To the Graduate Council:

I am submitting herewith a thesis written by James Tigrett Hopper entitled "Animal Variation in Chromium Sesquioxide Excretion Patterns of Grazing Cows." I 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:

Eric W. Swanson

Will T. Butts Jr.

Accepted for the Council:

Vice Chancellor
Graduate Studies and Research

Thesis
77
.H669
cop. 2

ANIMAL VARIATION IN CHROMIUM SESQUIOXIDE EXCRETION PATTERNS OF GRAZING COWS

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

James Tigrett Hopper

June 1977

1324047

ACKNOWLEDGEMENTS

The author would like to express his gratitude to the entire faculty and staff of The University of Tennessee Animal Science Department for allowing his graduate study not only to be a learning experience but also an enjoyable one.

The author is most grateful to his major professor, Dr. J. W. Holloway, for advice, supervision, encouragement, motivation, inspiration, philosophy and friendship he has given during this course of graduate study.

The author is appreciative to Dr. W. T. Butts, Jr. for his interest, advice and friendship throughout his graduate work and to Dr. E. W. Swanson for his participation on the graduate committee and helpful criticism of the manuscript.

Others who aided the author in completion of this research and to whom the author is thankful are: Roger Munsinger, William A. Lyke and Marvis E. Fryer for chemical analysis of forage and fecal samples; Dr. W. L. Sanders for his aid in statistical analyses; Mrs. Viola Gibbons for her participation in construction of the graphs; the staff of The University of Tennessee Computer Center for making available the computer facilities used in the analysis of data.

The author is grateful to Dr. Frank B. Masincupp and Dr. Dennis O. Onks and their families for their kindness and friendship during the two years of his graduate work.

The author also expresses gratitude to Stan Hall, Bob Montgomery, Johnny D. Beaty, Michael Hunter, Dan T. Brown, Becky Garland and George

Beckman for their helpfulness, friendship and morale boosting.

The author is extremely grateful to his parents, Mr. and Mrs. Billy E. Hopper, for their encouragement, interest and financial support while he was completing requirements for this degree.

ABSTRACT

The chromium sesquioxide (Cr_2O_3) diurnal excretion patterns of 40 mature lactating Angus cows were characterized with the Fourier series: $\hat{y} = A_0 + A_1 \sin(ct) + A_2 \cos(ct) + A_3 \sin(2ct) + A_4 \cos(2ct)$ where $\hat{y}$ = mg Cr_2O_3/g fecal DM at time t, A_0 = mean Cr_2O_3 concentration, c = the fundamental period (radians/hour) and t = time (hours). C was found to be circadian and was fixed at 0.1309 corresponding to a 24 hour fundamental period. Cows were allowed either fescue-legume or fescue pasture. Within pasture quality, size of cow was intentionally confounded with pasture (2 pastures for each pasture quality). Within-cow standard deviation was .45 mg Cr_2O_3/g fecal DM. Pasture quality, pasture within pasture quality, and cow weight influenced A_0 ($P < .01$, $R^2 = .68$) much more than other A_i ($P > .10$, $R^2 = .10 - .20$). No influence ($P > .10$) was found on any other parameter except for the influence of calf weaning weight and percent butterfat on A_1 ($P < .05$) for cows grazing fescue pastures. No cow characteristics measured influenced A_1 for cows grazing fescue-legume pastures. Therefore, an interaction between pasture quality and calf weaning weight ($P < .02$) and between pasture quality and percent butterfat ($P < .01$) were detected for A_1.

Although cows were shown to differ in Cr_2O_3 excretion patterns, an unbiased estimate of A_0 could be predicted. Each cow's model was evaluated at t = 8:00 A. M. and 5:00 P. M. Regressing A_0 values on means of these values gave a b value of $.97 \pm .020$ ($R^2 = .98$).

TABLE OF CONTENTS

CHAPTER		PAGE
I.	INTRODUCTION	1
II.	REVIEW OF LITERATURE	3
	Methods of Administering Cr_2O_3	3
	Time and Frequency of Feeding Chromic Oxide	9
	Time and Frequency of Feeding Rations	13
	Frequency of Sample Collection	15
III.	ANIMAL VARIATION IN CHROMIUM SESQUIOXIDE EXCRETION PATTERNS OF GRAZING COWS	18
	Summary	18
	Introduction	19
	Materials and Methods	20
	Results and Discussion	26
LITERATURE CITED		35
APPENDIX		44
VITA		54

LIST OF TABLES

TABLE		PAGE
1.	Characteristics of Experimental Pastures	22
2.	Means and Standard Deviation of Cow Characteristics	23
3.	Least Squares Means For Parameters Describing The Excretion Pattern That Were Influenced by Certain Cow Characteristics.	29
4.	Partial Regression Coefficients For Parameters Describing The Excretion Pattern That Were Influenced by Certain Cow Characteristics	30
5.	Individual Cow Characteristics of Cows Grazing Fescue-Legume Pastures	45
6.	Individual Cow Characteristics of Cows Grazing Fescue Pastures	46
7.	Individual Cow Fourier Coefficients of Cows Grazing Fescue-Legume Pastures	47
8.	Individual Cow Fourier Coefficients of Cows Grazing Fescue Pastures	48
9.	Percentage of Time Cows Spent Grazing	49

LIST OF FIGURES

FIGURE		PAGE
1.	Diurnal Excretion Patterns of Angus Cows Grazing Fescue and Fescue-Legume Pastures	25
2.	Relationship of Average Cr_2O_3 Excretion Rate (A_0) With Estimated Excretion Rate From The Average of Point Estimates at 8:00 A. M. and 5:00 P. M.	34
3.	Chromic Oxide Excretion Pattern of Large Cows Grazing Fescue-Legume Pasture	50
4.	Chromic Oxide Excretion Pattern of Small Cows Grazing Fescue-Legume Pasture	51
5.	Chromic Oxide Excretion Pattern of Large Cows Grazing Fescue Pasture	52
6.	Chromic Oxide Excretion Pattern of Small Cows Grazing Fescue Pasture	53

CHAPTER I

INTRODUCTION

Chromic oxide has been employed as an external indicator when indirectly determining fecal quantity in studies concerning humans (Irwin and Crampton, 1950; King and Moore, 1957; Sharpe and Robinson, 1970), dogs (Lloyd and McCay, 1954), rats (Lloyd et al., 1955; Schurch et al., 1950), swine (Clawson et al., 1955; Schurch et al., 1952), rabbits (Huang et al., 1954), poultry (Dansky and Hill, 1952; Mueller, 1956; Yoshida and Morimoto, 1957), goats (Chanda et al., 1951; Kameoka et al., 1956), burrows (Knapka et al., 1967), horses (Haenlein et al., 1966; Vander Noot et al., 1967), sheep (Lambourne, 1957a; Johnson et al., 1964; Faichney, 1975) and cattle (Hardison and Reid, 1953; Smith and Reid, 1955; Brisson et al., 1957; Holmes et al., 1961). The use of this external indicator eliminates the need for total fecal collection, permits digestion trials to be conducted in ordinary barn stalls or on pastures, and results in a saving of time, labor and expense. Of the various species mentioned above, the Equine, Ovine and Bovine have been observed to excrete Cr_2O_3 in a more uneven rate denoting a distinct diurnal pattern.

Several suggestions on the administration of Cr_2O_3 and the collection of feces have been reported to solve the diurnal excretion of Cr_2O_3.

While there are numerous reports in the literature on the diurnal variation in Cr_2O_3 excretion, only a limited number of trials have been reported in which the animals were free of a total fecal collection apparatus, fecal samples taken upon natural defication or on a relatively

large number of animals on different grazing regimes.

The purpose of this experiment was to study the Cr_2O_3 excretion patterns of different size cows giving different amounts of milk on different quality pastures.

CHAPTER II

REVIEW OF LITERATURE

Chromium sesquioxide (Cr_2O_3) has been incorporated into many experiments as an external indicator in determining fecal output. Reports of variation in the excretion of this inert substance precludes the indiscriminate sampling of the feces. Various reports of causes of this variation and solutions to the variation are contradictory. Method of Cr_2O_3 administration, time and frequency of administration, time and frequency of feeding the ration and time and frequency of fecal sample collection have yielded differences in recovery rates, rate of passage and therefore Cr_2O_3 excretion. These aspects have been reviewed and reported in this section in order to give the reader a general idea of the problems and complications involved in the utilization of Cr_2O_3 as an external indicator.

I. METHODS OF ADMINISTERING Cr_2O_3

The form in which Cr_2O_3 is administered has been shown to influence the precision with which quantity of feces can be measured (Crampton and Lloyd, 1951; Pigden and Brisson, 1957; Bradley et al., 1958; Johnson et al., 1964; Yadava et al., 1973). The most precise estimates are obtained when Cr_2O_3 is administered in a form that allows improvement of distribution of the inert substance with the ingesta and allows passage of the Cr_2O_3 through the digestive tract in a manner similar to that of the ingested feedstuffs.

Incorporation of Cr_2O_3 Into the Diet

When Cr_2O_3 was incorporated into the diet of dairy cattle (Kane et al., 1950), beef cattle (Clanton, 1962), yearling steers (Cross et al., 1973), sheep (Elam et al., 1952) and goats and cows (Chanda et al., 1951) the recovery rates of Cr_2O_3 were "practically 100%", 95.1%, 102.5%, 100.7% and 98.5%, respectively, when the animals were confined to metabolism crates. However, Lassiter et al.(1966) reported an average chromium recovery of only 78%, probably due to a short (4 days) preliminary feeding of Cr_2O_3. McGuire et al. (1966) and Phar et al. (1971) found no difference ($P > .05$) in digestion coefficients calculated from Cr_2O_3 in "grab samples" and the conventional method when a completely pelleted ration was fed to confined steers; however, a difference ($P < .05$) in rate of excretion of the indicator by the steers was noted in both reports. Phar et al. (1970) compared the recovery of Cr_2O_3 fed in a complete pelleted ration of steers in metabolism crates (95.7%) and of steers in individual pens (87.5%). No significant diurnal variation occurred in this study.

