfa x late	αβ ₁₃	.0495	.0676	.0886	.0574	.0814
Grass x early	αβ ₂₁	.0110	.0318	-.0006	.0119	.0107
Grass x mid	αβ ₂₂	.0385	.0358	.0892	.0455	.0707
Grass x late	αβ ₂₃	-.0495	-.0676	-.0886	-.0574	-.0814
Early x hay	βγ ₁₁	-.0319	-.0307	-.0415	-.0273	-.0439
Mid x hay	βγ ₂₁	.0729	.0703	.0756	.0793	.1095
Late x hay	βγ ₃₁	.0119	-.0396	-.0341	.1066	-.0656
Early x hay + corn	βγ ₁₂	.0319	.0307	.0415	.0273	.0439
Mid x hay + corn	βγ ₂₂	-.0729	-.0703	-.0756	-.0793	-.1095
Late x hay + corn	βγ ₃₂	-.0119	.0396	.0341	-.1066	.0656
Early x coarse	βδ ₁₁	-.0354	-.0306	-.0264	-.0276	-.0433
Mix x coarse	βδ ₂₁	-.0147	-.0226	-.0307	-.0238	-.0019
Late x coarse	βδ ₃₁	.0501	.0532	.0571	.0514	.0452
Early x pelleted	βδ ₁₂	.0354	.0306	.0264	.0276	.0433
Mid x pelleted	βδ ₂₂	.0147	.0226	.0307	.0238	.0019
Late x pelleted	βδ ₃₂	-.0501	-.0532	-.0571	-.0514	-.0452
Hay x coarse	γδ ₁₁	.0886	.0850	.0818	.0880	.0934
Hay x pelleted	γδ ₁₂	-.0886	-.0850	-.0818	-.0880	-.0934
Corn + hay x coarse	γδ ₂₁	-.0886	-.0850	-.0818	-.0880	-.0934
Corn + hay x pelleted	γδ ₂₂	.0886	.0850	.0818	.0880	.0934
Coefficient of determination	R ²	.878	.883	.896	.883	.897
Residual standard deviation	(Mcal/kg)	.15	.15	.14	.15	.14
Coefficient of variation	(%)	5.6	5.6	5.2	5.6	5.2

^aEquations are of the form $Y = b_0 + b_1X_1 + a_1 + B_j + Y_k + \delta_k + \alpha\beta_{1j} + \beta\gamma_{jk} + \beta\delta_j + \gamma\delta_{k2}$, where Y is the predicted digestible energy (Mcal/kg) and X₁ is the nutrient percent content (%), with the respective regression constant and regression coefficient. The regression constant is adjusted by qualitative indicators (a₁, β₁, . . . γδ_{k2}) according to the description of the ingredient or diet. All indicators must be used as they apply. For example, if the diet was alfalfa hay (a₁), late maturity (β₃), fed alone (γ₁), and pelleted (δ₂); the calculation for digestible energy in a feed containing 42% CW would be: $Y = b_0 + (b_1X_1) + a_1 + \beta_3 + \gamma_1 + \delta_2 + \alpha\beta_{13} + \beta\gamma_{31} + \beta\delta_{32} + \gamma\delta_{12} = 3.277 + [(-.0138)(42)] + .069 - .068 - .149 - .018 + .068 + .040 + .053 - .085 = 2.42$ Mcal/kg.

^bPercent cell walls determined using detergent procedures by Fornesbeck and Harris (1970a).

directly with Type I models was only slightly closer to observed DE than DE estimated indirectly using Type I predicted digestible amounts and physiological fuel values (compare table 14 to table 19).

Indicator variables selected for the most efficient Type I model were identical between cellulose, cell wall, neutral detergent fiber, acid detergent fiber, and crude fiber models (table 16). Though the maturity-by-texture interaction did not significantly affect the apparent digestibility of cellulose, cell walls, neutral detergent fiber, or acid detergent fiber; it was shown important in all Type I equations (table 8). The forage-by-maturity interaction also appeared important to all Type I equations, but significantly affected neutral detergent fiber apparent digestibility only (table 8). Selected independent variables in a regression model do not always fit observed phenomena. No matter how strong the statistical relationship may be, a cause-and-effect pattern is not necessarily implied by the regression equation.

The dummy variables selected for Type I equations to estimate DE nearly matched the dummy variable selection for corresponding Type I equations for estimating digestible amounts (compare tables 11 and 16). Cell wall, neutral detergent fiber and crude fiber Type I equations for estimating digestible amounts, however, did not contain the maturity-by-texture interaction s own necessary in the Type I DE estimating equations.

Type II equations for cellulose, cell walls, neutral detergent fiber, acid detergent fiber, and crude fiber showed very little improvement over Type I equations in estimating DE (compare tables 16 and 17). The F test comparing the error-sum-of-squares (SSE) showed a significant reduction in the unexplained variation for the acid

detergent fiber Type II model only (table 18). The regression of estimated DE against observed DE showed no advantage in using Type II over Type I equations for estimating DE (table 19).

The order of accuracy in equations for estimating DE changed between cellulose, cell walls, neutral detergent fiber, acid detergent fiber, and crude fiber going from Simple to Type I models. The model using neutral detergent content was the most precise for the Simple models followed by cell walls, cellulose, acid detergent fiber, and crude fiber simple models respectively (table 11). However, the Type I equations for crude fiber and neutral detergent fiber were similar in precision and were the most accurate (table 16). Cell wall and acid detergent equations were comparable in precision and were second in predictability followed by the cellulose equation.

From a practical standpoint complex regression equations similar to those developed in this study would be useful in a computer program for calculating least-cost rations for growing and fattening lambs. Nearly all equations developed by previous researchers use chemical parameters for estimating digestible dry or organic matter for forage rations only. It is recommended that regression models be generated capable of predicting diet digestible energy for all-forage diets as well as mixed diets containing forages, high energy feed, and protein supplements.

Though indicator variables increase the precision of a predicting equation, they also limit the equation to specific diet treatments. However, with further research using additional forage types, grain types and grain to forage mixtures; more flexible models can be developed still utilizing the indicator variable concept.

Table 17. Type II regression models for estimating DE (Mcal/kg) directly from nutrient content (%)

Item		Feed Nutrient ^a				
		Cellulose (CL)	Cell walls ^b (CW)	Neutral detergent fiber (NDF)	Acid detergent fiber (ADF)	Crude fiber (CF)
Regression constant	b_0	2.5902	1.0856	5.0935	3.1574	3.8360
Regression coefficient	b_1	.0054	.0387	-.0593	-.0019	-.0566
Adjustments to the regression constant (b_0) for specification of diet ³ .						
Forage type	α_1	.1859	.4974	-.2397	.1221	.2060
Alfalfa	α_1	.1859	.4974	-.2397	.1221	.2060
Grass	α_2	-.1859	-.4974	.2397	-.1221	-.2060
Stage of maturity						
Early	β_1	-.0216	-.2006	-.0202	-.2906	1.8365
Mid	β_2	.1135	1.5800	.1708	.2891	-1.1826
Late	β_3	-.0919	-1.3794	-.1506	.0015	.6539
Energy level						
Hay	γ_1	.2777	.4957	-.6368	-.7805	-.6131
Hay + corn	γ_2	-.2777	-.4957	.6368	.7805	.6131
Texture						
Coarse	δ_1	.0016	.0236	.1366	.0085	.0274
Pelleted	δ_2	-.0016	-.0236	-.1366	-.0085	-.0274
Diet interactions						
Alfalfa x early	$\alpha\beta_{11}$	-.0942	-1.9752	.0702	-.0611	-.8504
Alfalfa x mid	$\alpha\beta_{12}$	.0202	.719	1.1382	-.0177	.9208
Alfalfa x late	$\alpha\beta_{13}$	.0740	1.2555	-1.2084	.0788	-.0704
Grass x early	$\alpha\beta_{21}$	.0942	1.9752	-.0702	.0611	.8504
Grass x mid	$\alpha\beta_{22}$	-.0202	-.7197	-1.1382	.0177	-.9208
Grass x late	$\alpha\beta_{23}$	-.0740	-1.2555	1.2084	-.0788	.0704
Early x hay	$\beta\gamma_{11}$	-.3428	-2.4472	-.0709	-1.3945	--
Mid x hay	$\beta\gamma_{21}$	.4529	1.3441	1.4514	1.1265	--
Late x hay	$\beta\gamma_{31}$	-.1101	1.1031	-1.4905	.2680	--
Early x hay + corn	$\beta\gamma_{12}$	.3428	2.4472	.0709	1.3945	--
Mid x hay + corn	$\beta\gamma_{22}$	.4529	-1.3441	-1.5614	-1.1265	--
Late x hay + corn	$\beta\gamma_{32}$	.1101	-1.1031	1.4905	-.2680	--

