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Evaluation of the precision and accuracy of the lignin ratio and fecal indices to estimate intake and digestibility of lactating beef females allowed an array of forage types

Paul Boateng

To the Graduate Council:

I am submitting herewith a thesis written by Paul Boateng entitled "Evaluation of the precision and accuracy of the lignin ratio and fecal indices to estimate intake and digestibility of lactating beef females allowed an array of forage types." 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:

W.T. Butts, J.B. McLaren

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

To the Graduate Council:

I am submitting herewith a thesis written by Paul Boateng entitled "Evaluation of the Precision and Accuracy of the Lignin Ratio and Fecal Indices to Estimate Intake and Digestibility of Lactating Beef Females Allowed an Array of Forage Types." I have examined the final 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.

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EVALUATION OF THE PRECISION AND ACCURACY OF THE LIGNIN RATIO AND FECAL INDICES TO ESTIMATE INTAKE AND DIGESTIBILITY OF LACTATING BEEF FEMALES ALLOWED AN ARRAY OF FORAGE TYPES

A Thesis

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Paul Boateng

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ABSTRACT

Thirty-five in vivo digestion determinations over one grazing season (from June to September) with three year old, spring-calving cows were made on fresh red clover, orchardgrass-white clover, fescue, N-fertilized fescue, bermudagrass, and bermudagrass-white clover harvested at various maturities to obtain an array of dry matter digestibility (DMD). Fecal samples were analyzed for proximate analysis, detergent fiber fractions and selected minerals, N of fiber fractions, and AIA. Acid soluble ash, NFE, and microbial-N were calculated. Samples were dry-sieved after grinding through a 1 1MM screen and percent finers for 1 MM, .5 MM, .25 MM screens, and smaller than .25 MM particles (MF1MM, MF5MM, MF25MM, MFBOTTOM) calculated. Plots of fecal components against DM intake, DM digestibility, fecal DM output, and digestible DM intake were examined for linearity. Simple linear correlations were used in determining relationships among feed components, intake and digestibility variables. Regression procedures were then used to determine the relationship of the measured variables (DMI, FOUT, DMD, AND DDMI) and counterparts calculated by the method of Holloway et al. (1983). The best method that predicted DM intake employed a regression procedure utilizing fecal output Ca, CF, and DM as independent variables (R^2 = .49, RSD = 66 Kg d^{-1}). The best method for predicting DM digestibility was a regression equation using the independent variables fecal DM output, Ca, DM, CF (R^2 = .57, RSD = 3.7%). The best model

predicting digestible DM intake was a regression equation using the independent variables final weight, cow condition score, Ca, CF (R^2 = .46, RSD = .65 Kg d^{-1}). None of the models evaluated was able to accurately predict fecal DM output. The R^2 values obtained from some of the models evaluated indicate that those models could be used to adequately predict forage intake and digestibility of extensively grazing beef cows. Lucas test of "ideal" indicators was employed to test the variables used in the predictive equations. ADL, Ca, and N were found to be "ideal" internal indicators.

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CHAPTER I

INTRODUCTION

The need to effectively evaluate pasture quality on an extensive basis, at the same time reducing the cost and labor involved, has led to the development of the fecal index ratios.

Techniques that are used to determine dry matter intake and digestibility of grazing animals normally restrict the grazing animals from exhibiting their selective and social behavior. These techniques involve: (1) observing and sampling forage as the animal selects its feed; (2) feeding harvested forage to the animal in metabolic stalls; (3) fecal collection via collection bags harnessed to the animal; (4) diet sampling via esophageal fistulazation; and (5) diet selection via rumen evacuation. This interference is almost impossible to measure and, therefore, degree of bias is difficult to bracket.

A review of the techniques employed to evaluate pasture quality in terms of dry matter intake and digestibility has shown many limitations in the techniques used. The fecal index ratio seems to have the greatest promise in eliminating most of the biases experienced in the other techniques. Therefore, the purpose of this experiment was to evaluate the precision and accuracy of the acid detergent lignin ratio and fecal index ratios to estimate dry matter intake and digestibility of beef cows.

CHAPTER II

REVIEW OF LITERATURE

Factors Controlling Intake and Digestibility

A knowledge of the factors that control intake and digestibility is of great academic and economic importance for experimental designs (Hafez, 1965), pasture management (Viosin, 1954), and efficiency in livestock production. The knowledge of the grazing animal to selectively graze has pointed to the study of its feeding behavior, ingestive capacity, and rate of passage as well as the forage characteristics including the condition of the pasture, palatability, and quality of the different plant species.

Feeding Behavior of Grazing Animals

The grazing animal follows a diurnal pattern of grazing, with rumination, periods of rest, and drinking being fitted into the intervals when he is not grazing (Arnold, 1981). Grazing begins at dawn and again in the late afternoon, ending near to sunset (Hughes and Reid, 1962; Hafez, 1965). Although there is some grazing at night, Johnstone-Wallace et al. (1944) found that 60% of grazing time is during the day. Hafez (1965) noted species and breed differences in the time that cattle and sheep spend grazing, the daily intake of fresh herbage, and the dry matter of the forage consumed. He attributed this differences in grazing intake to anatomical characteristics which causes differences in number of bites per minute, intake per bite, and efficiency of selective grazing. Time spent ruminating after grazing indicate that the ratio of ruminating time to eating time is affected by the TDN content of the forage being selected (Lofgreen et al., 1957). Thus on a highly digestible diet, the animal spends proportional less time ruminating than on one of lower digestibility.

Condition of Pasture on Feeding Behavior

Forage intake is generally influenced by forage quality. McCullough (1956) reported a positive correlation (0.512) between dry matter digestibility and dry matter intake. In addition to stage of maturity, the condition of pasture influences intake through effects on such variables as quantity available, forage density, mixture of species, and palatability (McCullough, 1956).

As a plant matures, its intake by ruminants is decreased. Arnold (1970) reported that ruminants prefer living to dead material, younger to older material, leaf to stem, and legumes to grass leaves. Springfield et al. (1951) found a positive correlation of 0.69 between the moisture content of the species and the percent of the species in the diet. Minson et al. (1964) also showed that intake of grasses is highest at the first cut in early spring and declines in subsequent cuts as the herbage matures. Ruminants will therefore select a younger, high moisture forage to an old, low moisture type.

The type of plant species on a ground may also play an important role in intake. Pieper et al. (1959) reported that as the intensity of grazing increases there is a change in preference from one species to another. Thus, increase intensity of grazing on different plant species will involve grazing certain species closer and a change in preference from one species to another. However, a mixture of forages may also influence intake by encouraging large amounts of selective grazing.

Specific differences in intake between grass species at the same maturity have also been shown. Greenhalgh and Reid (1969) noted that corksfoot has a lower intake by dairy cows than perennial ryegrass. Ulyatt (1971) also noted that annual ryegrass produced higher intake than perennial ryegrass. Some evidence has also been shown that intake of legumes is higher than grasses. Thompson (1971) found the intake of white clover to be higher than perennial ryegrass.

Although all the above factors play a role in the intake of forage in the grazing animal, consideration should be given to the fact that harvesting takes time and if the most acceptable components are distributed too thinly on the ground for the animals appetite to be readily satisfied in a given time, then a balance will be struck between a lowered level of preference and a depression in intake (Freer and Dennis, 1973).

Ingestive Capacity and Rate of Passage

Montgomery and Baumgardt (1965) noted that the intake of low quality, low energy density forage is controlled by the animal's physical capacity; whereas, the consumption of high quality energy dense forage is influenced largely by the energy requirement of the animal.

Van Soest (1982) indicated that rumen stretch and increased passage rate are both associated with higher intakes, thus the animal with a larger appetite tolerates a greater rumen fill. Balch and Campling (1962) also stated that the amount of food voluntarily eaten by the ruminant might depend on the filling effect in the gut, and especially in the reticulo-rumen and hence on such factors as digestibility and rate of passage of the food. Putnam et al. (1964) observed that large framed cattle spent less time consuming an equal amount of forage then small framed cattle. However, Nutt et al. (1980) concluded that rumen capacity as a percent of body weight was not significantly related to body size. Campling and Balch (1961) stated that the voluntary intake of roughages might be limited by the capacity of the reticulo-rumen. thus, though physical distension of the reticulo-rumen is an important factor in controlling intake of forages, it is not the only one explaining it.

Wehner (1982) indicated that the rate of passage of ingested material may possibly be more important than amount of rumen fill in regulating forage intake. Other investigators, Campling and Balch (1961) and Van Soest (1982) have also found intake to be more highly related to rate of passage then to rate of digestion.

The Feeding Value of Forages

Ulyatt (1981) defines nutritive value of a forage as the concentration of nutrients in the forage or the animal response per unit of intake. The nutritive value of a forage is thus determined by these animal variables; intake, utilization, and maintenance requirements (Ulyatt, 1973).

Ulyatt et al. (1976) found legumes to have a higher feeding value then grasses, and the addition of white clover to grass diets consistently increased the feeding value of the mixture for live weight gain in both sheep and calves. However, bloat is likely to reduce legume intake and thus invalidate any comparisons.

Raymond (1969) proposed that the proportion of a pasture plant that is digested is a major component of nutritive value. Digestibility is related to plant maturity, thus as a plant matures, digestibility declines and its nutritive value also declines (Davis et al., 1966). Terry and Tilly (1964) found the decline in digestibility with maturity to be caused by changes in the chemical composition of the plant. These authors also found structural carbohydrates (cellulose and bemicellulose) which are digested slowly, increase rapidly in stems and slowly in leaves.

Many problems are these associated with the accurate measurement of forage intake and forage utilization which are needed to accurately determine the feeding value of forages (Reid, 1952).

Ratio Technique

The need for a method that can measure the feeding value of a forage that cannot actually be sampled and analyzed chemically has led to the rise and development of the various ratio and fecal index techniques. The various techniques such as the acid detergent lignin (ADL) ratio, the fecal index technique, and the fecal nitrogen ratio has been employed not only to measure digestibility but also the intake of forages (Reid et al., 1950).

The successful rise of the ratio and fecal index technique requires an indicator. Such an indicator should be a naturally occurring feed constituent (Reid et al., 1950; Cook and Harris, 1957). 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. It should also be indigestible and completely recoverable (Reid et al., 1950; Reid, 1952; Cook and Harris, 1957). Many researchers have also emphasized the need for a quick, accurate, and simple analysis of the indicator (Reid et al., 1950; Schneider and Flatt, 1975).

Schneider and Flatt (1975) reviewing indicators found chromium oxide (Cr_2O_3) to be the best indicator for the ratio techniques.

Lignin Ratio Technique

Lignin, a naturally occurring plant constituent, has been used extensively in digestion studies as an internal marker. Although lignin is a 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, 1952; Reid, 1952; Balch et al., 1954; Richards et al., 1958). Ellis et al. (1946) pointed out that the 72% sulfuric acid method of determining lignin was more reliable then the permanganate procedures, since the 72% sulfuric acid method was developed to isolate an indigestible residue rather then to determine a chemical compound.

Therefore, this discussion only considers literature using the 72% sulfuric acid method.

Lignin is often regarded as being indigestible because there is no evidence of any known anerologic microboial or mammalian enzymes for lignin degradation (Van Soest, 1982). However, there are reports indicating that varying amounts of lignin might be digested or degraded in the ruminant digestive tract (Forbes and Garrigus, 1950a; Sullivan, 1955; Elam and Davis, 1961; Elam et al, 1962; Allinson and Osbourn, 1970; Minson, 1971; Fahey et al., 1979, 1980). Forbes (1950a) evaluated a wide variety of grasses and legumes and reported an average digestion coefficient for lignin of 5%. On the contrary, other investigators (Ellis et al., 1946; Forbes et al., 1946; Swift et al., 1947; Forbes and Garrigus, 1948; Kane et al., 1950) reported that lignin was indigestible.

Streeter (1969) reported that the most important complications in lignin determination are incomplete carbohydrate hydrolysis and partial lignin degradation. Analysis can also be hindered by nitrogen content of lignin due to improper sample preparation such as heating and drying which can cause a millard reaction resulting in artifact lignin that has variable digestibility (Forbes and Garrigus, 1950b; Van Soest, 1967; Streeter, 1969).

Although the lignin ratio technique has been used successfully to predict forage digestibility (Forbes and Garrigus, 1950a,b; Kane et al., 1950; Cook and Harris, 1957; Kimivar, 1960; Sosulski and Patterson, 1961), Fahey and Jung (1983) concluded that the use of the lignin ratio should be viewed with caution as incomplete recovery will result in underestimation of nutrient digestibility.

Fecal Index Technique

The fecal index technique involves the prediction of digestibility from the composition of the feces (Lerncaster, 1954; Greenhalgh et al., 1960; Skreeter, 1969). In this technique, a fecal indicator concentration is related to digestibility and the resulting equation with a particular fecal constituent is used to predict digestibility (Reid, 1952; Lancaster, 1954; Greenhalgh et al., 1960; Skreeter, 1969). Reid and Kennedy (1956) and Streeter (1969) suggested the use of the fecal index technique in predicting digestibility because it had the advantage of using only the fecal composition for the prediction, without the difficulty of a representative forage sample as used in other techniques (Conventional Methods).

The indicator used in the application of the fecal index method does not have to be indigestible or completely recoverable, since only the indicator's concentration in the feces is measured for prediction of digestibility (Estell, 1979).

Local regression equations have also been developed and used to predict digestibility (Greenhalgh et al., 1960). However Langlands (1969) reported significantly different relationships of fecal N equations that was used for various stocking rates, levels of digestibility, and levels of herbage availability. Greenhalgh and Corbett (1960) found a variation in the prediction equation between first growth and aftermath herbages and for different fertilizer treatments. Lambourne and Reardon (1962) also found a difference in predictive equations between leaf and stem components of the herbage and between seasons of the year.

Langlands et al. (1963) indicated that the difference in the grazing behavior of sheep and their digestive powers make it invalid to use sheep to establish an index for grazing cattle. Also it has been shown that bias exists when stall-fed animals are used to establish an index, since restricting them limits their ability to express normal selectivity (Raymond et al., 1954).

Holloway et al. (1981) noted that the development of multiple indices with broad application have potential to overcome the problems associated with the fecal index techniques

Fecal Nitrogen Index

Fecal nitrogen has been used as a fecal index technique to estimate the dry matter intake of grazing animals and as a measure of digestibility in grazing animals as well (Gallup and Briggs, 1948; Raymond, 1948; Lancaster, 1949a). Lambourne and Reardon (1963) observed the simplicity, quickness, and accuracy of fecal nitrogen determination. Raymond (1948) showed that the nitrogen concentration in the feces is related to the nitrogen consumed by grazing sheep. However, other investigators found this relationship different for grasses and legumes (Kimivar 1959; Minson and Brown, 1959; Greenhalgh and Corbett, 1960; Reid et al., 1950). Gallup and Briggs (1948) stated that a constant relationship exists between the amount of fecal nitrogen and the dry matter intake, regardless of the amount of protein in the diet. Thus, fecal N can be used to predict forage dry matter intake. However work by Forbes (1949) and Blaxter and Mitchell (1948) have stated the contrary.

