12-1979

Fecal indices for prediction of forage intake and quality by steers

Richard E. Estell

To the Graduate Council:

I am submitting herewith a thesis written by Richard E. Estell entitled "Fecal indices for prediction of forage intake and quality by steers." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Animal Science.

J. W. Holloway, Major Professor

We have read this thesis and recommend its acceptance:

K. M. Barth, W. T. Butts Jr.

Accepted for the Council:
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(Original signatures are on file with official student records.)

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We have read this thesis
and recommend its acceptance:

Karl M. Barth

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FECAL INDICES FOR PREDICTION OF FORAGE INTAKE AND QUALITY BY STEERS

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

Richard E. Estell II

December 1979

ACKNOWLEDGMENTS

The author is deeply indebted to his major professor, Dr. J. W. Holloway, for the tremendous amount of help and advice offered during the course of study at The University of Tennessee, Knoxville.

The author would like to express his appreciation to Dr. K. M. Barth and Dr. W. T. Butts, Jr., for their helpful criticism and time spent reviewing the manuscript and serving on his graduate committee.

Many others who aided in completion of his research and to whom the author is grateful are: Marvis Fryer, Eddie Jarboe, and the laboratory staff for their invaluable aid in completion of the chemical analyses; the faculty and graduate students in the Animal Science Department at The University of Tennessee, Knoxville, for their friendship and help with data collection and computer analyses; to Bill Brown for his help and friendship throughout the program and to Zainol CheMamat for his assistance in the data collection and willingness to help the author throughout the project.

The author is deeply appreciative of the love, cooperation, and financial assistance given by his family throughout his studies.

Above all, the author wishes to thank his wife, Gail, whose love, encouragement, and hard work made it all possible.

ABSTRACT

Six *in vivo* digestion trials were conducted, in which a total of thirty-nine fecal samples were obtained from Angus steers receiving tall fescue-legume mixtures of varying proportions. The forages were of diverse maturities and digestibilities. The forage and fecal samples were analyzed for dry matter, nitrogen, ether extract, crude fiber, ash, cell wall constituents, acid-detergent fiber, acid-detergent lignin, *in vitro* dry matter digestibility, and *in vitro* organic matter digestibility, and in addition, the fecal samples were analyzed for acid-insoluble ash, sodium, zinc, and urobilinogen. Nitrogen-free extract, cellulose, hemicellulose, and acid-soluble ash were calculated.

Wet matter intake, dry matter intake, wet fecal output, fecal dry matter output, dry matter digestibility, digestible dry matter intake, total digestible nutrients, total digestible nutrient intake, crude protein digestion coefficient, and digestible crude protein intake were determined for each steer.

A factor analysis was conducted to aid in explaining how each variable was related to other variables. Several equations were developed in which fecal variables served as indpendent variables for the prediction of digestion trial variables.

For each dependent variable, a series of multiple regression equations containing one to eleven variables was formulated which best predicted (maximum R^2) that particular variable. These equations included squared and interaction terms of fecal variables when its addition produced greater increase in R^2 values than addition of any other variable.

Over 91% and 89% of the variation in wet matter intake and dry matter intake, respectively, were accounted for with each best-fit eleven-variable index.

The fecal index containing ten independent variables explained almost 65% of the variation in wet fecal output, whereas the eleven-variable model for prediction of fecal dry matter output explained about 63% of its variation.

A ten-variable model provided a fecal index which explained approximately 79% of the variation in dry matter digestibility; 81.62% of the variation in digestible dry matter intake was accounted for by the best-fit eleven-variable prediction equation.

The eleven-variable indices developed for the prediction of total digestible nutrients and total digestible nutrient intake explained approximately 88% and 85% of the variation, respectively.

Digestible crude protein and digestible crude protein intake, when predicted from eleven-variable models, accounted for over 88% of the variation in each of these dependent variables.

The R^2 values obtained from these fecal indices support the theory that the fecal index technique is a valuable method of evaluation of pasture, and that large amounts of variation can be accounted by using a broad spectrum of forage compositions.

TABLE OF CONTENTS

LIST OF TABLES

TABLE PAGE

CHAPTER I

INTRODUCTION

Ruminants are an efficient means of utilizing non-tillable, low-productive pasture land. Pasture research is lagging compared to many other areas of animal nutrition, mainly due to complications unique to grazing situations, such as difficulty in conducting studies without confining animals, which may bias results. Several attempts to develop methods to assess nutritive value of pastures have been exercised.

Ratio techniques involving determination of an indigestible indicator in forage and fecal samples were explored by many researchers, but were not completely successful due to the difficulty in obtaining a forage sample representative of forage selected for consumption.

The fecal index technique, in which forage quality is predicted by fecal composition, appears to be more satisfactory since the indicator need not be indigestible and forage samples are not required.

In this study, conventional digestion trials were conducted such that prediction equations for several dependent variables could be developed from fecal composition. The diets consisted of a wide range of forage species and maturities, such that more general prediction equations could be developed.

Variables which were available for development of fecal indices include fecal dry matter, nitrogen, ether extract, crude fiber, ash, nigrogen-free extract, acid-insoluble ash, acid-soluble ash, zinc, sodium, cell wall constituents, acid-detergent fiber, acid-detergent

lignin, cellulose, hemicellulose, urobilinogen, *in vitro* dry matter digestibility, and *in vitro* organic matter digestibility.

The evaluation of pasture quality with fecal indices could prove a valuable method of estimating pasture value without the bias which accompanies animal restriction.

CHAPTER II

REVIEW OF LITERATURE

I. EFFECT OF MANAGEMENT ON SELECTIVITY

Selective grazing is a major concern whenever one deals with studies of pasture digestibility. Hardison et al. (1954) stated that selectivity is the major deterrent to the measurement of pasture digestibility. They define selective grazing as that which occurs when an ingested diet has a composition dissimilar to that of whole, clipped herbage.

Whenever the opportunity is presented, ruminants will select for plants and plant parts that are high in crude protein (CP) content and low in crude fiber (CF) content (Waite et al., 1950; Arnold, 1960; Jensen et al., 1965; Blaser et al., 1970; Coleman et al., 1971; Coleman and Barth, 1973), high in ether extract (EE) content (Blaser et al., 1977), high in dry matter digestibility (DMD) (Coleman et al., 1971; Coleman and Barth, 1973; Lampeter and Schmeisser, 1974), and low in lignin content (Johnstone-Wallace and Kennedy, 1944). Rarely is a pasture so uniform that no selective behavior is exhibited (Spedding et al., 1966). Blaser et al. (1960) noted that selective grazing occurs on both high and low quality pastures.

Stapleton (1948) suggested that it is an inate ability of grazing ruminants to select a nutritious diet when possible. He supported his theory with evidence from a grazing experiment. In this experiment he provided cattle with access to a rough, mature pasture as well as to a lush, leafy pasture. He observed that the animals spent equal time on

the two pastures, to meet their nutrient requirements. However, the concept of inherent nutritional wisdom has been undermined by the findings of Coppock et al. (1974). These workers conducted studies with dairy cows which indicated that animals consume assorted feeds on the basis of individual preference or need.

Palatability

Plant palatability can affect selectivity (Hardison et al., 1954; Lampeter and Schmeisser, 1974). When given the opportunity to select forages with varying degrees of maturity, grazing cattle select immature, leafy plant material (Johnstone-Wallace and Kennedy, 1944; Stobbs, 1973). In view of studies by Coppock et al. (1974), young leafy plants are apparently more palatable.

Ideally, one should incorporate highly palatable forage species into the pasture, but since this is not always practical, unpalatable species should be managed such that grazing animals will be more inclined to consume them for more efficient pasture utilization (Clements, 1970).

Regulation of Grazing Behavior

One can regulate the degree of selective grazing behavior exhibited by cattle by implementing various management practices and grazing systems. One objective of this paper is to discuss the practices and grazing systems and the extent to which they influence selective grazing by ruminants.

Pasture Productivity

When examining pasture systems and selectivity effects on pasture systems, one must establish the terms in which pasture productivity is measured. Total production of a grazing system can be described in terms of beef production per acre or individual animal performance.

Maximum individual animal performance is associated with systems which promote high digestible dry matter intake (DDMI) due to the ease of selective grazing; whereas maximum beef production per acre is associated with systems which discourage selection, thus resulting in an increase in number of animals per acre and an increase in efficiency of pasture utilization, at the expense of individual animal performance (Harrison et al., 1948; Brundage and Peterson, 1952; Blaser et al., 1959; Blaser et al., 1960; Blaser et al., 1977).

The individual producer must decide which type of production is most beneficial to him, and this decision will determine whether the management system should promote or discourage selective grazing.

Clipping Pasture

Selective behavior is minimal on immature pasture containing a high leaf to stem ratio (Raymond et al., 1956; Arnold, 1960; Blaser et al., 1970). As the pasture forage progresses in stage of maturity, the animals become increasingly more selective, and devote more hours per day to grazing (Hancock and McMeekan, 1954; Arnold, 1959, 1960).

One management technique which can be used to alter the selective behavior of grazing cattle is pasture clipping. Pasture clipping reduces selective grazing by maintaining the pasture in an immature, more palatable growth stage (Anonymous, 1926; Brundage and Peterson, 1962;

Hafez, 1965). When less palatable forages, such as fescue, are present in a grass-legume mixture, clipping will increase grass palatability and consequently aid in the reduction of excessive grazing of the legume (Blaser et al., 1970).

Clipping can also aid in restoring undergrazed areas of the pasture (Johnstone-Wallace and Kennedy, 1944). Another advantage of clipping is the tendency to decrease the weed population (Larin, 1956), therefore reducing the amount of available unpalatable plant material.

Types of Plants

The types of plants offered in the pasture can affect the degree of selective grazing exhibited by grazing animals (Meyer et al., 1957; Arnold, 1960). The grazing animal has greater abilility to selectively graze tall plant species, such as alfalfa, than low-growing species such as trefoils (Raymond et al., 1956; Lofgreen et al., 1957). Meyer et al. (1957) compared the degree of selective grazing expressed by cattle and sheep in a pasture containing short, dense orchardgrass-trefoil mixture and also on an alfalfa pasture. Their observations were that sheep were more adept selectors while grazing alfalfa, but that cattle and sheep selected with equal efficiency on the orchardgrass-trefoil mixture.

Plant types which have dense, leafy, uniform canopies reduce the potential for the animal to selectively graze and also lessen the reduction in bite size which inadvertently accompanies selection (Spedding et al., 1966; Stobbs, 1973; Stobbs and Hutton, 1974). This extra dry matter intake (DMI) which accompanies the increase in animal bite size may compensate for the loss of DMD associated with normal selectivity behavior (Stobbs, 1973).

Grazing Pressure

Manipulation of grazing pressure is another management practice which influences the degree of selective grazing. High grazing pressure is associated with reduced selectivity, increased beef production per acre, reduced DDMI, and increased time spent grazing per day, whereas increased selectivity, increased individual animal production, increased DDMI, and decreased grazing hours per day are associated with low grazing pressure (Pieper et al., 1959; Mott, 1960; Kennedy et al., 1960; Blaser et al., 1960; Raymond et al., 1970; Blaser et al., 1973; Delgado and Alfonso, 1974).

Stobbs (1973) and Blaser et al. (1977) observed that grazing pressure was at the lowest level when cattle were introduced to a pasture and gradually increased each day, although this type of change in grazing pressure will only occur when the initial stocking rate and available pasture are such that pasture removed by grazing exceeds pasture growth.

In order to attain maximum utilization of pasture without grazing to the point where pasture is short in supply, Blaser et al. (1959) and Blaser et al. (1973) recommend that grazing pressure remains constant throughout the grazing season. Blaser et al. (1977) suggests that a group of "put-and-take" animals be maintained to regulate stocking rate so that a constant grazing pressure can be maintained. Their suggestion is based on research which indicated that steers performed similarly on continuous and rotational systems when a constant grazing pressure was maintained. It is the opinion of this writer that the impracticality of the "put-and-take" system drastically limits the feasibility of the system.

Several workers have suggested that maintaining a high grazing pressure can decrease the number and size of over/undergrazed areas in a pasture (Mott, 1960; Blaser et al., 1973; Leithead, 1974; Blaser et al., 1977).

Blaser et al. (1970) suggested that a high grazing pressure can discourage the preferential grazing of legumes in a mixed pasture containing a less palatable grass species.

Continuous Grazing System

The continuous grazing system is the most extensive grazing system since the animals remain on the same pasture for the entire grazing season. Blaser et al. (1959), Blaser et al. (1960), and Blaser et al. (1970) stated that selective grazing is usually associated with extensive systems.

Due to the nature of the continuous system, over/undergrazing is most commonly associated with this system (Blaser et al., 1970; Blaser et al., 1973). The over/undergrazed areas occur due to the preference of the grazing animal for the immature forage from previously grazed areas. As the grazing season progresses, the overgrazed areas become short and stunted, develop low root reserves, and no longer have adequate surface area for light reception; whereas the undergrazed sections become mature, fibrous, unpalatable, and less nutritious (Blaser et al., 1959).

Blaser et al. (1973) and Blaser et al. (1977) felt that a continuous system is adequate during lush spring growth, but noted that pasture utilization during the dry summer growth might be facilitated by the implementation of a rotational system.

Rotational Grazing System

As stated earlier in this paper, management schemes can influence the degree to which selective grazing occurs. McMeekan (1960) stated that for management purposes, the factors most easily altered are frequency and severity of forage defoliation.

The rotational system is designed such that pasture is divided into sections, with each location being grazed for shorter periods of time and with higher grazing pressure than would be possible on a continuous grazing system. Selection is minimized due to the increased grazing pressure, thus the utilization of available pasture is often more complete (Blaser et al., 1960; Brundage, 1960; Mott, 1960; Stobbs, 1969; McMeekan, 1960; Blaser et al., 1973; Leithead, 1974; Blaser et al., 1977).