Kane et al. (1952) and Bloom et al. (1957) when Cr_2O_3 was incorporated in similar concentrate rations and Elam et al. (1959) when Cr_2O_3 was pelleted with the entire ration of confined dairy and beef cattle reported that the fecal excretion of Cr_2O_3 followed a diurnal pattern. However, the excretion curves differed in rhymatic patterns due to the different times of feeding the ration in which Cr_2O_3 was incorporated.

Elam et al. (1959) and Drennan et al. (1970) suggested separation of Cr_2O_3 from other digesta in the rumen possibly causing a dirunal excretion pattern reflecting the concentration present in the ingesta leaving the rumen when Cr_2O_3 was incorporated into the diet. A similar

observation was reported by Kameoka et al. (1956) in his studies with goats fed .5% Cr_2O_3 incorporated into the ration, suggesting that Cr_2O_3 may accumulate in some part of the digestive tract, such as the omasum or abomasum, and be excreted at uneven rates.

Administered in Gelatin Capsules

The recovery rates of Cr_2O_3 administered in gelatin capsules to confined animals has been reported to be 98.4% for ponies (Haenlein et al., 1966), 94.2% and 93.5% for Holstein heifers (Murdock et al., 1957 and Hardison et al., 1959, respectively) and 99.6% for dairy cows (Putnam et al., 1957). Recovery rates of 76 to 119% were reported by Davis et al.(1958) when he administered Cr_2O_3 in gelatin capsules to confined lactating dairy cows. Christian et al. (1965) administered Cr_2O_3 to stall-fed sheep in a cardboard capsule and reported a recovery rate of 92.8%, Recovery rates of 97.5% (Smith and Reid, 1955) and 85.4% (Brisson et al., 1957) were obtained when gelatin capsules were administered to grazing cows. The relatively low recovery rate by Brisson et al. (1957) was attributed to losses of feces incurred during the collection periods.

A diurnal variation of Cr_2O_3 excretion was reported with confined dairy heifers, dairy cows, sheep and horses (Linkous et al., 1954; Murdock et al., 1957; Putnam et al., 1957; Putnam et al., 1958; Hardison et al., 1959; Haenlein et al., 1966) and with grazing dairy and beef cows (Lancaster et al., 1953; Smith and Reid, 1955; Brisson et al., 1957) when Cr_2O_3 was administered in gelatin capsules. Putnam et al. (1957) devised the equation $E(y) = a + b \sin [(x - 8AM)\ 15^{o}]$ (x = hours post midnight, y = percent of the daily mean, averaged over all observations

at the time x) as best describing the Cr_2O_3 excretion pattern of confined dairy cows. Haenlein et al. (1959) reported that the excretion curve of stall-fed horses was best described by a sinusoidual periodic function, for which the Fourier coefficients were estimated for two harmonies.

The equation being:

$$Y = a_o + a_1 \sin (2\frac{t}{T} + a_2 \sin (2(2\frac{t}{T}) + b_1 \cos (2\frac{t}{T}) + b_2 \cos (2(2\frac{t}{T}))$$

where T = the fundamental period (24 hrs.), t = time and Y = predicated Cr_2O_3 fecal concentration. The amplitude of the curve was 7.9 in the first harmonic (day period) and 8.9 in the second harmonic (night period).

Administered as an Impregnated Paper

Fairly high recoveries of Cr_2O_3 in feces have been reported by Hoogendoorn and Grieve (1969) of 94.2% and 97.5% with grazing dairy cows and by Nelson and Green (1969) of 103% with caged Holstein steers when the oxide was impregnated into paper. However, when Vander Noot et al. (1967) fed horses in stalls and Keisling et al. (1969) fed grazing steers Cr_2O_3 impregnated paper, low and dilatory recoveries were reported. They indicated that low recoveries may be attributed to the non-uniform coating of the indicator paste on the paper carrier, loss of Cr_2O_3 by regurgitation, incomplete collection of feces and/or improper sampling.

MacRae and Armstrong (1969) introduced Cr_2O_3 impregnated paper into the rumen of fistulated sheep at each feeding and reported a mean recovery of 100% from feces, 83.7% from duodenum and 77.3% from terminal

ileum. These results indicated that the rate of flow of Cr_2O_3 differed from that of the digesta along the digestive tract. Hogan and Phillipson (1960) studied the rate of flow of digesta in sheep, the mean rate of flow was 360 ml per hour in the duodenum and 180 ml per hour in the ileum indicating more retention of digesta in the small intestine than in the abomasum.

Administered in Sustained Release Pellets

Since the diurnal excretion of Cr_2O_3 is primarily a reflection of sudden large doses of Cr_2O_3 entering the alimentary tract, uniform release of Cr_2O_3 over a 23 hour period should promote a more uniform excretion. Chromic oxide administered in "sustained-release pellets" have been reported to give recovery rates from 95.3 to 102.4% (Brisson and Pigden, 1958) and from 90 to 110% (Pigden and Brisson, 1957) when fed to confined cows. A recovery of 100.4% was reported by Brisson and Pigden (1958) when the "sustained-released pellets" were administered to confined steers. When grazing cows were given the Cr_2O_3 in this form, recovery rates varied more (80 to 117%) as reported by Pigden and Brisson (1957). The "sustained-release pellets" have been regurgitated by sheep (Pigden and Brisson, 1957; Troelsen, 1965) but this phenomenon has not been noticed with cattle.

Variation in excretion of Cr_2O_3 has been reported by Troelsen (1961), Fisher et al. (1965) and Troelsen (1965) in their research with cattle and sheep administered "sustained-release pellets."

Troelsen (1961) slaughtered 36 wethers to study the distribution of Cr_2O_3 from "sustained-release pellets" in the alimentary tract. Rate

of disintegration of the pellets in the tract varied between animals. Of all "sustained-release pellet" recoveries 24% were in the rumen, 75% in the reticulum, a trace in the omasum and 1% in the abomasum. No pellets were found in the small intestine, large intestine or caecum indicating disintegration of the pellet occurring in the reticulomasum, therefore most of the Cr_2O_3 would not be able to mix thoroughly with rumen contents causing a variation in Cr_2O_3 excretion.

Comparison of Methods of Administration

Chromic oxide excretion patterns obtained when administered by gelatin capsules was compared to the patterns obtained when administered orally as part of a complete pelleted ration (Bradley et al., 1958), mixed with a portion of the ration (Crampton and Lloyd, 1951) and impregnated in "cubed" feed (Curran et al., 1967). In all instances the Cr_2O_3 in the feces collected from the indicator administered by gelatin capsules had larger variations from the mean and had a lower recovery rate. Corbett (1960) reported that Cr_2O_3 was cleared from the rumen more slowly and regularly if administered as a component of paper containing 35 to 40% Cr_2O_3 on a dry matter basis than if administered by gelatin capsules and that the diurnal variation in the Cr_2O_3 concentration in feces would be reduced ($P < .05$).

Raymond and Minson (1955) reported diurnal excretion patterns for Cr_2O_3 administered in two forms to grazing and hand-fed sheep: (1) as a drench (specific gravity similar to the rumen contents) and (2) in gelatin capsules. No evidence was reported in either the hand-fed or the grazing sheep of any reduction in amplitude of the diurnal pattern

due to administration as a drench. Larger variations were apparent, however, for grazing animals (ranging from 70 to 130% of the mean) than for the hand-fed sheep. The dosing of numbers of animals with a drench was more difficult than with capsules and there may be a small loss of Cr_2O_3 during drenching, however, Cr_2O_3 administered with gelatin capsules may not be swallowed or may be regurgitated by the animal.

Crampton and Lloyd (1951) observed that when Cr_2O_3 was fed with some part of the ration, the rate of recovery of the inert substance is faster than when administered in a concentrated form indicating that with a roughage diet, the Cr_2O_3 fed in highly concentrated pellets is partially retained in the digestive tract resulting in low recovery rates and therefore low digestibility coefficients.

Johnson et al. (1964) showed that administration of Cr_2O_3 as an impregnated paper resulted in higher ($P < .05$) recovery rates than when administered in concentrated form to confined wethers. However, Vander Noot et al. (1967) and Kiesling et al. (1969) when Cr_2O_3 was administered impregnated in shredded paper to confined horses and grazing steers, respectively, found this administration technique no better than other methods and resulted in wide variations among animals.

II. TIME AND FREQUENCY OF FEEDING CHROMIC OXIDE

The frequency of Cr_2O_3 feeding depends upon the balance desired between two opposing considerations: (1) the more frequently Cr_2O_3 is fed the more labor required and the more stress on the animals (2) the more frequently Cr_2O_3 is fed the less variation in excretion pattern (Hardison et al, 1956; Brisson et al., 1957; McGuire et al., 1966).

When Cr_2O_3 was incorporated into a concentrate ration and fed ad libitum no difference ($P < .05$) in fecal output values was obtained by total collection or by the indicator method, but in all cases the recovery rate was slightly less than 100% in confined ruminants (Kane et al., 1950; Crampton and Lloyd, 1951; Kane et al., 1953; Clanton, 1962; Lassiter et al., 1966; Phar et al., 1971).

When Cr_2O_3 was administered once daily to confined steers a high recovery rate and symmetrical excretion patterns were observed (Putnam et al., 1957; Putnam et al., 1958). Bloom et al. (1957), Bradley et al. (1958), McCoy et al. (1966) and Thomas (1975) reported similar Cr_2O_3 excretion patterns when the indicator was administered once daily to confined cattle. However, no diurnal excretion of Cr_2O_3 was found by Brisson and Pigden (1958) in a similar study.