Table 17. (Continued)

Item		Feed nutrient ^a				
		Cellu- lose (CL)	Cell Walls (CW)	Neutral detergent fiber (NDF)	Acid detergent fiber (ADF)	Crude fiber (CF)
Early x coarse	β_{11}^X	-.0275	--	--	-.0386	.1605
Mid x coarse	β_{21}^X	-.0248	--	--	-.1738	-.1828
Late x coarse	β_{31}^X	.0523	--	--	.2124	.0223
Early x pelleted	β_{12}^X	.0275	--	--	.0386	-.1605
Mid x pelleted	β_{22}^X	.0248	--	--	.1738	.1828
Late x pelleted	β_{32}^X	-.0523	--	--	-.2124	-.0223
Hay x coarse	γ_{11}^{δ}	.0846	.2353	.0819	.0726	.0565
Hay x pelleted	γ_{12}^{δ}	-.0846	-.2353	-.0819	-.0726	-.0565
Hay + corn coarse	γ_{21}^{δ}	-.0846	-.2353	-.0819	-.0726	-.0565
Hay + corn pelleted	γ_{22}^{δ}	.0846	.2353	.0819	.0726	.0565
Adjustments to regression co- efficient (b_1) for specification of diet ^a						
CL x (early x hay)	$\beta_{11}^{X_1}$	.0155	--	--	--	--
CL x (mid x hay)	$\beta_{21}^{X_1}$	-.0175	--	--	--	--
CL x (late x hay)	$\beta_{31}^{X_1}$	.0020	--	--	--	--
CL x (early x hay + corn)	$\beta_{12}^{X_1}$	-.0155	--	--	--	--
CL x (mid x hay + corn)	$\beta_{22}^{X_1}$	.0175	--	--	--	--
CL x (late x hay + corn)	$\beta_{32}^{X_1}$	-.0020	--	--	--	--
CW x early	$\beta_{11}^{X_1}$	--	.0040	--	--	--
CW x mid	$\beta_{21}^{X_1}$	--	-.0385	--	--	--
CW x late	$\beta_{31}^{X_1}$	--	.0345	--	--	--
CW x (alfalfa x early)	$\alpha_{11}^{X_1}$	--	.0480	--	--	--
CW x (alfalfa x mid)	$\alpha_{12}^{X_1}$	--	-.0246	--	--	--
CW x (alfalfa x late)	$\alpha_{13}^{X_1}$	--	-.0234	--	--	--
CW x (grass x early)	$\alpha_{21}^{X_1}$	--	-.0480	--	--	--
CW x (grass x mid)	$\alpha_{22}^{X_1}$	--	.0246	--	--	--
CW x (grass x late)	$\alpha_{23}^{X_1}$	--	.0234	--	--	--
CW x (early x hay)	$\beta_{11}^{X_1}$	--	.0634	--	--	--
CW x (mid x hay)	$\beta_{21}^{X_1}$	--	-.0253	--	--	--
CW x (late x hay)	$\beta_{31}^{X_1}$	--	-.0381	--	--	--
CW x (early x hay + corn)	$\beta_{12}^{X_1}$	--	-.0634	--	--	--
CW x (mid x hay + corn)	$\beta_{22}^{X_1}$	--	.0253	--	--	--
CW x (late x hay + corn)	$\beta_{32}^{X_1}$	--	.0381	--	--	--
CW x (hay x coarse)	γ_{11}^{δ}	--	-.0036	--	--	--
CW x (hay x pelleted)	γ_{12}^{δ}	--	.0036	--	--	--
CW x (hay + corn x coarse)	γ_{21}^{δ}	--	.0036	--	--	--
CW x (hay + corn x pelleted)	γ_{22}^{δ}	--	-.0036	--	--	--

Table 17. (Continued)

Item		Feed nutrient ^a				
		Cellu- lose (CL)	Cell Walls ^b (CW)	Neutral detergent fiber (NDF)	Acid detergent fiber (ADF)	Crude fiber (CF)
NDF x hay	$\gamma_1 X_1$	--	--	.0209	--	--
NDF x hay + corn	$\gamma_2 X_1$	--	--	-.0209	--	--
NDF x coarse	$\delta_1 X_1$	--	--	-.0020	--	--
NDF x pelleted	$\delta_2 X_1$	--	--	.0020	--	--
NDF x (alfalfa x early)	$\beta_{11} X_1$	--	--	.0014	--	--
NDF x (alfalfa x mid)	$\beta_{12} X_1$	--	--	-.0321	--	--
NDF x (alfalfa x late)	$\beta_{13} X_1$	--	--	.0307	--	--
NDF x (grass x early)	$\beta_{21} X_1$	--	--	-.0014	--	--
NDF x (grass x mid)	$\beta_{22} X_1$	--	--	.0321	--	--
NDF x (grass x late)	$\beta_{23} X_1$	--	--	-.0307	--	--
NDF x (early x hay)	$\beta\gamma_{11} X_1$	--	--	.0006	--	--
NDF x (mid x hay)	$\beta\gamma_{21} X_1$	--	--	-.0349	--	--
NDF x (late x hay)	$\beta\gamma_{31} X_1$	--	--	.0343	--	--
NDF x (early x hay + corn)	$\beta\gamma_{21} X_1$	--	--	-.0006	--	--
NDF x (mid x hay + corn)	$\beta\gamma_{22} X_1$	--	--	.0349	--	--
NDF x (late x hay + corn)	$\beta\gamma_{23} X_1$	--	--	-.0343	--	--
ADF x hay	$\gamma_1 X_1$	--	--	--	.0223	--
ADF x hay + corn	$\gamma_2 X_1$	--	--	--	-.0223	--
ADF x (early x hay)	$\beta\gamma_{11} X_1$	--	--	--	.0462	--
ADF x (mid x hay)	$\beta\gamma_{21} X_1$	--	--	--	-.3047	--
ADF x (late x hay)	$\beta\gamma_{31} X_1$	--	--	--	-.0211	--
ADF x (early x hay + corn)	$\beta\gamma_{12} X_1$	--	--	--	-.0462	--
ADF x (mid x hay + corn)	$\beta\gamma_{22} X_1$	--	--	--	.0347	--
ADF x (late x hay + corn)	$\beta\gamma_{32} X_1$	--	--	--	.0122	--
CF x early	$\beta_1 X_1$	--	--	--	--	-.0949
CF x mid	$\beta_2 X_1$	--	--	--	--	.0659
CF x late	$\beta_3 X_1$	--	--	--	--	.0290
CF x hay	$\gamma_1 X_1$	--	--	--	--	.0303
CF x hay + corn	$\gamma_2 X_1$	--	--	--	--	-.0303
CF x (early x hay)	$\beta\gamma_{11} X_1$	--	--	--	--	.0607
CF x (mid x hay)	$\beta\gamma_{21} X_1$	--	--	--	--	-.0522
CF x (late x hay)	$\beta\gamma_{31} X_1$	--	--	--	--	-.0085
CF x (early x hay + corn)	$12 X_1$	--	--	--	--	-.0607
CF x (mid x hay + corn)	$22 X_1$	--	--	--	--	.0522
CF x (late x hay + corn)	$32 X_1$	--	--	--	--	.0085

Table 17. (Continued)

Item		Feed nutrient ^a				
		Cellu- lose (CL)	Cell Walls (CW)	Neutral detergent fiber (NDF)	Acid detergent fiber (ADF)	Crude fiber (CF)
CF x (early x coarse)	$\beta\delta_{11}X_1$	--	--	--	--	-.0058
CF x (mid x coarse)	$\beta\delta_{21}X_1$	--	--	--	--	.0052
CF x (late x coarse)	$\beta\delta_{31}X_1$	--	--	--	--	.0006
CF x (early x pelleted)	$\beta\delta_{12}X_1$	--	--	--	--	.0058
CF x (mid x pelleted)	$\beta\delta_{22}X_1$	--	--	--	--	-.0052
CF x (late x pelleted)	$\beta\delta_{32}X_1$	--	--	--	--	-.0006
Coefficient of determination	R^2	.887	.913	.917	.910	.913
Standard deviation	(Mcal/kg)	.15	.14	.13	.14	.14
Coefficient of variation	(%)	5.6	5.2	4.8	5.2	5.2