Brundage and Peterson (1952) observed an increased DDMI of cattle on rotated pasture, although Brundage (1960) observed no increase in DDMI of cattle on rotated pasture when compared to DDMI on a continuous grazing system. Rotational systems result in more uniform pastures with fewer over/undergrazed areas (Harrison et al., 1948; Mott, 1960; Blaser et al., 1973; Blaser et al., 1977).

Rotational grazing systems are more complicated to manage than continuous systems, and particular attention must be paid to seasonal fluctuations in available pasture and length of recovery period needed for the pasture to recuperate (Harrison, 1948). Also, Leithead (1974) noted that the pasture recovery period should not be extended to the point that stage of forage maturity advances past the most palatable stage.

One advantage of frequent pasture rotation is that plants are grazed a minimal number of times, thus desirable plants are given more opportunity to recuperate, build root reserves, and maintain a light receptive canopy (McMeekan, 1960; Leithead, 1974). Also, on rotational grazing systems, the grazing animals consume the highly digestible plant tips when introduced to the pasture, and the DMD of pasture intake will decline gradually as the plant tips dwindle in supply (Sjollema, 1949; Raymond et al., 1956).

Rotational grazing systems occur in many forms. The systems are categorized in terms of frequency of rotation and intensity of grazing pressure. Blaser et al. (1959) compared high and low frequency rotational systems (ten lots vs. two lots; each system containing the same total pasture area) and observed an increase in individual animal performance and increased carrying capacity of the high frequency rotational pasture.

Later studies conducted by Stobbs (1969) also implied that higher individual animal performance was achieved on high-frequency rotation than on low-frequency rotational systems. In both studies discussed above, the improved individual performance of high-frequency rotation was attributed to the ability of the animal to consume plant tips with greater regularity.

In contrast, a comparison of high vs. moderate-frequency rotation (ten-lot vs. four-lot rotation) by Delgado and Alfonso (1974) indicated that individual steers performed similarly on the two systems and carrying capacities were similar.

Strip Grazing System

Strip grazing is a highly intensified form of the rotational grazing system in which animals are provided with a small section of pasture, in which all available herbage should be consumed in one day (Holmes et al., 1950). The animals are relocated to an adjacent pasture strip daily, by means of a manually adjustable fencing system.

Ideally, animals on the strip grazing system will consume all available herbage offered each day rather than exhibit selection tendencies which exist on other management systems (Holmes et al., 1950; Procter et al., 1950), in which case, pasture should be utilized more efficiently and total animal production per acre should increase (Procter et al., 1950; Brundage and Peterson, 1952; DeGeus et al., 1953; Procter and Hood, 1953).

Strip grazing allows daily exposure of the highly digestible plant tips to grazing ruminants (Procter et al., 1950; Brundage, 1960). Also, less variation in DMD of available forage occurs with strip grazing than for continuously or rotationally grazed pastures (Raymond et al., 1956; Kennedy et al., 1960).

Due to the increased consistency of DMD of consumed forage by the animals on strip grazing systems, individual animal performance is also much more consistent (Holmes et al., 1950; Procter et al., 1950; Brundage, 1960).

Blaser et al. (1959) and Blaser et al. (1977) observed that total beef production per acre was similar when the strip grazing and high frequency rotational systems were compared. They felt that since strip grazing systems require a larger labor input, the high frequency rotational system is the superior system. Similarly, Kennedy et al. (1960)

compared total animal production per acre from grazing animals with high frequency and strip grazing systems. They observed only a slight production advantage from strip grazing and concluded that from a practical standpoint, high frequency rotation was the superior system.

Top-and-Bottom Rotational Grazing System

A variation of the rotational grazing system which might be implemented to elevate production is the "top-and-bottom" rotational grazing technique. This system is composed of a highly productive, economically important group of animals to graze approximately one half of the available pasture, and a group of lower producing less valuable stock to consume the remaining, lower quality herbage (Anonymous, 1926; Blaser et al., 1959). The objective of the "top-and-bottom" grazing system is to graze high producers on a sequence of high quality pastures followed by low producing animals to consume the remaining available forage. The high producing groups of animals, or those animals consuming the "top" portion of the pasture, have the advantage of selecting the highly digestible plant tips, and should be able to produce more animal products because of the exposure to the highest quality plant parts (Blaser et al., 1959; Blaser et al., 1960; Blaser et al., 1970).

Blaser et al. (1959) and Blaser et al. (1960) conducted tests to evaluate the possible advantage of the "top-and-bottom" rotational system. They conducted one test with dairy cows, in which one group of cows was top grazers, one group was bottom grazers, and another group was placed on a normal (whole plant) rotational grazing system. They observed that "top" grazing cows had the highest milk productions, followed by milk productions from "whole plant" grazing cows, with the

milk production from "bottom" grazing cows being at the lowest levels. They repeated these experiments using beef steers and observed the same decline for beef production that had previously been observed for milk production. Suggested "top" grazers include: milking cows or ewes and fattening steers (Blaser et al., 1960; Blaser et al., 1977). Suggested "bottom" grazing animals include: dry cows and ewes and feeder calves, which have lower requirements (Blaser et al., 1960; Hafez, 1965; Blaser et al., 1977).

Although the combined production from top and bottom grazers may not prove superior to production from animals grazing in a normal (whole plant) rotational system, the system is nevertheless an effective means of obtaining greater individual performance from one group of animals if the producer has access to a group of animals with lower requirements, suitable to function as "bottom" grazers (Blaser et al., 1973).

Blaser et al. (1960) suggested that if the producer is extremely interested in individual animal performance, he might use only rotational "top" grazing. Top grazing by itself will sacrifice animal output per acre, but will decrease the length of time required for pasture recovery.

Creep Grazing System

Creep grazing is another grazing system which can be utilized which may allow the producer to capitalize on the selective grazing phenomenon. Creep grazing is a management system in which cows are confined to a particular area of a pasture and their calves have access to other pasture areas not obtainable to the cows. The purpose of creep grazing is to utilize the selective behavior to maximize calf gains (Blaser et al., 1973). In the opinion of Blaser et al. (1978), creep

grazing will accelerate calf gains only if grazing pressure is high or pasture quality is low.

Zero Grazing System

The zero grazing system, in which pasture is harvested mechanically and immediately fed to confined livestock, is one management technique that virtually eliminates the effects of animal selectivity (Hardison et al., 1954; Meyer et al., 1957; Blaser et al., 1973).

The effects of the zero grazing system are that cattle consume forage of lower DMD, spend fewer hours per day eating, and have a lower DDMI than grazing cattle (Hardison et al., 1954; Lofgreen et al., 1957; Blaser et al., 1977). Studies by Lofgreen et al. (1957) indicated that steers which consumed mechanically harvested forage had gains equivalent to steers grazing pasture. The efficiency of utilization of forage was probably increased due to the decrease in forage intake of steers on the zero grazing system.

The zero grazing system is a method of utilizing pasture more efficiently, even though individual animal productivity may be less than if the animal could graze selectively (Blaser et al., 1959; Raymond, 1970).

Other problems associated with grazed pastures which may be eliminated by the zero grazing system are fecal and urine contamination, the effects of soil compaction, trampling of pasture by livestock, as well as the harmful effects of overgrazing (Blaser et al., 1959; Bryant and Blaser, 1961; Raymond, 1970). One other advantage discussed by Raymond (1970) is the ability of the livestock producer to manage grass and legume pastures separately and yet feed in the form of a grass-legume mixture.

The disadvantages of zero grazing are that mechanization is expensive, and that labor increases will arise from both the daily mechanical harvesting of pasture as well as from the maintenance of confined livestock. Also, the producer must deal with the difficulty of cutting adequate forage for sufficient daily consumption without harvesting more forage than the animals will consume, in order to prevent wastage (Raymond, 1970). Another shortcoming of the zero grazing system is that the types of plants which are tall and easily harvested are typically stemmy and lower in digestibility than forages commonly occurring in pastures (Raymond, 1970).

Summary

The selectivity phenomenon affects pasture studies to a large extent. Several attempts have been made to alter the degree of selection via various management schemes. Pasture clipping, grazing pressure regulation, and pasture rotation have been examined extensively in search for methods to regulate selectivity. "Top-and-bottom" grazing, creep grazing, and zero grazing are more specialized methods of controlling selective grazing.

In conclusion, several management schemes exist in which selective grazing can be minimized or used to an advantage, although many systems will increase labor and expense. Thus, economics plays an important role in the practicality of implementation of systems which regulate selective grazing.

II. PREDICTION OF FORAGE DIGESTIBILITY

A great deal of effort has been directed towards assessment of the nutritional value of forages grazed by ruminants. Many problems are inherent in the estimation of pasture value (Reid, 1952; Brisson, 1954).

One method of evaluation of *in vivo* pasture forage digestibility is via the conventional digestion trial. Forage intake and fecal output can be determined and digestibility can subsequently be calculated. Digestion trials tend to restrict intake and metabolic activity, which may affect digestibility estimates (Raymond, 1954; Arnold and Dudzinski, 1963; Streeter, 1969). Also, clipped, handfed forage causes restriction of the selective behavior of grazing animals, which again may lead to prediction errors (Reid, 1952). Although biases do exist with the conventional method, fairly accurate digestibility estimates may be obtained. Since direct determination of forage quality cannot be derived from grazing studies, a reliable method using a plant constituent to serve as an indicator for prediction of digestibility would be quite practical (Forbes and Garrigus, 1948; Gallup and Briggs, 1948; Reid, 1950; Raymond *et al.*, 1954; Cook and Harris, 1957; Hall, 1978).

Two types of indirect methods for estimation of forage digestibility are the ratio technique and the fecal index method (Raymond, 1954; Reid and Kennedy, 1956).

Ratio Technique

The internal ratio technique involves the use of an indigestible forage constituent present in the feed and feces of the grazing animal to calculate digestibility of a nutrient without knowledge of either dry matter intake or fecal output. The digestion coefficient is

calculated by the formula (Reid, 1950; Kane et al., 1950; Balch et al., 1954; Van Dyne and Meyer, 1964; Church, 1976):

$$\text{Digestibility} = 100 - \left(100 \times \frac{\%\ \text{Indicator in feed}}{\%\ \text{Indicator in feces}} \times \frac{\%\ \text{Nutrient in feces}}{\%\ \text{Nutrient in feed}}\right).$$

The ratio method requires the analysis of a forage sample, thus the problem of acquiring a representative hand-plucked sample becomes evident (Forbes, 1952; Reid, 1952; Raymond et al., 1954; Weir et al., 1959; Corbett, 1960). Forbes (1952), Raymond et al. (1954), and Streeter (1969) emphasize the need to obtain representative fecal samples.

Certain desirable characteristics have been defined for an indicator to be used in the ratio technique. Reid et al. (1950) and Cook and Harris (1957) noted that the indicator should be a naturally occurring feed constituent. Reid et al. (1950) stated that the indicator should not be affected by rate of passage through the gastro-intestinal tract, stage of forage maturity, or treatments such as heating or curing. They also emphasized the need for a quick, accurate, and simple analysis of the indicator. It is also essential that the indicator is indigestible and completely recoverable (Reid et al., 1950; Reid, 1952; Cook and Harris, 1957). Reid (1952) noted that a representative forage sample would not be mandatory if the indicator was present in equal concentration throughout the plant; however, no indicator has this characteristic.

Lignin-Ratio Technique

Lignin is a forage constituent which has been extensively used as a means of predicting forage digestibility via the lignin-ratio technique (Kane et al., 1950; Balch et al., 1954).

Although lignin is a naturally occurring plant constituent, the fact that lignin is not a chemical entity, and that composition varies

with plant species and maturity causes confusion in the use of lignin as an indicator (Ellis et al., 1946; Forbes and Garrigus, 1948; Kane et al., 1950; Forbes et al., 1952; Reid, 1952; Balch et al., 1954; Richards et al., 1958).

Although early workers (Ellis et al., 1946; Forbes and Garrigus, 1948; Kane et al., 1950) suggested that lignin is not digested or absorbed, Forbes and Garrigus (1950a), Sullivan (1955), Elam and Davis (1961), and Elam et al. (1962) have reported variable lignin recovery.

Although an indicator should be uniformly distributed in the voided feces, conflicting opinions exist as to the uniformity of lignin excretion. Forbes et al. (1952) reported uneven lignin excretion, but Ellis et al. (1946), Elam and Davis (1961), and Elam et al. (1962) have suggested that grab samples can accurately assess lignin excretion.

The chemical analysis of an indicator should be quick, accurate, and simple, but many procedures exist for lignin determination. MacLeod and Minson (1974) compared forage digestibility as predicted by the lignin ratio method, using the Van Soest and Wine (1968), Christian (1971), and Edwards (1973) methods of lignin determination, to DMD as predicted by in vitro forage digestion. Only the 72% H_2SO_4 method (Christian, 1971) gave estimates similar to the digestibility estimates produced by in vitro forage digestion. All researchers discussed in the remainder of this section used the Ellis et al. (1946) method (also a 72% H_2SO_4 method) for lignin determination.

Streeter (1969) refers to complications in lignin determination such as incomplete carbohydrate hydrolysis, as well as partial lignin degradation. Analysis can also be hindered by the nitrogen content of

lignin, as well as by methods of sample treatment such as heating and drying (Forbes and Garrigus, 1948; Van Soest, 1967; Streeter, 1969).

The lignin ratio technique has successfully been used to predict forage digestibility, and results were in agreement with estimates yielded from total collection digestion trials in studies by Forbes and Garrigus (1950a, b), Kane et al. (1950), Cook and Harris (1957), Kimivae (1960), and Soluski and Patterson (1961).

Using the same method to assess the value of the lignin ratio technique as a predicator of digestibility, Forbes and Garrigus (1948), Reid and Kennedy (1956), Elam et al. (1962), and Jarrige (1965) concluded that the lignin ratio technique does not predict forage digestibility with sufficient accuracy.