The administration of Cr_2O_3 twice daily to confined sheep (Elam et al., 1962; Christian et al., 1965; MacRae and Armstrong, 1969), dairy cows (Hardison et al., 1959; Curran et al., 1967) and ponies (Haenlein et al., 1967) resulted in mean recoveries ranging from 92.8% to 100.7%. A distinct diurnal excretion pattern of Cr_2O_3 was noted in each instance. Haenlein et al. (1967) suggested that the more removed the time of sampling from the administration of Cr_2O_3, the greater the extinction of the curve from the oscillation center indicating that the time after Cr_2O_3 administration was the major determinant for the diurnal excretion curve in horse feces.

McGuire et al. (1966) fed confined beef steers Cr_2O_3 in a complete pelleted ration once daily and six times daily at 4 hour intervals with

a recovery rate of 94.2% for both groups. He noted that Cr_2O_3 was excreted in the same general pattern, but the steers fed six times daily tended to show a slightly less total variation but more abrupt changes from hour to hour than did steers fed once daily. Elam et al. (1959) conducted a similar trial with confined beef heifers and compared feeding Cr_2O_3 incorporated into a ration once daily, twice daily and ad libitum. Recovery rates ranged from 74 to 135%. Differerences in excretion patterns of Cr_2O_3 between feeding schedules were detected ($P < .05$) although heifers fed ad libitum and those fed once daily had similar ($P < .05$) Cr_2O_3 excretion patterns. Because McGuire et al. (1966) and Elam et al. (1959) fed Cr_2O_3 mixed in a complete ration, frequency of Cr_2O_3 feeding was confounded with frequency of feeding the ration.

A maximum of 79.5% recovery of Cr_2O_3 in the feces was reported by Kiesling et al. (1969) when the indicator was administered once daily to grazing steers due to incomplete recovery of feces with the total collection harness.

Lancaster et al. (1953), Murdock et al. (1957) and Brisson (1960), however, reported fecal Cr_2O_3 recoveries of 90.3 to 98.4% when the material was administered twice daily to grazing cows. These researchers also indicated that Cr_2O_3 was excreted diurnally.

Brisson et al. (1957) compared feeding Cr_2O_3 once, twice, and six times daily to grazing dairy cows and steers. Recovery rates were low due to the incomplete recovery of feces. However, as the frequency of Cr_2O_3 feeding increased, the amplitude of the Cr_2O_3 excretion curve decreased. When dosed six times daily, Cr_2O_3 was excreted at a constant

rate which could be estimated from a fecal sample taken at any time. From these results Brisson et al. (1957) hypothesized that an important factor controlling the shape and amplitude of the Cr_2O_3 excretion curve of grazing animals is the relationship between time of Cr_2O_3 administration and grazing periods which agrees with Lambourne (1957a). Smith and Reid (1955) however, noted that the effectiveness of measuring fecal output by the Cr_2O_3 method was the same whether Cr_2O_3 was administered at 6:00 A. M. or 4:00 P. M. or at 6:00 A. M. and 4:00 P. M. in grazing cows. But, indiscriminate times for sampling may yield erroneous estimates of fecal Cr_2O_3 concentration due to a definite variation in Cr_2O_3 excretion.

A study of Cr_2O_3 in "barn feeding conditions" (Hardison et al., 1956) revealed a recovery range of 97 to 103% when dairy cows were administered Cr_2O_3 twice daily and a recovery range of 91 to 111% when administered once daily. They indicated that if the indicator was fed twice daily, random sampling of feces would allow precise estimates of fecal output. Error from once-a-day administration of the indicator was approximately five times greater than error resulting from twice-a-day administration.

Comparison of feeding Cr_2O_3 once daily with feeding Cr_2O_3 once every other day (Nelson and Green, 1969) indicated recovery rates of 103% with once a day feeding and recovery rates of 76% on the day of administration and 98% on the following day when fed every other day.

Troelsen (1961, 1965) found results contradictory to Nelson and Green (1969) reporting unsatisfactory recovery and uneven distribution of fecal Cr_2O_3 when administered to confined sheep once every 48 hours.

III. TIME AND FREQUENCY OF FEEDING RATIONS

The relationship between time of administering Cr_2O_3 and feed consumption may slightly affect rate of passage, presumably through its relation to grazing periods. Lambourne (1957a) reported that doses of Cr_2O_3 given at or near times of greatest feed intake were passed more rapidly by grazing sheep.

Confined sheep fed twice daily which consumed the total ration soon after feeding were reported to have recovery rates of 92.8% (Christian et al., 1965) and 99.6% (MacRae et al., 1969). Recovery rates of 100.7% with confined sheep (Elam et al., 1962) and 102.5% with confined steers (Cross et al., 1973) were reported when the animals were fed ad libitum.

Haenlein et al. (1966) indicated a recovery rate of 98.4% with horses fed at 12 hour intervals, whereas Knapka et al. (1967) reported that 81.5% of Cr_2O_3 was recovered in the feces of partially confined burrows fed at 7:30 A. M. and 3:30 P. M. when Cr_2O_3 was administered at the time of feeding.

Diurnal Cr_2O_3 excretion patterns have been reported when the ration was fed once daily (Bradley et al., 1958; Thomas, 1975), twice daily (Kane et al., 1952; Kameoka et al., 1956), four times daily (Bloom et al., 1957) and ad libitum (Elam et al., 1962).

Kane et al. (1952) and Putnam et al. (1958) reported that ration feeding schedules had no influence upon the general characteristics of Cr_2O_3 excretion curves of confined ruminants when Cr_2O_3 was fed twice and once daily, respectively. However, Kameoka et al. (1956) indicated

that time of ingestion influenced the excretion rate of fecal Cr_2O_3 of confined goats when Cr_2O_3 contained in the feed was administered twice daily.

Elam et al. (1959) reported a difference ($P < .05$) in Cr_2O_3 excretion pattern between limited-feeding ration once daily, full-feeding ration once daily, full-feeding ration twice daily and ad libitum feeding of confined Hereford heifers when Cr_2O_3 was incorporated into the ration. No difference ($P < .05$) in excretion pattern was found by McGuire et al. (1966) when confined Angus steers were fed a pelleted ration containing Cr_2O_3 once daily or six times daily. Due to the incorporation of Cr_2O_3 into the ration, frequency of feeding was confounded with frequency of Cr_2O_3 administration.

Recovery rates of Cr_2O_3 from grazing cattle of 65 to 141% reported by Smith and Reid (1955) varied more than recovery rates of 78 to 107% reported by Brisson et al. (1957). Murdock indicated 94.0, 90.3 and 98.4% as the recovery rates obtained from three grazing Holstein heifers. Low recoveries of Cr_2O_3 in the feces were reported by Kiesling et al. (1969) indicating a maximum recovery of 79.5% at 5:00 P. M. due to incomplete recovery of feces. These reports indicated a distinct Cr_2O_3 excretion pattern as did reports of Brisson (1960) and Lancaster et al. (1953).

Reid (1952), Raymond and Minson (1955) and Langlands et al. (1967) reported that Cr_2O_3 excretion pattern varied with grazing behavior. However, Lambourne and Reardon (1963) found no relationship between Cr_2O_3 excretion pattern and grazing pattern.

IV. FREQUENCY OF SAMPLE COLLECTION

Since Cr_2O_3 is not excreted at a uniform rate (Crampton and Lloyd, 1951; Hardison and Reid, 1953; Bradley et al., 1958; Davis et al., 1958; McGuire et al., 1966) indiscriminate fecal sampling can result in serious biases in estimating quantity of feces. In order to obtain samples which result in the mean daily fecal Cr_2O_3 excreted rate, collections must be acquired either at the times of the inflection points or either combined samples equidistant from the mean Cr_2O_3 excretion (i. e., relative maximum and relative minimum points). However, if the Cr_2O_3 excretion curve is known, samples may be taken at any time and corrected to the mean.

Fecal samples taken at 12 hour intervals (Hardison et al., 1959; Kane et al., 1952; Putnam et al., 1958) were reported to yield estimates of total fecal dry matter output very similar to the actual total fecal dry matter obtained from total fecal collection of confined ruminants. Hardison et al. (1959) composited fecal samples of 6:00 A. M. and 6:00 P. M. and obtained recovery rates from 89.7 to 97.5% compared to 89.4 to 97.5% recovery from samples taken from mixed total fecal collections.

Thomas (1975) reported optimum collection times at 1:24 A. M. and 11:12 A. M. in a study with penned beef cows. Davis et al. (1958) also reported the same time interval as being the optimum points of collection although their samples were taken at 6:00 A. M. and 4:00 P. M. with Cr_2O_3 recovery of $102 \pm 4.3\%$ for confined dairy cows.

Elam et al. (1962) combined fecal samples at 8:00 A. M. and 4:00 P. M. of confined sheep and reported Cr_2O_3 recovery rates between 94

and 100%. Fecal samples composited from these times resulted in a Cr_2O_3 recovery of 81.5% (Knapka et al., 1967) when taken from partially confined burrows.

Compositing four fecal samples daily were found to be adequate in estimating fecal excretion from confined sheep (Lassiter et al., 1966) and grazing animals (Kane et al., 1953). However, Brisson et al., (1957) composited four fecal samples taken at 4 hour intervals from 8:00 A. M. to 8:00 P. M. and obtained a Cr_2O_3 recovery of only 85.4% from grazing animals.

Lancaster et al. (1953) reported that fecal output could be predicted as accurately from morning grab samples alone as from morning and evening grab samples together when studying grazing dairy cattle.

Coop and Hill (1962) combined grab samples at 8:00 A. M. and 5:00 P. M. and obtained a Cr_2O_3 concentration within 1% of the mean concentration of all samples collected at 2 hour intervals from grazing sheep. Combined fecal collections at 6:00 A. M. and 4:00 P. M. have been reported to be in good agreement with total collection values with recovery rates near 100% for grazing ruminants (Hardison and Reid, 1953; Smith and Reid, 1955; Hardison et al., 1956; Murdock et al., 1957).