^aEquations are of this form $Y = b_0 + b_1X_1 + \alpha_1 + \beta_j + \gamma_k + \delta_k + \alpha\beta_{1j} + \dots + \gamma\delta_{kl} + \alpha_1X_1 + \beta_3X_1 + \delta_kX_1 + \alpha\beta_{1j}X_1 + \dots + \gamma\delta_{kl}X_1$; where Y is the predicted digestible energy (Mcal/kg) and X_1 is the nutrient percent content (%) with the respective regression constant b_0 and regression coefficient b_1 . The regression constant is adjusted by qualitative variables ($\alpha_1, \beta_j, \dots, \gamma\delta_{kl}$) according to the description of the ingredient or diet. The regression coefficient is also adjusted by qualitative-quantitative variable interactions ($\alpha_1X_1, \beta_jX_1, \dots, \gamma\delta_{kl}$) according to the description of the ingredient or diet and the specific feed nutrient. All indicators must be used as they apply. For example, if the diet was alfalfa (α_1), late maturity (β_3), feed alone (γ_1), and pelleted (δ_k) the calculation for digestible energy in a feed containing 42% CW would be: $Y = (b_0 + \alpha_1 + \beta_3 + \gamma_1 + \delta_2 + \alpha\beta_{13} + \beta\gamma_{31} + \gamma\delta_{12}) + (b_1 + \beta_3X_1 + \alpha\beta_{13}X_1 + \beta\gamma_{31}X_1 + \gamma\delta_{12}X_1) X_1 = (1.086 + .497 - 1.379 - .496 - .024 + 1.256 + 1.103 - .235) + (.039 + .035 - .023 - .038 + .004) 42 = 2.52$ Mcal/kg.

^bPlant cell walls determined using procedures by Fomnesbeck and Harris (1970a).

Table 18. Statistical comparison between the error-sum-of-squares (SSE) of Simple (A), Type I (B), and Type II (C) models for estimating DE

Item		Feed nutrient				Crude fiber
		Cellulose	Cell walls ^a	Neutral detergent fiber	Acid detergent fiber	
(A)	d.f. _A	46	46	46	46	46
	SSE _A	2.03312134	1.98772670	1.90462540	2.09384692	2.88973978
(B)	d.f. _B	34	34	34	34	34
	SSE _B	.79621268	.76534000	.68241162	.76230754	.67327922
(C)	d.f. _C	32	29	30	31	29
	SSE _C	.74203360	.56734469	.54003210	.58628223	.56992076
B versus A	F ^b	4.40	4.53	5.07	4.95	9.33
	P	.001	.001	.001	.001	.001
C versus B	F ^c	1.17	2.02	1.98	3.10	1.05
	P	NS	NS	NS	.05	NS

^aPlant cell walls determined using detergent procedures by Fennesbeck and Harris (1970a).

$$F = \frac{(SSE_A - SSE_B)/df_A - df_B}{SSE_B/df_B}$$

$$F = \frac{(SSE_B - SSE_C)/df_B - df_C}{SSE_C/df_C}$$

TABLE 19. DE estimated directly; using Simple, Type I, and Type II equations; regressed against DE observed

Predictant	Equation type	Coefficient of determination	Standard deviation (Mcal/kg)	Coefficient of variation (%)
Cellulose	Simple	.69	.21	7.7
	I	.88	.13	4.8
	II	.88	.13	4.9
Cell walls ^a	Simple	.69	.21	7.7
	I	.88	.13	4.8
	II	.91	.11	4.1
Neutral detergent fiber	Simple	.71	.20	7.4
	I	.89	.12	4.4
	II	.92	.11	4.1
Acid detergent fiber	Simple	.71	.21	7.7
	I	.89	.13	4.8
	II	.92	.11	4.1
Crude fiber	Simple	.56	.25	9.2
	I	.90	.12	4.4
	II	.91	.11	4.1

^aPlant cell walls determined using procedures by Fonnesebeck and Harris (1970 a).

SUMMARY AND CONCLUSIONS

1. Lambs were fed in a factorial designed experiment to collect information on the digestibility of diet chemical attributes as influenced by forage type, forage maturity, ingredient mixture, and feed texture.

2. Crude protein and available carbohydrate true digestibility was near 100% regardless of diet source. True digestibility of fibrous constituents (cellulose, hemicellulose, cell walls, neutral detergent fiber, acid detergent fiber and crude fiber) was dependent on diet source.

3. The apparent digestibility of fibrous constituents in grass diets was significantly greater than in alfalfa diets. Hemicellulose was more digestible in grass than in alfalfa, but the difference was not significant. Crude protein and available carbohydrates were more apparently digestible in alfalfa diets.

4. Forage maturity significantly lowered the apparent digestibility of all diet fibrous components except hemicellulose at the fullbloom stage. Fibrous constituent apparent digestibility differences between late vegetative and midbloom stages were not significantly different because of a significant interaction between forage type and stage of maturity. Crude protein and available carbohydrate were significantly lower in apparent digestibility in the fullbloom and midbloom diets respectively.

5. The apparent digestibility of fibrous constituents was not significantly different between all-hay and hay-corn diets. A

significant interaction between diet energy level and texture level was responsible for hiding differences in fiber apparent digestibility when corn was added to the diet. The apparent digestibility of available carbohydrates and total lipids significantly increased when corn was added to the diet.

6. Pelleting significantly lowered the apparent digestibility of all fibrous components except hemicellulose, although hemicellulose apparent digestibility was lower in pelleted diets.

7. Significantly higher apparent digestibility for grass fibrous residues and significantly lower available carbohydrate and crude protein apparent digestibility in grass resulted in significant forage type-by-forage maturity and forage type-by-energy level interaction effects on the apparent digestibility of fibrous, available carbohydrate, and crude protein diet constituents.

8. An interaction between forage type and diet energy level significantly affected available carbohydrate apparent digestibility. This interaction effect together with the maturity-by-energy level effect on available carbohydrate digestibility occurred as a result of an extremely low available carbohydrate content in midbloom grass.

9. An interaction between diet energy level and texture significantly altered the apparent digestibility of all fibrous residues. A significant reduction in the apparent digestibility of fibrous components in coarse hay-corn diets was cancelled out when differences were averaged over coarse and pelleted textures.

10. Simple and complex linear models were developed for estimating nutrient digestible amount (%) from the nutrient content (%) in the diet. The complex equations differed from simpler models in that

the complex models contained added indicator variables representing variation due to treatment main effects and two-way interactions not explained by the single chemical parameter. The complex equations were significantly better than simple models in estimating digestible amounts of diet chemical constituents. Caloric values were applied to the digestible amounts of carbohydrates, proteins, and lipids to calculate digestible energy. Estimated DE was closer to observed DE when complex models were used.

11. Simple and complex models were also developed for estimating DE directly from the percent content of cellulose, cell walls, neutral detergent fiber, acid detergent fiber, and crude fiber. Indicator variables were also used in complex equations. Complex equations were significantly more precise in estimating DE than simple equations. DE estimated directly from nutrient content was nearly the same as DE estimated indirectly using estimated digestible amounts and caloric values.

12. The results of this study indicate that indicator variables are useful in developing regression models to accurately estimate nutritional quality of animal diets. Digestibility variation between forages, stages of maturity, diet energy levels, and diet textures not explained by chemical parameters may be explained by appropriate qualitative indicators.

13. It was unfortunate that the rain damaged midbloom grass had such a dominant effect on the overall apparent digestibility of diet chemical constituents. Some of the significant main effects and two-way interactions affecting apparent digestibility may not have occurred had this damage been avoided. It is recommended that the experiment

be repeated using more careful control over the growing and harvesting of forages.

14. The crude fiber model gave the poorest prediction among the simple models using fibrous parameters to estimate DE, $R^2 = .56$. Other models gave R^2 values near .70. This indicates that new chemical methods do partition plant dry matter more accurately than crude fiber procedures.

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APPENDIX

Table 20. Crude protein apparent digestibility interactions between forage maturity and diet energy level and between diet texture and energy level

Item	Energy level		Average
	All-hay	Hay-corn	
<u>Stage of maturity</u>			
Late vegetative	67.3 ^a (8)	64.9 (8)	66.1 (16)
Midbloom	65.8 (8)	60.3 (8)	63.1 (16)
Fullbloom	58.2 (8)	61.9 (8)	60.0 (16)
Average	63.8 (24)	62.4 (24)	
<u>Texture</u>			
Coarse	64.7 (12)	59.5 (12)	62.1 (24)
Pelleted	62.9 (12)	65.2 (12)	64.0 (24)
Average	63.8 (24)	62.4 (24)	

^aAverage apparent digestion coefficient with total observations in parenthesis.

Table 21. Available carbohydrate apparent digestibility interactions between forage type and stage of maturity

Stage of Maturity	Forage type		Average
	Alfalfa	Grass	
Late vegetative	88.1 ^a (8)	81.9 (8)	85.0 (16)
Midbloom	89.4 (8)	56.2 (8)	72.8 (16)
Fullbloom	92.3 (8)	83.1 (8)	87.7 (16)
Average	89.9 (24)	73.7 (24)	

^aAverage apparent digestion coefficient with total observations in parenthesis.