Chromagen Ratio Technique

Plant pigments have been examined by several workers in regard to their use to predict forage digestibility via the ratio method. Although chromagens are a combination of all pigments present in plants, they are thought to be predominately products of chlorophyll degradation (Kane and Jacobson, 1954; Reid and Kennedy, 1956; Corbett, 1960).

Chromagens are naturally occurring substances, and very little absorption or digestion of chromagens occurs in the gastro-intestinal tract (Reid et al., 1950; Forbes, 1952; Irwin et al., 1953), thus chromagens possess certain characteristics of a good indicator. One problem with the chromagen ratio method is that endogenous pigment secretions, such as bile pigments, may affect the quantitation of chromagens (Streeter, 1969).

Conflict exists as to the error caused by grab sampling of feces. Forbes (1952) and Soni et al. (1954) observed only slight errors in digestibility prediction when grab fecal samples were analyzed for chromagen content using the chromagen ratio technique, but Brisson (1960) indicated that grab fecal sampling resulted in prediction errors with this technique due to diurnal variation. Reid et al. (1950) made reference to a grazing selectivity bias associated with the chromagen ratio technique, due to the fact that chromagen concentration is highest in the leafy portions of plants, which may not be consistent with the forage sample to be analyzed using the ratio method because the forage sample may not accurately represent the forage consumed.

The extraction of chromagens from both forage and feces may be incomplete (Streeter, 1969). It appears that fecal extraction may be more complete than forage chromagen extraction, probably as a result of maceration of the ingesta through the gastro-intestinal tract (Reid et al., 1950). Chromagen analysis is further hindered by the inconsistency of opinion which exists as to the ideal wavelength for spectrophotometric measurement of its content. The appropriate wavelength for measurement of chromagen concentration, based on work by Reid et al. (1950) and Reid et al. (1951), was determined to be 406 mμ. Brisson et al. (1954) supported 406 mμ as the correct wavelength for fecal extractions of sheep, but found 404 mμ to be more suitable for steer feces. Other suggested wavelengths include 415 mμ (Irwin et al., 1953; Kane and Jacobson, 1954; Greenhalgh, 1960), 416 mμ (Davidson et al., 1954), and 413 mμ (Troelson, 1961).

Chromagen analysis is also hampered by the fact that chromagens are light labile (Reid et al., 1950; Lancaster and Bartrum, 1954; Cook

and Harris, 1957), and absorption values are altered by time between extraction and reading (Reid et al., 1950; Lancaster and Bartrum, 1954; Troelson, 1961).

Reid et al. (1950), Brisson et al. (1954), Bradley et al. (1956), and Richards et al. (1959) conducted digestion trials on various freshly clipped forages with steers and/or wethers, and compared digestibility estimates to estimates obtained from the chromagen ratio technique. In each case, the prediction of digestibility was similar for the two methods of estimation.

In contrast, Lancaster and Bartrum (1954), Reid and Kennedy (1956), Cook and Harris (1957), Kennedy et al. (1959), Brisson (1960), and Troelson (1961) have compared the chromagen ratio technique to conventional methods of determination of forage digestibility and have concluded the chromagen ratio technique to be an inferior method.

Fecal Index Technique

The fecal index technique involves the use of a particular fecal constituent to predict digestibility by the following equation relating that fecal indicator concentration to digestibility (Lancaster, 1954; Greenhalgh et al., 1960; Streeter, 1969):

$$\text{Digestibility} = a + b\ (\text{indicator concentration}).$$

Digestion trials are utilized to obtain relationships of fecal constituents and forage digestibility, and once these equations are developed, fecal components can be used to estimate digestibility of an unknown forage (Reid, 1952; Streeter, 1969). Although bias exists in the sense that stall-fed animals are restricted and may have limited ability to express selectivity, Raymond et al. (1954), Reid and Kennedy

(1956), and Streeter (1969) noted that the fecal index method has an advantage in that only the fecal composition is used for prediction purposes, thus is not affected by the difficulty in obtaining a representative forage sample.

Desirable characteristics of an indicator to be employed in the fecal index are similar to those mentioned previously for the ratio technique, with the exception that the indicator does not have to be indigestible or completely recoverable, since only the indicator concentration in the feces is measured for prediction of digestibility by the fecal index method.

Fecal Nitrogen Index

Several attempts have been made to relate fecal nitrogen (FN) concentration to forage digestibility. Lambourne and Reardon (1963) note the simplicity, quickness, and accuracy of FN determination. Although Soni et al. (1954) noted diurnal variation in FN excretion to be minimal, Brisson (1960) and Lambourne and Reardon (1963) suggested that grab fecal samples may not provide representative FN values.

FN has two components: metabolic FN (MFN) and residual feed nitrogen (Gallup and Briggs, 1948). MFN originates primarily from epithelial cells, bacteria, mucus, bile, and digestive juice residues (Hutchison, 1958; Jarrige, 1965; Stronzinski and Chandler, 1972; Stallcup et al., 1975). MFN is thought to be excreted at a fairly constant rate, and to compose a large amount of the total FN (Gallup and Briggs, 1948; Forbes, 1949; Brisson, 1960). Forbes (1949) noted that, due to the preceeding characteristics of FN, FN concentration should be related to forage digestibility.

Early studies of FN by Gallup and Briggs (1948) indicated that steers consuming hay in digestion trials excreted FN at a rate of .55 g/100 g of dry matter intake (DMI), and increased to .71 g/100 g DMI when cottonseed meal was fed as a protein supplement. Forbes (1949) observed FN excretion to be .67 and .76 g/100 g DMI when consuming forages of 8-16% CP and 16-24% CP, respectively. Lancaster (1949) felt that if nitrogen is excreted at a constant rate, digestibility could be related to FN by the equation:

$$\text{Digestibility} = 100\ (1 - C/FN)$$

They calculated the constant term (C) to be .83 and .67 g/100 g DMI for forages containing > 15% CP and < 15% CP, respectively. Homb and Breimen (1952) noticed that sheep consuming timothy-clover mixtures excreted linearly increasing amounts of FN as CP content of forage intake increased. Later efforts by Hutchison (1958) and Stallcup et al. (1975) also supported earlier conclusions that CP levels in the forage are related to FN excretion.

Hutchison (1958) and Stallcup et al. (1975) found FN to be dependent upon DMI. These findings can be explained by observations of Virtanen (1966), in which FN was composed predominately of indigestible microbial protein, which varies with DMI.

Greenhalgh et al. (1960) advise that a range of forage digestibility as wide as grazing cattle are likely to encounter should be included when forming FN indices.

Lancaster (1954) states that since FN does not appear to be excreted constantly by cattle consuming forages, digestibility might be predicted by formulating regressions of DMD on FN to obtain prediction equations.

Young and Corbett (1972) estimated DMD by the FN index and compared these results to *in vitro* DMD of forage samples. The estimates were not consistent for the two methods, thus they concluded that FN indices were inaccurate. It is the opinion of this writer that those conclusions might be biased, since a representative sample of actual consumption was probably not obtained.

Since various equations have been proposed to obtain DMD from FN concentrations, the concept of local regressions has been developed (Corbett, 1960; Greenhalgh and Corbett, 1960; Pearce *et al.*, 1962; Greenhalgh, 1966). Local regressions are formed from data from an individual sward, using a given species of animal, and feeding forage of a given maturity in a given environment (Greenhalgh *et al.*, 1966). The fecal index should be developed for animals in a narrow weight range, as FN excretion is affected by body weight (Hall, 1978). Also, a part of the FN may be encrusted in lignin and unavailable for digestion, and since lignin N content of plants varies with plant species and maturity, another advantage of local regressions seems evident (Kimivae, 1960; Van Soest, 1967).

When local regressions are not used for digestibility prediction, application errors may arise (Raymond *et al.*, 1954; Pearce *et al.*, 1962). Homb and Briemen (1952), Brisson (1960), and Minson and Kemp (1961) found a seasonal bias when sheep were fed several forage species and mixtures of various maturity.

Likewise, Arnold and Dudzinski (1963) found that several prediction equations were formed from feeding sheep diets differing in botanical composition and maturity which predicted digestibility accurately

but that the equation formed from combined data was less accurate for prediction purposes.

Pearce et al. (1962) and Lambourne and Reardon (1963) fed ruminants top, bottom, and whole-cut pasture and observed three distinct regression equations when DMD was regressed on FN concentration. They concluded that seasonal regressions were produced as a result of varying stem to leaf ratios; therefore, local regressions should be based on pasture morphology rather than calendar date.

Langlands et al. (1963) also examined pasture of various maturities fed to sheep and steers in an attempt to produce local regressions, but found more variation in DMD and FN for individual animals than for animal species or season. Similarly, Lambourne and Reardon (1963) suggested that local regressions from individual swards produced inconsistent predictions of forage digestibility and concluded that FN could not be used to predict digestibility with precision due to individual animal variation. Vera (1973) arrived at the same conclusion when he attempted to predict DMD from FN concentration of cattle consuming tropical forages.

Summary

Barnes and Marten (1979) stated that an accurate prediction of forage digestibility could aid in determination of the economic feasibility of utilizing the forage as a feed source. It is quite obvious that an indirect method of prediction of digestibility is far more practical than determination by in vivo digestion trials, and the indirect method of prediction results in determination of digestibility in a natural grazing state.

It is also evident that an indirect method of determination has not been perfected. The FN index technique seems superior to the ratio techniques, in that a representative forage sample is not required for the index. Uniform excretion of the indicator is necessary for both methods.

The lignin ratio technique has problems associated with disagreement as to the composition and digestibility of lignin, whereas the chromagen ratio technique has limitations such as extraction difficulties and indecision as to the correct wavelength for measurement of absorption.

The FN index technique seems to be the preferred method of estimation of forage digestibility, although most researchers seem to think that local regressions must be obtained to prevent application errors.

CHAPTER III

MATERIALS AND METHODS

Six *in vivo* digestion trials were conducted in the metabolism room of the Animal Science Building at The University of Tennessee, Knoxville. A series of six digestion trials were initiated on April 27, May 17, June 26, August 7, September 11, and October 16, 1978. The same Angus steers were used for each of the six trials. Each trial consisted of a seven-day preliminary period, followed by a five-day collection period. Between trials, the steers grazed pasture consisting predominately of red clover, orchardgrass, and tall fescue.

The steers were confined to digestion crates and randomly placed on either a tall fescue (*Festuca arundinacea* Schreb.) diet or an array of tall fescue-legume mixtures which are presented in Table 1. Crimson clover (*Trifolium incarnatum*), first cutting red clover (*Trifolium pratense*), second cutting red clover, third cutting red clover, and Korean lespedeza (*Lespedeza stipulacea*) served as the legume fraction of the mixtures in Trials 1, 2, 3, 4, and 5, respectively. No legume mixtures were fed in Trial 6. The legume and tall fescue obtained for each trial were characterized in terms of estimated mean height and maturity, and these observations appear in Table 1.

The steers were weighed prior to each digestion trial. These weights appear in Table 2 summarized for all thirty-nine steers. They also appear in Table A-1 by individual trial. These steers were smaller than would be expected for yearlings and were not in good condition.

TABLE 1

FORAGES FED TO STEERS IN DIGESTIBILITY TRIALS[a]

Trial number	Date trial initiated (1978)	Legume source	Ratios of Fescue:Legume												Est. mean height of fescue (in)	Est. fescue mat.	Est. mean height of legume (in)	Est. legume mat.
			100.0	95:5	90:10	85:15	80:20	75:25	70:30	65:35	60:40	55:45	50:50	40:60				
1	April 27	Crimson clover	2				2				2			2	13	Prehead	20	Prebloom
2	May 17	1st Cutting Red clover	2		1		1		1		1		1	1	8	Midhead	25	Prebloom
3	June 26	2nd Cutting Red clover	1		1		1							1	16	Vegetative	17	Prebloom, early bloom
4	August 7	3rd Cutting Red clover	2		1		1		1		1		1	1	15	Dry/ dormant	16	Early bloom, midbloom
5	Sept. 11	Korean lespedeza	3	1		1		1		1		1			10	Vegetative/ tough	4	Vegetative/ dry
6	Oct. 16	None	3												11	Vegetative		

[a] Numbers indicate number of animals allotted to particular forage ratios.

TABLE 2

DIGESTION TRIAL DATA[a]

Variable	Mean	SD	Range
Steer wt. (kg)	217.75	35.22	119.86
WETMI (kg)	12.78	5.02	21.57
DMI (kg)	2.95	0.78	3.03
WETFO (kg)	6.19	1.52	6.90
FDMO (kg)	1.01	0.24	1.25
% DMD	64.02	11.26	44.96
DDMI (kg)	1.94	0.76	2.84
% TDN	54.11	10.32	32.79
TDNI (kg)	1.62	0.56	1.85
% DCP	61.21	11.43	48.41
DCPI (kg)	1.74	0.64	2.29

[a]All values are based on 39 individual observations except DCP and DCPI, which include 31 observations, and TDN and TDNI, which include 23 observations.

Digestion Trial Management

The steers received water twice daily and were hand fed forages in ad libitum amounts each morning throughout the trial.

The tall fescue used for each trial was harvested daily with a lawn mower equipped with a grass catching device. In each trial, the fescue was harvested and fed within an hour after cutting.

The crimson clover fed in Trial 1 was cut with a hand scythe prior to onset of the trial, placed in sacks, and frozen until shortly before use. The red clover used as the legume fraction of steer diets in Trials 2, 3, and 4 was acquired by means of a lawn mower prior to each trial and frozen. The Korean lespedeza which served as a legume source in Trial 5 was mown and collected daily.

The source of fescue in Trial 3 was a pasture which had been harvested for hay earlier in the season and consequently contained large amounts of dead grass.

Trial 6 consisted of steers consuming fescue as the sole forage source in their diet.