Corbett (1960) indicated that grabbing of samples upon each defecation is preferred to the non-random grab sampling of feces at fixed times of the day in determining the natural Cr_2O_3 excretion pattern.

Brisson (1960) obtained a coefficient of variation of 15.5% in fecal Cr_2O_3 concentration from 660 grab samples taken from grazing cows. From this data it was calculated that approximately 40 samples would be

required to predict the true mean concentration of feces excreted at a specific time within $\pm$ 5% (P = .05).

CHAPTER III

ANIMAL VARIATION IN CHROMIUM SESQUIOXIDE EXCRETION PATTERNS OF GRAZING COWS[1]

I. SUMMARY

The chromium sesquioxide (Cr_2O_3) diurnal excretion patterns of 40 mature lactating Angus cows were characterized with the Fourier series: $\hat{y} = A_0 + A_1 \sin(ct) + A_2 \cos(ct) + A_3 \sin(2ct) + A_4 \cos(2ct)$ where $\hat{y}$ = mg Cr_2O_3/g fecal DM at time t, A_0 = mean fecal Cr_2O_3 concentration, c = the fundamental period radians/hour and t = time (hours). C was found to be circadian and was fixed at 0.1309 corresponding to a 24 hour fundamental period. Cows were allowed either fescue-legume or fescue pastures. Within pasture quality, size of cow was intentionally confounded with pasture (2 pastures for each pasture quality). Within-cow standard deviation was .45 mg cr_2O_3/g fecal DM. Pasture quality, pasture within pasture quality, and cow weight influenced A_0 ($P < .01$, $R^2 = .68$) much more than other A_i ($P > .10$, $R^2 = .10 - .20$). No influence ($P > .10$) was found on any other parameter except for the influence of calf weaning weight and percent butterfat on A_1 ($P < .05$) for cows grazing fescue pastures. No cow characteristics measured influenced A_1 for cows grazing fescue-legume pastures. Therefore, an interaction between pasture quality and calf weaning weight ($P < .02$) and between pasture quality and percent butterfat ($P < .01$) were detected for A_1.

Although cows were shown to differ in Cr_2O_3 excretion patterns, an unbiased estimate of A_0 could be predicted. Each cow's model was

evaluated at t = 8:00 A. M. and 5:00 P. M. Regressing A_0 values on means of these values gave a b value of .97 $\pm$ .020 (R^2 = .98).

II. INTRODUCTION

Quantity of feces excreted by grazing ruminants has been estimated by many researchers with the chromium sesquioxide (Cr_2O_3) dilution technique. A serious problem with this technique is the uneven excretion rate of Cr_2O_3 (Lancaster et al., 1953; Smith and Reid, 1955; Brisson et al., 1957; Brisson, 1960). A procedure for sampling and feeding Cr_2O_3 at 8:00--9:00 A. M. and 3:00--5:00 P. M. has been widely adopted as convenient with the assumption that the diurnal excretion pattern is compensated for by sampling at equidistant points above and below the inflection point of a symmetrical excretion curve (Linkous et al., 1954; Smith and Reid, 1955; Lambourne, 1957b; Elam et al., 1962; Lambourne and Reardon, 1963; Troelsen, 1965).

Most of the work concerning the diurnal excretion pattern of Cr_2O_3 has been conducted with confined animals and the work reported concerning the excretion pattern of grazing animals has usually been limited to intensive measurements on small numbers of animals (Hardison and Reid, 1953; Lambourne, 1957a; Kiesling et al., 1969). Hardison and Reid (1953), Smith and Reid (1955), Raymond and Minson (1955) and Brisson et al., (1957) have reported considerable differences in the periodicity of excretion between penned and grazing animals. Blaxter et al. (1956) reported different fecal excretion patterns for sheep fed different quantities and forms of dried grass. Lambourne (1957b) discussed

theoretical considerations indicating that the Cr_2O_3 excretion pattern would depend upon rate of passage and therefore on level of intake and ration digestibility.

Systematic deviations in excretion pattern could lead to biases in estimation of fecal quantity. The purpose of this research is to determine animal variation in Cr_2O_3 and acid detergent lignin excretion patterns of Angus cows grazing fescue and fescue-legume pastures.

III. MATERIALS AND METHODS

Forty mature lactating Angus cows were selected to represent the variation in mature cow fall weight and milk production of Angus cows. A stratified randomization based on mature cow fall weight and progeny weaning weights was employed to allot cows to two types of pastures managed to provide distinctly different qualities of forage. This stratification was employed to insure a large variation in both cow weight and milking ability in both pasture qualities. The low quality pasture consisted of a homogeneous sward of tall fescue (Festuca arundinaceae) managed to allow the forage to mature. The high quality pasture consisted primarily of tall fescue (approximately 70% of total forage available) and regal ladino clover (Trifolium repens L., approximately 30% of total forage available). This pasture was mowed regularly to maintain the plants in a vegetative stage of growth.

Within pasture quality animals were allotted to two 20 acre pastures (10 cows with calves/pasture) according to cow fall weight. Within pasture quality, cow size (weight) was intentionally confounded with

pasture so that large cows could be mated to large bulls. Only small differences in species composition or forage quality were apparent between pastures within pasture quality (Table 1); whereas, the available forage from the fescue-legume pasture was higher ($P < .05$) in crude protein and lower ($P < .05$) in crude fiber than the fescue pasture. The samples for this analysis were obtained by the cage and strip procedure (5 randomly placed cages per pasture) described by Linehan (1952).

No estimates of either forage intake or fecal output independent of the Cr_2O_3 dilution technique were made. Certain cow measurements, however, were taken to provide information concerning nutrient requirements and to provide information useful in explaining animal variation in Cr_2O_3 excretion patterns. Cow weight and fatness were determined at the time the diurnal excretion pattern was estimated. Fatness was estimated ultrasonically at the 12th rib (Swaim et al., 1966). Cow milk productions were estimated monthly during lactation for a total of seven estimates by the calf-suckle technique (Drewery et al., 1959). These values were averaged to obtain one estimate of milk production per cow. Total milk collections were taken during the mean fourth, fifth and sixth months of lactation with a milking machine after the intramuscular injection of 2 c. c. of oxytocin. Butterfat was estimated with the Mark III Milk-O-Tester. The calves were weaned at a mean age of 240 days. The means and standard deviations of these cow characteristics are shown in Table 2.

Cows were fed sequentially by pasture 10 grams of Cr_2O_3 in 263 grams of a pelleted feed in individual stalls at approximately 8:00 A. M.

TABLE 1. CHARACTERISTICS OF EXPERIMENTAL PASTURES[a]

Item	Pasture Quality							
	Fescue + Legume				Fescue			
	Large Cow Pasture		Small Cow Pasture		Large Cow Pasture		Small Cow Pasture	
	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD
Dry Matter	35.60[c]	6.40	36.12[c]	6.60	29.46[cd]	4.70	31.67	8.00
Crude Protein (%)[b]	14.84[c]	1.99	15.11[c]	2.01	10.29[d]	0.61	11.50[d]	2.43
Crude Fiber (%)[b]	26.63[c]	1.67	25.76[c]	1.77	30.06[d]	2.04	29.62[d]	1.39
Ash (%)[b]	9.49[c]	0.51	10.18[c]	1.60	13.52[d]	2.28	10.21[c]	1.66
Ether Extract (%)[b]	3.02[c]	0.42	3.25[c]	0.43	2.97[c]	1.93	2.50[c]	0.38
Gross Energy (Kcal/g DM)[b]	4.19[c]	0.22	4.04[c]	0.20	4.00[c]	0.24	4.29[c]	0.22
ADF (%)[b]	35.56[c]	1.63	39.37[c]	2.58	41.89[c]	1.91	43.90[c]	1.62
ADL (%)[b]	6.59[c]	0.54	7.84[c]	0.94	6.97[c]	0.83	7.06[c]	0.98

[a]Means were separated by Duncan's New Multiple Range Test procedures (Snedecor and Cochran, 1967).

[b]All values are on a dry matter basis.

[c,d]Means on a line with different superscripts differ significantly ($P < .05$).

TABLE 2. MEANS AND STANDARD DEVIATIONS OF COW CHARACTERISTICS

Cow Characteristics	Fescue-Legume				Fescue			
	Large Cow Pasture		Small Cow Pasture		Large Cow Pasture		Small Cow Pasture	
	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD
Number of cows	10		10		10		10	
Cow weight (kg)	493.20[b]	47.45	421.65[c]	42.52	462.72[d]	33.57	421.62[c]	26.52
Cow fat (mm)	8.50[b]	4.74	6.67[b]	4.06	7.90[b]	3.54	8.50[b]	4.92
Calf weaning weight (kg)	243.17[b]	25.44	247.88[b]	20.76	234.96[c]	29.54	224.26[d]	28.66
Milk production (kg)	7.20[b]	1.83	6.68[b]	1.53	7.28[b]	1.73	7.42[b]	1.60
Butterfat content (%)	3.69[bc]	1.46	3.96[b]	1.42	3.32[c]	1.04	3.47[c]	1.13

[a]Means were separated by Duncan's New Multiple Range Test procedures (Snedecor and Cochran, 1967).

[b,c,d]Means on a line with different superscripts differ significantly ($P < .05$).

and 5:00 P. M. Each group of 10 cows remained in the stalls no longer than 10 minutes during each feeding. All cows had been managed in this manner for a period of 72 days prior to this experiment.

Chromium sesquioxide excretion patterns were estimated for a continuous 48 hour period during the early summer. The 48 hour period was divided into six 8 hour periods. One technician per period sampled each fecal passage of every cow in respective pastures. A grazing behavior study was incorporated into the experiment; technicians estimated, at 15 minute intervals, numbers of cows "grazing" or "not grazing." Fecal samples were frozen until dry matter (A. O. A. C., 1960), chromium (Williams et al., 1962), acid detergent fiber and acid detergent lignin (Van Soest and Wine, 1967) determination.