Wehner (1982) noted that the variation in prediction of intake and digestibility with fecal nitrogen indices may be due to individual animal variation. However, when Minson and Raymond (1958) determined the relationship between digestibility and fecal nitrogen for a wide range of herbages, they attributed 90% of the error to variation in the food due to the effect of species, season, stage of growth, and fertilizer treatment. Only 10% of the error was attributed to animal variation. Arnold and Dudzinski (1963), using a fecal nitrogen index equation to predict intake of grazing animals, noted an error which they attributed to the measurement of feces as well as from the prediction error of the equation. They attributed this to the fact that since fecal output is lowest on highly digestible material, the effect of errors in its measurement will be greatest on young pasture.

Holloway et al. (1981) noted that fecal nitrogen indicies alone do not explain adequate amount of variation in forage digestibility or intake of calves grazing pastures within a grazing season. However, when other fecal components were added larger amounts of the variation was explained. Holloway et al. (1983) using multiple fecal indicies were able to explain a considerable amount of the variation in intake and digestibility of grazing cows.

Test for "Idealness" of Chemical Procedures

Lucas (1964) indicated that if feed fractions, for which the indigestible or digestible amounts could be predicted for composition is found, then a system of feed analysis could be developed. Lucus (1964) defined an "idea" fraction as "the mixture of substances measured by a chemical procedure, which has exactly the same pertinent properties regardless of materials analyzed."

Lucas (1962) stated that if values for digestible amount of a nutrient from digestion trials on a wide variety of feeds are plotted against values for nutrient composition as a percent of diet, the data will adhere closely to a smooth surface, linear or nonlinear. The more linear the data, the more "ideal" is the chemical procedure used. Van Soest (1982) also stated that the "ideal" fraction should have a low standard deviation of the regression slope and a zero or negative intercept.

Lucas (1962) used this test to check the "idealness" of chemical procedures used in digestion studies and concluded that the test could be used to check idealness of other procedures and fractions. Van Soest (1982) using Lucas' test, found the sulfuric acid detergent lignin to be an ideal fraction.

CHAPTER III

MATERIALS AND METHOD

Introduction

Estimates of forage intake and digestibility of grazing ruminants, especially under extensive pasture conditions is often imprecise and biased. Holloway et al. (1981) indicated that no reliable and simple technique for measuring intake or digestibility of forage ingested by individual animals for large numbers of cattle grazing under extensive pasture conditions is available. Langlands (1975) concluded in a review of the technique of pasture research that "Techniques available for studying the nutrition of grazing animals are characterized by relatively low precision, a high labour demand and a high sensitivity to bias." Holloway et al. (1983) stated that the fecal index technique has the potential for estimating forage intake and quality on an extensive basis while accounting for animal selectivity. Since the fecal index method does not require forage sampling, it has the flexibility of providing estimates on an individual animal basis for large numbers of cattle grazing under extensive pasture conditions. Multivariable regression equations developed from the research of Holloway et al. (1983), utilizing fecal-forage relationships, have indicated the possibility of these equations for predicting forage intake and quality of forage consumed by beef cows grazing extensively. The purpose of this experiment was to evaluate the precision and accuracy of the ADL ratio and some selected fecal index equations (see Appendix, page 67) to estimate intake and digestibility of beef cows utilizing these forage species: tall fescue, red and white ladino clover, orchardgrass and bermudagrass.

Thirty-five in vivo digestibility trials were conducted during the summer of 1982. The animals and procedures employed were designed to be similar to Wehner (1983) so that an adequate test of the equations he developed could be accomplished.

Ten 3-year-old spring calving lactating Angus, Hereford, and Angus-Hereford crossbred cows were fed a wide array of forage species which included: Kentucky-31 tall fescue (2-01-902), red clover (2-01-428), orchard grass (2-03-440); white clover (2-01-378), tall fescue (2-03-440) fertilized with nitrogen (30 Kg N/Ha); tall fescue (2-01-902), red clover (2-01-428) and white clover (2-01-378) lespedeza (2-02-540); common bermudagrass (2-00-712) and common bermudagrass (2-00-712), red clover (2-01-428), and white clover (2-01-378), (see Appendix, page 67). These forages were harvested at different maturities to obtain an array of dry matter digestibilities.

Trial Procedure

Trials consisted of 5-d preliminary and 5-d fecal collection periods and were iniated on June 9, July 7, August 7, and September 7. Trials are described in Table 1.

At 0730 hours cows were separated from their calves and confined to individual stalls with headgates where they remained until 1700 hours. One hundred fifty-five grams of a 76-percent TDN carrier feed (Holloway et al., 1979) containing C_2O_3 was fed to each cow twice

Table 1. Description of Individual Digestion and Intake Trials

Date Initiated	Forages Fed						
	Red Clover	Fescue Legume[a,b]	Fescue -N[e]	Bermuda-grass	Bermuda-grass White Clover[c]	Orchard grass White Clover[d]	Fescue
June 9	3[f]	3	3				
July 7	3			2	2	2	
August 9				3	3		3
September 7		2	3				3

[a]All grass-legume mixtures were about 70 percent grass, 30 percent legume.

[b]Legume was red and ladino clover and lespedeza.

[c]Clover was red and ladino clover.

[d]About 60 percent orchardgrass and 40 percent ladino.

[e]30 Kg N/ha.

[f]Number of cows.

daily at 0800 and 1630 hours. Forages were harvested from grazed pastures in long form with a sickle bar mower and fed between 0800 and 1000 hours daily. A summary of forage composition appears in Table 2. Nine cows were allotted to forage types in each trial in a manner to avoid confounding forage type and breed as described in Table 3. At 1700 hours each day, cows were turned out into a dry lot for overnight exercise where they received water and trace minerals (Table 4) ad libitum. Cows were weighed and conditions scored (1 to 17 with 17 being fattest) at 1700 hours in the beginning and end of each trial. On the last day of each trial, milk production was determined by the weigh suckle-weigh technique after an 8 hr. separation of cow and calf. Milk production was the difference in the weights before and after suckling. A summary of data for the four trials appears in Table 5.

Sample Management

Fecal grab samples and forage and ort samples were collected twice daily during the 5-d collection period following the feeding of Cr_2O_3 carrier feed at 0800 and 1630 hours, respectively. The AM and PM samples were pooled on a wet basis. Fecal, forage, and ort samples were dried at 60°C, ground through a 1 mm screen, and composited on a dry matter (DM) basis to provide 1 sample/cow/trial. The fecal samples and carrier feed were analyzed for Cr by the procedure of Williams et al. (1962). DM intake and digestibility were calculated by the method of Crampton and Harris (1969). These values are presented in Table 5.

Table 2. Forage Composition[a,b]

Variable	N	Forage				Orts			
		Mean	SD[c]	Minimum	Maximum	Mean	SD	Minimum	Maximum
DM (%)	33	22.48	1.85	17.8	24.74	23.96	2.56	18.65	29.9
Crude Protein (%)	33	16.95	2.65	12.1	21.88	16.19	2.80	11.01	21.68
Crude Fiber (%)	33	30.22	1.89	26.75	32.48	31.02	2.29	24.53	35.92
Acid Detergent Fiber	33	40.38	2.41	36.95	45.05	40.79	1.26	37.35	42.9
Acid Detergent Ligmin (%)	33	6.60	2.26	4.45	12.04	7.22	1.92	4.7	12.12
Ash (%)	33	9.32	1.34	7.41	11.38	9.21	1.44	6.96	13.76
N mg/g of DM	33	2.71	.42	1.94	3.5	2.59	.45	1.76	3.47
CA mg/g of DM	33	5.64	2.71	3.4	12.16	6.12	2.67	3.66	12.40
P mg/g of DM	33	3.86	.45	6.31	9.83	3.74	.47	2.83	4.70
Mg mg/g of DM	33	2.82	.57	2.26	4.36	2.89	.53	2.24	4.29
Mn mg/g of DM	33	.13	.04	.08	.33	.16	.06	.07	.38
Na mg/g of DM	33	43.80	28.03	10.20	81.08	.53	.22	.16	1.0
Zn mg/g of DM	33	.02	.01	.01	.04	.03	.01	.01	.04

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

[b]33 forage analyses included in forage composition summary.

[c]Standard deviation.

Table 3. Breed Assignments to Forage Types[a,b]

Date Initiated	Forages Fed						
	Red Clover	Fescue Legume	Fescue N	Bermuda Grass	Bermuda Grass White Clover	Orchard Grass White Clover	Fescue
June 9	2A 1H	2A 1H	1A 1H 1HXA				
July 7	2A 1H			2A	1H 1HXA	1A 1H	
August 9				2A 1H	1A 1H 1HXA		2A 1H
September 7		2A	1A 1H 1HXA				1H 2A

[a]A = Angus; H = Hereford; HXA = Crossbred.

[b]Numbers preceding breed acronyms indicate numbers of cows fed each forage.

Table 4. Trace Mineralized Salt Formulation

Ingredients	IFN	Percent[a]
NaCl	6-04-152	99.00
LnO_2	6-05-553	0.30
MnO_2	6-03-042	0.20
EDDI	6-01-842	0.10
$FeCO_3$	6-01-863	0.10
MgO_2	6-01-756	0.10
$CaSO_4$	6-01-087	0.05
CuO_2	6-01-711	0.03
$CoCO_3$	6-01-566	0.01

[a]Analysis on a DM basis.

Table 5. Description of Intake-Digestibility Trials[a]

Variable	Mean	SD[b]	Minimum	Maximum
DM Intake (Kg/d)	6.11	.92	4.52	8.19
Fecal DM Output (Kg/d)	2.02	0.28	1.38	2.75
DM Digestibility (%)	66.48	5.59	54.26	77.36
Digestible DM Intake (Kg/d)	4.09	0.87	2.82	5.86
Cow Weight (Kg)	375.47	34.68	319.27	463.49
Condition Score[c]	6.61	2.18	3.0	10.0
Milk Production	5.0	3.59	0	16.0

[a]All values are based on 33 individual observations.

[b]Standard deviation.

[c]Values 1 = very trim to 17 = very fat.

Laboratory Analyses

Forage, ort, and fecal composition were anlayzed for DM, ash, crude fiber (CF), and nitrogen (AOAC, 1975), for acid detergent fiber (ADF) and 72 percent H_2SO_4 lignin (ADL; Van Soest, 1963). Samples were also prepared for mineral anlysis by AOAC (1975) procedures and analyzed spectrophotometrically for calcium (Ca), zinc (Zn), sodium (Na), magnesium (Mg), phosphorus (P), and maganese (Mn). The nitrogen content of ADF was also obtained (AOAC, 1975) for the fecal samples.

Ribonucleic acid (RNA) was determined on fecal composites according to the perchloric acid oxidation procedure outlined by Zinn and Owen (1980). Sample RNA concentrations were obtained by the standard curve: RNA = .068+(-.00073 x Sample Absorbance) developed by Wehner (1982) (Table 6).

Acid insoluble ash (AIA) content of fecal samples was determined according to the 2N HCL procedure described by Van Keulen and Young (1977). Percent of finess on each screen using .1, .5, and .25 mm screens were determined on fecal samples. Fecal composition is summarized in Table 7.

Statistical Analyses

Plots of fecal components against fecal and forage valuables of interest; namely DM intake, fecal DM output, DM digestibility, and digestible DM intake were examined for linearity. Simple linear correlations were used in determining relationships among fecal components, intake, and digestibility variables. Regression procedures were then used to determine the relationship of the measured variables

Table 6. Formulas for Calculation of Fecal Variables

Variables	Formulas
Non CWC	1-CWC/100-ASH/100
ASH	ASH-Cr
AIA	AIA-Cr
RNA	.068 + (-.00073 x Sample Absorbance)

Table 7. Feces Composition[a,b]

Variable	Mean	SD	Minimum	Maximum
DM, %	12.20	1.48	9.44	15.18
Crude Protein, %	14.91	1.79	12.64	18.76
Crude Fiber, %	28.34	1.64	24.77	31.77
Acid Detergent Ligmin, %	15.13	1.96	12.33	19.14
Acid Detergent Fiber, %	45.03	1.39	43.36	48.62
Ash	13.07	1.87	9.96	18.54
Acid Detergent Fiber Nitrogen, %	29.43	3.20	24.72	35.27
Acid Insoluble Ash, %	5.48	1.57	3.45	10.58
% of Particles on Screen				
.1 mm	.02	.02	.003	.12
.5 mm	.38	.09	.25	.58
.25 mm	.12	.03	.07	.17
Ether Extract, %	3.84	1.23	2.38	6.41
Ribonucleic Acid	.08	.03	.01	.11
Ca Mg/g of DM	11.1	3.62	6.11	20.23
Zn mg/g of DM	.08	.05	.02	.20
Na mg/g of DM	2.54	1.74	.6	8.58
Mg mg/g of DM	5.64	1.36	3.35	9.93
Mn mg/g of DM	.34	.12	.12	.63
P mg/g of DM	7.64	.73	6.31	9.83
N mg/g of DM	2.39	.29	2.02	3.0

[a]All values are on analyses of 35 individual fecal samples.

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

(DMI, FOUT, DMD, and DDMI) and counterparts calculated from fecal components. Models which included variables such as percent forage that was legume and percent forage that was fescue were also employed to test the effect of pasture characteristics. Plots of nutrient composition of forage digested against nutrient composition of forage (Lucas, 1962) were employed to check linearity. Regression procedures were also employed to determine the "idealness" of internal markers (Lucas, 1962).

All the models evaluated are presented in Table 8 with their R^2 and RSD.