Data Collection

Daily records were kept of forage allotted and orts remaining for each steer for each of the twelve trial days. Fecal output was recorded during the five-day collection period. Forage intake (WETMI) and fecal output (WETFO) are presented in Table 2 for all trials and Table A-1 by trial.

Random samples of fescue, legume, and orts were obtained daily throughout each trial. Samples were dried in duplicate in a 60°C forced air draft oven. Due to the occurrence of rain during mowing of forage

on several days, large day-to-day variations in forage dry matter were observed.

The dried forage samples were ground in a Wiley Mill, then daily samples were combined into six sequential two-day composite samples for each trial, then stored in glass jars until further forage analyses.

Daily composite fecal samples were collected during the five-day collection period and combined into one composite sample for each steer, and a portion of each composite fecal sample was frozen in a plastic bag for future chemical analyses. The remaining composite samples were dried in a 60°C forced air draft oven in duplicate for assessment of dry matter content (DM). Average DM values for the thirty-nine *in vivo* digestion observations are presented in Table 3, and average DM values appear for each of the six trials in Table A-2.

These dried fecal samples were then ground in a Wiley Mill and stored in glass jars until further analyses could be conducted.

Other trial data which was subsequently calculated include dry matter intake (DMI), fecal dry matter output (FDMO), dry matter digestibility (DMD), digestible dry matter intake (DDMI), total digestible nutrients (TDN), total digestible nutrient intake (TDNI), crude protein digestion coefficient (DCP), and digestible crude protein intake (DCPI). These values are summarized in Table 2 as averages of all trials and are presented by trial in Table A-1.

Chemical Analyses

The dried, ground forage samples were analyzed in duplicate for a wide variety of constituents, except for samples from the first trial. Crude protein (CP), crude fiber (CF), nitrogen free extract (NFE),

TABLE 3

FECES COMPOSITION[a,b]

Variable	Mean	SD	Range
DM	16.46	2.18	9.00
N	2.33	0.38	1.33
EE	3.86	1.11	4.66
NFE	43.54	3.03	11.72
CF	24.07	2.14	9.94
ASH	13.95	1.80	6.64
CWC	58.67	3.82	17.01
HEMIC	14.29	7.48	38.24
ADF	44.39	7.48	38.87
CELLU	26.21	5.96	29.03
ADL	18.18	3.74	14.96
NA	1.11	0.45	1.72
ZN	0.53	0.31	1.27
AIA	0.85	0.28	1.46
ASA	13.09	1.61	6.05
UROB	2.81	1.23	5.91
IVDMD	17.00	6.41	33.70
IVOMD	24.31	6.99	36.84

[a]All values are based on analyses of all 39 individual fecal samples.

[b]All feces composition data (excluding DM) are expressed on a dry matter basis.

ether extract (EE), and ash content for each forage sample was analyzed (A.O.A.C., 1975).

Cell wall constituents (CWC), acid-detergent fiber (ADF), and acid-detergent lignin (ADL) were determined by a modified version of the forage fiber analysis described by Van Soest (1963). Cellulose (CELLU) and hemicellulose (HEMIC) were also calculated.

In vitro dry matter digestibility (IVDMD) and in vitro organic matter digestibility (IVOMD) were estimated for fescue and legume samples by the technique of Tilley and Terry (1963).

The forage composition data is presented in Table 4, and is further summarized by trial for fescue, legume, and orts in Tables A-3, A-4, and A-5, respectively. Dried, ground fecal samples were analyzed for the same characteristics as those determined for forage, using procedures described previously.

Sodium and zinc concentrations of fecal samples were determined using a Perkin-Elmer (Model 303) Atomic Absorption Spectrophotometer (Perkin-Elmer, 1968).

Acid-insoluble ash (AIA) content of fecal samples was determined according to the 2N HCl procedure outlined by Van Keulen and Young (1977). Acid-soluble ash (ASA) content was then determined by subtraction. Fresh frozen fecal samples were thawed for urobilinogen (UROB) analysis by a technique (Method A) discussed by Schwartz and Bracho (1972).

Average values for the fecal constituents of the thirty-nine fecal samples obtained from individual steers are presented in Table 3, and the same information is presented by trial in Table A-2.

TABLE 4

FORAGE COMPOSITION[a,b]

Variable	Fescue				Legume				Orts			
	N	Mean	SD	Range	N	Mean	SD	Range	N	Mean	SD	Range
% DM	36	27.30	9.38	34.80	30	25.45	11.55	40.45	36	27.43	12.27	40.65
CP	30	12.46	2.01	7.60	24	19.87	2.07	7.12	29	13.60	2.05	8.15
EE	27	2.35	0.43	1.41	24	2.17	0.40	1.48	26	2.06	0.45	1.44
NFE	22	49.54	3.05	11.62	21	48.25	7.49	28.05	23	48.31	3.13	12.06
CF	22	26.68	1.44	5.48	21	20.19	4.04	12.45	23	27.49	1.33	6.06
ASH	29	8.71	1.20	4.28	24	7.59	1.09	3.37	29	8.56	1.47	5.25
CWC	30	65.49	1.92	7.13	24	50.11	8.49	40.28	29	66.65	1.96	6.60
HEMIC	27	29.17	10.43	2.32	24	19.74	33.25	6.42	27	26.79	8.99	2.75
ADF	27	36.31	1.89	8.10	24	30.37	6.22	18.03	27	39.91	2.33	10.42
CELLU	27	31.51	7.48	1.58	24	22.53	15.43	3.24	27	33.26	12.92	2.66
ADL	27	4.80	1.07	5.00	24	7.85	4.02	13.82	--	--	--	--
IVDMD	26	57.45	4.95	23.51	22	62.13	6.99	23.15	--	--	--	--
IVOMD	26	51.53	5.15	23.96	22	55.32	6.09	20.16	--	--	--	--

[a]All values (excluding % DM) are expressed on a dry matter basis.

[b]N indicates the number of forage analyses included in forage composition summary.

Statistical Analyses

Factor Analysis using the principle axis with interation method and varimax rotation (Barr et al., 1979) was employed in an effort to describe variations in the fecal variables.

Stepwise procedures (Barr et al., 1979) were used to produce regressions of dependent variables (digestion trial data) on independent variables (fecal constituents) in order to produce fecal indices which best (maximum R^2) predicted the dependent variables.

The independent variables considered were DM, N, EE, CF, NFE, ASH, CWC, ADF, ADL, HEMIC, CELLU, AIA, ASA, NA, ZN, UROB, IVDMD, and IVOMD.

CHAPTER IV

RESULTS AND DISCUSSION

I. DESCRIPTION OF FECAL VARIABLES

Factor analysis was employed to describe the relationships between fecal variables. The rotated factor pattern appears in Table 5.

Factor 1 is composed of N, EE, IVOMD, and IVDMD, all of which are positively related. Fecal N has been shown to be mainly of endogenous origin (Hutchinson, 1958; Virtanen, 1966; Stallcup et al., 1975), although Van Soest (1967) noted that some lignin N escapes degradation. Lipid materials are generally degraded in the rumen, thus fecal EE should be predominately of endogenous origin (Jarrige, 1965; Crampton and Harris, 1969; Dawson and Hemington, 1974). N and EE were positively related to the IVOMD and IVDMD of the feces. N and EE comprise a large portion of the endogenous excretions and also are the most digestible portion of the feces. They would be expected to act as dilutants of the indigestible residue, consequently a positive relation to feces digestibility would be expected.

Factor 2 consists of ADF and ADL in a positive relationship. ADF consists of ADL and cellulose (Van Soest, 1963). Since ADL is a component of ADF, these fibrous components would be expected to vary together to some extent.

Factor 3 appeared to be a feces moisture factor. The variables which loaded were fecal DM and WETFO, and these factors varied in an inverse manner. This response would be expected since both variables are primarily dependent on water excretion.

TABLE 5

ROTATED FACTOR PATTERN[a]

Variable	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6	Factor 7
N	.57577						
NFE				-.69120			
CF						-.52474	
FDM			.81769				
WETFO			-.66459				
ADF		.80941					
ADL		.88904					
ASH				.87553			
EE	.52932						
CWC					.83040		
NA							.67708
ZN							.51270
UROB						.51985	
AIA				.75971			
IVDMD	.95574						
IVOMD	.83704						

[a]Only salient loadings appear in this table.

Factor 4 contained AIA and ASH, which varied positively, and NFE which varied negatively. The AIA and ASH relationship was expected, since AIA contains part of the fecal ash content, particularly the insoluble silious compounds (Van Keulen and Young, 1977). The ash component contains all minerals in the feces from both endogenous and exogenous sources including both dietary minerals and those from soil contamination. NFE varied inversely with ash, possibly because of a dilution effect of ash on NFE concentration, since NFE is calculated by subtraction of ash, CF, CP, and EE from the feces dry matter.

Factor 5 consisted solely of CWC. The cell wall constituents are comprised of ADF and hemicellulose (Van Soest, 1963), thus should be totally exogenous in origin. Although CWC did not load in the factor with ADF and ADL, this could possibly be explained by the observation by Van Soest (1967) that legumes have lower hemicellulose content than grasses.

Factor 6 included UROB and CF, which were inversely related. Urobilinogen originates from ruptured red blood cells. The heme group is used to make the bile pigment biliverdin, which in turn is reduced to bilirubin and added to the bile and is reduced to urobilinogen after secretion in the intestine (Guyton, 1971). Bile is secreted fairly constantly by the liver in response to fat content of the intestine (Guyton, 1971), thus should be constantly secreted due to minimal fluctuation fat content of forages (Hall, 1978). Since these pigments are totally endogenous in nature and excreted fairly constantly, it would be expected that CF would vary inversely since the exogenous plant fiber would have a dilutant effect on UROB concentration.

Factor 7 consisted of Na and Zn, which varied together. The majority of endogenous Zn secretion occurs in the upper small intestine, whereas Zn absorption (dietary as well as endogenous Zn) occurs in the lower intestine (Miller and Cragle, 1965; Hiers et al., 1968). Most Zn excretion occurs via the feces (Feaster et al., 1954; Miller et al., 1966). Fecal Zn is composed of unabsorbed dietary zinc and endogenous secretions (particularly from pancreatic juice) (Church and Pond, 1974).

Na excretion is primarily via the urine (Beal and Budtz-Olsen, 1968). Absorption occurs in the small intestine, although the small amount of Na which is excreted from the feces is approximately 80% endogenous in origin, primarily from bile and pancreatic juice (Church and Pond, 1974). Thus, excretion of both Na and Zn are associated with endogenous secretions to some extent, which might explain their relationship.

A table of correlation coefficients for the dependent and independent variables appears in Table A-6.

II. PREDICTION EQUATIONS

Data from digestion trials (dependent variables) and feces composition data (independent variables) were used to form fecal indices.

Many workers believe that local equations (fecal N indices) must be formed to avoid application errors (Raymond et al., 1954; Brisson, 1960; Greenhalgh and Corbett, 1960; Pearce et al., 1962; Arnold and Dudzinski, 1963; Lambourne and Reardon, 1963; Greenhalgh, 1966). Local equations require that individual indices be formed for each location, season, plant species and/or mixture, as well as each stage of maturity. The formation of fecal indices applicable over a wide range of locations,

seasons, and for several plant species and mixtures would be very desirable.

This research has utilized four plant species and a wide variety of plant maturities and digestibilities, with the intention of forming less restrictive prediction indices applicable for less specific pasture conditions.

Stepwise procedures were implemented to obtain models for the best (highest R^2) indices, using one to eleven independent (fecal composition) variables. Then, stepwise procedures were repeated, except that indices were formed using independent variables, their square terms, and their interactions. When square or interaction terms appeared to have value as a prediction tool, they were included in models with their component variables, in an attempt to find indices with greater R^2 values than what was obtained from the same number of fecal variables without mathematical manipulations.

Prediction equations for all dependent variables have been formed using a fecal N index, as a means of comparison, since fecal N is the most widely accepted predictor of many of the dependent variables.

Wet Matter Intake

The prediction equations for WETMI with highest R^2 values obtained for one through eleven independent fecal variables are presented in Table 6.

Fifty-three percent of the variation in WETMI could be attributed to its regression of fecal N. A positive relationship existed between fecal N and WETMI, which might be expected since the literature indicates that fecal N and DMI have a positive relationship, thus the same relationship might be expected for WETMI.