Table 22. Available carbohydrate apparent digestibility interactions between forage maturity and diet energy level and between forage type and diet energy level

Item	Energy level		Average
	All-hay	Hay-corn	
<u>Stage of maturity</u>			
Late vegetative	80.6 ^a (8)	89.4 (8)	85.0 (16)
Midbloom	56.6 (8)	89.0 (8)	72.8 (16)
Fullbloom	83.9 (8)	91.5 (8)	87.7 (16)
Average	73.7 (24)	90.0 (24)	
<u>Forage type</u>			
Alfalfa	87.5 (12)	92.4 (12)	90.0 (24)
Grass	59.9 (12)	87.6 (12)	73.8 (24)
Average	73.7 (24)	90.0 (24)	

^aAverage apparent digestion coefficient with total observations in parenthesis.

Table 23. Cellulose apparent digestibility interactions between forage type and stage of maturity

Stage of maturity	Forage type		Average
	Alfalfa	Grass	
Late vegetative	46.3 ^a (8)	55.1 (8)	50.7 (16)
Midbloom	44.0 (8)	55.1 (8)	49.6 (16)
Fullbloom	37.7 (8)	48.5 (8)	43.1 (16)
Average	42.7 (24)	52.8 (24)	

^aAverage apparent digestion coefficient with total observations in parenthesis.

Table 24. Cellulose apparent digestibility interactions between forage maturity and diet energy level and between diet texture and energy level

Item	Energy level		Average
	All-hay	Hay-corn	
<u>Stage of maturity</u>			
Late vegetative	50.1 ^a (8)	51.3 (8)	50.7 (16)
Midbloom	54.4 (8)	44.6 (8)	49.6 (16)
Fullbloom	41.0 (8)	45.2 (8)	43.1 (16)
Average	48.5 (24)	47.0 (24)	
<u>Texture</u>			
Coarse	52.7 (12)	45.9 (12)	49.3 (24)
Pelleted	44.2 (12)	48.1 (12)	46.2 (24)
Average	48.5 (24)	47.0 (24)	

^aAverage apparent digestion coefficient with total observations in parenthesis.

Table 25. Hemicellulose apparent digestibility interactions between forage type and stage of maturity

Stage of maturity	Forage type		Average
	Alfalfa	Grass	
Late vegetative	49.1 ^a (8)	56.9 (8)	53.0 (16)
Midbloom	49.5 (8)	57.4 (8)	53.5 (16)
Fullbloom	51.7 (8)	50.1 (8)	50.9 (16)
Average	50.1 (24)	54.8 (24)	

^a Average apparent digestion coefficient with total observations in parenthesis.

Table 26. Hemicellulose apparent digestibility interactions between forage maturity and diet energy level and between diet texture and energy level

Item	Energy level		Average
	All-hay	Hay-corn	
<u>Stage of maturity</u>			
Late vegetative	50.0 ^a (8)	55.9 (8)	53.0 (16)
Midbloom	54.8 (8)	52.2 (8)	53.5 (16)
Fullbloom	49.0 (8)	52.8 (8)	50.9 (16)
Average	51.3 (24)	53.6 (24)	
<u>Texture</u>			
Coarse	54.8 (12)	51.8 (12)	53.3 (24)
Pelleted	47.8 (12)	55.5 (12)	51.7 (24)
Average	51.3 (24)	53.6 (24)	

^aAverage apparent digestion coefficient with total observations in parenthesis.

Table 27. Lignin apparent digestibility interactions between forage type and stage of maturity

Stage of maturity	Forage type		Average
	Alfalfa	Grass	
Late vegetative	5.1 ^a (8)	22.7 (8)	13.9 (16)
Midbloom	9.4 (8)	37.6 (8)	23.5 (16)
Fullbloom	10.0 (8)	15.8 (8)	10.0 (16)
Average	8.2 (24)	25.4 (24)	

^aAverage apparent digestion coefficient with total observations in parenthesis.

Table 28. Cell wall^a apparent digestibility interactions between forage type and stage of maturity

Stage of maturity	Forage type		Average
	Alfalfa	Grass	
Late vegetative	39.7 ^b (8)	49.3 (8)	44.5 (16)
Midbloom	39.8 (8)	51.6 (8)	45.7 (16)
Fullbloom	36.1 (8)	42.8 (8)	37.5 (16)
Average	38.5 (24)	47.9 (24)	

^aPlant cell walls determined using detergent procedures by Fannesbeck and Harris (1970a).

^bAverage apparent digestion coefficient with total observations in parenthesis.

Table 29. Cell wall^a apparent digestibility interactions between forage maturity and diet energy level and between diet texture and energy level

Item	Energy level		Average
	All-hay	Hay-corn	
<u>Stage of maturity</u>			
Late vegetative	42.4 ^b (8)	46.6 (8)	44.5 (16)
Midbloom	48.6 (8)	42.9 (8)	45.7 (16)
Fullbloom	36.6 (8)	42.3 (8)	39.5 (16)
Average	42.5 (24)	43.9 (24)	
<u>Texture</u>			
Coarse	46.5 (12)	42.4 (12)	44.4 (24)
Pelleted	38.5 (12)	45.4 (12)	42.0 (24)
Average	42.5 (24)	43.9 (24)	

^aPlant cell walls determined using detergent procedures by Fannesbeck and Harris (1970a).

^bAverage apparent digestion coefficient with total observations in parenthesis.

Table 30. Neutral detergent fiber apparent digestibility interactions between forage type and stage of maturity

Stage of maturity	Forage type		Average
	Alfalfa	Grass	
Late vegetative	42.5 ^a (8)	48.5 (8)	45.5 (16)
Midbloom	38.7 (8)	54.7 (8)	46.7 (16)
Fullbloom	37.6 (8)	39.9 (8)	38.8 (16)
Average	39.6 (24)	47.7 (24)	

^aAverage apparent digestion coefficient with total observation in parenthesis.

Table 31. Neutral detergent fiber apparent digestibility interaction between forage maturity and diet energy level and between diet texture and energy level

Item	Energy level		Average
	All-hay	Hay-corn	
<u>Stage of maturity</u>			
Late vegetative	44.1 ^a (8)	46.9 (8)	45.5 (16)
Midbloom	51.0 (8)	42.4 (8)	46.7 (16)
Fullbloom	38.9 (8)	38.7 (8)	38.8 (16)
Average	44.7 (24)	42.7 (24)	
<u>Texture</u>			
Coarse	49.2 (12)	42.2 (12)	45.7 (24)
Pelleted	40.1 (12)	43.1 (12)	41.6 (24)
Average	44.6 (24)	42.6 (24)	

^aAverage apparent digestion coefficient with total observations in parenthesis.

Table 32. Acid detergent fiber apparent digestibility interactions between forage type and stage of maturity

Stage of maturity	Forage type		Average
	Alfalfa	Grass	
Late vegetative	42.5 ^a (8)	46.1 (8)	44.3 (16)
Midbloom	40.1 (8)	50.1 (8)	45.1 (16)
Fullbloom	36.2 (8)	37.6 (8)	37.0 (16)
Average	39.6 (24)	44.6 (24)	

^aAverage apparent digestion coefficient with total observations in parenthesis.

Table 33. Acid detergent fiber apparent digestibility interactions between forage maturity and diet energy level and between diet texture and energy level

Item	Energy level		Average
	All-hay	Hay-corn	
<u>Stage of maturity</u>			
Late vegetative	42.2 ^a (8)	46.3 (8)	44.2 (16)
Midbloom	49.3 (8)	40.9 (8)	45.1 (16)
Fullbloom	34.5 (8)	39.4 (8)	37.0 (16)
Average	42.0 (24)	42.2 (24)	
<u>Texture</u>			
Coarse	46.7 (12)	42.5 (12)	44.6 (24)
Pelleted	37.3 (12)	41.8 (12)	39.6 (24)
Average	42.0 (24)	42.2 (24)	

^aAverage apparent digestion coefficient with total observations in parenthesis.

Table 34. Dry matter apparent digestibility interaction between forage type and stage of maturity

Stage of maturity	Energy level		Average
	Alfalfa	Grass	
Late vegetative	64.5 ^a (8)	61.1 (8)	62.8 (16)
Midbloom	65.6 (8)	56.7 (8)	61.2 (16)
Fullbloom	64.8 (8)	55.3 (8)	60.1 (16)
Average	65.0 (24)	57.7 (24)	

^aAverage apparent digestion coefficient with total observations in parenthesis.