The Gauss-Newton iterative process was employed to find the least-squares estimates of the Fourier coefficients for data from each cow employing the model:

$$\hat{y} = A_0 + A_1 \sin(ct) + A_2 \cos(ct) + A_3 \sin(2ct) + A_4 \cos(2ct)$$

where y = predicted Cr_2O_3 fecal concentration in mg Cr_2O_3 per gram fecal dry matter at time t, A_0 = mean Cr_2O_3 fecal concentration (mg/g fecal dry matter), c = the fundamental period or the length of the cycle in radians per hour and t = time in hours (hour 0 = 8:00 A. M. of first day of collection).

The sampling technique employed in this experiment resulted in a disproportionate distribution of points, but enough data points for each cow were distributed over the range in time so that equations could be developed for predicting diurnal excretion patterns for each group of cows (Figure 1).

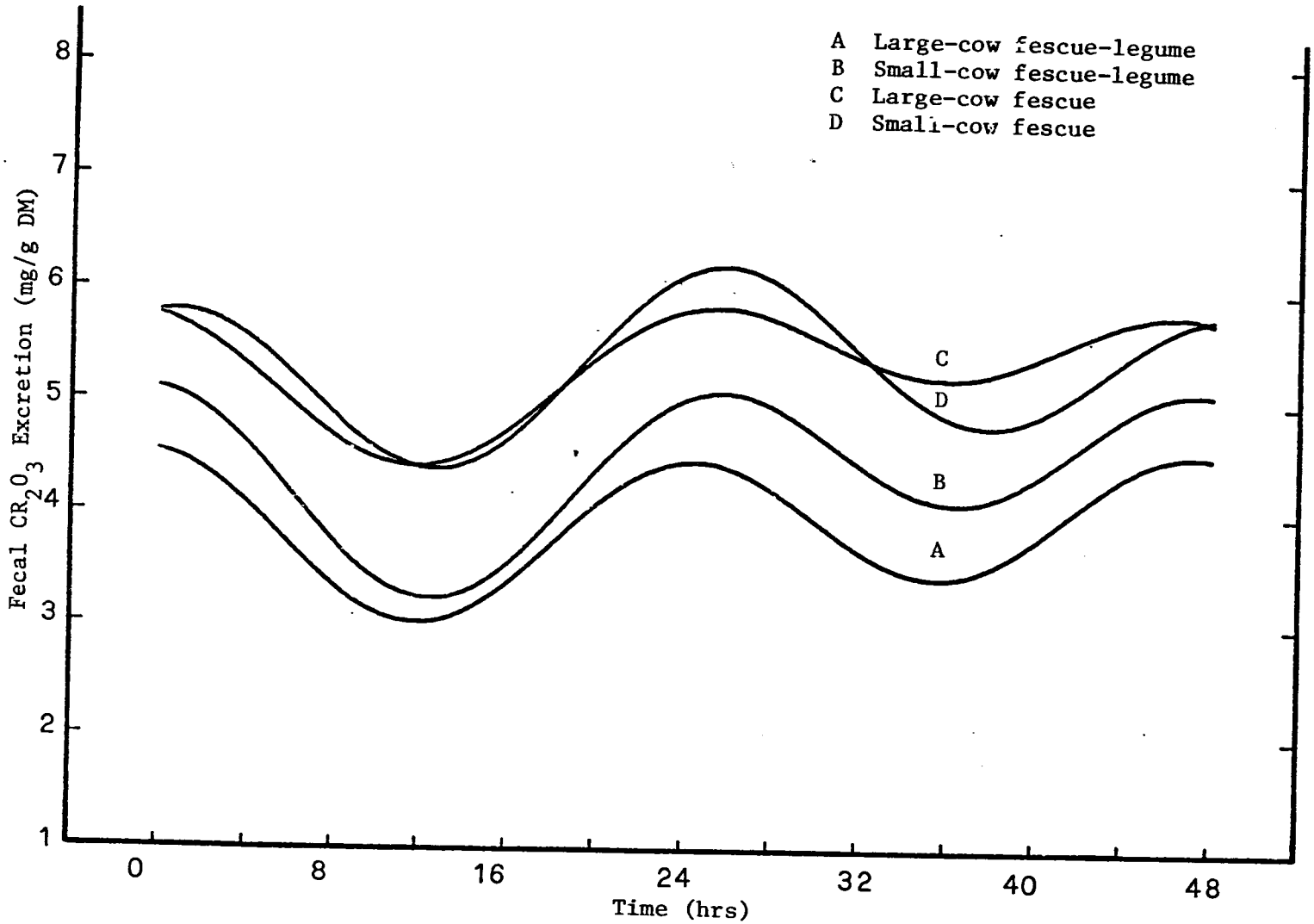


Figure 1. Diurnal excretion patterns of Angus cows grazing fescue and fescue-legume pastures (each curve is the average of 10 cows).

Although considerable physical and theoretical evidence exists that the fundamental period is 24 hours (Lambourne, 1957b), c was estimated initially from the data. The mean estimate obtained from all cows for c was 0.132 $\pm$ 0.0057 radians/hour which could not be declared different ($P > .10$) from the value of 0.1309 radians/hour which corresponds to a 24 hour fundamental period. Also, little animal variation was noted for c (coefficient of variation = 0.043). Therefore, c was fixed at 0.1309 radians/hour and the other five parameters (A_0, A_1, A_2, A_3 and A_4) were estimated from data for each cow. These estimates were then employed as a data set in analyses of variance procedures.

IV. RESULTS AND DISCUSSION

General Characteristics. A diurnal pattern in Cr_2O_3 excretion was noted for all cows. These patterns are more rhythmic in nature and are more distinctly diurnal than those reported by Kane et al. (1952) and Kameoka et al. (1956). The concentration of Cr_2O_3 in the feces of all cows was at its relative maximum at approximately 9:00 A. M. and at its relative minimum at approximately 8:00 P. M. for each series (day). These results agree with Brisson et al. (1957) when he administered Cr_2O_3 in gelatin capsules at 8:00 A. M. and 4:30 P. M. to grazing cattle. Lancaster et al. (1953), Linkous et al. (1954), Raymond and Minson (1955) and Smith and Reid (1955) also noted lower Cr_2O_3 concentrations in the afternoon fecal samples of grazing cattle.

The model obtained when all the data were pooled was: $y = 4.694 - 0.152 \sin(ct) + 0.208 \cos(ct) + 0.542 \sin(2ct) - 0.340 \cos(2ct)$. Of the parameters estimated only A_0 and A_1 were influenced ($P < .05$)

by any of the variables considered. Although the numerical value of A_0 has intrinsic meaning (average fecal Cr_2O_3 concentration) the numerical value of the other parameters do not. In general terms, however, the other parameters (A_1, A_2, A_3 and A_4) influence the shape of the curve. Specifically, as the value of A_1 (the sine function of the first harmonic) becomes more negative, the curve generally becomes flatter. The characteristics of the curve will be discussed in two parts: (1) variations in the average fecal Cr_2O_3 concentration (A_0) and (2) variations in curve shape (A_1).

The predicted rhythms expressed graphically in Figure 1 are the non-stationary type (mean value generally increase as time progresses). The presence of technicians in the pastures possibly interfered with grazing thus reducing intake, reducing the amount of fecal dry matter produced and therefore increasing fecal Cr_2O_3 concentration. This, however, would mean a relatively short rate of passage (less than 48 hours). Another possibility is that a natural change in either intake or digestibility or both was taking place resulting in a rising Cr_2O_3 concentration in fecal dry matter. Acid detergent lignin (ADL) was excreted in a linear fashion ($P < .0001$) through the 48 hour interval. The ADL values decreased ($P < .0001$ as time progressed at the rate of -.0485% ADL per hour giving further evidence to a decrease in dry matter intake possibly accompanied by an increase in digestibility.

Variations in Average Fecal Cr_2O_3 Concentrations. Cows allowed fescue pastures had higher ($P < .0001$) A_0 values than those allowed fescue-legume pastures (Table 3 and Figure 1) indicating smaller amounts of fecal dry matter production. When pasture within pasture quality was included in the model, an influence ($P < .03$) on A_0 was noted. When the cow characteristics shown in Table 4 were added to the model, however, they accounted for the influence of pasture within pasture quality on A_0 so that its influence was no longer significant ($P > .37$). Thus, it seems that the influence of pasture within pasture quality was completely accounted for by the differences between pastures in the various cow characteristics. As can be seen in Table 4, higher values for A_0 (higher fecal Cr_2O_3 concentration) were associated with lower cow weights, smaller calf weaning weights, fatter cows and cows giving less milk but more butterfat. In other words, those cows with larger nutrient requirements had lower fecal Cr_2O_3 concentration and therefore larger amounts of feces as would be expected. In general, values for A_0 decreased ($P < .0001$) as percent time spent grazing increased ($b = -0.066\%$ Cr_2O_3 per percent time spent grazing). The proportion of time spent grazing accounted for 41% of the variation in A_0. This agrees with the supposition of Reid (1952) that fecal Cr_2O_3 concentration is influenced by grazing habits and the conclusions of Hancock (1953) that a relationship between grazing time and feed requirements exists. Raymond and Minson (1955) and Langlands (1967) also found that fecal Cr_2O_3 concentration varies with changes in the pattern of eating behavior. Lambourne and Reardon (1963), however, found no relationship

TABLE 3. LEAST SQUARES MEANS FOR PARAMETERS DESCRIBING THE EXCRETION PATTERN THAT WERE INFLUENCED BY CERTAIN COW CHARACTERISTICS

	Pasture Quality[a]		
Parameter	Fescue + Legume	Fescue	Significance[b]
A_0	4.269	5.371	.0001
A_1	-0.095	-0.192	NA[c]

[a]The model also contained terms for pasture within pasture quality, cow weight, calf weaning weight, cow fat, milk production, percent butterfat, cow weight x pasture quality calf weaning weight x pasture quality, cow fat x pasture quality, milk production x pasture quality, percent butterfat x pasture quality.