TABLE 6

REGRESSION COEFFICIENTS FOR MODELS PREDICTING WET MATTER INTAKE (KG/DAY)

Model No.	Model	R^2	RSD
1	$-9.5 + 9.55\ (N^{***})$	.5303	3.49
2	$65.8 - 1.22\ (NFE^{***})$	.5388	3.46
3	$81.8 - 1.18\ (NFE^{***}) - .74\ (CF^{**})$	.6366	3.11
4	$91.7 - .80\ (FMD^{***}) - 1.04\ (NFE^{***}) - .85\ (CF^{***})$	.7468	2.63
5	$93.2 - .88\ (FDM^{***}) - .94\ (NFE^{***}) - .94\ (CF^{***}) - .76\ (UROB^{*})$	.7770	2.51
6	$99.0 - .84\ (EE) - .66\ (FDM^{**}) - 1.18\ (NFE^{***}) - 1.02\ (CF^{***}) + .15\ (CELLU^{*})$	.7980	2.42
7	$47.8 + 4.69\ (N^{*}) - .58\ (FDM^{**}) - .82\ (NFE^{***}) - .60\ (CF^{*}) + .20\ (HEMIC^{*}) + .43\ (CELLU^{**})$	.8190	2.33
8	$38.8 + 6.06\ (N^{**}) - .55\ (FDM^{**}) - .68\ (NFE^{**}) - .71\ (CF^{**}) + .29\ (HEMIC^{**}) + .54\ (CELLU^{***}) - 2.21\ (NA^{*})$	.8444	2.19
9	$-29.5 + 9.42\ (N^{***}) + .41\ (EE) - .51\ (FDM^{*}) + .91\ (ASA^{**}) + .04\ (IVOMD) + .27\ (HEMIC^{**}) + .50\ (CELLU^{**}) - 2.27\ (NA^{*})$	.8483	2.20
10	$-32.1 + 8.84\ (N^{***}) - .47\ (FDM^{*}) - .19\ (CF) + 1.15\ (ASA^{**}) + .07\ (IVOMD) + .19\ (CWC) + .19\ (HEMIC) + .36\ (CELLU^{*}) = 2.89\ (NA^{**})$	.8509	2.22

TABLE 6 (continued)

Model No.	Model	R^2	RSD
11	42.3 + 12.89 (NA) + 1.02 (FDM) - 1.1637 (NA FDM*) + .05 (HEMIC) + .2266 (HEMIC*NA) - 27.77 (N) + 8.5965 (NSQ*) - 1.09 (CELLU) - 3.28 (ASA) + .288 (CELLU*ASA)	.8913	1.93
12	184.44 + 9.55 (NA) + .85 (FDM) - .9660 (NA*FDM*) + .03 (HEMIC) + .2661 (HEMIC*NA*) + .62 (CELLU) - 2.35 (CWC) - .0026 (CELLU*CWC) - 121.54 (N***) + 15.8137 (NSQ***) + 1.0084 (N CWC**)	.9139	1.75

* P < .05
** P < .01
*** P < .001

The best one-variable index consisted of NFE ($P < .001$) as the independent variable ($R^2 = .5388$). Van Soest (1965b) noted that NFE contains some lignin and hemicellulose, and Jarrige (1965) stated that feces contain very little soluble carbohydrates. Thus, NFE probably represents a portion of the undigested feed residues, which could explain the inverse relationship of WETMI and NFE.

The addition of CF and FDM in the model (models 2 and 3, Table 6) increased R^2 values to .6366 and .7486, respectively. The negative effect of CF on WETMI might be explained by observations by Van Soest (1965b), in which fibrous forage materials decrease DMI, assuming that fecal CF content is positively related to forage CF. This effect could be due to highly fibrous forages resulting in more bulk in the rumen, thus allowing rumen fill to limit intake.

The negative effect of FDM on WETMI might also be expected, since a higher percent fecal DM would occur on highly fibrous, highly indigestible, mature forages, because these types of plants are known to have a higher percent DM (Church and Pond, 1974). Thus, a lower WETMI intake would be required for the same dry matter intake when compared to an immature, high moisture forage.

The largest R^2 value ($R^2 = .9139$) obtained for prediction of WETMI was from the eleven-variable index. The signigicant terms were N and N squared ($P < .001$), with N squared being positively related to WETMI. This relationship might be expected since the literature suggests that the same relationship occurs with N and DMI.

Dry Matter Intake

The prediction equations for DMI appear in Table 7. The best one-variable index contained fecal N ($P < .001$), and explained 31.51% of the variation in DMI. Several other workers have studied N content of feces as a predictor of DMI, with varying degrees of success. The positive relationship between N and DMI might be explained by the increase in microbial activity associated with increased intake (Virtanen, 1966).

Additions of the variables EE, CWC, and DM in models 2, 3, and 4, respectively, were also significant ($P < .001$). The positive association of DMI and fecal EE might be an indication of increased erosion of the intestinal tract attributed to increased DMI.

A positive relationship was also observed for DMI and fecal CWC. The inverse relationship between DMI and DMD has been well substantiated (Church, 1976). Since increased CWC are associated with decreased DMD, the positive relationship of CWC and DMI might be expected, assuming fecal CWC and forage CWC content are positively related.

An equation containing the eleven variables providing the highest R^2 value accounted for 89.20% of the variation in DMI. The significant terms appearing in this model include NA ($P < .001$), N ($P < .05$), NA squared ($P < .05$), NA*CWC ($P < .001$), and NA*EE ($P < .01$). The negative association of NA with DMI might be expected if NA originates from endogenous sources and is excreted at a fairly constant rate, because NA would be diluted with increases in DMI, due to a decrease in digestibility and consequently greater amounts of undigested fecal material.

TABLE 7

REGRESSION COEFFICIENTS FOR MODELS PREDICTING DRY MATTER INTAKE (KG/DAY)

Model No.	Model	R^2	RSD
1	.28 + 1.15 (N^{***})	.3151	0.66
2	-.78 + 1.16 (N^{***}) + .26 (EE^{**})	.4569	0.59
3	-10.36 + 1.92 (N^{***}) + .36 (EE^{***}) + .13 (CWC^{***})	.6859	0.46
4	-8.76 + 1.77 (N^{***}) + .39 (EE^{***}) - .06 (FDM^{***}) + .12 (CWC^{***})	.7039	0.45
5	-9.79 + 1.91 (N^{***}) + .38 (EE^{***}) - .05 (FDM^{***}) + .13 (CWC^{***}) - .01 (HEMIC)	.7177	0.45
6	-9.66 + 1.82 (N^{***}) + .42 (EE^{***}) - .07 (FDM^{***}) + .14 (CWC^{***}) - .02 (HEMIC) + .35 (ZN)	.7307	0.44
7	-10.52 + 1.93 (N^{***}) + .41 (EE^{***}) - .07 (FDM^{***}) + .15 (CWC^{***}) - .02 (HEMIC) + .39 (ZN) - .22 (NA)	.7432	0.44
8	6.12 - .33 (EE) - .07 (CWC) + .0201 (EE CWC) - 3.98 (N) + 1.3127 (NSQ^{*}) - 6.20 (NA^{*}) + .1288 ($NA^{*}CWC^{**}$) - 43.18 ($NA^{*}EE^{*}$)	.8203	0.37
9	7.44 + .31 (EE^{***}) - .01 (CWC) - 2.30 (N) + 1.0500 (NSQ) + .1713 ($NA^{*}CWC^{***}$) - 10.45 (NA^{***}) - .47 (ASH) - .13 (ADF) + .0116 ($ASH^{*}ADF$)	.8333	0.37

TABLE 7 (continued)

Model No.	Model	R^2	RSD
10	-9.19 + .59 (EE + .21 (CWC) - 4.54 (N) + 1.4777 (NSW*) + .1735 (NA*CWC***) -9.24 (NA**) - .3776 (NA*EE*) + .55 (CELLU) - .0096 (CELLU*CWC) + .0054 (CELLU*EE)	.8719	0.33
11	-8.56 + .70 (EE) + .18 (CWC) - 4.22 (N) + 1.3965 (NSQ*) + .2159 (NA*CWC***) -10.06 (NA***) - .4318 (NA*EE**) + .58 (CELLU) - .0102 (CELLU*CWC) + .0044 (CELLU*EE) - .6194 (NASQ*)	.8920	0.30

* P < .05
** P < .01
*** P < .001

Wet Fecal Output

The prediction indices for WETFO appear in Table 8. Fecal N is apparently a poor predictor of WETFO, whereas CWC ($P < .01$) produced the best ($R^2 = .1971$) one-variable model.

The positive association of WETFO with fecal CWC can be explained by the fact that cell wall constituents represent a lowly digestible portion of the forage, thus forages high in CWC should result in feces high in CWC, when compared to forages low in CWC content. Since the forage high in CWC result in greater undigestible fecal residues, WETFO should increase.

The second variable to enter the equation was FDM ($P < .01$). This inverse relationship was expected, since the same relationship appeared by the factor analysis.

A negative relationship of NA and WETFO was observed in model 3. This effect would also be expected if NA is excreted constantly, because NA concentration would be diluted by increases in WETFO.

The largest R^2 value (.6467) was obtained from the best-fit ten-variable index (model 11, Table 8). The significant terms include FDM ($P < .05$), ZN*NA ($P < .05$), and AN*UROB ($P < .05$). The interactions of ZN, NA, and UROB are again evidence that endogenous secretions are valuable tools for the prediction of WETFO due to their proportion in the total output.

Fecal Dry Matter Output

The models for indices to predict FDMO are presented in Table 9. A poor relationship of N and FDMO was observed. As with WETFO, the best predictor of FDMO was CWC ($P < .001$) probably for the same reasons given above.

TABLE 8

REGRESSION COEFFICIENTS FOR MODELS PREDICTING WET FECAL OUTPUT (KG/DAY)

Model No.	Model	R^2	RSD
1	.68 - .25 (N)	.0040	1.54
2	-42. + .18 (CWC^{**})	.1971	1.38
3	.15 - .26 (FDM^{**}) + .18 (CWC^{**})	.3385	1.27
4	-16.4 + 2.00 (N^{**}) + .34 (CWC^{***}) - 1.55 (NA^{**})	.4411	1.19
5	.15 - .24 (FDM^{**}) + .22 (CWC^{***}) - .07 ($CELLU^{*}$) - 1.17 (NA^{**})	.5031	1.14
6	4.4 - .18 (FDM^{*}) - .15 (NFE) - 1.76 (AIA^{*}) + .24 (CWC^{***}) - 1.04 (NA^{*})	.5386	1.11
7	6.5 - .19 (FDM^{*}) - .17 (NFE^{*}) - .15 (CF) - 1.99 (AIA^{*}) + .29 (CWC^{***}) - 1.37 (NA^{**})	.5604	1.10
8	-6.8 + .32 (EE) - .30 (FDM^{**}) + .27 (ASH) - 2.45 (AIA^{*}) + .27 (CWC^{***}) + 1.20 (ZN) - 1.39 (NA^{**})	.5870	1.08
9	-6.5 + .30 (EE) - .29 (FDM^{**}) + .26 (ASH) - 2.35 (AIA^{*}) + .28 (CWC^{***}) - .02 (ADF) + 1.03 (ZN) - 1.43 (NA^{**})	.5973	1.09
10	-6.1 + .31 (EE) - .30 (FDM^{**}) + .25 (ASH) - 2.16 (AIA) - .11 (UROB) + .28 (CWC^{***}) + .99 (CELLU) + .99 (ZN) - 1.31 (NA^{**})	.6027	1.10

TABLE 8 (continued)

Model No.	Model	R^2	RSD
11	30.6 - .88 (CWC) + .0091 (CWCSQ) + 2.01 (NA) + .05 (CELLU) - .1925 (CELLU*NA) = .24 (FDM*) + .45 (ZN) + 3.1872 (ZN*NA*) + .40 (UROB) - 1.2284 (ZN*UROB*)	.6467	1.05
12	-6.0 + .52 (N) + .46 (EE) - .30 (FDM*) + .23 (ASH) - 2.32 (AIA) - .04 (IVDMD) - .11 (UROB) + .27 (CWC**) - .02 (ADF) + .86 (ZN) - 1.24 (NA*)	.6124	1.13

* P .05
** P .01
*** P .001

TABLE 9

REGRESSION COEFFICIENTS FOR MODELS PREDICTING FECAL DRY MATTER OUTPUT (KG/DAY)

Model No.	Model	R^2	RSD
1	1.4 - .17 (N)	.0755	0.23
2	-.9 + .03 (CWC***)	.2578	0.21
3	-.9 + .04 (CWC***) - .16 (NA*)	.3508	0.20
4	-1.2 + .04 (CWC***) + .21 (ZN) - .20 (NA**)	.4168	0.19
5	-1.5 + .04 (EE) + .04 (CWC***) + .25 (ZN*) - .20 (NA**)	.4545	0.19
6	-1.3 + .05 (EE) - .19 (AIA) + .04 (CWC***) + .23 (ZN*) - .20 (NA**)	.4964	0.18
7	-2.2 + .05 (EE) + .04 (ASH) - .36 (AIA*) + .05 (CWC***) + .24 (ZN*) - .22 (NA**)	.5252	0.18
8	-2.4 + .04 (EE) + .02 (FDM) + .05 (ASH) - .40 (AIA) + .05 (CWC***) + .20 (ZN) - .23 (NA**)	.5443	0.18
9	-3.0 + .12 (N) + .03 (EE) + .02 (FDM) + .04 (ASH) - .34 (AIA) + .05 (CWC***) + .18 (ZN) - .24 (NA**)	.5566	0.18
10	7.0 - .24 (CWC) + .0024 (CWCSQ) + .20 (ZN) + .01 (CELLU) + .29 (NA) - .0288 (CELLU*NA) + .06 (UROB) - .1990 (ZN*UROB*) + .4763 (ZN*NA)	.5984	0.17

TABLE 9 (continued)

Model No.	Model	R^2	RSD
11	-2.6 + .13 (N) + .06 (EE) + .02 (FDM) + .04 (ASH) - .37 (AIA) - .007 (IVDMD) - .02 (UROB) + .05 (CWC***) + .15 (ZN) - .21 (NA*)	.5702	0.18
12	1.7 - .06 (CWC) + .0009 (CWCSQ) + .16 (ZN) + .01 (CELLU) + .36 (NA) - .0323 CELLU*NA) - .03 (UROB) - .1839 (ZN*UROB) + .5224 (ZN*NA) - 02 (EE) + .0217 (UROB*EE)	.6295	0.17

* P < .05
** P < .01
*** P < .001

NA, ZN, EE, and AIA entered into models 2, 3, 4, and 5, respectively. The trends for NA and ZN were negative and positive in relation to FDMO, respectively. The NA relationship explained earlier would be expected to appear for FDMO, assuming NA excretion was fairly constant. The positive relationship of fecal ZN with FDMO was possibly a result of higher FDMO from more fibrous, less digestible forages, and higher ZN secretion (as endogenous cofactors) in response to the extra effort of digestion.

The positive relationship of fecal EE and FDMO might be an indication of increased erosion of the intestinal lining as a result of the increased fiber associated with increased FDMO.

The negative relationship of AIA with FDMO might be expected, since AIA is indigestible, because of a dilution effect on AIA from increases in FDMO which arise due to decreased digestibility.

The largest R^2 achieved was for the eleven-variable index (.6295), although no individual variables were significant due to the dilution of accountable variation of a particular variable by the inclusion of interactions in the model. The maximum R^2 achieved for both WETFO and FDMO were much lower than for the other dependent variables.