Table 35. Dry matter apparent digestibility interactions between forage maturity and diet energy level and between diet texture and energy level

Item	Energy level		Average
	All-hay	Hay-corn	
<u>Stage of maturity</u>			
Late vegetative	56.7 ^a (8)	68.9 (8)	62.8 (16)
Midbloom	57.0 (8)	65.4 (8)	61.2 (16)
Fullbloom	52.9 (8)	67.2 (8)	60.0 (16)
Average	55.5 (24)	67.2 (24)	
<u>Texture</u>			
Coarse	57.6 (12)	65.4 (12)	61.5 (24)
Pelleted	53.4 (12)	68.9 (12)	61.2 (24)
Average	55.5 (24)	67.2 (24)	

^aAverage apparent digestion coefficient with total observations in parenthesis.

Table 36. Gross energy apparent digestibility interactions between forage type and stage of maturity

Stage of maturity	Forage type		Average
	Alfalfa	Grass	
Late vegetative	64.1 ^a (8)	60.4 (8)	62.2 (16)
Midbloom	65.7 (8)	57.0 (8)	61.4 (16)
Fullbloom	64.1 (8)	55.1 (8)	59.6 (16)
Average	57.5 (24)	64.6 (24)	

^aAverage apparent digestibility coefficient with total observations in parenthesis.

Table 37. Gross energy apparent digestibility interactions between diet texture and energy level

Texture	Energy level		Average
	All-hay	Hay-corn	
Coarse	57.1 ^a (12)	65.7 (12)	61.4 (24)
Pelleted	53.1 (12)	68.5 (12)	60.8 (24)
Average	55.1 (24)	67.1 (24)	

^aAverage apparent digestion coefficient with total observations in parenthesis.

Table 38. Computer estimated nutrient digestible amounts and DE^a using simple models compared to observed DE

Estimated nutrient digestible amounts					Energy		Diet description
Crude protein %	Available carbohydrates %	Total lipids %	Cellulose %	Hemicellulose %	DE estimated Mcal/kg	DE observed Mcal/kg	
7.303	3.391	2.823	17.12	13.33	2.08	2.02	Grass, midbloom, all-hay,
7.484	2.391	2.865	12.58	13.15	2.07	2.36	pelleted
7.312	21.15	2.670	12.18	8.906	2.41	2.28	Grass, late vegetative,
7.683	21.57	2.611	11.98	8.822	2.44	2.40	all-hay, pelleted
11.37	41.70	1.732	6.279	3.755	2.95	2.76	Alfalfa, late vegetative,
11.73	37.75	1.762	6.267	4.256	2.83	3.33	hay-corn, coarse
6.689	39.76	2.434	6.803	6.545	2.81	2.95	Grass, late vegetative,
6.897	36.71	2.428	7.145	7.324	2.74	2.57	hay-corn, coarse
7.574	31.87	2.157	9.668	8.459	2.71	2.82	Grass, midbloom, hay-corn
7.394	30.23	2.175	9.821	9.003	2.66	2.92	pelleted
15.96	18.93	2.912	12.60	2.873	2.60	2.28	Alfalfa, late vegetative,
16.36	15.74	2.941	12.78	4.473	2.57	2.61	all-hay, pelleted
10.34	41.19	2.110	5.766	6.122	2.99	3.12	Alfalfa, midbloom, hay-corn,
9.209	48.35	2.110	5.312	3.254	3.08	3.25	pelleted
6.482	41.40	2.452	6.603	6.279	2.85	3.31	Grass, late vegetative, hay-
6.445	40.44	2.499	6.503	6.974	2.84	2.94	corn, pelleted
3.935	17.02	2.552	15.51	10.41	2.24	2.03	Grass, fullbloom, all-hay
3.664	16.48	2.564	15.72	10.55	2.22	2.02	pelleted
7.656	42.35	3.224	5.737	4.437	2.92	3.16	Alfalfa, fullbloom, hay-
6.044	41.90	3.324	5.601	4.455	2.92	3.13	corn, coarse
14.21	23.45	2.593	11.35	3.894	2.65	2.65	Alfalfa, midbloom, hay-
13.43	24.93	2.540	11.61	3.380	2.65	2.86	corn, pelleted
15.66	17.72	2.882	12.56	4.262	2.59	2.61	Alfalfa, late vegetative,
15.78	16.96	2.906	12.81	3.543	2.55	2.82	all-hay, coarse
6.572	29.12	2.157	10.08	9.377	2.59	2.81	Grass, midbloom, hay-corn
6.454	30.99	2.122	9.874	8.824	2.63	2.67	coarse
10.18	42.22	2.104	6.279	4.486	2.97	2.95	Alfalfa, midbloom, hay-corn,
10.46	42.06	2.139	6.438	3.725	2.96	2.93	coarse
8.577	25.60	2.405	13.45	5.385	2.55	2.75	Alfalfa, fullbloom, all-hay
10.01	26.70	2.481	12.07	4.781	2.61	2.72	coarse
3.501	15.81	2.540	15.51	10.89	2.19	2.17	Grass, fullbloom, all-hay
3.203	13.84	2.552	16.56	10.83	2.13	2.14	coarse
4.258	1.412	2.829	17.81	13.53	2.03	2.33	Grass, midbloom, all-hay
7.114	1.175	2.841	18.46	12.98	2.02	2.32	coarse
12.95	21.39	2.517	13.27	3.755	2.56	2.76	Alfalfa, midbloom, all-hay
15.21	18.32	2.617	12.92	3.857	2.56	2.86	coarse
5.172	35.75	2.434	8.678	7.831	2.69	2.45	Grass, fullbloom, hay-corn,
5.145	35.96	2.475	8.613	7.988	2.70	2.85	pelleted
6.762	19.95	2.558	12.15	9.359	2.34	2.44	Grass, late vegetative, all-
7.005	28.65	2.593	12.70	9.009	2.73	2.39	hay, coarse
11.07	42.29	1.756	6.462	3.936	2.98	3.09	Alfalfa, late vegetative,
12.24	38.74	1.756	6.857	4.449	2.93	3.32	hay-corn, pelleted
9.335	26.30	3.077	11.96	5.253	2.62	2.41	Alfalfa, fullbloom, all-
9.615	26.31	3.159	11.94	4.866	2.63	2.33	hay, pelleted
4.847	37.62	2.428	8.796	7.227	2.73	2.60	Grass, fullbloom, hay-corn,
4.982	35.68	2.434	9.085	7.837	2.69	2.84	coarse
8.225	47.22	2.788	5.937	3.447	3.08	3.28	Alfalfa, fullbloom, hay-
8.053	48.87	2.776	6.090	3.260	3.13	3.23	corn, pelleted

^aDE was estimated using the equation: $DE = 4.65 (Y_{CP}) + 4.15 (Y_{AC} + Y_{CL} + Y_{HC}) + 9.40 Y_{TL}$; where Y_N equals the decimal fraction of the nutrient (CP = crude protein, AC = available carbohydrates, CL = cellulose, HC = hemicellulose, or TL = total lipids) digestible amount as estimated using simple models. The 4.65, 4.15, and 9.40 are assigned caloric values for diet protein, carbohydrates, and lipids respectively.

Table 39. Computer estimated nutrient digestible amounts and DE^a using Type I models compared to observed DE