[b]Level of significance as determined by the F test for partial sum of squares (prob < F).

[c]Not applicable because pasture quality interacted with calf weaning weight ($P < .02$) and percent butterfat ($P < .01$).

TABLE 4. PARTIAL REGRESSION COEFFICIENTS FOR PARAMETERS DESCRIBING THE EXCRETION PATTERN THAT WERE INFLUENCED BY CERTAIN COW CHARACTERISTICS

	Parameters[a]					
	A_0		A_1			
	Both Pasture Qualities		Fescue-Legume		Fescue	
Cow Characteristics[b]	b_1	Significance	b_1	Significance	b_1	Significance
Cow weight	-.0780	.02	+.0003	.85	-.00246	.25
Calf weaning weight	-.0029	.40	-.0011	.56	+.00577	.02
Cow fat	+.0306	.28	-.0059	.76	+.00993	.54
Milk production	-.1392	.10	+.0002	.99	-.08741	.16
Butterfat content	+.0158	.03	-.0032	.36	+.01310	.03
R^2	.75		.38		.67	

[a]The other parameters (A_2, A_3, A_4) were not influenced ($P < .10$) by these cow characteristics.

[b]The model also contained pasture within pasture quality.

[c]Level of significance as determined by the F test for partial sum of squares (Probability > F).

between Cr_2O_3 excretion pattern and grazing pattern. The average grazing time for all animals for both days of observation was 35.1 $\pm$ 5.48 percent. Values near 42% were reported by Wagnon (1963), Herbel and Nelson (1966). Nelson and Furr (1966), Sneva (1970) and Kropp et al. (1973) for cattle grazing arid and semi-arid Western ranges.

Variation in Curve Shape. Of the parameters that describe the shape of the Cr_2O_3 excretion curve, only A_1 (the coefficient of the sine function of the first harmonic) was influenced by the factors considered in this experiment. Pasture quality influenced ($P < .04$) A_1, whereas, pasture within pasture quality had no influence ($P > .10$). The numerical value for A_1 was more negative (Table 3) and the curves appeared flatter (Figure 1) for cows on fescue-legume than for cows on fescue pastures.

A pasture quality x weaning weight ($P < .02$) and a pasture quality x percent butterfat ($P < .01$) interaction, however, was detected for A_1. As shown in Table 4, butterfat content and calf weaning weight influenced ($P < .02$) A_1 for cows grazing fescue pastures but not ($P > .10$) for cows grazing fescue-legume pastures. The model accounted for 68% of the variation in A_1 for cows in fescue pastures ($P < .02$) but only 38% of the variation in A_1 for cows in fescue-legume pastures. A test for homogeneity of regression indicated that cows grazing fescue pastures expressed different ($P < .01$) Cr_2O_3 excretion patterns whereas no difference ($P > .05$) was detected for cows grazing fescue-legume pastures. The variation in A_0 was much larger among cows grazing fescue pastures than for cows grazing fescue-legume pastures (Figures 1 and 4) indicating either more variation in forage intake or forage digestibility

or both. These larger variations would be related to larger variations among cows for rates of passage and therefore larger variations in Cr_2O_3 excretion pattern would be expected. Blaxter et al. (1956); Shellenberger and Kesler (1961); and, Putnam et al. (1967) have shown that as nutrient requirements (and therefore forage intake) increases, rate of passage also increases. As rate of passage increases, the excretion pattern of Cr_2O_3 also increases in amplitude (Lambourne, 1957b).

Another possible explanation of the variation among cows in excretion pattern of Cr_2O_3 is variation among cows in forage selectivity. Several researchers have shown that grazing cattle and sheep select higher quality species from mixed swards and select higher quality segments of the plant from homogenous swards than what is available (Hardison et al., 1954; Heady and Torrell, 1959; Ridley et al., 1963; Hodge and Doyle, 1967). Coppock et al. (1974) showed a large variation among dairy cows in willingness to select a balanced diet when allowed an array of feedstuffs. Thus, a possibility exists that cows grazing the same pasture consume a wide variation in quality of diet. Lambourne (1957a) showed different excretion rates of monastral blue for sheep fed forage ranging from 71 to 81% digestibility. Although the fescue-legume pasture consisted of a wider array of plant species, selective grazing was more apparent for cows grazing fescue pastures as evidenced by a greater tendency to over-graze areas of immature plants and to under-graze areas of mature plants. None of the parameters that describes the shape of the excretion curve were influenced ($P > .10$) by the proportion of time the cows spent grazing.

Time of Sampling. Assuming that the most convenient times of fecal collection are the times of feeding, each cow's model was evaluated at t = 8:00 A. M. and 5:00 P. M. Regressing A_0 values on means of these values resulted in a b value of .97 $\pm$ .020 (R^2 = .98, Figure 2). This standard error does not include within-cow variation. If the within-cow variation is included the standard error is increased to .030. Even though animals varied in their Cr_2O_3 excretion patterns and this variation was associated with certain cow characteristics, pooled samples taken at 8:00 A. M. and 5:00 P. M. could result in unbiased estimates of fecal Cr_2O_3 excretion. The b value obtained agrees with the value of 1.0 suggested by Hardison and Reid (1953), Linkous et al. (1954), Raymond and Minson (1955), Murdock et al. (1957) and Coop and Hill (1962). Smith and Reid (1955), however, reported that for grazing cows, chromic oxide concentration estimated in grab samples taken at 6:00 A. M. and 4:00 P. M. (y) was related to mean concentration (x) by the equation: $y = 1.13x - 0.64$ ($s_{y \cdot x}$ = 0.45 mg/g DM, R^2 = .94). This equation was developed from the data of 4 grazing cows, only 2 of which were fed twice per day. Langlands et al. (1963) also noted that biased estimates of fecal quantity were obtained when grazing animals were sampled and fed Cr_2O_3 at 8:00 to 9:00 A. M. and 4:00 to 4:30 P. M.

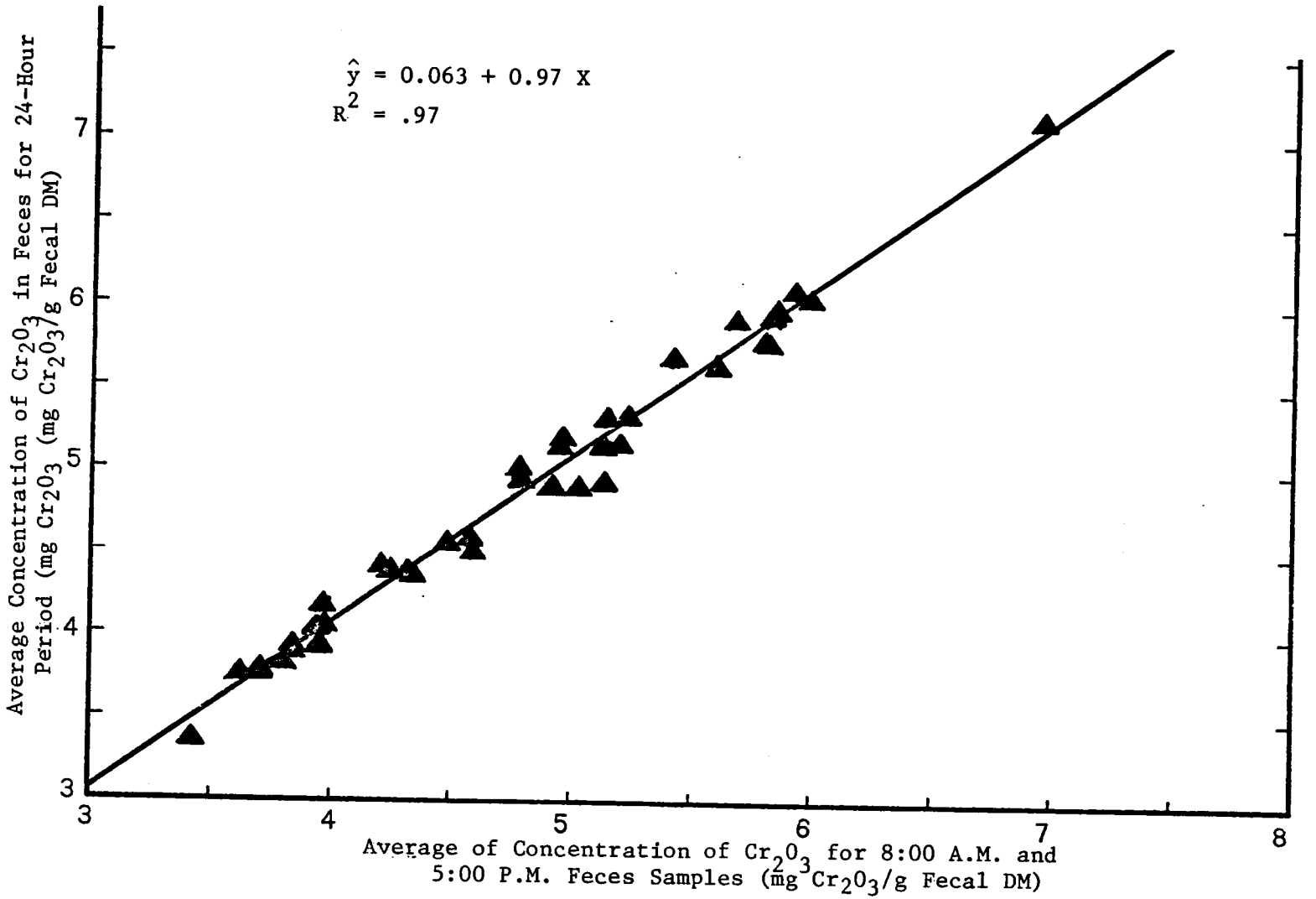


Figure 2. Relationship of average Cr_2O_3 excretion rate (A_0) with estimated excretion rate from the average of point estimates at 8:00 A.M. and 5:00 P.M.