Dry Matter Digestibility

The best (highest R^2) models for prediction of DMD appear in Table 10. The best one-variable model contained fecal N, and other workers (Lancaster, 1954; Raymond et al., 1954; Richards et al., 1958; Kennedy et al., 1959; Arnold and Dudzinski, 1963) have indicated that fecal N has value as a predictor of DMD.

TABLE 10

REGRESSION COEFFICIENTS FOR MODELS PREDICTING DRY MATTER DIGESTIBILITY (PERCENT)

Model No.	Model	R^2	RSD
1	$17.84 + 19.78\ (N^{***})$	.4534	8.43
2	$6.16 + 19.94\ (N^{***}) + 2.93\ (EE^{*})$	.5376	7.86
3	$33.50 + 17.09\ (N^{***}) + 3.91\ (EE^{***}) - 1.49\ (FDM^{*})$	.6010	7.41
4	$31.22 + 15.88\ (N^{***}) + 4.35\ (EE^{***}) - 1.65\ (FDM^{*}) + 5.52\ (NA^{*})$	.6472	7.07
5	$34.45 + 16.52\ (N^{***}) + 4.11\ (EE^{***}) - 1.69\ (FDM^{**}) - .29$ (HEMIC) $+ 6.49\ (NA^{*})$	.6821	6.81
6	$54.41 + 14.32\ (N^{***}) + 3.91\ (EE^{**}) - 1.79\ (FDM^{**}) - .53$ (HEMIC) $- .38$ (CELLU) $+ 7.25\ (NA^{*})$	.6917	6.81
7	$62.71 + 13.08\ (N^{**}) + 3.55\ (EE^{**}) - 1.86\ (FDM^{**}) + 4.43$ (AIA) $- .63\ (HEMIC^{*}) - .59$ (CELLU) $+ 7.69\ (NA^{**})$	.6990	6.84
8	$4.40 + 18.40\ (N^{**}) + 3.73\ (EE^{**}) - 1.84\ (FDM^{**}) + .61$ (NFE) $+ 8.37$ (AIA) $- .37$ (CWC) $+ .75\ (ADL^{*}) + 6.21\ (NA^{*})$	.7112	6.86
9	$-151.53 + 28.38\ (N^{***}) - 3.29$ (EE) $- .24$ (ADF) $+ .1563\ (EE^{*}ADF)$ $+ 95.90\ (NA^{*}) + 1.58$ (NFE) $- .2030\ (NA^{*}NFE) - 5.1399\ (NA^{*}FDM^{**})$ $+ 4.51\ (FDM^{*})$	.7675	6.21

TABLE 10 (continued)

Model No.	Model	R^2	RSD
10	$-244.28 + 92.57\ (N^{*}) - 2.24\ (EE) - .19\ (ADF) + .1378\ (EE^{*}ADF) + 112.72\ (NA^{*}) + 1.88\ (NFE) - .5392\ (NA^{*}NFE) - 5.2561\ (NA^{*}FDM^{**}) + 4.69\ (FDM^{*})$	.7876	6.04
11	$69.37 + 14.72\ (N^{**}) + 3.09\ (EE) - 1.61\ (FDM^{*}) - .68\ (CF) + 3.50\ (AIA) - .53\ (IVDMD) + .52\ (IVOMD) - .46\ (CWC) + .77\ (ADL) - 3.90\ (ZN) + 6.31\ (NA)$	.7277	6.97

* P < .05
** P < .01
*** P < .001

EE, FDM, and NA entered models 2, 3, and 4, respectively. EE had a positive association with DMD. Fecal EE is assumed to be almost totally endogenous in origin and would be expected to be in higher proportions when the diet is higher in digestibility.

The inverse relationship observed between DMD and FDM was expected, since a highly digestible diet would be highly absorbed, thus low amounts of undigested residues would appear as fecal DM. Also, the intake of lush, immature (highly digestible) forages has a laxative effect, which is more evidence that digestibility and FDM should be related.

NA was positively related to DMD, as would be expected in view of the earlier hypothesis that NA is excreted in constant amounts and would compose a larger fraction of the feces on more highly digestible diets.

HEMIC and CELLU entered the fecal index in models 5 and 6, respectively. These variables were both negatively related to DMD. HEMIC and CELLU, being components of cell walls and being more encrusted by lignin in more mature, less digestible forage, are likely to appear in higher concentrations in the feces when digestibility is lower.

AIA entered as a predictor of DMD in model 8 and had a positive association with DMD which could be explained by the dilution of AIA as digestibility decreases.

Model 10 (R^2 = .7876) provided the best index for DMD prediction and included N ($P < .05$), NA ($P < .05$), FDM ($P < .05$), and NA*FDM ($P < .01$) as significant terms. It is the opinion of this writer that this model is quite usable from a practical standpoint, since the amount of variation in DMD explained is relatively large and the variables in the model can be analyzed with minimal laboratory facilities.

Digestible Dry Matter Intake

Fecal indices for prediction of DDMI appear in Table 11. A one-variable model (R^2 = .4405) containing N ($P < .001$) was the best prediction equation. This was expected in view of the high R^2 achieved from models containing only fecal N for both DMI and DMD.

E and CWC entered to form the best two-variable (R^2 = .5806) and three-variable model (R^2 = .7026), respectively. The positive relationship between EE and DDMI was expected, in view of the fact that EE is largely of endogenous origin, thus would increase with DDMI due to a decrease in percent of undigestible residues.

There was a positive relationship between fecal CWC and DDMI. Since CWC was positively related to DMI and negatively related to DMD, it would appear that the CWC is associated with the intake factor of DDMI.

FDM ($P < .05$) entered model 4 and was negatively related to DDMI, which was expected since FDM had a negative relationship with both DMI and DMD.

The general trends for subsequent models were negative relationships of CF, HEMIC, and NFE with DDMI. Since these are fibrous fractions, which when present in large amounts in the forage generally depress digestibility, these trends were expected.

The largest R^2 achieved for prediction of DDMI was obtained from the eleven-variable model (R^2 = .8162), and the significant terms were FDM ($P < .05$), CWC ($P < .01$), and ADL ($P < .05$). This model could be of great value in prediction of pasture productivity, assuming subsequent research indicates that the high R^2 is reproducible for a large number of observations.

TABLE 11

REGRESSION COEFFICIENTS FOR MODELS PREDICTING DIGESTIBLE DRY MATTER INTAKE (KG/DAY)

Model No.	Model	R^2	RSD
1	$-1.13 + 1.32\ (N^{***})$	.4405	0.58
2	$-2.15 + 1.33\ (N^{***}) + .26\ (EE^{**})$	.5806	0.51
3	$-8.94 + 1.87\ (N^{***}) + .32\ (EE^{***}) + .09\ (CWC^{***})$	.7026	0.43
4	$-6.66 + 1.65\ (N^{***}) + .37\ (EE^{***}) - .08\ (FDM^{*}) + .08\ (CWC^{**})$	.7414	0.41
5	$-7.90 + 1.82\ (N^{***}) + .36\ (EE^{***}) - .08\ (FDM^{*}) + .10\ (CWC^{***})$ - .02 (HEMIC)	.7624	0.40
6	$-6.41 + 1.69\ (N^{***}) + .33\ (EE^{***}) - .08\ (FDM^{*}) - .05$ (CF) $+ .10\ (CWC^{***})$ - .02 (HEMIC)	.7730	0.39
7	$-6.40 + 1.65\ (N^{***}) + .35\ (EE^{***}) - .10\ (FDM^{*}) -.05$ (CF) $+ .10\ (CWC^{***})$ - .02 (HEMIC) + .20 (ZN)	.7774	0.40
8	671.48 - 40.91 (N) - 6.52 (EE) - 0.9 FDM) - 6.79 (NFE) - 6.83 (CF) - 6.70 (ASH) $+ .09\ (CWC^{***}) + .05\ (ADL^{*})$	.8026	0.38
9	676.73 - 41.21 (N) - 6.59 (EE) $- .08\ (FDM^{*})$ - 6.85 (NFE) - 6.91 (CF) - 6.75 (ASH) $+ .10\ (CWC^{***}) + .05\ (ADL^{*}) - .14$ (NA)	.8064	0.38

TABLE 11 (continued)

Model No.	Model	R^2	RSD
10	693.40 - 42.22 (N) - 6.70 (EE) - .09 (FDM*) - 7.01 (NFE) - 7.05 (CF) - 6.92 (ASH) - .03 (IVDMD) + .03 (IVOMD) + .08 (CWC**) + .05 (ADL)	.8130	0.38
11	689.92 - 42.00 (N) - 6.70 (EE) - .09 (FDM*) - 6.97 (NFE) - 7.03 (CF) - 6.88 (ASH) - .03 (IVDMD) + .03 (IVOMD) + .09 (CWC**) + .05 (ADL*) - .13 (NA)	.8162	0.39

* P < .05
** P < .01
*** P < .001

Total Digestible Nutrients

Models for prediction of forage TDN appear in Table 12. The best one-variable model (R^2 = .1601) contained ADL as the independent variable. ADL was positively related to TDN. ADL, being highly indigestible, would be expected to increase as a percent of feces as the TDN of the forage increased.

CELLU and CF entered indices 2 and 3, respectively, and were inversely related to TDN. These variables would be expected to compose a greater proportion of the feces when steers were consuming forages of advanced maturity and low digestibility, thus these variables would vary inversely with TDN.

IVDMD was the fourth fecal variable to enter the index, and the relationship was positive. Thus, feces of higher digestibility probably contain less fibrous material, and forage of higher TDN results in less fecal fiber.

EE was significantly positively related to TDN in all models containing five or more variables. This observation can be explained by the fact that forages of high TDN would be more thoroughly digested, thus endogenous excretions will comprise a greater percent of the total fecal output than when forages low in TDN are consumed.

The eleven-variable model attained an R^2 of .8798 and significant terms were EE ($P < .01$) and ADL ($P < .05$).

Total Digestible Nutrient Intake

The indices for prediction of TDNI are presented in Table 13. Again, ADL provided the best one-variable index (R^2 = .3035), probably for the same reason explained for prediction of TDN.

TABLE 12

REGRESSION COEFFICIENTS FOR MODELS PREDICTING TOTAL DIGESTIBLE NUTRIENTS (KG/DAY)

Model No.	Model	R^2	RSD
1	19.78 + 16.07 (N)	.1601	9.68
2	26.32 + 1.42 (ADL**)	.3083	8.79
3	36.37 + 1.63 (ADL**) - .55 (CELLU*)	.4617	7.94
4	113.06 - 2.94 (CF**) + 1.53 (ADL***) - .63 (CELLU**)	.6392	6.67
5	106.22 - 3.12 (CF**) + .62 (IVDMD**) + 1.40 (ADL***) - .63 (CELLU**)	.7541	5.66
6	-46.46 + 7.22 (EE***) - 1.09 (FDM*) + 1.83 (NFE**) + 1.38 (ADL***) - .76 (CELLU***)	.8246	4.92
7	-20.01 + 7.25 (EE***) - 1.23 (FDM*) + 1.16 (NFE) + 1.34 (ADL***) - .68 (CELLU***) + 4.25 (NA)	.8459	4.75
8	-15.97 + 8.31 (EE***) - 1.57 (FDM*) + 1.01 (NFE) + 1.24 (ADL***) - .58 (CELLU**) + 4.28 (ZN) + 4.87 (NA)	.8555	4.75
9	-22.18 + 7.73 (EE***) - 1.42 (FDM*) + 1.92 (NFE*) - 1.60 (UROB) - .48 (CWC) + 1.52 (ADL***) - .75 (CELLU***) + 5.45 (NA)	.8687	4.69
10	16.90 + 6.92 (EE**) - 1.50 (FDM*) + 1.46 (NFE) - .84 (CF) - 1.70 (UROB) - .36 (CWC) + 1.51 (ADL***) - .73 (CELLU**) + 5.22 (NA)	.8712	4.82

TABLE 12 (continued)

Model No.	Model	R^2	RSD
11	-156.21 + 7.36 (N) + 7.19 (EE**) - .65 (FDM) + 3.25 (NFE**) + 2.53 (IVDMD) - 2.27 (IVOMD) - 1.25 (UROB) + 1.40 (ADL*) - .62 (CELLU) + 2.82 (ZN)	.8777	4.82
12	-127.36 + 6.08 (N) + 7.67 (EE**) - .89 (FDM) + 2.74 (NFE) + 2.14 (IVDMD) - 1.99 (IVOMD) - 1.26 (UROB) + 1.39 (ADL*) - .61 (CELLU) + 3.19 (ZN) + 2.07 (NA)	.8798	5.06

* P < .05
** P < .01
*** P < .001

TABLE 13

REGRESSION COEFFICIENTS FOR MODELS PREDICTING TOTAL DIGESTIBLE NUTRIENT INTAKE (KG/DAY)

Model No.	Model	R^2	RSD
1	-.36 + .93 (N*)	.1830	0.51
2	.14 + .08 (ADL**)	.3035	0.48
3	-1.11 + .12 (ADL***) + .03 (HEMIC*)	.4611	0.43
4	.55 + .39 (EE***) - 1.56 (AIA***) + .04 (ADL)	.6990	0.33
5	-1.95 + .44 (EE***) - 1.51 (AIA***) + .04 (CWC) + .04 (ADL)	.7466	0.31
6	-2.74 + .42 (EE***) - 1.05 (AIA) + .05 (CWC*) + .05 (ADL*) - .02 (CELLU)	.7647	0.31
7	-2.30 + .40 (EE***) - .04 (FDM) - .75 (AIA) + .05 (CWC*) + .05 (ADL*) - .02 (CELLU)	.7877	0.30
8	-1.87 + .46 (EE***) - .05 (FDM) - .85 (AIA) - .02 (IVOMD) + .05 (CWC*) + .05 (ADL*) - .02 (CELLU)	.8069	0.30
9	1.30 + .31 (EE**) - .07 (FDM) - .12 (CF) - .33 (AIA) - .12 (UROB) + .05 (CWC*) + .08 (ADL*) - .03 (CELLU)	.8294	0.29
10	.73 + .39 (EE*) - .10 (FDM*) - .08 (CF) - .02 (IVOMD) - .14 (UROB) + .05 (CWC) + .09 (ADL***) - .04 (CELLU*) + .19 (NA)	.8353	0.29

TABLE 13 (continued)

Model No.	Model	R^2	RSD
11	-9.96 + .39 (N) + .42 (EE**) - .04 (FDM) + .12 (NFE) + 15 (IVDMD) - .17 (IVOMD) - .13 (UROB) + .05 (CWC) + .09 (ADL*) - .03 (CELLU)	.8479	0.29
12	-12.28 + .64 (N) + .41 (EE**) - .04 (FDM) + .15 (NFE) + .36 (AIA) - .18 (IVDMD) - .19 (IVOMD) - .14 (UROB) + .05 (CWC) + .09 (ADL*) - .04 (CELLU*)	.8494	0.31

* P < .05
** P < .01
*** P < .001

HEMIC entered equation 2 and was positively correlated with TDNI, although this was the only model in which HEMIC appeared for prediction of TDNI.