Estimated nutrient digestible amounts					Energy		Diet description
Crude protein %	Available carbohydrates %	Total lipids %	Cellulose %	Hemicellulose %	DE estimated Mcal/kg	DE observed Mcal/kg	
7.009	2.741	2.410	18.24	13.87	2.07	2.02	Grass, midbloom, all-hay, pelleted
7.194	1.841	2.475	18.84	13.65	2.06	2.36	Grass, late vegetative, all-hay, pelleted
6.947	19.24	2.139	12.34	8.636	2.26	2.28	Grass, late vegetative, all-hay, pelleted
7.326	19.63	2.046	12.08	8.530	2.28	2.40	Grass, late vegetative, all-hay, pelleted
11.20	41.78	1.611	6.518	3.941	2.95	2.76	Alfalfa, late vegetative, hay-corn, coarse
11.57	38.20	1.657	6.503	4.570	2.85	3.33	Grass, late vegetative, hay-corn, coarse
6.413	27.43	2.387	8.908	6.680	2.79	2.95	Grass, late vegetative, hay-corn, coarse
6.625	34.66	2.377	9.350	7.659	2.74	2.57	Grass, midbloom, hay-corn, pelleted
7.594	31.13	2.339	10.50	8.434	2.72	2.82	Grass, midbloom, hay-corn, pelleted
7.209	29.63	2.366	10.69	9.117	2.68	2.92	Grass, late vegetative, all-hay, pelleted
15.80	19.82	2.838	11.17	1.823	2.52	2.28	Alfalfa, late vegetative, all-hay, pelleted
16.22	16.92	2.884	11.41	3.833	2.52	2.61	Alfalfa, midbloom, hay-corn, pelleted
10.23	42.18	2.586	5.114	6.932	3.07	3.12	Grass, late vegetative, hay-corn, pelleted
9.069	41.69	2.586	4.557	3.329	2.81	3.25	Grass, late vegetative, hay-corn, pelleted
6.781	40.15	2.768	8.891	6.759	2.96	3.31	Grass, late vegetative, hay-corn, pelleted
6.744	39.28	2.841	8.761	7.631	2.96	2.94	Grass, fullbloom, all-hay, pelleted
3.824	16.32	1.843	11.94	8.577	1.92	2.03	Alfalfa, fullbloom, all-hay, pelleted
3.542	15.83	1.861	12.20	8.752	1.90	2.02	Alfalfa, fullbloom, all-hay, pelleted
7.735	43.20	4.680	5.365	5.091	3.10	3.16	Alfalfa, fullbloom, hay-corn, pelleted
8.133	42.79	4.836	5.190	5.114	3.12	3.13	Alfalfa, midbloom, hay-corn, pelleted
14.09	23.55	2.372	10.47	3.454	2.57	2.65	Alfalfa, midbloom, hay-corn, pelleted
13.08	21.90	2.289	10.81	2.810	2.44	2.86	Alfalfa, late vegetative, all-hay, coarse
15.87	19.42	2.434	12.71	4.456	2.64	2.61	Grass, midbloom, hay-corn, coarse
16.00	18.74	2.471	13.03	3.554	2.60	2.82	Grass, midbloom, hay-corn, coarse
5.787	27.41	2.194	11.10	9.175	2.51	2.81	Grass, midbloom, hay-corn, coarse
5.666	29.10	2.139	10.83	7.820	2.50	2.67	Grass, midbloom, hay-corn, coarse
9.487	41.78	2.433	5.875	4.460	2.93	2.95	Alfalfa, midbloom, hay-corn, coarse
9.746	41.74	2.488	6.081	3.508	2.94	2.93	Alfalfa, fullbloom, all-hay, coarse
8.949	27.41	2.424	12.46	5.397	2.61	2.75	Alfalfa, fullbloom, all-hay, coarse
10.42	27.41	2.544	10.69	4.638	2.60	2.72	Grass, fullbloom, all-hay, coarse
3.852	15.92	2.314	14.66	10.06	2.12	2.17	Grass, fullbloom, all-hay, coarse
3.445	14.14	2.333	16.02	9.989	2.08	2.14	Grass, midbloom, all-hay, coarse
7.337	1.657	2.271	21.02	15.01	2.19	2.33	Grass, midbloom, all-hay, coarse
7.189	1.441	2.289	21.86	14.33	2.18	2.32	Grass, midbloom, all-hay, coarse
13.17	22.39	2.103	14.85	4.168	2.66	2.76	Alfalfa, midbloom, all-hay, coarse
15.48	19.61	2.260	14.39	4.297	2.68	2.86	Grass, fullbloom, hay-corn, pelleted
5.772	35.84	2.269	7.798	7.524	2.66	2.45	Grass, fullbloom, hay-corn, pelleted
5.744	36.03	2.693	7.714	7.227	2.71	2.85	Grass, late vegetative, all-hay, coarse
6.757	18.86	1.606	13.89	10.09	2.31	2.44	Grass, late vegetative, all-hay, coarse
7.007	16.76	1.661	14.61	9.653	2.24	2.39	Grass, late vegetative, all-hay, coarse
11.48	43.55	2.001	6.997	4.580	2.94	3.09	Alfalfa, late vegetative, hay-corn, pelleted
12.68	40.72	2.001	7.507	5.225	3.12	3.32	Alfalfa, fullbloom, all-hay, pelleted
9.351	27.34	2.985	7.808	4.341	2.44	2.41	Alfalfa, fullbloom, all-hay, pelleted
9.638	27.35	3.114	7.785	3.856	2.46	2.33	Grass, fullbloom, hay-corn, coarse
4.848	36.31	3.114	8.856	6.354	2.70	2.60	Grass, fullbloom, hay-corn, coarse
4.997	34.55	3.123	9.229	7.120	2.69	2.84	Alfalfa, fullbloom, hay-corn, pelleted
8.699	48.85	3.503	4.719	4.259	3.23	3.28	Grass, fullbloom, hay-corn, pelleted
8.723	50.35	3.485	4.918	4.024	3.28	3.23	

^aDE was estimated using the equation: $DE = 4.65 (Y_{CP}) + 4.15 (Y_{AC} + Y_{CL} + Y_{HC}) + 9.40 Y_{TL}$; where Y_N equals the decimal fraction of the nutrient (CP = crude protein, AC = available carbohydrates, CL = cellulose, HC = hemicellulose, or TL = total lipids) digestible amount as estimated using Type I models. The 4.65, 4.15, and 9.40 are assigned caloric values for diet protein, carbohydrates, and lipids respectively.

Table 40. Computer estimated nutrient digestible amounts and DE^a using Type I and Type II models compared to observed DE

Estimated nutrient digestible amounts					Energy		Diet description
Type I equation			Type II equation		DE estimated Mcal/kg	DE observed Mcal/kg	
Crude protein %	Available carbo- hydrates %	Total lipids %	Cellu- lose %	Hemi- cellu- lose %			
7.009	2.741	2.410	17.81	13.51	2.04	2.02	Grass, midbloom, all-hay,
7.194	1.841	2.475	18.35	13.24	2.03	2.36	pelleted
6.947	19.24	2.139	12.56	8.598	2.27	2.24	Grass, late vegetative,
7.326	19.63	2.046	13.08	8.537	2.36	2.40	all-hay, pelleted
11.20	41.78	1.611	6.417	3.349	2.92	2.76	Alfalfa, late vegetative,
11.57	38.20	1.657	6.378	4.729	2.86	3.33	hay-corn, coarse
6.413	37.43	2.387	3.653	7.235	2.80	2.95	Grass, late vegetative,
6.625	34.66	2.377	9.776	7.979	2.77	2.57	hay-corn, coarse
7.394	31.13	2.339	9.507	7.640	2.64	2.82	Grass, midbloom, hay-corn
7.209	29.63	2.366	9.647	8.741	2.62	2.92	pelleted
15.80	19.82	2.838	10.95	1.419	2.50	2.28	Alfalfa, late vegetative,
16.22	16.92	2.884	10.47	5.459	2.55	2.61	all-hay, pelleted
10.23	42.18	2.586	5.415	7.596	3.11	3.12	Alfalfa, midbloom, hay-corn,
9.069	41.69	2.586	4.999	2.751	2.81	3.25	pelleted
6.781	40.15	2.768	8.302	6.808	2.94	3.31	Grass, late vegetative, hay-
6.744	39.28	2.841	8.052	7.324	2.92	2.94	corn, pelleted
3.824	16.32	1.843	12.60	7.814	1.91	2.03	Grass, fullbloom, all-hay
3.542	4.83	1.861	12.86	8.053	1.90	2.02	pelleted
7.738	43.20	4.680	4.982	4.826	3.08	3.16	Alfalfa, fullbloom, hay-
8.133	42.79	4.836	4.944	4.857	3.09	3.13	corn, pelleted
14.09	23.55	2.372	10.55	4.076	2.60	2.65	Alfalfa, midbloom, hay-corn
13.28	21.90	2.289	10.85	3.439	2.47	2.86	pelleted
15.57	19.42	2.434	13.28	4.586	2.68	2.61	Alfalfa, late vegetative,
16.00	18.74	2.471	12.65	2.723	2.55	2.82	all-hay, coarse
5.787	27.41	2.194	12.32	10.32	2.61	2.81	Grass, midbloom, hay-corn
5.666	29.10	2.139	11.97	7.879	2.55	2.67	coarse
9.487	41.89	2.433	5.322	4.638	2.92	2.95	Alfalfa, midbloom, hay-corn,
9.746	41.74	2.488	5.594	3.196	2.88	2.93	coarse
8.949	27.41	2.424	11.73	5.190	2.57	2.75	Alfalfa, fullbloom, all-hay
10.42	27.41	2.544	9.867	4.910	2.58	2.72	coarse
3.852	15.92	2.314	15.03	9.769	2.10	2.17	Grass, fullbloom, all-hay
3.445	14.14	2.333	16.45	9.652	2.08	2.14	coarse
7.337	1.657	2.271	21.20	15.51	2.22	2.33	Grass, midbloom, all-hay,
7.189	1.441	2.289	22.00	14.54	2.20	2.32	coarse
13.17	22.39	2.103	15.07	3.559	2.64	2.76	Alfalfa, midbloom, all-hay,
15.48	19.61	2.260	14.64	3.707	2.66	2.86	coarse
5.772	35.84	2.269	7.177	7.817	2.65	2.45	Grass, fullbloom, hay-corn,
5.744	36.03	2.693	7.161	8.289	2.71	2.85	pelleted
6.757	18.86	1.606	14.84	9.741	2.34	2.44	Grass, late vegetative, all-
7.007	16.76	1.661	13.43	9.416	2.20	2.39	hay, coarse
11.48	43.55	2.001	7.436	4.155	3.13	3.09	Alfalfa, late vegetative,
12.68	40.72	2.001	8.422	5.462	3.17	3.32	hay-corn, pelleted
9.351	27.34	2.985	7.521	5.163	2.46	2.41	Alfalfa, fullbloom, all-hay,
9.638	27.35	3.114	7.498	5.064	2.49	2.33	pelleted
4.858	36.31	3.114	8.627	6.373	2.70	2.60	Grass, fullbloom, hay-corn,
4.997	34.55	3.123	8.922	8.336	2.72	2.84	coarse
8.899	48.64	3.503	6.021	3.500	3.21	3.28	Alfalfa, fullbloom, hay-corn,
8.723	50.35	3.485	6.057	3.210	3.29	3.23	pelleted