Table 8. Multiple Regression Equations Evaluated

Dependent Variable	Method Number	Method	R^2	RSD[a]
DM intake Kg d^{-1}	1	$17.9003 + .28064 \times CA + .0019 \times CA^2 - .0001422 \times CA^3 - 12.7771 \times ASH + .18478 \times ASH^2 - .0042194 \times ASH^3$	.62	1.10
	2	$-1.73 + 1.76 \times FOUT$[b] $+ .22 \times NONCWC$[c]	.50	1.22
	3	$6.37 + .37 \times CA - .002 \times CA^2 + .0000816 \times CF$[d] $- 1.92 \times MON$[e] $+ .657 \times MON^2 - .265 \times ASH + 2.49 \times NA - 1.03 \times NA^2 + .111 \times NA^3$	.68	1.02
	4	$1.37808 + .20482 \times CA + .10381 \times CF$	.53	1.18
	5	$4.81152 + .192242 \times CA$	.46	1.27
	6	$-11.19 + 2.51 \times FOUT + .95 \times CA - .1446 \times FOUT \times CF + .08 \times DM + .2302 \times FOUT \times DM - .0579 \times CA \times DM + .41 \times CF$	.70	.98
	7	FOUT ÷ (1 - DMD as predicted by model no. 12)		
	8	FOUT ÷ (1 - DMD as predicted by model no. 13)		
DM Digestibility %	9	$126.49 - 116.54 \times N + 63.67 \times N^2 - 10.28 \times N^3$	.35	6.81
	10	DMI as predicted by model no. 6 ÷ FOUT − DMI as predicted by model no. 6		
	11	1 - (FEEDADL ÷ FECAL ADL)		
	12	1 - ADL Intake - DMI ÷ ADL[f]		
Digestible DM Intake	13	$2.65 - .105 \times CA + .024 \times CA^2 - .001 \times CA^3$	.42	1.11
	14	$-13.66 + .216 \times CA - .004 \times CA^2 + 2.289 \times NONCWC - .107 \times NONCWC^2 + .002 \times NONCWC^3$	.49	1.07
	15	$-58.6632 + .77799 \times CA - .008387 \times CA^2 + 5.0923 \times CF - .1472 \times CF^2 + .00145 \times CF^3 - .010597 \times CA \times CF$	.53	1.03
	16	$-62.65 + .0035 \times FINALWT$[g] $+ .0983 \times Cowscore$[h] $+ .7681 \times CA - .007 \times CA^2 + 5.1663 \times CF - .1500 \times CF^2 + .0015 \times CF^3 - .0114 \times CA \times CF$	.60	.96

Table 8. (Continued)

Dependent Variable	Method Number	Method	R^2	RSD
	17	DMI predicted by model no. 8 x DMI predicted by model no. 16		
	18	DMI predicted by model no. 9 x DMD predicted by model no. 17		
Fecal DM output, Kg d^{-1}	19	$3.3815 - .39884 \times P + .028 \times P^2 - .0263 \times ADFN^i + 6.464 \times 10^{-4} \times ADFN^2 + .50044 \times AIA^j - .01965 \times AIA^2 + 7.254 \times 10^{-4} \times AIA^3 - .02981 \times P \times AIA - .0046864 \times ADFN \times AIA$	.73	.37
	20	$5.2964 - .5144 \times P - .05912 \times ADFN + 8.489 \times 10^{-4} \times ADFN^2 + .025435 \times P^2 + 7.34618 \times MF1MM^k$	.65	.42
	21	$4.5885 - .20074 \times P - .0506 \times ADFN\ 6.223 \times 10^{-4} \times ADFN^2$	.54	.47
	22	$3.50 - .0311 \times Cowscore + .0270 \times MILKPRO^l - .3831 \times P + .0261 \times P^2 - .0281 \times ADF\ N + .0006 \times ADFN^2 + .4822 \times AIA - .0276 \times AIA^2 + .0010 \times AIA^3 - .0247 \times P \times AIA - .0037 \times ADFN \times AIA$	.76	.36

[a]RSD = Residual Standard Deviation, [b]FOUT = Fecal DM Output, [c]NONCWC = 1-cell wall, [d]CF - Crude Fiber.

[e]MON = Microbial Nitrogen, [f]ADL = Acid Detergent Lignin, [g]FINALWT = Cow's Final Weight.

[h]COWSCORE = Cow's Condition Score, [i]ADFN = Acid Detergent Fiber Nitrogen, [j]AIA = Acid Insoluble Ash.

[k]MF1MM - Percent of finess at 1 mm screen.

Source: Holloway, J. W., G. R. Wehner, P. Boateng and W. T. Butts, Jr., 1983. Fecal indices for predicting forage digestibility and intake by lactating beef cows. Submitted to J. Anim. Sci.

CHAPTER IV

RESULTS AND DISCUSSION

DM Intake

The equation that explained the greatest amount of variation in DM intake was method 6 (table 8) explaining 49% of the variation (Table 9) with a residual standard deviation of .66 Kg d^{-1}. This method predicted DM intake from fecal DM output, fecal Ca, CF, and DM. Method 6 explained a lower variation and had a lower residual standard deviation in DM intake than Holloway et al. (1983) (tables 8 and 9). When new regression equations were generated with data from this experiment using the same variables as in method 6, the R^2 increased to .57 with a residual standard deviation of .68 Kg d^{-1} (Table 10). There was thus not much difference between the two equations. Regression of DM intake calculated by method 6 on measured DM intake resulted in a low intercept which was not significantly different than 0 (1.8 Kg d^{-1}) and a coefficient of partial regression not significantly different than 1 (.65, table 9). Also, when method 6 was plotted against DM intake, a linear relationship was found (Figure 1). This indicates that method 6 yields unbiased estimations of DM intake. Reid (cf. Holloway et al., 1983) has found that forage Ca is an important variable in equations predicting forage intake of steers consuming cool and warm season grasses.

Another method that explained some variations in DM intake was method 3 (R^2 = .35, table 9). The independent variables in this

Table 9. Relationships of Measured Forage Intake and Digestibility to Those Calculated by ADL Ratio and Fecal Indices

Predicted Variable		Method No.	Partial Regression Coefficient: Intercept	Partial Regression Coefficient: x	R^2	RSD[a]
DMI	DMI	1	2.41 ± .96	.54 ± .14**	.33	.76
	DMI	2	3.12 ± 1.1	.42 ± .15*	.21	.83
	DMI	3	2.9 ± .82	.39 ± .1**	.34	.77
	DMI	4	1.7 ± 1.13	.66 ± .17**	.33	.76
	DMI	5	.81 ± 1.34	.76 ± .19**	.34	.76
	DMI	6	1.8 ± .79	.65 ± .12***	.49	.66
	DMI	7	6.3 ± .59	-.04 ± .12	.004	.93
	DMI	8	6.32 ± .53	-.04 ± .09	.005	.93
DMD	DMD	9	-.08 ± .23	.01 ± .01*	.25	4.9
	DMD	10	.12 ± .08	.79 ± .12***	.57	3.7
	DMD	11	.85 ± .05	-.33 ± .08**	.35	4.5
	DMD	12	.82 ± .04	-.27 ± .07	.33	4.6
DDMI	DDMI	13	6.77 ± 2.08	-.92 ± .71	.05	.86
	DDMI	14	3.15 ± .43	.1 ± .04*	.15	.82
	DDMI	15	1.61 ± .55	.54 ± .12***	.41	.68
	DDMI	16	2.2 ± .39	.57 ± .11***	.46	.65
	DDMI	17	4.89 ± .38	-.27 ± .12	.14	.82
	DDMI	18	4.81 ± .35	-.22 ± .10	.14	.82
FOUT	FOUT	19	1.65 ± 1.56	.17 ± .75	.002	.31
	FOUT	20	2.46 ± .54	-.22 ± .26	.028	.31
	FOUT	21	1.96 ± 1.02	.02 ± .47	.026	.31
	FOUT	22	2.0 ± .04	.001 ± .44	.006	.31

[a]Residual standard deviation.

H_0:B = 0.

*P<.01.

**P<.001.

***P<.0001.

Table 10. New Multiple Regression Equations Attained From Data

Dependent Variable	Method No.	Method	R^2	RSD[a]
DM intake Kg d^{-1}	1	-43.84863 - .866983 x Ca** + .077998 x Ca^2 - .00193 x Ca^3 + 11.51276 x Ash - .819615 x Ash^2 + .0109 x Ash	.43	.77
	2	1.92074 + 1.108058 x FOUT[b] + 0.082248 x NONCWC[c]	.22	.83
	3	2564711.83 + .201174 x Ca** - .000898 x Ca^2 - .025378 x CF[d] - 755.84 x MON[e] + 555.64.69 x MON^2 - .1982 x Ash + .2384 x NA - .07374 x NA^2 + .007588 x NA^3	.42	.82
	4	4.1517 + .14572 x Ca** + .012024 x CF	.34	.77
	5	4.48199 + .146667 x Ca**	.34	.76
	6	-22.96758 + 12.2779 x FOUT* + .3285 x Ca*** - .562177 x FOUT x Ca - .57874 x DM + .39225 x FOUT x DM - .014775 x Ca x DM + 1.13358 x CF	.57	.68
	7	FOUT - (1 - DMD as predicted by Method No. 12).		
	8	FOUT - (1 - DMD as predicted by Method No. 13).		
DM digestibility %	9	6.27022 - 6.7979 x N*** + 2.6724 x N^2 - .33975 x N^3	.46	4.3
	10	DMI as predicted by Model No. 6 - FOUT - DMI as predicted by Method No. 6		
	11	1 - (FEED ADL - FECAL ADL)		
	12	1 - ADL Intake - DMI - ADL[f]		
Digestible DM intake Kg d^{-1}	13	4.01658 - .278172 x Ca*** + .035315 x Ca^2 - .00089 x Ca^3	.45	.68
	14	2.32536 + .090693 x Ca*** + .00254 x Ca^2 - .003939 x NONCWC + .002284 x $NONCWC^2$ - .0000561 x $NONCWC^3$	.45	.71
	15	264.3116 - .037095 x Ca*** + .00526 x Ca^2 - 27.86915 x CF + .98659 x CF^2 - .011584 x CF^3 + .001802 x Ca x CF	.47	.71

Table 10 (Continued)

Dependent Variable	Method No.	Method	R^2	RSD[a]
	16	438.4625 + .00189 x FINALWT[g] + .129474 x COWSCORE[h] - .37385 x Ca + .021417 x Ca^2 - 47.8772 x CF + 1.7447 x CF^2 - .02104 x CF^3 - .00013 x Ca x CF	.56	.67
	17	DMI predicted by Method No. 8 x DM predicted by Method No. 16		
	18	DMI predicted by Method No. 9 x DMD predicted by Method No. 17		
Fecal DM output, Kg d^{-1}	19	-15.3572 + 3.1093 x P - .0975 x P^2 - .6526 x ADFN[i] + .0095 x $ADNF^2$ + 6.783 x AIA[j] - .7452 x AIA^{2*} + .0346 x AIA^{3*} - .2953 x P x AIA + .01397 x ADFN x AIA	.53	.26
	20	8.2908 + .0994 x P - .4523 x ADFN + .00774 x $ADFN^2$ - .0081 x P^2 - 2.0453 x MF1MM[k]	.11	.32
	21	9.5257 + .00059 x P - .5208 x ADFN + .0089 x $ADFN^2$	.08	.31
Fecal DM output, Kg d^{-1}	22	-15.4576 + .00067 x COWSCORE + .00157 x MILKPRO[l] + 3.1324 x P - .0985 x P^2 - .6562 x ADFN + .00958 x $ADFN^2$ + 6.8136 x AIA - .7504 x AIA^2 + .0348 x AIA^3 - .2965 x P x AIA + .01436 x ADFN x AIA	.53	.27

[a]RSD = Residual Standard Deviation, [b]FOUT - Fecal DM Output, [c]NONCWC = 1-cell wall, [d]CF - Crude Fiber.

[e]MON = Microbial Nitrogen, [f]ADL = Acid Detergent Lignin, [g]FINALWT = Cow's Final Weight.

[h]COWSCORE = Cow's Condition Score, [i]ADFN = Acid Detergent Fiber Nitrogen, [j]AIA = Acid Insoluble Ash.

[k]MF1MM = Percent of finess, [l]MILKPRO = Milk Production.

$H = \rho \neq 0$.

*$P<.01$.

**$P<.001$.

***$P<.0001$.

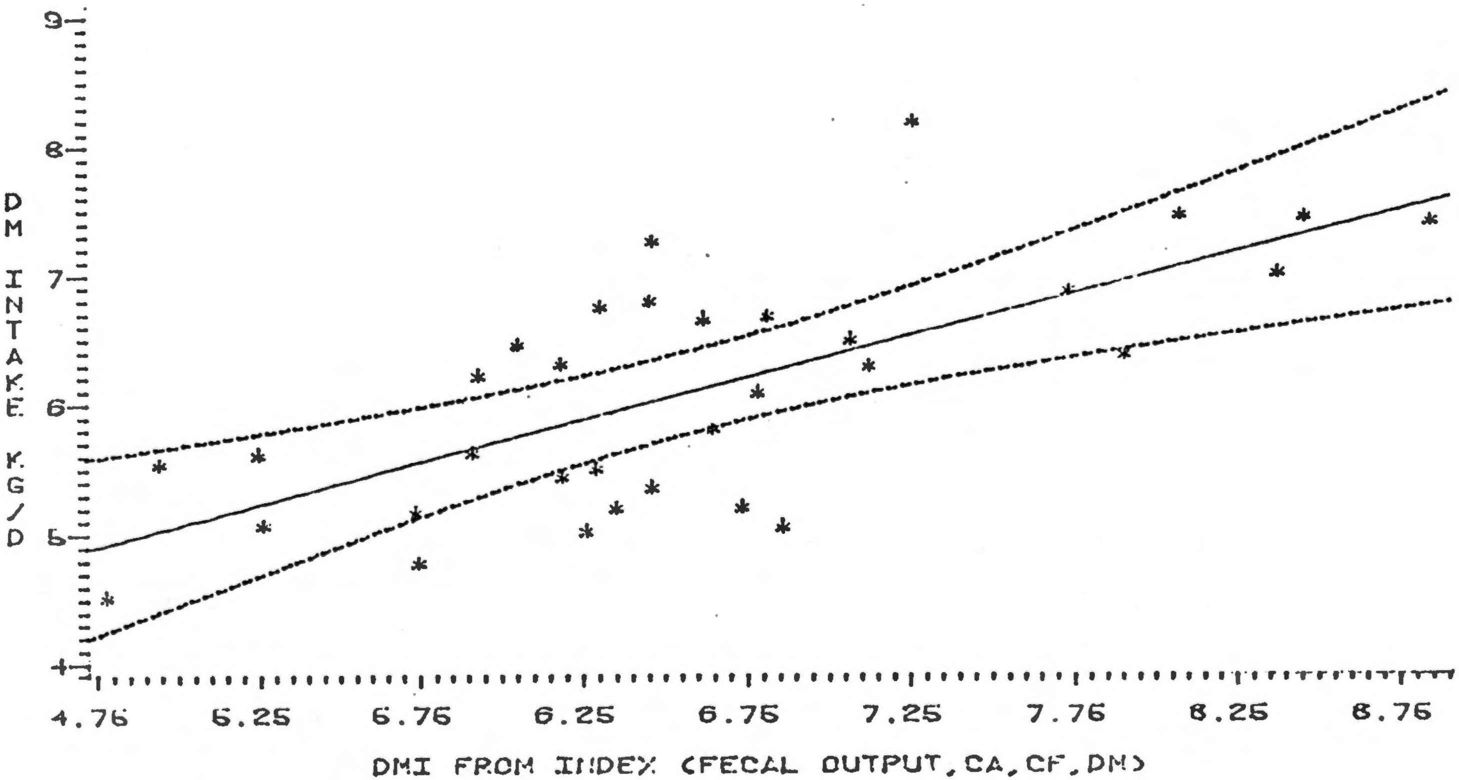

Figure 1. DM intake on index containing fecal output, fecal Ca, CF, and DM.