EE tended to be positively associated with TDNI, as would be expected based on the explanation given earlier for TDN.

AIA also exhibited a tendency to be related to TDNI, although it was a negative relationship. Since AIA is indigestible, a decrease in AIA would be expected for a steer for which TDNI increased.

CWC displayed a general tendency to be positively correlated with TDNI, which would not be expected in view of the previous explanation of the relation of CF and TDN.

The greatest R^2 (.8494) was obtained from an eleven-variable index, in which EE ($P < .01$) and ADL ($P < .05$) were significant.

Crude Protein Digestion Coefficient

The indices for prediction of DCP appear in Table 14. Fecal N was a poor predictor of DCP, which is logical since fecal N is mainly endogenous rather than being related to dietary N to any great degree.

The best predictor of DCP for the single variable model was IVDMD ($P < .001$). The relationship between IVDMD of feces and DCP was positive, although an explanation for this relationship was not apparent.

FDM, ASH, and AIA tended to be negatively related to DCP, which might have been attributed to increased concentrations of these feces variables for lowly digestible forages, thus a higher concentration of entrapped N in the fibrous portion of the plants.

There was a trend for DCP and EE to be positively related, possibly because of a dilution of EE with a decrease in DCP.

TABLE 14

REGRESSION COEFFICIENTS FOR MODELS PREDICTING APPARENT CRUDE PROTEIN DIGESTIBILITY (PERCENT)

Model No.	Model	R^2	RSD
1	.32 + .13 (N)	.0465	0.11
2	.35 + .01 (IVDMD***)	.3277	0.10
3	.71 - .03 (ASH*) + .01 (IVDMD***)	.4272	0.09
4	.85 + .07 (EE***) - .02 (FDM**) - .21 (AIA**)	.6184	0.07
5	.85 + .07 (EE***) - .01 (FDM) - .26 (AIA**) - .08 (ZN)	.6503	0.07
6	.90 + .07 (EE***) - .02 (FDM) - .28 (AIA**) - .002 (HEMIC) - .07 (ZN)	.6702	0.07
7	1.06 + .06 (EE***) - .01 (FDM) - .26 (AIA**) + .01 (UROB) - .005 (CWC) - .09 (ZN)	.6877	0.07
8	.74 + .19 (N**) + .09 (EE***) - .02 (FDM**) - .03 (ASA) - .008 (ADL) - .005 (HEMIC) + .06 (NA*)	.7207	0.07
9	.72 + .18 (N**) + .08 (EE***) - .02 (FDM*) - .03 (ASH) - .006 (ADL) - .004 (HEMIC) - .03 (ZN) + .06 (NA)	.7262	0.07
10	.75 + .18 (N**) + .08 (EE***) - .02 (FDM*) - .03 (ASH) + .008 (UROB) - .008 (ADL) - .005 (HEMIC) - .04 (ZN) + .05 (NA)	.7317	0.07

TABLE 14 (continued)

Model No.	Model	R^2	RSD
11	-1.37 + .13 (ADL**) + .02 (IVDMD) + .0008 (HEMIC) + .02 (UROB) + .19 (ZN) + .02 (IVOMD) - .0028 (ADLSQ**) - .0009 (IVOMDSQ**) + .0012 (HEMIC*UROB) - 0.705 (ZN*UROB*)	.7964	0.06
12	-.76 + .11 (ADL**) + .02 (IVDMD) - .01 (HEMIC) - .08 (UROB) + .01 (IVOMD) - .009 (CELLU) - .0023 (ADLSQ**) - .0008 (IVOMDSQ**) + .0072 (HEMIC*UROB***) - .0200 (UROBSQ**) + .0042 (CELLU*UROB)	.8817	0.05

* P < .05
** P < .01
*** P < .001

The highest R^2 (.8817) was obtained with an eleven-variable model, which contained ADL ($P < .01$), ADL squared ($P < .01$), IVOMD squared ($P < .01$), UROB squared ($P < .01$), and the HEMIC*UROB ($P < .001$) interaction as significant terms.

Digestible Crude Protein Intake

The best-fit indices for prediction of DCPI are presented in Table 15. Fecal N was of very little value in prediction of DCPI, probably for the same reason as stated for prediction of DCP.

ADL was the best single predictor ($R^2 = .2657$) and existed in a positive relationship with DCPI. It would seem that the relationship would be negative if ADL contains lignin N; however, forages high in DCP are higher in digestibility, thus resulting in feces containing a higher ADL concentration.

AIA, ZN, and FDM were inversely related to DCPI. AIA does not follow the expected pattern, since a decrease in DCPI would be expected to cause a dilution effect on AIA.

FDM would probably be increased by lowly digestible cell wall constituents, which contain lignified N, thus an inverse relationship between FDM and DCPI would be expected.

EE was generally positively associated with DCPI, which was probably due to the same type of relationship described for EE with DCP.

The greatest R^2 (.8303) was attained from the eleven-variable index, which included ADL ($P < .01$), ADL squared ($P < .01$), NA ($P < .01$), NA*FDM ($P < .05$), and NA*ADL ($P < .05$) as significant variables.

TABLE 15

REGRESSION COEFFICIENTS FOR MODELS PREDICTING DIGESTIBLE CRUDE PROTEIN INTAKE (KG/DAY)

Model No.	Model	R^2	RSD
1	.05 + .77 (N)	.1246	0.61
2	.01 + .09 (ADL***)	.2657	0.56
3	1.61 + .45 (EE***) - 1.98 (AIA***)	.6822	0.37
4	2.12 + .41 (EE***) - 2.13 (AIA***) - .48 (ZN*)	.7365	0.35
5	1.59 + .35 (EE***) - 1.95 (AIA***) + .03 (ADL) - .52 (ZN*)	.7616	0.34
6	2.02 + .38 (EE***) - .05 (FDM) - 1.73 (AIA***) + .03 (ADL) - .37 (ZN)	.7763	0.33
7	2.24 + .40 (EE***) - .05 (FDM) - 1.79 (AIA***) - .01 (IVOMD) + .03 (ADL) - .43 (ZN)	.7823	0.33
8	2.87 + .40 (EE***) - .05 (FDM) - .02 (CF) - 1.76 (AIA***) .01 (IVOMD) + .03 (ADL) - .42 (ZN)	.7854	0.34
9	-1.39 + .67 (N) + .38 (EE***) - .06 (FDM) - .04 (CF) - .94 (AIA) + .04 (CWC) + .03 (ADL) - .24 (ZN)	.7992	0.34
10	-.60 + .52 (N) + .37 (EE***) - .05 (FDM) - .05 (CF) - .12 (AIA) + .05 (CWC) + .03 (ADL) - .26 (ZN) - .13 (NA)	.8026	0.34

TABLE 15 (continued)

Model No.	Model	R^2	RSD
11	540.51 - 32.95 (N) - 5.02 (EE) - 09 (FDM*) - 5.45 (NFE) - 5.47 (CF) - - 5.43 (ASH) - .67 (AIA) + .06 (CWC) - 0.3 (ADL) + .01 (CELLU)	.8109	0.34
12	-20.82 + .04 (EE) + .15 (CWC) + .0050 (EE CWC) + .62 (ADL**) - .0126 (ADLSQ**) + 3.79 (N) - .0425 (N*CWC) + 4.72 (NA**) + .14 (FDM) - .1904 (NA*FDM*) - .0883 (NA*ADL*)	.8803	0.28

* P < .05
** P < .01
*** P < .001

The increase in NA which was observed when DCPI increased might be attributed to an increase in endogenous NA concentration in the feces due to an increase in DCPI.

CHAPTER V

SUMMARY

Several equations have been developed in this study in an attempt to predict a series of dependent variables: WETMI, DMI, WETFO, FDMO, DMD, DDMI, TDN, TDNI, DCP, and DCPI.

The eighteen fecal analyses, as well as squared terms and interaction terms, have been provided as potential variables for fecal indices ranging from one to eleven variable best-fit models.

The intake variables attained R^2 values over .91 (WETMI) and .89 (DMI) from eleven fecal variables. These variables achieved the highest accountable variation of any dependent variables. Some of the more important variables included N, NFE, NA, EE, FDM, CWC, and HEMIC.

Fecal indices for WETFO (ten-variable model) and FDMO (eleven-variable model) accounted for almost 65% and 63% of the total variation, respectively. Of the ten variables tested, the fecal output variables were the least predictable. Variables which appeared to be important were CWC, FDM, NA, ZN, AIA, EE, and ASH.

When predicted by the ten-variable fecal index, almost 79% of the total variation in DMD was explained by the model. Important variables for prediction of DMD appear to be N, EE, NA, FDM, HEMIC, and NA*FDM. A slight increase in variation in DDMI was explained (81.6%) with an eleven-variable fecal index. The important variables appear to be N, EE, CWC, FDM, and HEMIC.

Approximately 88% and 85% of the total variation in TDN and TDNI, respectively, were accounted for with eleven-variable fecal indices.

The variables which were important for prediction of these dependent variables were ADL, EE, CF, CELLU, AIA, NFE, and FDM.

More than 88% of the variation in both DCP and DCPI was accounted for with prediction equations containing eleven variables. The variables which were important were ADL, AIA, IVDMD, EE, NA, FDM, and ZN.

The data from the in vivo digestion trials indicate that fecal indices might be effectively used for pasture evaluation and also suggests that local equations need not be formed for purposes of prediction of forage quality, since prediction equations developed from a wide variety of pasture species with large variation in maturity accounted for up to 90% of the variation in the parameters studied.

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APPENDIX

TABLE A-1

DIGESTION TRIAL DATA BY TRIAL[a]

Variable	Trial 1				Trial 2				Trial 3				Trial 4				Trial 5				Trial 6		
	N	Mean	SD	Range	N	Mean	SD	Range	N	Mean	SD	Range	N	Mean	SD	Range	N	Mean	SD	Range	N	Mean	SD	Range
Steer wt. (kg)	8	189.15	19.30	48.12	8	182.39	18.29	55.84	4	203.73	21.73	49.94	8	236.42	18.64	57.20	8	258.89	16.49	52.66	3	247.43	8.18	15.89
WETMI (kg)	8	20.24	4.88	14.94	8	12.59	3.47	10.49	4	11.74	0.97	2.36	8	11.57	1.80	6.27	8	9.88	0.92	2.95	3	5.78	0.60	1.09
DMI (kg)	8	3.68	0.83	2.67	8	2.32	0.61	1.84	4	2.07	0.09	0.22	8	3.06	0.43	1.54	8	3.36	0.48	1.61	3	2.49	0.30	0.54
WETFO (kg)	8	5.47	1.48	4.63	8	5.18	1.06	3.27	4	7.14	0.97	2.36	8	6.55	1.90	5.72	8	6.82	1.25	3.77	3	6.86	1.46	2.91
FDMO (kg)	8	0.83	0.17	0.61	8	0.81	0.12	0.36	4	1.20	0.10	0.20	8	1.09	0.17	0.55	8	1.10	0.18	0.54	3	1.27	0.44	0.88
% DMD	8	77.10	2.53	6.44	8	63.70	5.86	18.90	4	42.01	3.46	8.43	8	64.18	4.39	13.99	8	67.37	1.92	4.93	3	49.98	13.11	24.62
DDMI (kg)	8	2.85	0.68	2.26	8	1.50	0.51	1.60	4	0.87	0.08	0.16	8	1.97	0.35	1.25	8	2.26	0.32	1.07	3	1.23	0.27	0.52
% TDN	0	--	--	--	0	--	--	--	4	36.57	3.32	7.86	8	57.60	3.90	12.42	8	61.77	2.13	5.52	3	47.78	11.28	21.14
TDNI (kg)	0	--	--	--	0	--	--	--	4	0.76	0.06	0.15	8	1.77	0.33	1.17	8	2.07	0.28	0.95	3	1.18	0.23	0.45
% DCP	0	--	--	--	8	59.68	10.63	30.81	4	49.93	6.85	14.59	8	64.76	4.04	12.90	8	71.39	2.71	7.95	3	43.70	14.83	26.32
DCPI (kg)	0	--	--	--	8	1.43	0.57	1.76	4	1.03	0.15	0.34	8	1.99	0.36	1.27	8	2.40	0.34	1.14	3	1.07	0.33	0.66

[a]N indicates number of steers from each trial on which data are based.