LITERATURE CITED

LITERATURE CITED

A. O. A. C. 1960. Official Methods of Analysis (9th ed.). Association of Official Agricultural Chemists, Washington, D. C.

Blaxter, K. L., N. Graham and F. W. Wainman. 1956. Some observations on the digestibility of food by sheep, and on related problems. British J. Nutr. 10:69.

Bloom, S., N. L. Jacobson, R. S. Allen, L. D. McGilliard and P. G. Homeyer. 1957. Effects of various hay:concentrate ratios on nutrient utilization and production responses of dairy cows. II. Observations on ration digestibility and on the excretion pattern of chromic oxide. J. Dairy Sci. 40:240.

Bradley, N. W., R. M. Forbes, W. W. Albert, G. E. Mitchell, Jr. and A. L. Neumann. 1958. Use of chromic oxide method for determining digestible energy and protein in complete pelleted steer rations. J. Anim. Sci. 17:1199 (Abstr.).

Brisson, German J. 1960. Indicator methods for estimating amount of forage consumed by grazing animals. Proc. 8th Int. Grassl. Congr., 435.

Brisson, German J. and W. J. Pigden. 1958. Chromic oxide in a sustained-release pellet to reduce variation in its diurnal excretion pattern in cattle. J. Anim. Sci. 17:2000 (Abstr.).

Brisson, German J., W. J. Pigden and P. E. Sylvestre. 1957. Effect of frequency of administration of chromic oxide on its fecal excretion pattern by grazing cattle. Can. J. Anim. Sci. 37:90.

Chanda, R., H. M. Clapham, Mary L. McNaught and E. C. Owen. 1951. The use of chromium sesquioxide to measure the digestibility of carotene by goats and cows. J. Agric. Sci. 41:179.

Christian, K. R., V. J. Williams and A. H. Carter. 1965. The estimation of faeces output of stall-fed sheep using the chromic oxide method. N. Z. J. Agric. Res. 8:530.

Clanton, Donald C. 1962. Variation in chromic oxide methods of determining digestibility of hand-fed beef cattle rations. J. Anim. Sci. 21:214.

Clawson, A. J., J. T. Reid, B. E. Sheffy and J. P. Willman. 1955. Use of chromic oxide in digestion studies with swine. J. Anim. Sci. 14:700.

Coop, I. E. and M. K. Hill. 1962. The energy requirements of sheep for maintenance and gain. II. Grazing sheep. J. Agric. Sci. 58:187.

Coppock, C. E., R. W. Everett, N. E. Smith, S. T. Slack and J. P. Harner. 1974. Variation in forage preference in dairy cattle. J. Anim. Sci. 39:1170.

Corbett, J. L. 1960. Faecal-index techniques for estimating herbage consumption by grazing animals. Proc. 8th Int. Grassl. Congr., 438.

Crampton, E. W. and L. E. Lloyd. 1951. Studies with sheep on the use of chromic oxide as an index of digestibility of ruminant rations. J. Nutr. 45:319.

Cross, D. L., J. A. Boling and N. W. Bradley. 1973. Chromic oxide and crude protein excretion in the bovine as influenced by water restriction. J. Anim. Sci. 36:982.

Curran, M. K., J. D. Leaver and E. W. Weston. 1967. A note on the use of chromic oxide incorporated in a feed to estimate faecal output in ruminants. Anim. Prod. 9:561.

Dansky, L. M. and F. W. Hill. 1952. Application of the chromic oxide indicator method to balance studies with growing chickens. J. Nutr. 47:449.

Davis, C. L., J. H. Byers and L. E. Luber. 1958. An evaluation of the chromic oxide method for determining digestibility. J. Dairy Sci. 41:152.

Drennan, J. J., J. H. G. Holmes and W. N. Garrett. 1970. A comparison of markers for estimating magnitude of rumen digestion. Brit. J. Nutr. 24:961.

Drewry, K. J., C. J. Brown and R. S. Honea. 1959. Relationships among factors associated with mothering ability in beef cattle. J. Anim. Sci. 18:938.

Elam, C. J., P. A. Putnam and R. E. Davis. 1959. Fecal excretion pattern of chromic oxide administered to Hereford heifers in a completely pelleted ration. J. Anim. Sci. 18:718.

Elam, C. J., P. J. Reynolds, R. E. Davis and D. O. Everson. 1962. Digestibility studies by means of chromic oxide, lignin and total collection techniques with sheep. J. Anim. Sci. 21:189.

Faichney, G. J. 1975. The effect of formaldehyde treatment of a concentrate diet on the passage of solute and particle markers through the gastrointestinal tract of sheep. Aust. J. Agric. Res. 26:319.

Fisher, L. J., C. M. Williams and J. M. Bell. 1965. Evaluating chromic oxide sustained release pellets in digestibility studies with ruminants. Can. J. Anim. Sci. 45:111.

Haenlein, G. F. W., R. C. Smith and Y. M. Yoon. 1966. Determination of the fecal excretion rate of horses with chromic oxide. J. Anim. Sci. 25:1091.

Hancock, John. 1953. Grazing behavior of cattle. Anim. Breeding 21:1 (Abstr.).

Hardison, W. A., R. W. Engel, W. N. Linkous, H. C. Sweeney and G. C. Graf. 1956. Fecal chromic oxide concentration in 12 dairy cows as related to time and frequency of administration and to feeding schedule. J. Nutr. 58:11.

Hardison, W. A., W. N. Linkous, R. W. Engel and G. C. Graf. 1959. Observation on the use of chromic oxide for estimating the fecal output of dairy animals. J. Dairy Sci. 42:346.

Hardison, W. A. and J. T. Reid. 1953. Use of indicators in the measurement of the dry matter intake of grazing animals. J. Nutr. 51:35.

Hardison, W. A., J. T. Reid, C. M. Martin and P. G. Woolfolk. 1954. Degree of herbage selection by grazing cattle. J. Dairy Sci. 37:89.

Heady, H. F. and D. T. Torrell. 1959. Forage preference exhibited by sheep with esophageal fistulas. J. Range Manage. 12:28.

Herbel, C. H. and A. B. Nelson. 1966. Activities of Hereford and Santa Gertrudis cattle on a southern New Mexico range. J. Range Manage. 19:173.

Hogan, J. P. and A. T. Phillipson. 1960. The rate of flow of digesta and their removal along the digestive tract of sheep. Brit. J. Nutr. 14:147.

Hodge, R. M. and J. J. Doyle. 1967. Diet selected by lambs and yearling sheep grazing on annual and perennial pastures in southern Victoria. Aust. J. of Exp. Agr. and Anim. Husb. 7:141.

Holmes, W., J. G. W. Jones and R. M. Drake-Brockman. 1961. The feed intake of grazing cattle: II. The influence of size of animal on feed intake. Anim. Prod. 3:251.

Hoogendoorn, A. L. and C. M. Grieve. 1969. Chromic oxide in digestibility studies with lactating dairy cows. Can. J. An. Sci. 9:383.

Huang, T. C., H. E. Ulrich and C. M. McCay. 1954. Antibiotics, growth, food utilization and the use of chromic oxide in studies with rabbits. J. Nutr. 54:621.

Irwin, Mary Isabel and Earle Wilcox Crampton. 1950. The use of chromic oxide as an index material in digestion trials with human subjects. J. Nutr. 43:77.

Johnson, D. E., W. E. Dinusson and D. W. Bolin. 1964. Rate of passage of chromic oxide and composition of digesta along the alimentary tract of wethers. J. Anim. Sci. 23:499.

Kameoka, K., S. Takahashi and H. Morimoto. 1956. Variation in the excretion of chromic oxide by ruminants. J. Dairy Sci. 39:462.

Kane, E. A., W. C. Jacobson, R. E. Ely and L. A. Moore. 1953. The estimation of the dry matter consumption of grazing animals by ration techniques. J. Dairy Sci. 36:637.

Kane, E. A., W. C. Jacobson and L. A. Moore. 1950. A comparison of techniques used in digestion studies with dairy cattle. J. Nutr. 41:583.

Kane, E. A., W. C. Jacobson and L. A. Moore. 1952. Diurnal variation in the excretion of chromic oxide and lignin. J. Nutr. 47:263.

Kiesling, H. E., H. A. Barry, A. B. Nelson and C. H. Herbel. 1969. Recovery of chromic oxide administered in paper to grazing steers. J. Anim. Sci. 29:361.

King, K. W. and W. E. C. Moore. 1957. Density and size factors affecting passage rate of ingesta in the bovine and human digestive tracts. J. Dairy Sci. 40:528.

Knapka, J. J., K. M. Barth, D. G. Brown and R. G. Cragle. 1967. Evaluation of polyethylene, chromic oxide and Cerium - 144 as digestibility indicators in borrows. J. Nutr. 92:79.

Kropp, J. R., J. W. Holloway, D. F. Stephens, Leon Knori, R. D. Morrison and Robert Totusek. 1973. Range behavior of Hereford, Hereford x Holstein and Holstein non-lactating heifers. J. Anim. Sci. 36:797.

Lambourne, L. J. 1957a. Measurement of feed intake of grazing sheep. I. Rate of passage of inert reference materials through the ruminant digestive tract. J. Agric. Sci. 48:273.

Lambourne, L. J. 1957b. Measurement of feed intake of grazing sheep II. The estimation of faeces output using markers. J. Agric. Sci. 48:415.

Lambourne, L. J. and T. F. Reardon. 1963. The use of chromic oxide to estimate the faecal output of Merinos. Aust. J. Agric. Res. 14:239.

Lancaster, R. J., M. R. Coup and J. C. Percinal. 1953. Measurement of feed intake by grazing cattle and sheep. III. Marker technique for investigating the feces output of grazing cows. N. Z. J. Agric. Res. 35:117.