equation were Ca, Microbial N, Ash, and Na. Regression of values obtained by this method on actual values resulted in an intercept of 2.9 Kg d^{-1} and a partial regression coefficient of .39 (table 10) which is not very close to 1 when compared with method 6 above. The plot of this method showed linearity (Figure 2) and indicated that it has some potential in predicting DM intake. Method 3 however had a higher residual standard deviation showing less precision than method 6. Method 5 had an R^2 = .34 and a residual standard deviation of .76 Kg d^{-1}. Although it accounted for less variation in DM intake it has a low residual standard deviation indicating that it has a high precision in predicting DM intake. The equation involved in method 5 contained Ca and Ash as independent variables. Regression of evaluated values on measured values of an independent data set resulted in an intercept closest to 0 (.8 Kg d^{-1}) and a partial regression coefficient of .76 (table 9). Method 5 had the lowest intercept of all the methods evaluated to predict DM intake. This indicated its accuracy in predicting DM intake. Methods 1 and 4 also explained variation in DM intake but not as much as the other methods discussed. Method 1 had a R^2 = .33 and a residual standard deviation of .76 Kg d^{-1} (table 9). It had an intercept of 2.41 Kg d^{-1} and a partial regression coefficient of .54 (table 9). When this method was compared to Holloway et al. (1983), it showed a lower residual standard deviation indicating more precision in predicting DM intake but less accuracy. The plot of Method 1 showing linearity is presented in Figure 3. Method 4 had a similar R^2 and

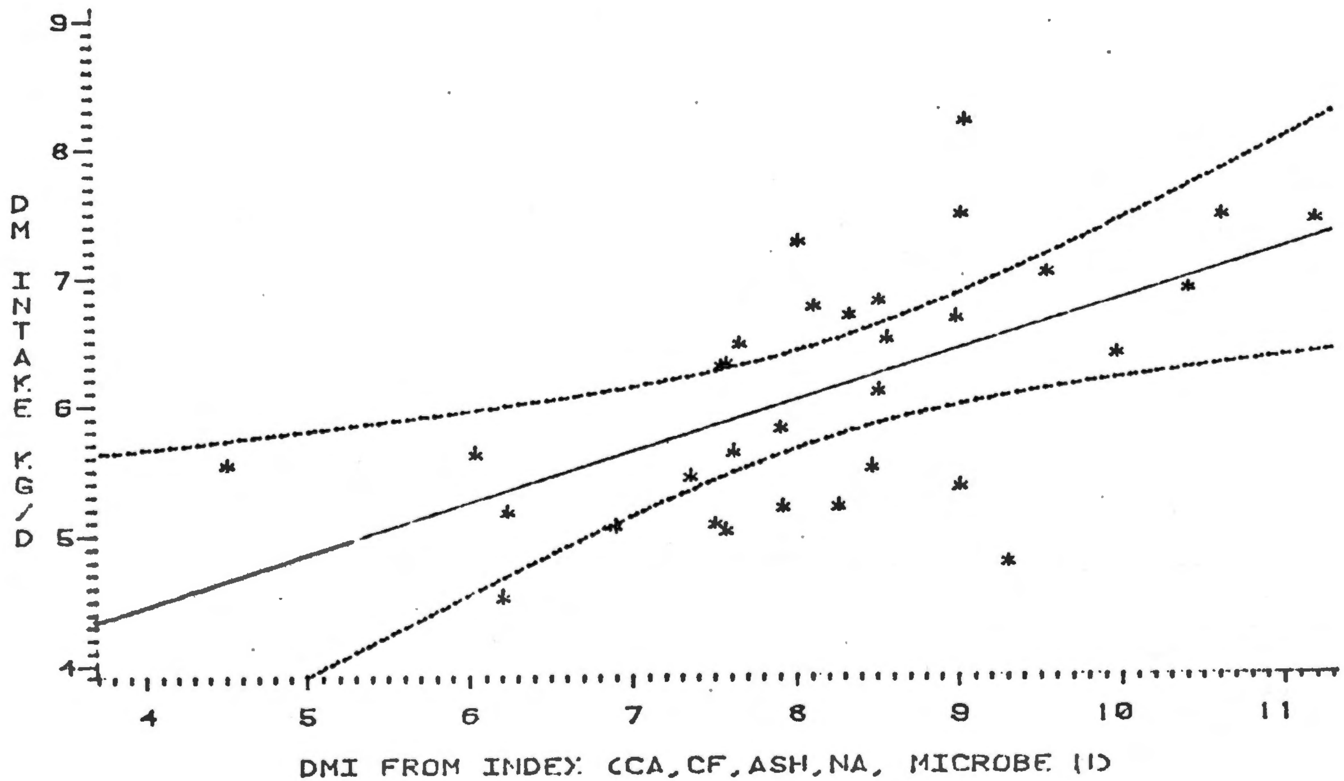

Figure 2. DM intake on index containing fecal Ca, CF, Ash, fecal NA, and microbe N.

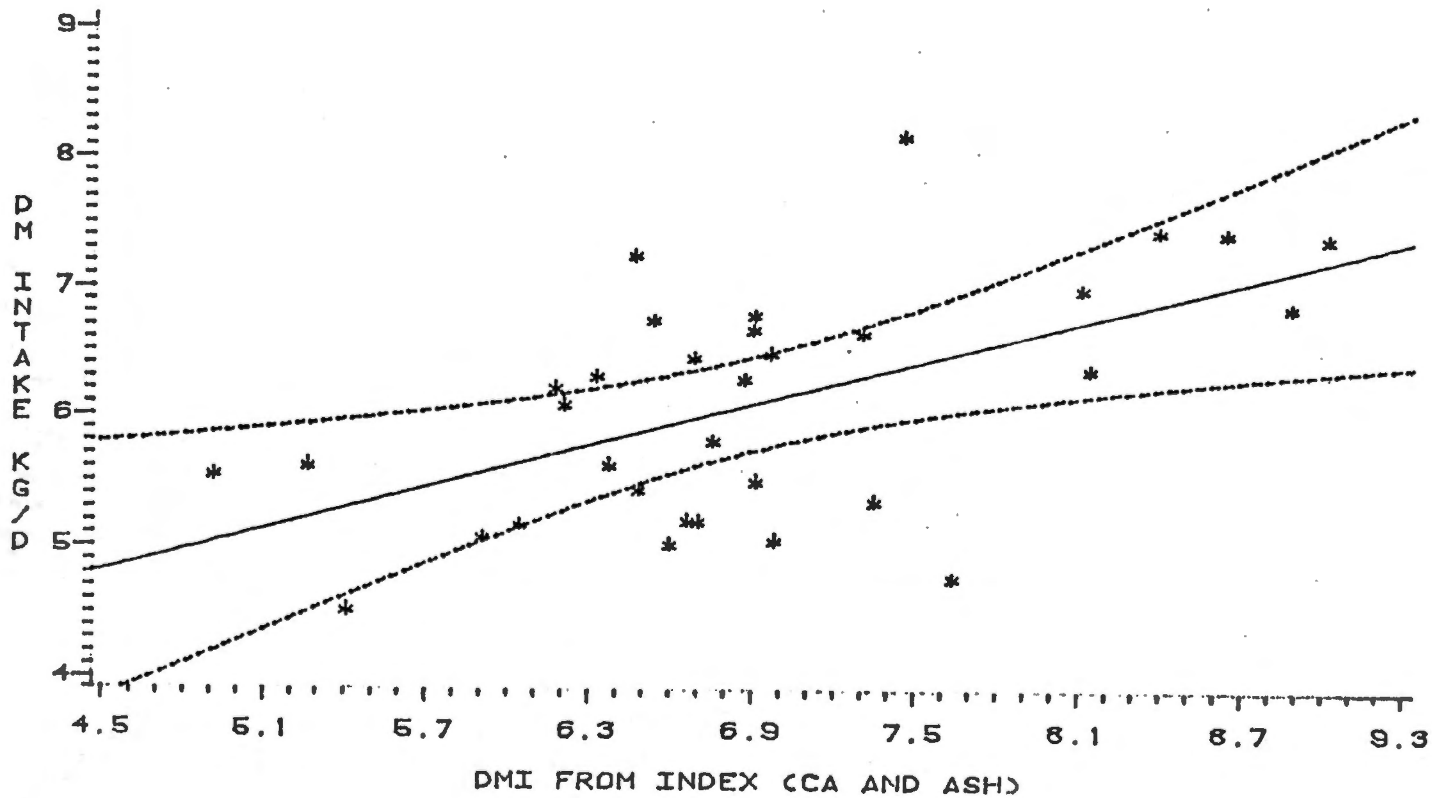

Figure 3. DM intake on index containing Ca and Ash.

residual standard deviation (R^2 = .34, RSD = .77, table 9) to method 1. Method 4 also had a linear plot and it is presented in Figure 4. Methods 7 and 8, which involved acid detergent lignin as one of the independent variables failed to explain much variation in DM intake (R^2 = .004 and .005, respectively). With accompanying large residual standard deviations (.93 Kg d^{-1} for both) the precision of these two methods for predicting DM intake was thus very low. Methods 7 and 8 were also quite inaccurate as indicated by large intercepts (6.3 Kg d^{-1} and 6.32 Kg d^{-1}, respectively) and partial regression coefficients significantly different than 1. Johnston and Waite (1965) found less lignin in the leaf than in the sheath, stem, or head, and also leaf lignin was considerably more digestible than that in other plant portions. This led them to conclude that these will be abias when lignin is used to determine DM intake due to the selective grazing of ruminants. Also the failure of Methods 7 and 8 to accurately predict DM intake could be due to artifact lignin. Van Soest (1967) found that improper preparation of lignin could lead to a millard reaction in which some N binds to lignin resulting in artifact lignin that has variable digestibilities resulting in varying amounts of lignin in feces.

<u>DM Digestibility</u>

The equation that best predicted DM digestibility was Method 10 (table 9) explaining 57% of the variation in DM digestibility. This method included Method 6 which explained more than 50% of the

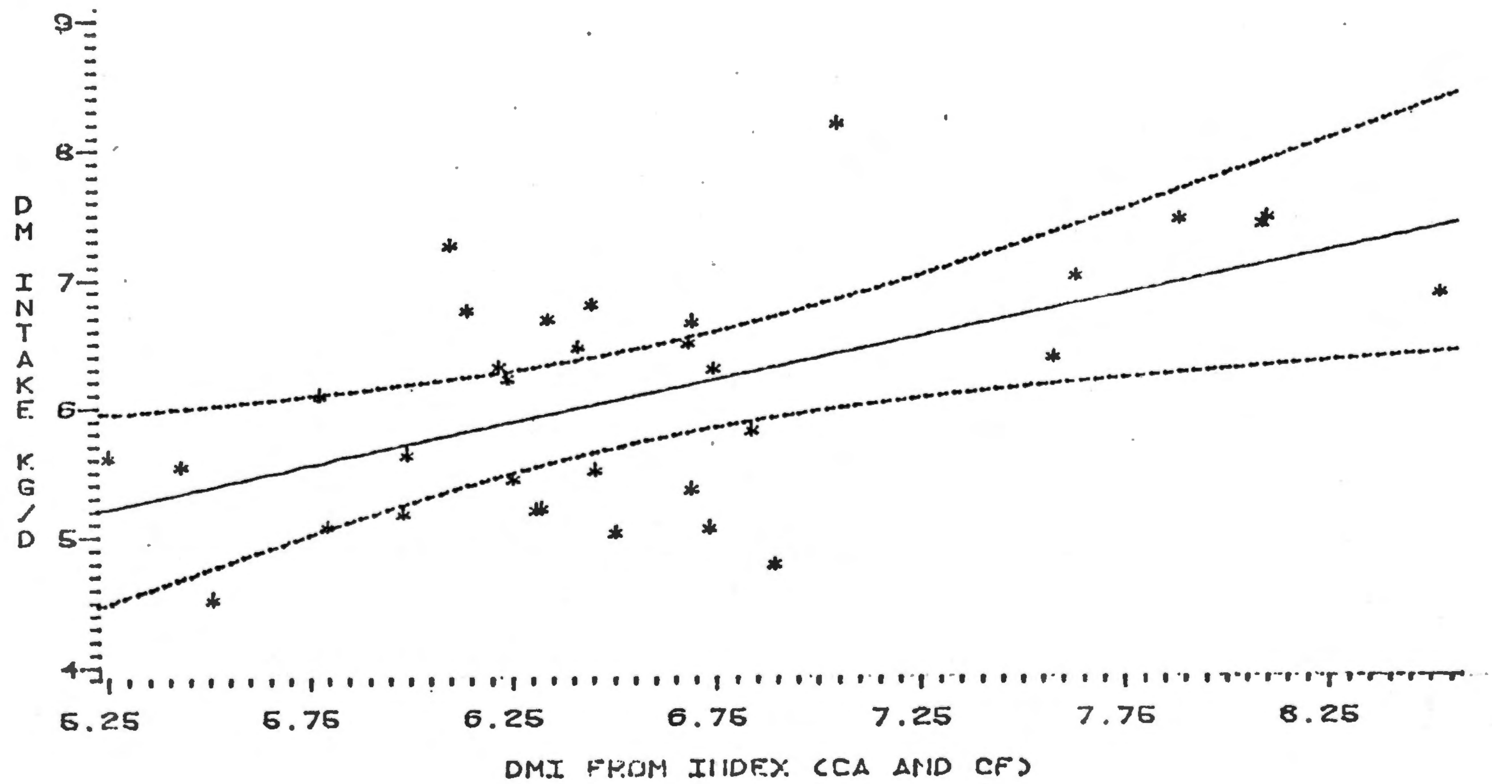

Figure 4. DM intake from index containing Ca and CF.

variation in DM intake. Method 10 had a low intercept which was closest to 0 (12%, table 9), and a partial regression coefficient of .79, P<.0001 (table 9). The residual standard deviation of Method 10 was 3.7% which indicated that Method 10 had a higher precision in predicting DM digestibility than any of the other methods evaluated to predict DM digestibility. Method 11 was the second best method in predicting DM digestibility. It explained 35% of the variation in DM digestibility and involved prediction from the ADL ratio. It had a low residual standard deviation (4.5%, table 9) showing that it had potential for predicting DM digestibility. This agrees with Richards et al. (1958) who reported a low negative correlation between fecal lignin and DM digestibility. The equation including N, Method 9 (table 9), explained 25% of the variation in DM digestibility with a residual standard deviation of 4.9% (table 9). This low variation might be due to different relationships between fecal N and DM digestibility for different seasons of the year (Langlands, 1975). Lancaster, 1954; Raymond et al., 1954; Richards et al., 1958; Kennedy et al., 1959; and Arnold and Duzinski, 1963 have indicated that fecal N has value as a predictor of DM digestibility. Several researchers have also reported limitations in the usefulness of fecal N in predicting DM digestibility over a wide range of forage types (Lambourne and Reardon, 1963; Langlands, 1967, 1969, 1975; Young and Corbett, 1972).