TABLE A-2

FECES COMPOSITION BY TRIAL[a,b]

Variable	Trial 1			Trial 2			Trial 3			Trial 4			Trial 5			Trial 6		
	Mean	SD	Range	Mean	SD	Range	Mean	SD	Range	Mean	SD	Range	Mean	SD	Range	Mean	SD	Range
% DM	5.54	2.14	5.40	15.94	1.87	5.60	16.95	1.46	3.00	17.23	2.44	6.00	16.29	2.33	6.70	18.13	2.67	4.90
N	2.87	0.11	0.29	2.36	0.34	0.95	1.87	0.19	0.47	2.25	0.33	0.83	2.19	0.15	0.42	2.06	0.08	0.16
EE	4.18	1.25	3.77	2.59	0.25	0.80	3.85	0.25	0.53	4.82	0.86	2.66	4.41	0.19	0.59	2.40	0.20	0.36
NFE	39.47	1.34	4.19	44.78	1.90	5.94	43.78	1.20	2.34	42.45	1.47	3.69	45.54	2.23	6.34	48.36	0.35	0.65
CF	21.81	2.31	7.03	24.54	2.26	5.34	26.33	0.21	0.43	24.53	1.62	4.51	24.23	1.56	4.19	24.16	0.58	1.08
CWC	55.48	2.99	9.39	57.09	2.64	7.55	61.10	1.59	3.58	56.28	1.30	4.00	63.21	2.20	5.67	62.44	2.26	4.50
HEMIC	15.08	2.03	7.02	11.93	1.55	4.15	14.69	1.35	2.79	10.59	15.44	38.24	18.56	3.31	10.22	16.38	2.50	4.91
ADF	40.40	2.33	5.38	45.16	2.30	6.57	46.42	0.43	0.87	45.69	16.04	38.24	44.65	3.21	9.20	46.06	2.14	4.16
CELLU	25.64	1.48	4.76	27.68	2.83	8.41	31.74	1.68	3.72	24.70	12.13	28.23	24.17	0.60	2.04	25.92	4.72	8.72
ADL	14.76	1.41	3.69	17.48	1.38	4.09	14.68	1.35	3.16	20.99	4.64	13.55	20.48	3.00	8.07	20.14	3.22	6.23
NA	1.37	0.26	0.70	0.98	0.21	0.63	0.73	0.21	0.50	0.66	0.28	0.81	1.40	0.49	1.22	1.70	0.13	0.25
ZN	0.64	0.09	0.26	0.43	0.06	0.20	0.34	0.12	0.27	0.53	0.37	1.15	0.33	0.07	1.21	1.30	0.17	0.33
AIA	1.12	0.31	0.96	0.75	0.23	0.64	1.04	0.23	0.52	0.87	0.25	0.68	0.66	0.07	0.21	0.66	0.08	0.15
ASA	15.49	0.68	2.16	12.57	0.63	1.66	13.32	1.02	2.32	13.29	1.20	3.17	11.47	0.58	1.53	11.57	0.59	1.15
IVDMD	31.57	7.06	18.77	21.74	5.87	20.33	22.98	2.54	5.46	24.20	2.18	6.20	24.34	5.76	18.07	13.87	9.28	18.41
IVOMD	24.08	6.52	16.51	14.19	4.83	16.71	15.77	1.57	3.56	16.21	2.31	6.54	17.36	5.37	16.23	8.39	8.84	17.44
UROB	2.44	0.76	2.39	2.64	1.26	3.91	1.68	0.39	0.72	3.01	0.67	2.06	3.39	1.61	4.90	3.64	2.15	3.15

[a]All variables (excluding % DM) are expressed on a dry matter basis.

[b]All variables based on analyses of eight fecal samples, except those for Trial 3 and 6, which are based on 4 and 3 analyses, respectively.

TABLE A-3

FESCUE COMPOSITION BY TRIAL[a,b]

Variable	Trial 2 N	Mean	S.D.	Range	Trial 3 N	Mean	S.D.	Range	Trial 4 N	Mean	S.D.	Range	Trial 5 N	Mean	S.D.	Range	Trial 6 N	Mean	S.D.	Range
% DM	6	21.06	2.00	5.15	6	20.50	4.18	12.00	6	23.28	3.73	8.50	6	29.18	6.89	17.20	6	42.46	5.08	14.10
CP	6	11.92	1.57	4.10	6	11.56	1.43	4.02	6	12.12	1.34	3.53	6	15.30	1.10	3.05	6	11.39	1.87	5.19
EE	4	1.71	0.12	0.25	6	2.12	0.52	1.25	5	2.63	0.18	0.42	6	2.55	0.16	0.39	6	2.57	0.19	0.55
NFE	0	--	--	--	6	49.26	1.04	2.54	5	48.05	1.03	2.63	5	46.38	1.84	4.76	6	53.69	1.17	3.29
CF	0	--	--	--	6	26.96	0.76	2.04	5	27.25	1.61	4.50	5	27.48	1.49	3.89	6	25.24	0.88	1.95
ASH	5	8.21	0.63	1.46	6	10.09	0.47	1.35	6	9.71	0.51	1.06	6	8.33	0.41	1.11	6	7.12	0.39	0.81
CWC	6	65.62	2.45	6.54	6	64.32	0.74	2.24	6	67.43	1.96	5.63	6	64.35	1.20	3.21	6	65.75	1.30	4.03
HEMIC	4	28.63	1.13	2.52	6	28.23	0.67	1.57	5	31.07	1.01	2.67	6	27.00	2.83	6.69	6	31.05	1.79	4.79
ADF	4	37.85	1.93	4.34	6	36.09	0.56	1.51	5	36.04	1.42	3.52	6	37.35	2.30	5.66	6	34.70	1.68	4.63
CELLU	4	33.41	1.40	3.24	6	31.54	0.71	1.67	5	32.20	1.17	3.22	6	31.40	1.15	3.10	6	29.77	1.40	3.41
ADL	4	4.44	0.85	1.91	6	4.55	0.39	1.05	5	3.85	0.44	1.17	6	5.95	1.51	3.70	6	4.93	0.49	1.22
IVDMD	3	65.46	7.11	14.20	6	55.11	1.67	4.28	5	59.98	3.76	9.68	6	54.81	3.90	10.17	6	56.31	3.43	9.22
IVOMD	3	61.08	6.25	12.13	6	48.63	1.78	4.52	5	53.07	3.64	9.11	6	48.50	3.58	8.69	6	51.41	3.49	9.80

[a]All analyses (excluding % DM) are expressed on a dry matter basis.

[b]N indicates number of samples analyzed for each variable.

TABLE A-4

LEGUME COMPOSITION BY TRIAL[a,b]

Variable	Trial 2				Trial 3				Trial 4				Trial 5			
	N	Mean	SD	Range	N	Mean	SD	Range	N	Mean	SD	Range	N	Mean	SD	Range
% DM	6	17.48	1.14	3.30	6	15.40	0.76	2.00	6	26.72	1.41	3.60	6	42.20	8.61	22.95
CP	6	20.73	1.23	2.84	6	21.78	0.78	2.07	6	20.07	0.94	2.31	6	16.90	1.00	2.71
EE	6	2.03	0.11	0.22	6	1.78	0.25	0.70	6	2.53	0.41	1.17	6	2.35	0.27	0.77
NFE	4	52.73	0.40	0.97	5	49.15	1.88	4.01	6	51.57	1.21	3.28	6	41.21	11.43	23.82
CF	4	15.47	0.72	1.55	5	18.69	0.93	2.18	6	18.94	1.58	4.49	6	25.82	1.30	3.64
ASH	6	8.29	0.52	1.23	6	8.82	0.19	0.49	6	6.89	0.36	0.89	6	6.37	0.48	1.39
CWC	6	40.52	1.66	4.41	6	48.46	1.42	3.28	6	55.34	11.58	29.63	6	56.11	1.78	4.37
HEMIC	6	16.82	2.46	6.47	6	21.74	1.66	4.63	6	23.14	11.78	31.00	6	17.25	2.38	6.45
ADF	6	23.70	1.79	4.98	6	26.72	2.14	5.47	6	32.20	2.80	8.19	6	38.87	1.56	3.89
CELLU	6	18.77	2.33	6.30	6	21.99	1.80	4.77	6	24.03	1.86	5.72	6	25.33	2.59	7.14
ADL	6	4.93	2.21	5.62	6	4.73	0.48	1.40	6	8.18	1.23	3.67	6	13.54	2.63	6.28
IVDMD	4	72.61	1.03	2.25	6	62.28	2.69	6.40	6	63.40	2.65	6.99	6	57.73	3.96	10.46
IVOMD	4	64.47	1.26	2.57	6	53.61	3.78	9.94	6	57.14	2.47	6.44	6	49.13	3.72	10.06

[a] All analyses (excluding % DM) are expressed on a dry matter basis.

[b] N indicates number of samples analyzed for each variable.

TABLE A-5

ORTS COMPOSITION BY TRIAL[a,b]

Variable	Trial 2				Trial 3				Trial 4				Trial 5				Trial 6			
	N	Mean	S.D.	Range	N	Mean	S.D.	Range	N	Mean	S.D.	Range	N	Mean	S.D.	Range	N	Mean	S.D.	Range
% DM	6	21.38	3.35	8.60	6	17.89	5.16	13.75	6	21.14	1.76	4.30	6	28.07	8.60	23.15	6	48.58	4.73	12.82
CP	6	13.95	2.04	5.54	6	12.99	1.52	4.55	5	14.22	1.59	4.06	6	28.07	0.80	2.05	6	11.35	1.66	4.56
EE	3	2.53	0.08	0.15	6	1.71	0.15	0.34	5	2.53	0.14	0.34	6	2.21	0.32	0.94	6	1.66	0.35	0.97
NFE	3	48.52	2.07	3.94	4	47.36	0.72	1.74	5	45.54	1.53	3.78	6	46.85	0.76	2.27	5	53.47	1.10	2.97
CF	3	26.97	3.14	5.99	4	28.28	0.87	1.98	5	27.90	0.58	1.20	6	27.37	0.59	1.47	5	26.90	1.43	3.45
ASH	6	8.80	0.61	1.76	6	10.11	0.48	1.24	5	9.82	0.36	0.93	6	7.99	0.26	0.83	6	6.28	0.42	1.18
CWC	6	66.71	2.72	6.54	6	66.46	0.91	2.24	5	68.27	1.22	2.60	6	64.63	0.74	1.97	6	67.46	1.79	5.09
HEMIC	4	30.97	1.16	2.40	6	25.44	1.04	3.14	5	26.03	1.95	4.81	6	24.17	1.01	2.62	6	28.61	2.11	6.09
ADF	4	36.08	1.98	4.77	6	41.01	0.68	1.55	5	42.24	1.55	4.17	6	40.46	1.35	3.53	6	38.85	1.17	2.58
CELLU	4	31.51	2.00	4.80	6	35.11	1.03	2.56	5	34.77	1.98	4.95	6	32.97	3.53	9.60	6	31.61	2.33	6.21
ADL	4	4.57	0.34	0.68	6	5.91	0.40	1.01	5	7.47	1.10	2.71	6	7.49	3.11	9.18	6	7.24	1.89	5.47

[a]All analyses (excluding % DM) are expressed on a dry matter basis.

[b]N indicates number of samples analyzed for each variable.

TABLE A-6

CORRELATION COEFFICIENTS

	Variable									
	WETMI	DMI	WETFO	FDMO	DMD	DDMI	TDN	TDNI	DCP	DCPI
FDM	-.4447	-.2669	-.3779	.1876	-.3540	-.3334	-.2630	-.2972	-.3914	-.2955
N	.7282	.5613	-.0630	-.2749	.6733	.6637	.4002	.4278	.3447	.3531
EE	.0588	.3659	-.0839	.0465	.2774	.3618	.4667	.4496	.4542	.5128
CF	-.3650	-.3458	.3769	.3500	-.5357	-.4656	-.4271	-.2352	-.2264	-.2129
ASH	.6640	.2281	-.3254	-.3488	.3445	.3442	-.3243	-.3532	-.2151	-.2776
NFE	-.7340	-.4692	-.0087	.1606	-.4604	-.5331	.0116	-.0959	-.1974	-20.66
CWC	-.4574	-.0457	.4440	.5077	-.4208	-.2064	-.1192	.0816	-.1065	-.0901
HEMIC	-.0444	.1036	.2849	.2179	-.0791	.0382	-.0656	-.0176	-.0808	.0077
ADF	-.1888	-.1269	-.0586	.0410	-.1355	-.1434	.0223	.0494	.0364	.0324
CELLU	-.0036	-.2374	-.1819	.0895	-.1978	-.2161	-.2697	-.2340	-.1724	-.2434
ADL	-.2723	.1246	.1729	.2249	.0442	.0575	.5552	.5509	.3945	.5154
AIA	.3021	-.0428	-.3606	-.2941	.0795	.0483	-.3899	-.4156	-.3419	-.4259
ASA	.6893	.2619	-.3016	-.3390	.3708	.3758	-.3019	-.3304	-.1752	-.2291
NA	-.0510	.0614	-.2179	-.1950	.2278	.1244	.1745	.0088	.0227	-.0026
ZN	-.0418	.0412	-.0244	.0956	-.0366	.0124	-.1198	-.2439	-.3612	-.2720
UROB	-.2293	.0026	-.0508	-.1182	.1729	.0398	.4504	.2200	.2815	.1943
IVOMD	.5383	.4390	-.1968	-.3388	.5782	.5579	.3735	.2306	.5489	.4481
IVDMD	.5414	.4366	-.2085	-.3401	.5835	.5559	.3812	.2521	.5725	.4403

VITA

Richard E. Estell II, son of Richard and Rachel Estell, was born in Muncie, Indiana on September 21, 1954. He was raised in Mt. Summit, Indiana and attended Blue River Valley Elementary, Jr. and Sr. High School, from which he graduated in 1972. He then entered Purdue University and received a Bachelor of Science degree in Animal Science in December 1976. He entered graduate school in the Animal Science Department of The University of Tennessee, Knoxville in September 1977. He received his Master of Science degree in December 1979. His area of interest lies in the field of ruminant nutrition. He was married to Gail Heath in June 1979.