^aDE was estimated using the equation: $DE = 4.65 (Y_{CP}) + 4.15 (Y_{AC} + Y_{CL} + Y_{HC}) + 9.40 Y_{TL}$; where Y_N equals the decimal fraction of the nutrient (CP = crude protein, AC = available carbohydrates, CL = cellulose, HC = hemicellulose, or TL = total lipids) digestible amount as estimated using Type I and Type II models. The 4.65, 4.15, and 9.40 are assigned caloric values for diet protein, carbohydrates, and lipids respectively.

Table 41. DE predicted directly^a with simple models compared to observed DE

DE (Mcal/kg) estimated using diet percent content of:						
Cellulose	Cell walls ^b	Neutral detergent fiber	Acid detergent fiber	Crude fiber	DE observed Mcal/kg	Diet description
2.18	2.06	2.01	2.18	2.09	2.02	Grass, midbloom, all-hay,
2.14	2.05	2.01	2.17	2.38	2.36	pelleted
2.57	2.51	2.47	2.57	2.57	2.28	Grass, late vegetative, all-hay
2.59	2.51	2.50	2.57	2.68	2.40	pelleted
3.05	3.07	3.02	3.05	2.92	2.76	Alfalfa, late vegetative, hay-
3.05	3.04	3.00	3.05	2.97	3.33	corn, coarse
3.01	2.90	2.88	3.03	2.97	2.95	Grass, late vegetative, hay-corn,
2.98	2.83	2.80	2.88	2.96	2.57	coarse
2.78	2.68	2.66	2.86	2.85	2.82	Grass, midbloom, hay-corn,
2.76	2.64	2.66	2.80	2.85	2.92	pelleted
2.54	2.78	2.73	2.57	2.55	2.28	Alfalfa, late vegetative, all-hay,
2.53	2.73	2.72	2.44	2.53	2.61	pelleted
3.09	3.01	3.12	3.15	3.02	3.12	Alfalfa, midbloom, hay-corn,
3.13	3.14	3.13	3.12	3.01	3.25	pelleted
3.02	2.92	2.95	3.03	3.02	3.31	Grass, late vegetative, hay-corn,
3.03	2.91	2.93	3.05	3.04	2.94	pelleted
2.31	2.28	2.34	2.37	2.49	2.03	Grass, fullbloom, all-hay,
2.29	2.27	2.32	2.33	2.47	2.02	pelleted
3.09	3.04	3.04	2.98	2.87	3.16	Alfalfa, fullbloom, hay-corn,
3.10	3.05	3.04	3.03	2.97	3.13	coarse
2.64	2.81	2.79	2.60	2.60	2.65	Alfalfa, midbloom, hay-corn,
2.62	2.82	2.82	2.61	2.64	2.86	pelleted
2.54	2.74	2.69	2.48	2.50	2.61	Alfalfa, late vegetative, all-hay,
2.52	2.75	2.73	2.44	2.57	2.82	coarse
2.74	2.61	2.64	2.81	2.80	2.81	Grass, midbloom, hay-corn,
2.76	2.65	2.62	2.80	2.82	2.67	coarse
3.05	3.05	3.08	3.05	2.98	2.95	Alfalfa, midbloom, hay-corn,
3.04	3.05	3.04	3.07	3.00	2.93	coarse
2.47	2.64	2.59	2.46	2.44	2.75	Alfalfa, fullbloom, all-hay,
2.58	2.72	2.68	2.57	2.56	2.72	coarse
2.31	2.26	2.28	2.30	2.43	2.17	Grass, fullbloom, all-hay,
2.22	2.21	2.23	2.25	2.43	2.14	coarse
2.12	2.01	2.01	2.14	2.01	2.33	Grass, midbloom, all-hay,
2.07	2.00	2.03	2.18	1.93	2.32	coarse
2.49	2.72	2.77	2.46	2.41	2.76	Alfalfa, midbloom, all-hay,
2.51	2.73	2.76	2.53	2.55	2.86	coarse
2.86	2.76	2.78	2.84	2.87	2.45	Grass, fullbloom, hay-corn,
2.86	2.75	2.81	2.91	2.90	2.85	pelleted
2.58	2.47	2.44	2.50	2.64	2.44	Grass, late vegetative, all-hay,
2.53	2.45	2.42	2.46	2.64	2.39	coarse
3.04	3.06	2.99	3.02	2.98	3.09	Alfalfa, late vegetative, hay-corn,
3.00	3.01	3.04	3.01	2.97	3.32	pelleted
2.59	2.70	2.73	2.62	2.57	2.41	Alfalfa, fullbloom, all-hay,
2.59	2.72	2.68	2.52	2.57	2.33	pelleted
2.85	2.77	2.81	2.90	2.90	2.60	Grass, fullbloom, hay-corn,
2.82	2.73	2.81	2.89	2.90	2.84	coarse
3.08	3.10	3.11	3.07	2.95	3.28	Alfalfa, fullbloom, hay-corn,
2.07	3.10	3.10	3.09	3.00	3.23	pelleted

^aDE was estimated using equations of the form $Y = b_0 + b_1X_1$, where Y is the estimated digestible energy (Mcal/kg), and X_1 is the nutrient content (%) of the diet (see also table 15).

^bPlant cell walls was determined using detergent procedures by Fonnebeck and Harris (1970a).