Fecal DM Output

None of the methods evaluated for the prediction of fecal DM output was useful in explaining the variation in fecal DM output. This was evidenced by generally small R^2 values and large RSD (table 9). Relatively high intercepts and low partial regression coefficients also indicated large inherent biases. Although Wehner (1982) found AIA and P to explain some of the variation in fecal DM output, he stated that adding pasture characteristics to model predicting fecal DM output increased the R^2 values. Holloway et al. (1981) also reported not finding any useful model that successfully predicted fecal DM output. When new equations predicting fecal DM output from this experiment were obtained, there was an improvement in some of the R^2 values and the residual standard deviation. Methods 19 and 22 (table 10) for example was able to explain 53% of the variation in fecal DM output. These methods employed models which contained P, ADFN, and AIA as independent variables.

Digestible DM Intake

The method that explained the most variation in digestible DM intake was Method 17 (table 9) explaining almost 50% (R^2 = .46) of the variation in an independent data set, with RSD of .65 Kg d^{-1}. This low RSD showed that it had a relatively high precision in predicting digestible DM intake. Method 16 had an intercept of 2.2 Kg d^{-1} and a partial regression coefficient of .57 (P<.0001, table 9). This method involved the independent variables: Ca, CF, and animal characteristics (weight and condition score). This result was expected since the method explaining the greatest amount of variation is DM intake included Ca and CF, and since digestible DM intake is correlated with DM intake (Table 11, r = .95, P<.001). Holloway et al. (1983) found Ca to be the best variable explaining the variation in digestible DM intake. The next method that explained a high variation in digestible DM intake was Method 15 explaining 41% of the variation with RSD of .68 Kg d^{-1}. The intercept of this method was 1.16 Kg d^{-1} with a partial regression coefficient of .54 (P<,0001, table 9, page 28). This shows that this method had a relatively low inherent bias and could be used to accurately predict digestible DM intake. The other two methods (17 and 18) evaluated in predicting digestible DM intake had low R^2 values and high RSD showing low precision. Their intercept was also high and their partial regression coefficients were both not significant. Thus Methods 17 and 18 failed to accurately predict digestible DM intake.

Influence of Forage Characteristics on Fecal Index

Methods Evaluated

The addition of a subjective estimate of percent legume in forage fed to models for predicting DMI, DM digestibility, fecal DM output, and digestible DM intake resulted in slight increases in R^2 values (Table 12), and a subsequent decrease in their RSD's. This supports the findings by Wehner (1982) who in developing fecal indices for lactating beef females noticed an increase in the R^2 values whenever pasture characteristics were added to his models.

DMI	DDMI-13	DDMI-14	DDMI-15	DDMI-16	DDMI-17	DDMI-18	FOUT	FOUT-19	FOUT-20	FOUT-21
.95***	-.19	.29	.56**	.59**	-.14	-.14	.30	-.16	-.33	-.17
66***	-.19	.65***	.97***	.92***	-.58**	-.54**	-.17	-.27	-.44	-.24
.35	-.11	.76***	.47*	.40	0	.05	.39	-.28	-.53*	-.28
63***	-.19	.64***	.85***	.81***	-.50*	-.46*	-.04	-.23	-.49*	-.23
.67***	-.22	.62***	.98***	.93***	-.59**	-.56**	-.22	-.31	-.40	-.30
.67***	-.33	.59**	.95***	.89***	-.56**	-.54**	-.18	-.29	-.33	-.24
.67***	-.21	.52**	.89***	-.84***	-.33	-.30	.18	-.31	-.46	-.32
.32	.16	-.44	-.50*	-.49*	.99***	.98***	.80***	.10	.06	.04
.33	.16	-.40	-.48*	-.49*	.98***	.99***	.78***	.06	.04	.01
.82***	-.20	.43	.59**	.64***	-.69***	-.69***	-.57**	-.15	-.14	-.13
.43*	.10	.49*	.75***	.70***	-.57**	-.55**	-.29	.02	.03	.05
53**	-.13	.60**	.86***	.83***	-.80***	-.77***	-.61**	-.28	-.28	-.27
44*	.22	-.52*	-.65***	-.61**	.92***	.90***	.46*	.09	.24	.04
40	.23	-.47*	-.62***	-.60**	.92***	.92***	.47*	.05	.20	-.0
	-.23	.39	.64***	.67***	-.38	-.37	-.02	-.19	-.29	-.18
		-.21	-.06	.02	.16	.17	.09	.05	-.02	.01
			.60**	.51*	-.46*	-.41*	-.23	-.26	-.38	-.23
				.96***	-.55**	-.52**	-.17	-.31	-.44	-.30
					-.54**	-.53**	-.17	-.31	-.42	-.34
						.99***	.71***	.10	.12	.05
							.70***	.06	.08	.01
								.05	-.16	.01
									.55*	.87***
										.58**

Table 12. Relationship of Measured Forage Intake and Digestibility With Pasture Characteristics to Those Calculated by ADL Ratio and Fecal Indices

Predicted Variable	X	Method No.	Partial Regression Coefficients						
			Intercept	% LEG[a]	% Leg^2	X	X^2	R^2	RSD[b]
DMI	DMI	1	4.148	.007	6.703×10^{-5}	.157	.012	.409	.752
	DMI	2	-2.778	.011	6.443×10^{-5}	2.219	-0.142	.456	.721
	DMI	3	4.592	.006	8.137×10^{-5}	.025	.0143	.447	.740
	DMID	4	4.267	.007	6.573×10^{-5}	.082	.023	.403	.756
	DMI	5	2.137	.007	5.79×10^{-5}	.591	-.009	.407	.753
	DMI	6	-0.363	-.002	.0001	1.40	-.066	.526	.673
	DMI	7	5.069	.013	.0001	0.027	.012	.38	.769
	DMI	8	4.732	.011	.0001	0.221	-0.011	.369	.777
DMD	DMD	9	15.659	-0.001	2.65×10^{-5}	-.439	.003	.450	4.4
	DMD	10	.071	-0.003	1.009×10^{-5}	1.027	-0.251	.605	3.7
	DMD	11	.469	-0.001	1.196×10^{-5}	1.007	-1.17	.462	4.4
	DMD	12	.335	-0.001	1.686×10^{-5}	1.545	-1.64	.526	4.1
DDMI	DDMI	13	7.738	.012	9.771×10^{-5}	-.2752	.453	.420	.712
	DDMI	14	2.1	.01	8.064×10^{-5}	.254	.008	.464	.684
	DDMI	15	4.15	.002	.0001	-0.543	.009	.533	.638
	DDMI	16	3.542	.002	.0001	-0.38	.113	.582	.604
	DDMI	17	3.683	.009	.0001	.040	-0.018	.421	.711
	DDMI	18	3.62	.008	.0001	.105	-0.026	.429	.704
FOUT	FOUT	19	1.016	.007	-0.0001	.879	-0.204	.046	0.322
	FOUT	20	3.819	.009	-0.0001	-1.436	0.253	.1	0.313
	FOUT	21	4.955	.006	-9.974×10^{-5}	6.859	-1.683	.078	0.317
	FOUT	22	2.075	.007	-.0001	-.153	.047	.046	0.322

[a]Leg = legume.

[b]RSD = residual standard deviation.

The partial regression coefficients were also lower showing that adding pasture characteristic to these methods lowered the level of bias (Table 12).

Test of Variables Evaluated Using Lucas' Ideal Indicator Test

Lucas (1962) indicated than an "ideal" indicator could be evaluated to show its "idealness" if values for digestible amount of the indicator from digestion trials on a wide variety of feeds are plotted against values for the indicator composition as a percent of diet. the "ideal" indicator will be: (1) linear with a negative intercept, (2) have small SD of intercept and regression coefficient, and (3) exhibit no lack of fit. When this test was employed to evaluate the variables used in the prediction equations, the acid detergent lignin (ADL) was found to have the greatest linearity (Figure 5). It also had a negative intercept (-.36 $\pm$ .03) and a partial regression coefficient of 7.17 $\pm$ .37. ADL had R^2 = .93 and RSD of .05 which showed its high precision. Van Soest (1982) has also found ADL to be an "ideal" indicator.

Ca was also found to be an "ideal" indicator with a negative intercept (Figure 6). It had R^2 of .93 and RSD of .05. Na was the next most ideal although it had a slightly positive intercept (.16 $\pm$ .21). The relationship was linear (Figure 7) with R^2 = .92 and RSD = .64 (Table 13) which was too high indicating it was not very precise. N was found to be linear with an intercept of -.09 $\pm$ .02 (Figure 8). Its regression coefficient was 7.76. It had an R^2 = .76

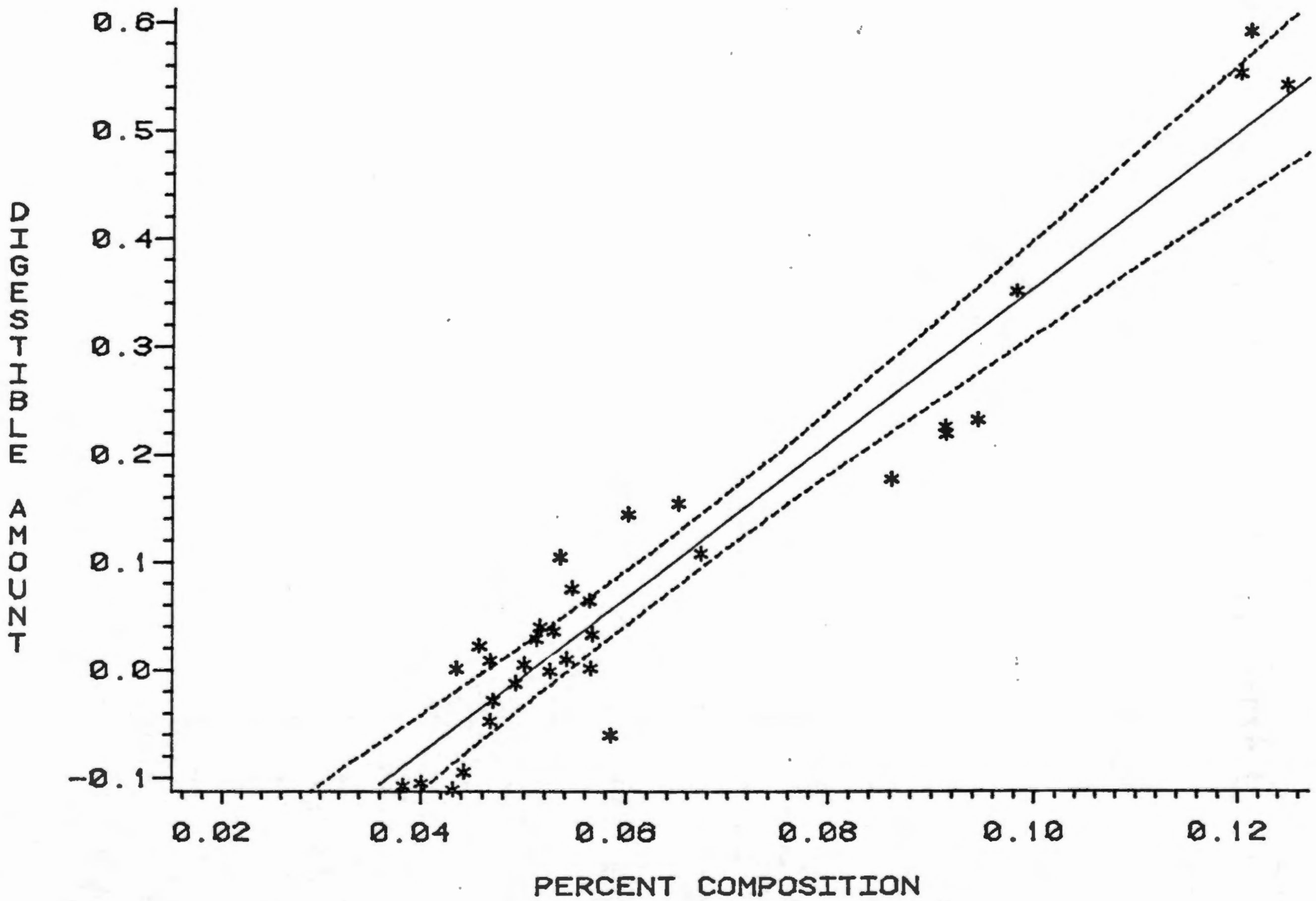

Figure 5. Acid detergent lignin (72% sulphuric acid).

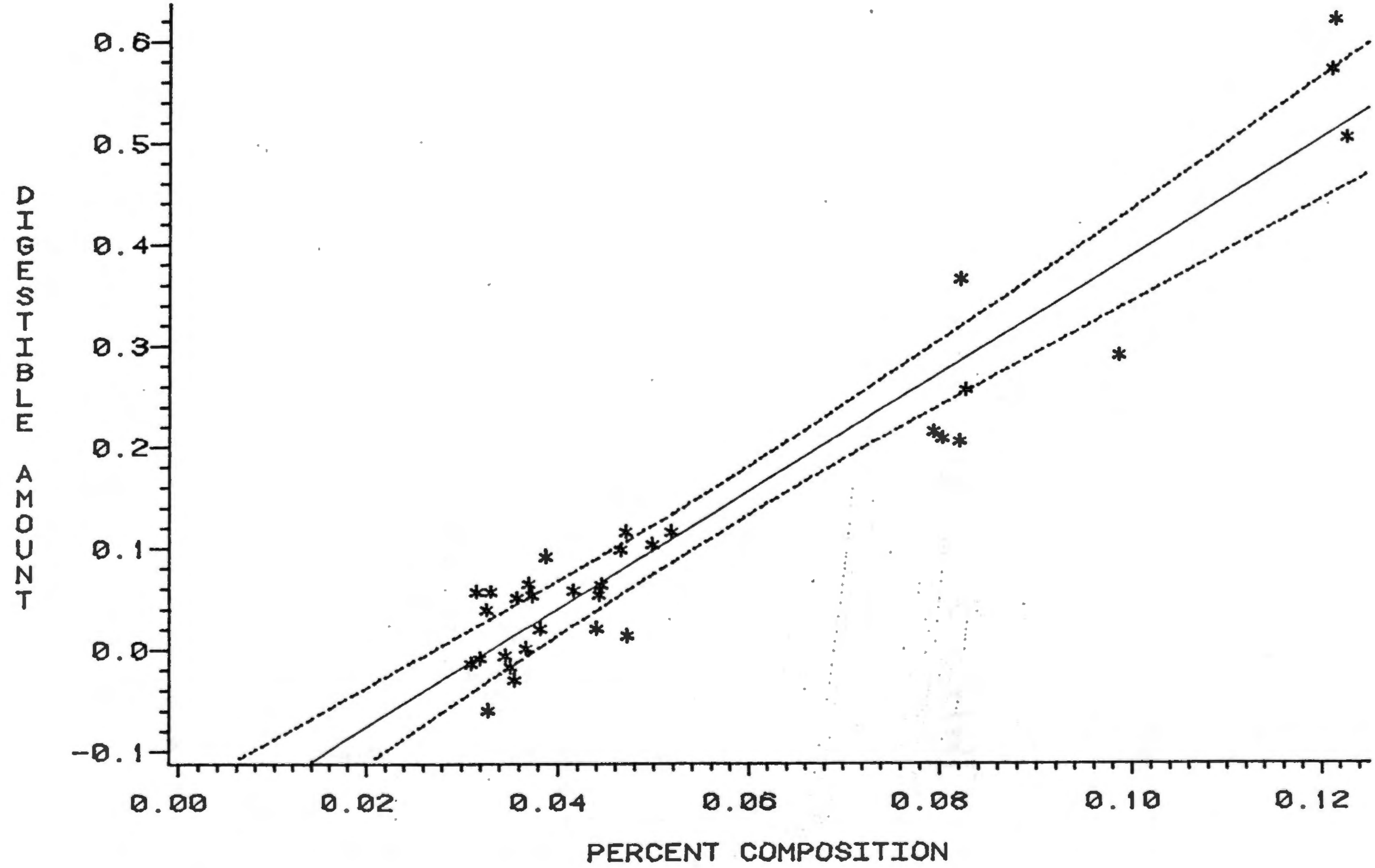

Figure 6. Calcium.

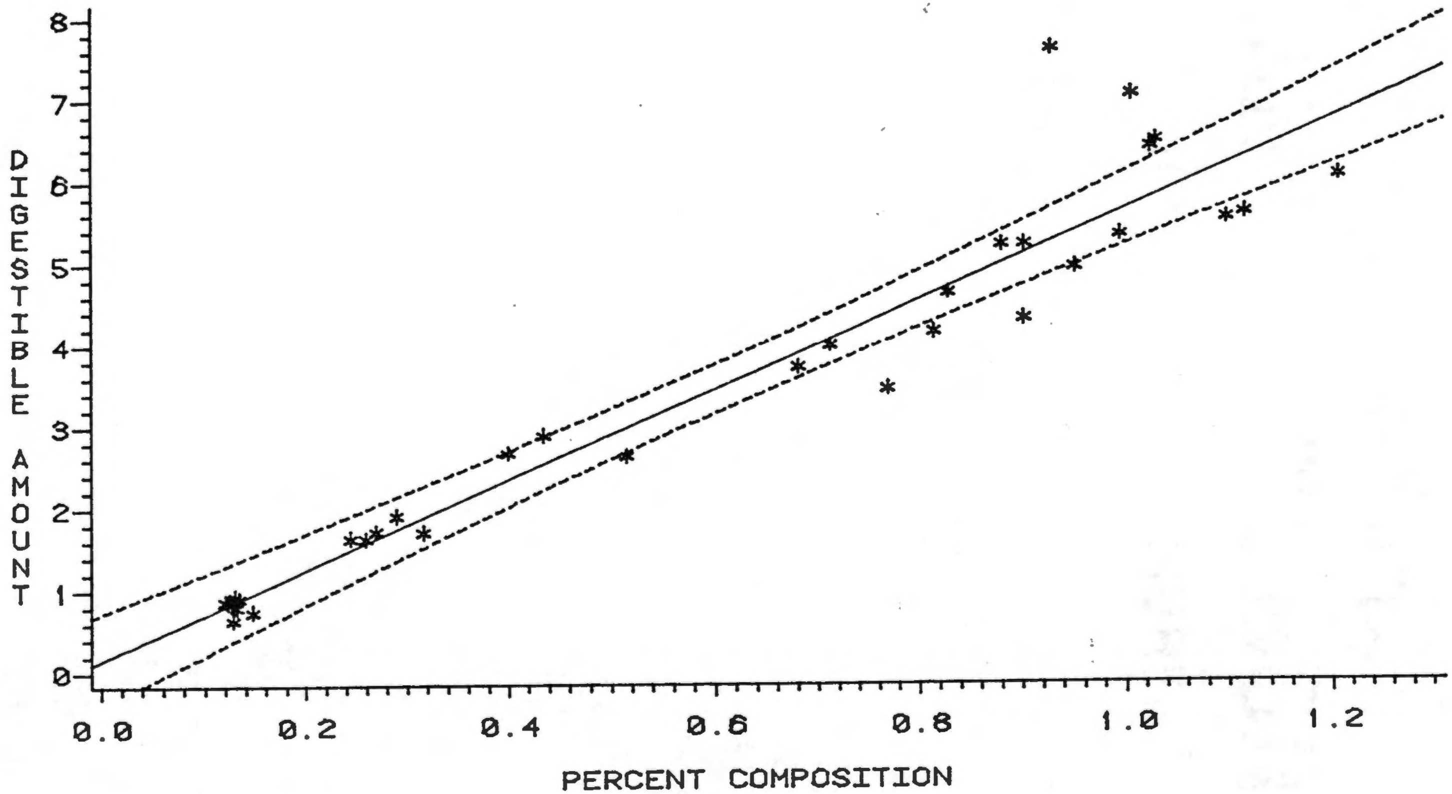

Figure 7. Sodium.

Table 13. Relationship of Amount of Forage Nutrient Digested and Forage Nutrient Composition

Predicted Variable	Independent Variable	Partial Regression Coefficient			
		Intercept	X	R^2	RSD[a]
ADL[b] digestible amt.	ADL composition	-.36 ± .03	7.17 ± .37	.93	.05
N digestible amt.	N composition	-.09 ± .02	7.76 ± .88	.76	.02
Ash digestible amt.	Ash composition	-.23 ± .12	5.71 ± 1.26	.41	.1
ADF[c] digestible amt.	ADF composition	-2.35 ± .76	9.71 ± 1.89	.49	.34
Mn digestible amt.	Mn composition	-.002 ± .001	2.53 ± .77	.27	.002
Na digestible amt.	Na composition	.16 ± .21	5.46 ± .29	.92	.64
Ca digestible amt.	Ca composition	-.19 ± .01	5.78 ± .31	.93	.05
Zn digestible amt.	Zn composition	-.003 ± .001	11.4 ± 2.34	.43	.001
CF digestible amt.	CF composition	.99 ± .59	.85 ± 1.96	.02	.23
P digestible amt.	P composition	-.08 ± .06	4.33 ± 1.45	.38	.04
Mg digestible amt.	Mg composition	-.04 ± .02	3.61 ± .73	.48	.03

[a]Residual standard deviation.

[b]Acid detergent lignin (72% H_2SO_4 lignin).

[c]Acid Detergent Fiber.

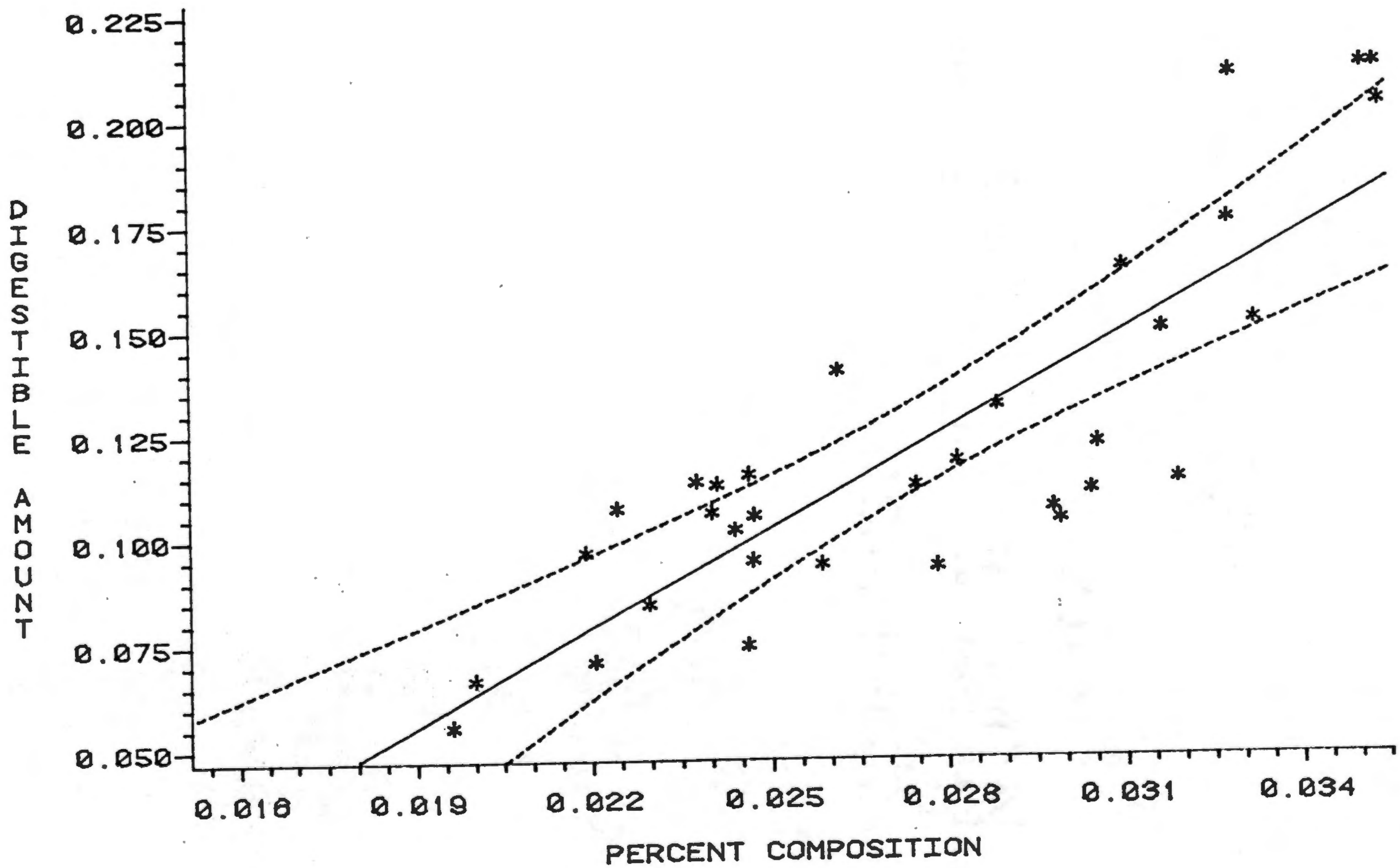

Figure 8. Nitrogen.

and RSD = .02. This supports the fact that fecal N can be used as an indicator in digestibility studies as discussed above.

Although the other variables studied were linearily related ($P<.001$) to digestible amount, the precision was relatively low as indicated by R^2 and RSD. An example was the acid detergent fiber (ADF) which had a high positive intercept ($-2.35 \pm .76$) (Figure 9) with a partial regression coefficient (9.71 ± 1.89, table 13), $R^2 = .49$ and RSD = .34. This agreed with Van Soest (1982) who found ADF not to be an "ideal" indicator. Ash was also found not to be an "ideal" indicator (Figure 10) with an intercept greater than 1 and $R^2 = .41$ with RSD = .1. The rest of the variables tested (Zn, Mg, Mn, CF, and phosphorus) did not qualify for the test of an "ideal" indicator as proposed by Lucas and presented in Figures 11, 12, 13, 14, and 15, respectively. Their R^2 and RSD are found in Table 13.

Conclusion

This research indicates that regression equations evaluated in predicting DM intake, DM digestibility, fecal DM output, and digestible DM intake were able to explain considerable amounts of variations in these dependent variables. Method 6 (independent variables: Ca, fecal DM output, DM, CF) was the best equation predicting DM intake. The rest of the equation predicting DM intake was less precise. Method 10 (independent variable: Ca, fecal DM output, DM, CF) was the best equation predicting DM digestibility.