Table 42. DE predicted directly^a with Type I models compared to observed DE

DE (Mcal/kg) estimated using diet percent content of:						
Cellulose	Cell wall ^b	Neutral detergent fiber	Acid detergent fiber	Crude fiber	DE observed Mcal/kg	Diet description
2.25	2.27	2.18	2.23	2.13	2.02	Grass, midbloom, all-hay
2.22	2.21	2.17	2.22	2.38	2.36	pelleted
2.33	2.31	2.28	2.35	2.26	2.28	Grass, late vegetative, all-
2.34	2.31	2.31	2.35	2.35	2.40	hay, pelleted
3.04	3.03	3.02	3.07	3.00	2.76	Alfalfa, late vegetative, hay-
3.04	3.01	3.00	3.07	3.04	3.33	corn, coarse
2.81	2.85	2.87	2.85	2.79	2.95	Grass, late vegetative, hay-corn,
2.80	2.82	2.80	2.73	2.79	2.57	coarse
2.86	2.90	2.91	2.88	2.88	2.82	Grass, midbloom, hay-corn,
2.85	2.87	2.91	2.03	2.88	2.92	pelleted
2.50	2.54	2.54	2.55	2.50	2.28	Alfalfa, late vegetative, all-
2.69	2.51	2.53	2.44	2.48	2.61	hay, pelleted
3.21	3.15	3.17	3.24	3.15	3.12	Alfalfa, midbloom, hay-corn,
3.23	3.22	3.18	3.22	3.15	3.25	pelleted
3.05	3.07	3.11	2.64	3.05	3.31	Grass, late vegetative, hay-corn,
3.05	3.07	3.09	2.06	3.07	2.94	pelleted
1.93	1.92	1.93	1.94	1.93	2.03	Grass, fullbloom, all-hay,
1.92	1.92	1.91	1.91	1.92	2.02	pelleted
3.17	3.13	3.13	3.11	3.10	3.16	Alfalfa, fullbloom, hay-corn,
3.17	3.14	3.13	3.15	3.18	3.13	coarse
2.70	2.71	2.72	2.69	2.70	2.65	Alfalfa, midbloom, hay-corn,
2.68	2.72	2.75	2.70	2.73	2.86	pelleted
2.64	2.65	2.66	2.64	2.61	2.61	Alfalfa, late vegetative, all-
2.63	2.65	2.69	2.61	2.67	2.82	hay, coarse
2.66	2.67	2.72	2.66	2.70	2.81	Grass, midbloom, hay-corn,
2.67	2.69	2.69	2.65	2.72	2.67	coarse
3.00	2.98	2.95	2.98	2.98	2.95	Alfalfa, midbloom, hay-corn,
2.99	2.98	2.92	3.00	3.00	2.93	coarse
2.66	2.70	2.68	2.68	2.65	2.75	Alfalfa, fullbloom, all-hay
2.74	2.75	2.76	2.76	2.76	2.72	coarse
2.24	2.21	2.20	2.21	2.21	2.17	Grass, fullbloom, all-hay,
2.18	2.18	2.15	2.17	2.21	2.14	coarse
2.39	2.34	2.31	2.37	2.31	2.33	Grass, midbloom, all-hay,
2.35	2.34	2.33	2.40	2.24	2.32	coarse
2.77	2.81	2.84	2.75	2.77	2.76	Alfalfa, midbloom, all-hay,
2.79	2.81	2.84	2.80	2.89	2.86	coarse
2.74	2.74	2.71	2.69	2.70	2.45	Grass, fullbloom, hay-corn
2.74	2.74	2.73	2.74	2.73	2.85	pelleted
2.46	2.43	2.41	2.46	2.48	2.44	Grass, late vegetative, all-hay,
2.43	2.41	2.39	2.43	2.48	2.39	coarse
3.25	3.23	3.16	3.23	3.27	3.09	Alfalfa, late vegetative, hay-
3.23	3.20	3.21	3.23	3.26	3.32	corn, pelleted
2.44	2.43	2.48	2.48	2.43	2.41	Alfalfa, fullbloom, all-hay,
2.44	2.44	2.44	2.40	2.43	2.33	pelleted
2.68	2.70	2.72	2.71	2.69	2.60	Grass, fullbloom, hay-corn,
2.66	2.68	2.72	2.70	2.69	2.84	coarse
3.20	3.20	3.20	3.21	3.21	3.28	Alfalfa, fullbloom, hay-corn,
2.19	3.21	3.20	3.23	3.25	3.23	pelleted

^aDE was estimated using equations of the form $Y = b_0 + b_1X_1 + \alpha_i + \beta_j + \gamma_k + \delta_l + \alpha\beta_{ij} + \beta\gamma_{jk} + \beta\delta_{jl} + \gamma\delta_{kl}$; where Y is the predicted digestible energy (Mcal/kg) and X_1 is the nutrient percent content (%) the regression constant (b_0) is adjusted by qualitative indicators ($\alpha_i, \beta_j, \gamma_k, \delta_l, \alpha\beta_{ij}, \beta\gamma_{jk}, \beta\delta_{jl}, \gamma\delta_{kl}$) according to the description of the ingredient or diet. (see also table 16)

^bPlant cell walls was determined using detergent procedures by Fonesbeck and Harris (1970a).

Table 43. DE predicted directly^a with Type II models compared to observed DE

DE (Mcal/kg) estimated using diet percent content of:						DE observed Mcal/kg	Diet description
Cellulose	Cell walls ^b	Neutral detergent fiber	Acid detergent fiber	Crude fiber	DE		
2.25	2.25	2.19	2.20	2.08	2.02	Grass, midbloom, all-hay,	
2.20	2.25	2.18	2.20	2.24	2.36	pelleted	
2.30	2.22	2.28	2.29	2.17	2.28	Grass, late vegetative, all-hay,	
2.31	2.23	2.33	2.29	2.34	2.40	pelleted	
3.09	2.46	3.14	3.07	2.88	2.76	Alfalfa, late vegetative, hay-	
3.09	3.01	3.07	3.08	3.20	3.33	corn, coarse	
2.85	2.90	2.88	2.90	2.80	2.95	Grass, late vegetative, hay-	
2.83	2.72	2.62	2.55	2.74	2.57	corn, coarse	
2.87	2.79	2.85	2.89	2.89	2.82	Grass, midbloom, hay-corn,	
2.84	2.87	2.85	2.88	2.89	2.92	pelleted	
2.47	2.31	2.47	2.41	2.56	2.28	Alfalfa, late vegetative, all-	
2.46	2.61	2.46	2.58	2.52	2.61	hay, pelleted	
3.18	3.17	3.16	3.15	3.17	3.12	Alfalfa, midbloom, hay-corn	
3.22	3.18	3.18	3.15	3.18	3.25	pelleted	
3.01	3.13	3.18	3.12	3.09	3.31	Grass, late vegetative, hay-	
3.01	3.10	3.11	3.16	3.18	2.94	corn, pelleted	
1.96	1.97	2.06	1.97	1.99	2.03	Grass, fullbloom, all-hay,	
1.98	2.00	2.03	1.96	1.98	2.02	pelleted	
3.12	3.18	3.07	3.15	3.09	3.16	Alfalfa, fullbloom, hay-corn,	
3.11	3.16	3.09	3.19	3.22	3.13	coarse	
2.75	2.74	2.67	2.76	2.76	2.65	Alfalfa, midbloom, hay-corn,	
2.73	2.78	2.81	2.77	2.79	2.86	pelleted	
2.67	2.75	2.68	2.62	2.59	2.61	Alfalfa, late vegetative, all-	
2.65	2.73	2.73	2.66	2.74	2.82	hay, coarse	
2.68	2.82	2.76	2.72	2.73	2.81	Grass, midbloom, hay-corn	
2.70	2.74	2.75	2.72	2.71	2.67	coarse	
2.09	2.95	3.01	2.97	2.95	2.95	Alfalfa, midbloom, hay-corn,	
2.07	2.95	2.89	2.98	2.93	2.93	coarse	
2.73	2.68	2.67	2.67	2.64	2.75	Alfalfa, fullbloom, all-hay,	
2.63	2.66	2.76	2.69	2.66	2.72	coarse	
2.16	2.12	2.17	2.23	2.23	2.17	Grass, fullbloom, all-hay,	
2.24	2.23	2.09	2.21	2.23	2.14	coarse	
2.38	2.26	2.31	2.30	2.32	2.33	Grass, midbloom, all-hay,	
2.31	2.26	2.35	2.33	2.30	2.32	coarse	
2.75	2.79	2.84	2.77	2.82	2.76	Alfalfa, midbloom, all-hay,	
2.79	2.82	2.81	2.83	2.85	2.86	coarse	
2.75	2.73	2.59	2.65	2.66	2.45	Grass, fullbloom, hay-corn,	
2.75	2.75	2.76	2.70	2.70	2.85	pelleted	
2.50	2.46	2.46	2.47	2.46	2.44	Grass, late vegetative, all-hay,	
2.46	2.51	2.42	2.51	2.45	2.39	coarse	
3.21	3.20	3.04	3.20	3.24	3.09	Alfalfa, late vegetative, hay-	
3.19	3.25	3.22	3.20	3.14	3.32	corn, pelleted	
2.43	2.45	2.36	2.43	2.41	2.41	Alfalfa, fullbloom, all-hay,	
2.43	2.44	2.41	2.40	2.41	2.33	pelleted	
2.62	2.54	2.70	2.68	2.71	2.60	Grass, fullbloom, hay-corn,	
2.64	2.75	2.70	2.68	2.71	2.84	coarse	
3.27	3.22	3.32	3.24	3.19	3.28	Alfalfa, fullbloom, hay-corn,	
3.28	3.21	3.32	3.25	3.26	3.23	pelleted	

^aDE was estimated using equations of the form $Y = b_0 + b_1X_1 + a_1 + \beta_1 + \gamma_k + \delta_k + a\beta_{ij} + \dots + \gamma_{k\ell}^k + a_1X_1 + \beta_1X_1 + \gamma X_1 + \gamma_2X_1 + a\beta_{ij}X_1 + \dots + \gamma_{k\ell}^kX_1$; where Y is the predicted DE, and X_1 is the nutrient content (%) of the diet. The regression constant is adjusted by qualitative variables ($a_1, \beta_1, \dots, \gamma_{k\ell}^k$) according to the description of the diet. The regression coefficient is also adjusted by qualitative variable interactions ($a_1X_1, \beta_1X_1, \dots, \gamma_{k\ell}^kX_1$) according to the description of the ingredient or diet, and the specific feed nutrient in question. (see also table 17)

^bPlant cell walls was determined using detergent methods by Fornesbeck and Harris (1970 a).