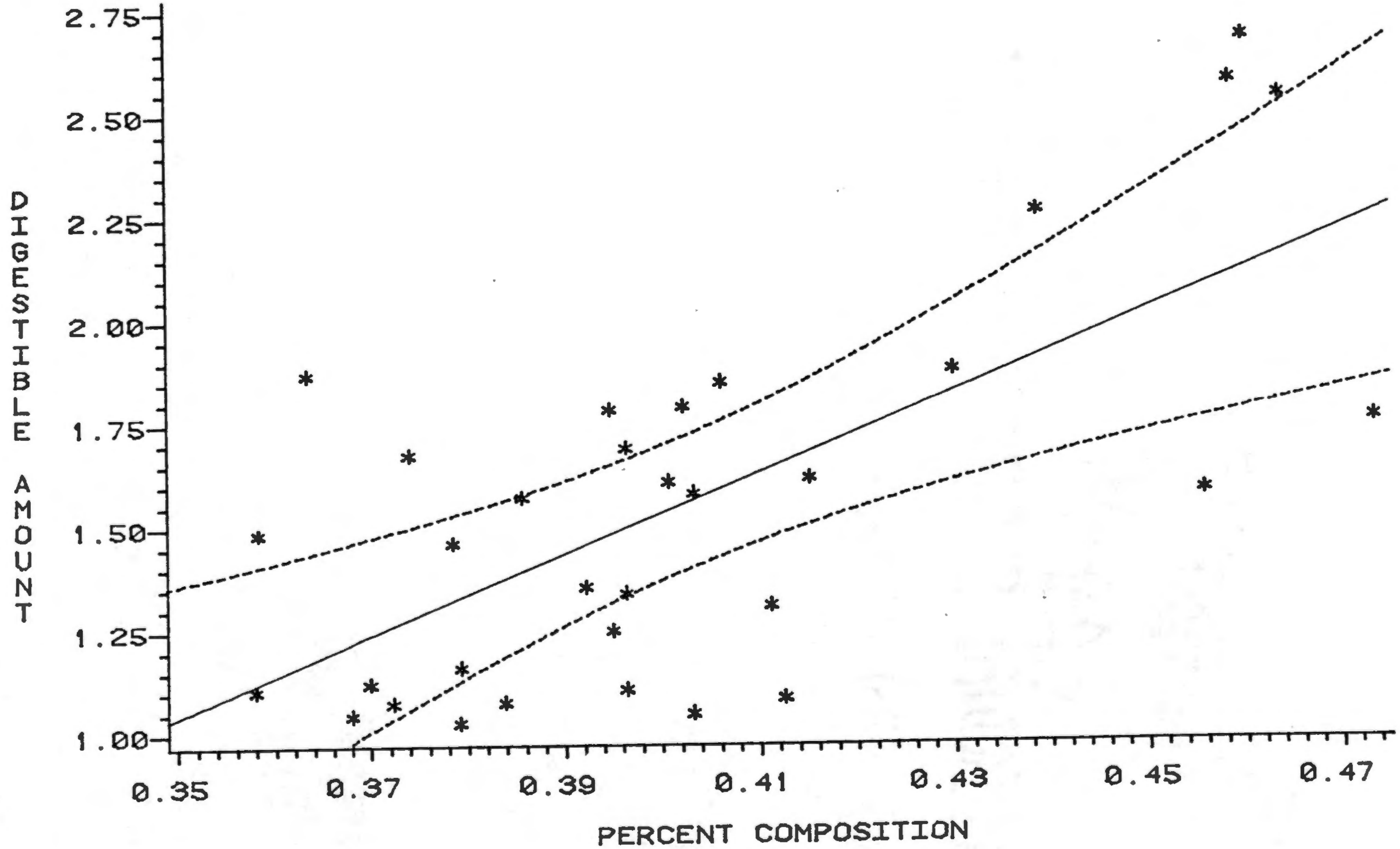

Figure 9. Acid detergent fiber.

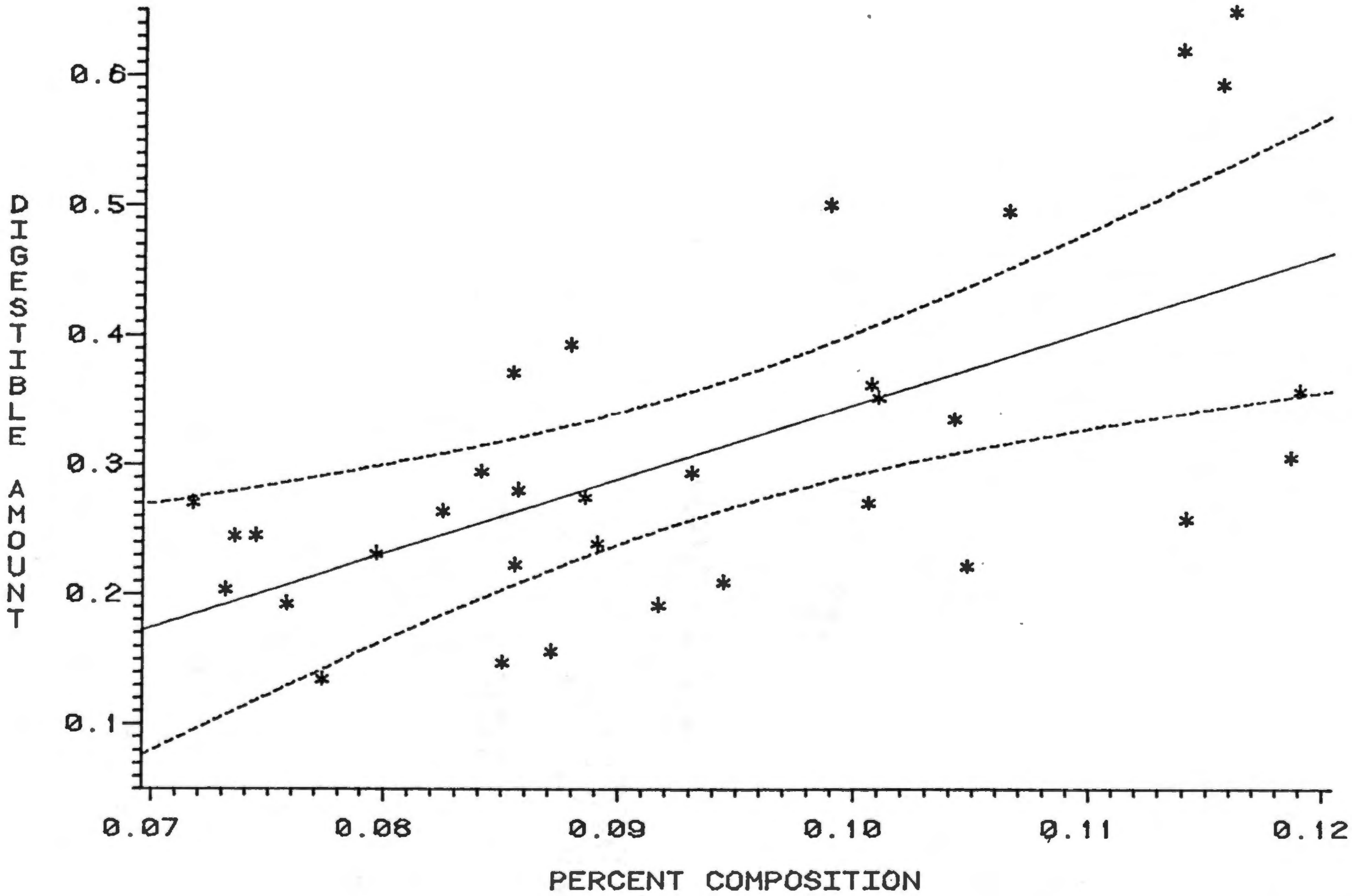

Figure 10. Ash.

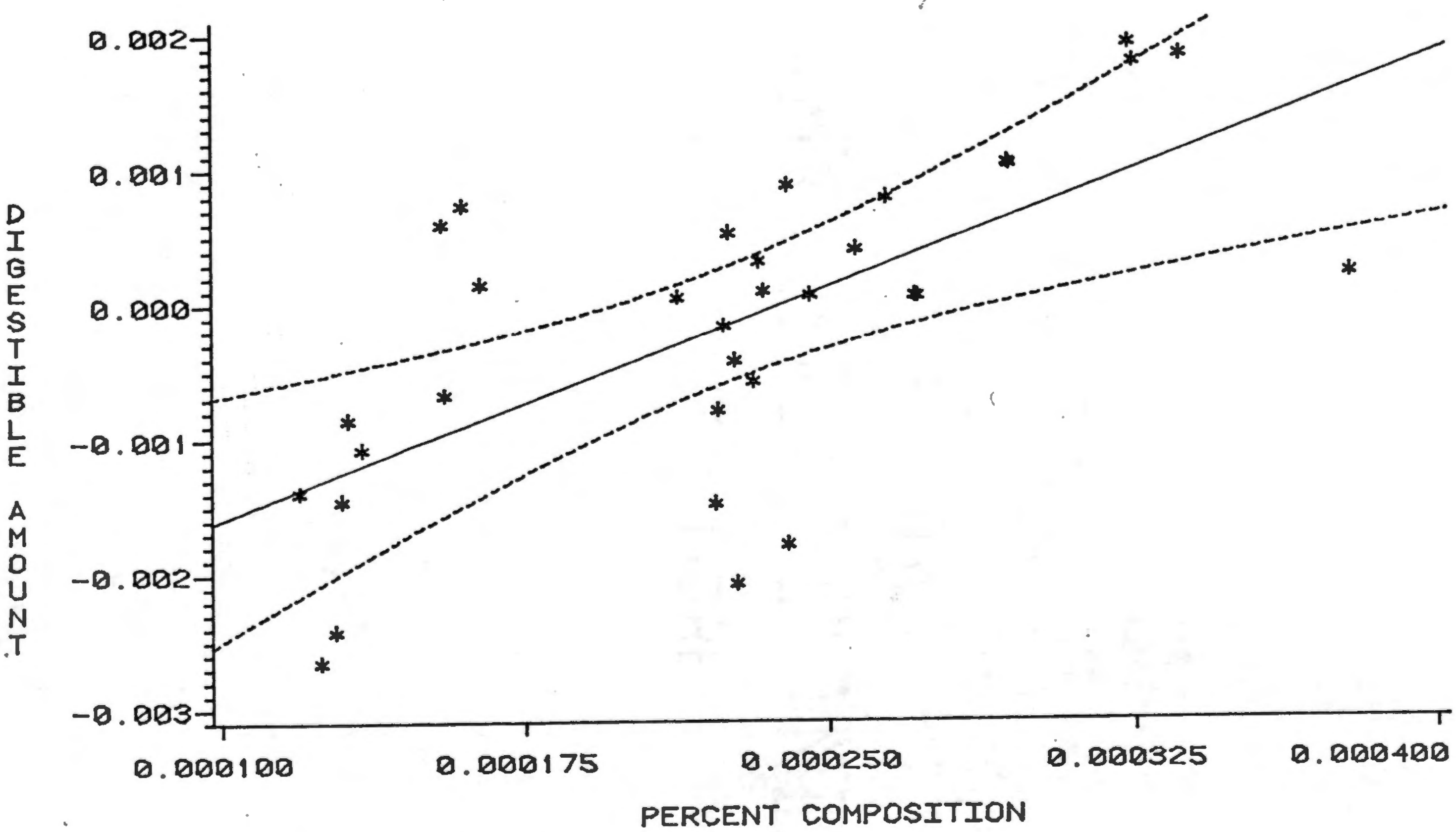

Figure 11. Zinc.

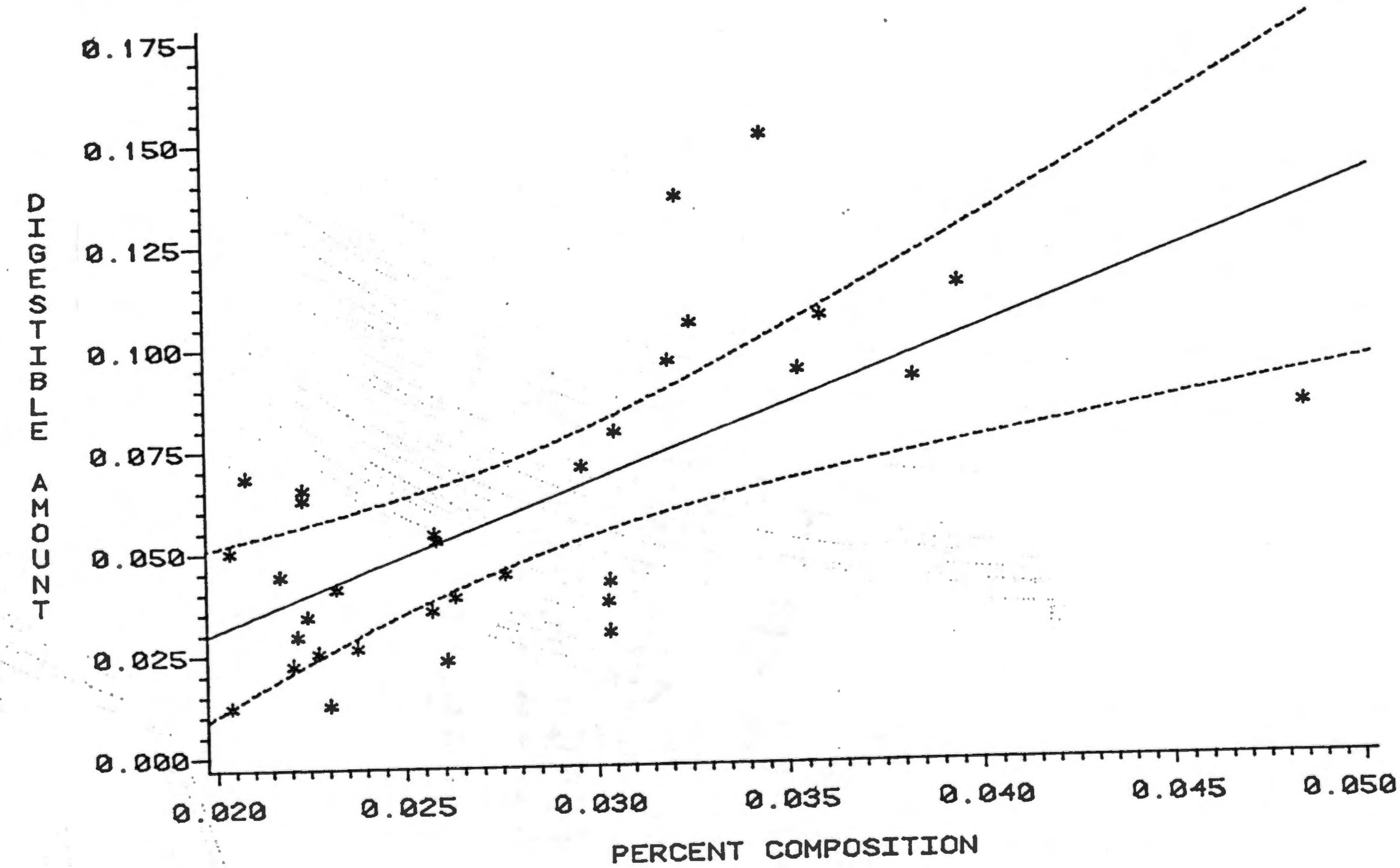

Figure 12. Magnesium.

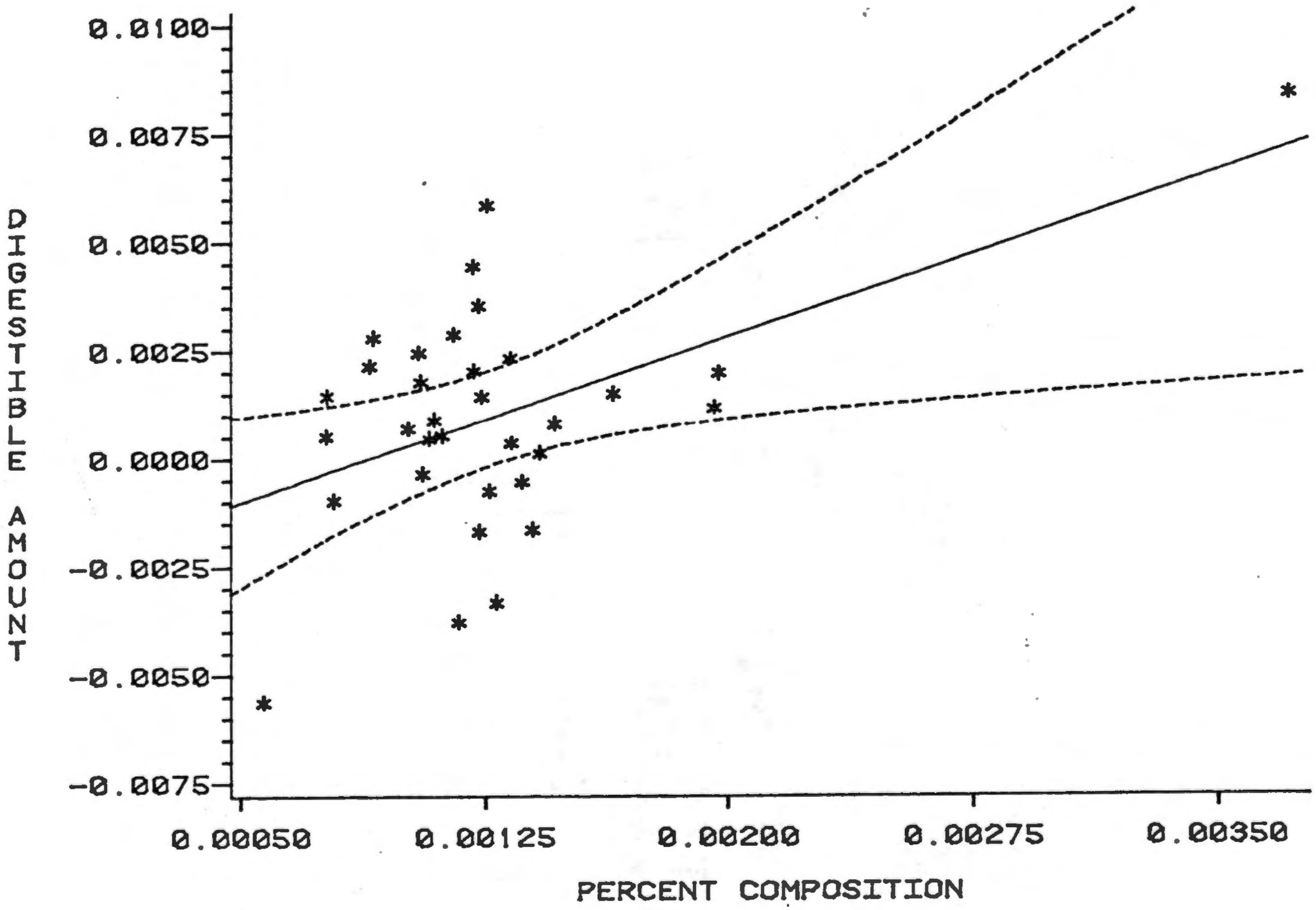

Figure 13. Mangenese.

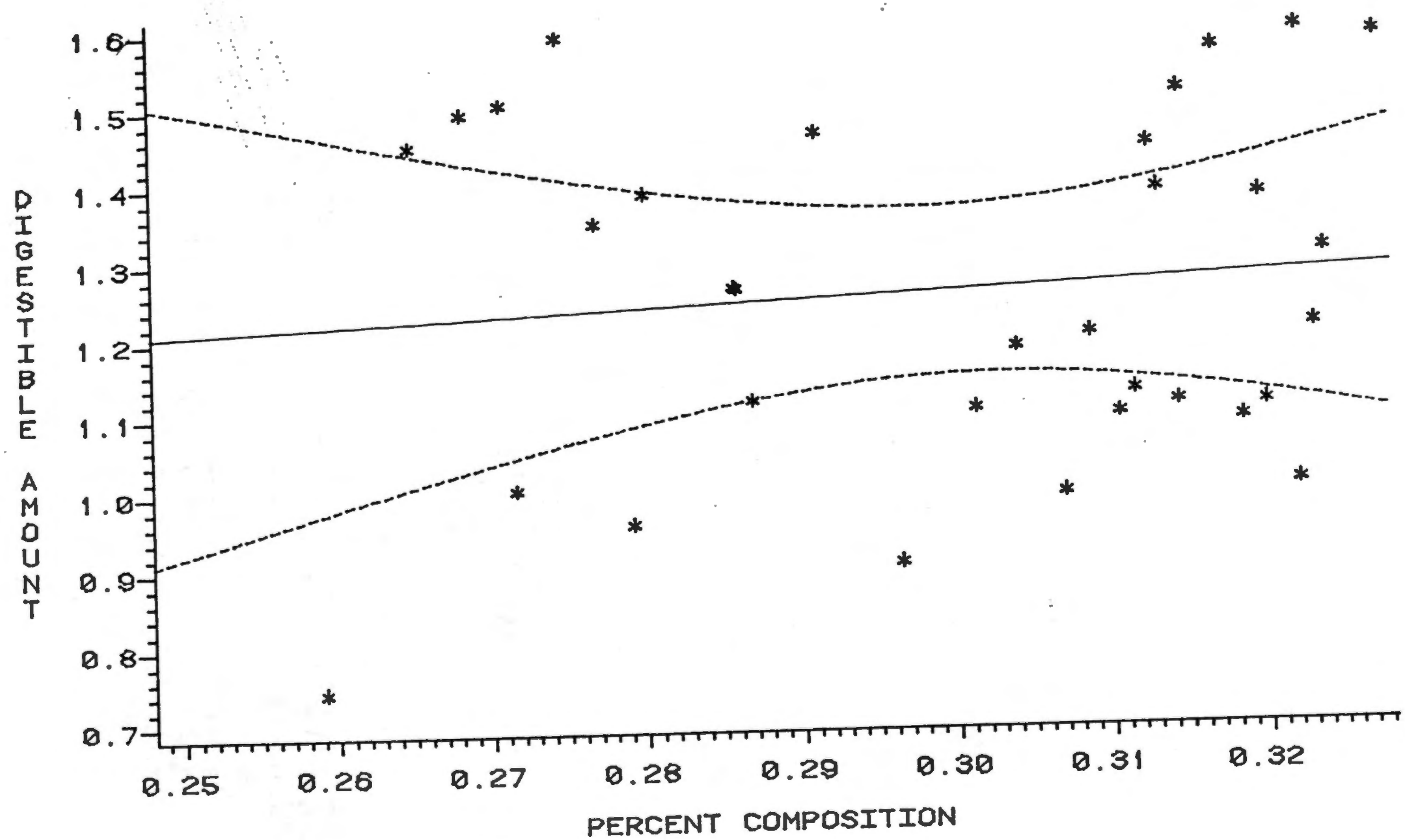

Figure 14. Crude fiber.

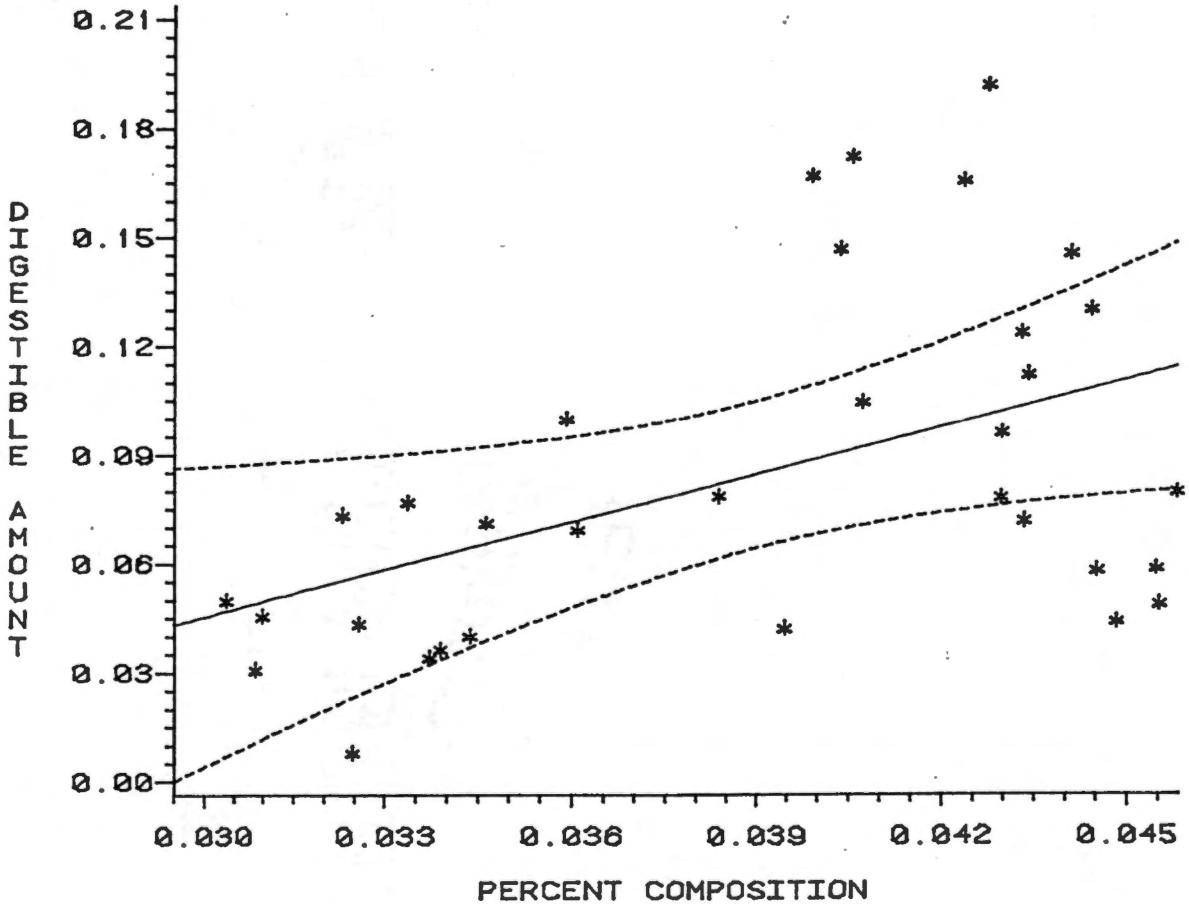

Figure 15. Phosphorus.

All the others evaluated had very low precision. None of the equations evaluated explained an appreciable amount of variation in fecal DM output. Method 15 was the best equation in predicting digestible DM intake.

Lucas' test of an "ideal" indicator showed ADL, Ca, and N to be "ideal" indicators.

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APPENDIX

Table A-1. Key to Forage Fed in Digestibility Trials

Date Trial Initiated	Forage Description	Forage	Percent of Mixture	Estimated Maturity
June 9	Red clover	Red clover	(50)	Vegetative
		Fescue	(10)	Vegetative
		Orchard grass	(35)	Vegetative
		Weed	(5)	
	Fescue legume	Fescue	(47)	Vegetative
		Red and Ladino clovers	(40)	Boot
		Bermuda grass	(10)	Vegetative
		Lespedeza	(2)	Vegetative
		Weed	(1)	
	Fescue (N)	Fescue	(98)	Vegetative
		Weed	(2)	
July 7	Red clover	Red clover	(60)	Bloom
		Ladino clover	(20)	Bloom
		Johnson grass	(3)	Vegetative
		Crab grass	(3)	Vegetative
		Orchard grass	(12)	Vegetative
		Weeds	(2)	
	Orchard grass White clover	Ladino clover	(35)	Bloom
		Red clover	(15)	Boot
		Orchard grass	(28)	Bloom
		Johnson grass	(8)	Vegetative
		Crab grass	(10)	Vegetative
		Weeds	(4)	
	Common Bermuda grass	Bermuda grass	(40)	Vegetative
		Ladino clover	(35)	Vegetative
		Bluegrass	(1)	Vegetative
		Fescue	(20)	Vegetative
		Weeds	(4)	
	Bermuda grass	Bermuda grass	(60)	Dormant
		Ladino clover	95)	Pre-bloom
		Bluegrass	(1)	Vegetative
		Fescue	(30)	Vegetative
		Weeds	(4)	

Table A-1 (Continued)

Date Trial Initiated	Forage Description	Forage	Percent of Mixture	Estimated Maturity
August 9	Fescue	Fescue	(80)	Vegetative
		Bermuda grass	(10)	Vegetative
		Ladino clover	(10)	Pre-bloom
		Weeds	(5)	
	Common Bermuda grass	Bermuda grass	(42)	Vegetative
		Ladino clover	(45)	Bloom
		Crab grass	(3)	Vegetative
		Weeds	(10)	
	Bermuda grass	Bermuda grass	(70)	Dormant
		Ladino clover	(15)	Vegetative
		Fescue	(10)	Vegetative
		Blue gras	(1)	Vegetative
		Weeds	(4)	
September 7	Fescue Legume	Ladino clover	(76)	Vegetative
		Fescue	(8)	Vegetative
		Blue grass	(8)	Vegetative
		Weeds	(8)	
	Fescue	Fescue	(85)	Vegetative
		Dallis grass	(10)	Bloom
		Johnson grass	(4)	Seed
		Red clover	(1)	Late bloom
	Fescue	Fescue	(83)	Vegetative
		Ladino clover	(10)	Vegetative
		Plains Bristol	(3)	Seed
		Weeds	(4)	

VITA

Paul Boateng, son of Edward and Elizabeth Boateng was born Nana Kofi Agyenim Boateng in Kumasi, Ghana on August 10, 1956. He attended the Modern City Academy and later the City of Kumasi Preparatory School where he graduated in June 1969. He continued his high school education at Prempeh College where he received his school certificate in division one in June 1974. He then went to Labone School where he received his advance level certificate in June 1976.

After gaining a few months experience with the research department of the Ghana Cocoa Marketing Board he went to Mogate College in London and studied for a year.

He accepted a scholarship to study agriculture at Hannibal LaGrange College in August 1977 and graduated with an A.S. in Agriculture in June 1979. His love for a practical knowledge in agriculture led him to the School of the Ozarks, Point Lookout, Missouri where he graduated with a B.S. in Agricultural Business with a minor in Animal Science in June 1981.

He accepted a scholarship in September 1981 from the Ghana Government to study towards a masters degree in Animal Science at the graduate school of The University of Tennessee, Knoxville. His scholarship was later redrawn due to a political coup d'etat in Ghana and he accepted a position as a research assistant at the Department of Animal Science to help complete his degree. He graduated from the department with a masters degree in March 1984.

The author is a member of the American Society of Animal Science and will be employed with the Pan African Institute of Development in Cameroon after graduation. His interest lies in the field of ruminant nutrition, especially pasture management and he plans to use his knowledge in rural development in Africa.