Langlands, J. P., J. L. Corbett, I. McDonald and G. W. Reid. 1963. Estimation of the faeces output of grazing animals from the concentration of chromium sesquioxide in a sample of faeces. II. Comparison of estimates from samples taken at fixed times of day with estimates from samples collected from the sward. Brit. J. Nutr. 17:219.

Lassiter, J. W., Vernon Alligood and C. H. McGaughey. 1966. Chromic oxide as an index of digestibility of all-concentrate rations for sheep. J. Anim. Sci. 25:44.

Linehan, P. A. 1952. Use of cage and mower-strip methods for measuring forage consumed by grazing animals. Proc. 6th Intern. Grassl. Congr. 6:1328.

Linkous, W. N., W. A. Hardison, G. C. Graf and E. W. Engel. Fecal chromic oxide concentration in 12 dairy cows as related to time and frequency of administration and to feeding schedule. J. Anim. Sci. 13:1009 (Abstr.).

Lloyd, L. E., B. Elaine Rutherford and E. W. Crampton. 1955. A comparison titanic oxide and chromium oxide as index materials for determining apparent digestibility. J. Nutr. 56:265.

Lloyd, L. E. and C. M. McCay. 1954. The use of chromic oxide in digrstibility and balance studies with dogs. J. Nutr. 53:613.

MacRae, J. C. and D. G. Armstrong. 1969. Studies on intestinal digestion in sheep. I. The use of chromic oxide as an indigestible marker. Brit. J. Nutr. 23:15.

McCoy, G. C., H. H. Olson and A. Reed. 1968. Diurnal excretion pattern of digestibility of three complete feeds. J. Dairy Sci. 49:211.

McGurie, R. L., N. W. Bradley and C. O. Little. 1966. Effects of frequency of feeding on excretion of chromic oxide, crude protein and gross energy and on nutrient digestibility by steers. J. Anim. Sci. 25:185.

Mueller, Werner J. 1956. Feasibility of the chromic oxide and the lignin indicator methods for metabolism experiments with chickens. J. Nutr. 58:29.

Murdock, F. R., A. S. Hodgson, V. L. Miller and Fumiko Kimura. 1957. Observations on the application of the chromic oxide technique to pasture nutrition studies. J. Dairy Sci. 40:618.

Nelson, A. B. and R. D. Furr. 1966. Interval of observation of grazing habits of range beef cows. J. Range Manage. 19:26.

Nelson, A. B. and G. R. Green. 1969. Excretion of chromic oxide administered in paper to steers fed prarie hay. J. Anim. Sci. 29:365.

Phar, P. A., N. W. Bradley, C. O. Little and L. V. Cundiff. 1970. Effects of confinement and level of feed intake on digestibility on nutrients and excretion of chromic oxide, crude protein and gross energy in the bovine. J. Anim. Sci. 30:589.

Phar, P. A., N. W. Bradley, C. O. Little, L. V. Cundiff and J. A. Bolin. 1971. Nutrient digestibility using collection apparatus and indicator method for steers fed ad libitum. J. Anim. Sci. 33:695.

Pigden, W. J. and German J. Brisson. 1957. Note on a chromium oxide pellet to provide uniform release of this indicator in the rumen of cattle. Can. J. Anim. Sci. 37:185.

Putnam, P. A., J. Bond and R. Lehmann. 1967. Gestation and feed intake effects on rate of passage of chromic oxide in beef heifers. J. Anim. Sci. 26:1428.

Putnam, P. A., J. K. Loosli and R. G. Warner. 1958. Excretion of chromium oxide by dairy cows. J. Dairy Sci. 41:1723.

Putnam, P. A., K. K. Loosli, R. G. Warner and S. R. Searle. 1957. Diurnal excretion of chromium oxide and ash by dairy cows. J. Dairy Sci. 40:618 (Abstr.).

Raymond, W. F. and D. J. Minson. 1955. The use of chromic oxide for estimating the fecal production of grazing animals. J. Brit. Grassl. Soc. 10:282.

Reid, J. Thomas. 1952. Indicator methods, their potentialities and limitation. Proc. 6th Int. Grassl. Congr., 1334.

Ridley, J. R., A. L. Lesperance, E. H. Jensen and V. R. Bobman. 1963. Relationship of animal perforance to botanical composition of irrigated pastures. J. Dairy Sci. 46:128.

Schurch, A. F., E. W. Crampton, P. R. Haskell and L. E. Lloyd. 1952. The use of chromic oxide in digestibility studies with pigs fed ad libitum in the barn. J. Anim. Sci. 11:261.

Schurch, A. F., L. E. Lloyd and E. W. Crampton. 1950. The use of chromic oxide as an index for determining the digestibility of a diet. J. Nutr. 41:629.

Sharp, Susan J. and Marion F. Robinson. 1970. Intermittent and continuous faecal markers in short-term metabolic balance studies in young women. Brit. J. Nutr. 24:489.

Shellenberger, P. R. and E. M. Kesler. 1961. Rate of passage feeds through the digestive tract of Holstein cows. J. Anim. Sci. 20:417.

Smith, A. M. and J. T. Reid. 1955. Use of chromic oxide as an indicator of fecal output for the purpose of determining the intake of pasture herbage by grazing cows. J. Dairy Sci. 38:515.

Snedecor, G. W. and W. G. Cochran. 1967. Statistical Methods (6th Ed.) Iowa State University Press, Ames, Iowa.

Sneva, Forrest A. 1970. Behavior of yearling cattle on eastern Oregon range. J. Range Manage. 24:155.

Swaim, J. R., III, C. B. Ramsey and J. B. McLaren. 1966. Somoscope estimates of fatness and muscling of bulls at Ames Plantation. Tennessee Farm and Home Science Progress Report No. 58.

Thomas, James Liddell. 1975. Determination of optimal collection time of fecal samples in a chromium sesquioxide indicator digestion trial. Master's Thesis, University of Tennessee.

Troelsen, J. E. 1961. Preliminary observations in the use of a sustained release pellet for administration of chromic oxide to sheep in digestibility studies. Can. J. Anim. Sci. 41:71.

Troelsen, J. E. 1965. A note on sustained release of chromic oxide in the rumen of sheep from a chromic oxide-dental plaster pellet. Anim. Prod. 7:127.

Vander Noot, O. W., L. D. Symons, R. K. Lydman and P. V. Fonnesbeck. 1967. Rate of passage of various feedstuffs through the digestive tract of horses. J. Anim. Sci. 26:1309.

Van Soest, P. J. and R. H. Wine. 1967. Use of detergents in the analysis of fibrous feeds. IV. Determination of plant cell wall constituents. J. Ass. Official Agr. Chem. 50:50.

Wagnon, K. A. 1963. Behavior of beef cows on a California range. Calif. Agric. Exp. Sta. Bull. 799:18.

Williams, C. H., C. J. David and O. Iismaa. 1962. The determination of chromic oxide in faeces samples by atomic absorption spectrophotometry. J. Agric. Sci. 59:381.

Yadava, R. K., L. O. Gilmore and H. R. Conrad. 1973. Beet pulp pellets as the carrier of chromic oxide for determining digestibility. J. Dairy Sci. 56:592.

Yoshida, M. and H. Morimoto. 1957. Reliability of the chromic oxide indicator method for the determination of digestibility with growing chickens. J. Nutr. 61:31.

APPENDIX

TABLE 5. INDIVIDUAL COW CHARACTERISTICS OF COWS GRAZING FESCUE-LEGUME PASTURES

Pasture	Cow No.	Weight (kg)	Fat (mm)	Milk Prod. (kg)	Milk Fat (%)	Calf Weaning Weight (kg)
Large	40	469.93	7	4.32	2.3	226.80
Large	180	530.71	16	3.11	3.2	276.70
Large	206	516.65	11	6.17	6.3	239.05
Large	335	510.75	6	4.85	3.1	290.30
Large	386	435.46	4	2.93	4.7	228.61
Large	1286	444.53	4	4.85	2.5	229.07
Large	1337	534.34	9	3.09	1.5	210.92
Large	1516	548.86	15	3.64	5.0	224.53
Large	1668	524.82	11	5.44	4.7	242.68
Large	2497	415.95	2	4.80	3.6	263.09
Small	25	360.16	3	3.34	3.7	232.24
Small	28	367.42	2	3.84	4.6	232.24
Small	85	438.18	8	5.43	4.8	281.23
Small	429	460.40	10	2.36	1.7	258.55
Small	445	456.78	5	3.83	4.2	256.28
Small	1436	365.60	1	4.05	1.8	244.94
Small	1561	433.64	12	3.42	4.7	242.68
Small	2477	381.93	3	3.90	3.8	233.60
Small	3100	415.04	8	3.94	6.1	213.19
Small	5106	475.83	11	5.27	3.9	269.44

TABLE 6. INDIVIDUAL COW CHARACTERISTICS OF COWS GRAZING FESCUE PASTURES

Pasture	Cow No.	Weight (kg)	Fat (mm)	Milk Prod. (kg)	Milk Fat (%)	Calf Weaning Weight (kg)
Large	35	427.75	2	6.22	3.0	274.43
Large	140	518.92	13	3.29	4.0	242.68
Large	448	451.33	3	5.79	3.0	281.23
Large	577	500.77	6	4.52	4.8	232.24
Large	836	500.32	9	3.12	3.9	225.44
Large	845	450.43	10	4.02	1.3	181.44
Large	890	457.23	8	3.71	3.0	224.53
Large	1040	413.68	7	4.94	2.5	254.02
Large	1127	451.33	9	3.57	4.6	217.73
Large	1659	455.41	12	4.50	3.1	215.91
Small	48	424.57	16	6.22	3.5	215.46
Small	70	469.02	18	3.79	4.9	210.02
Small	201	403.70	5	3.74	3.5	192.33
Small	305	401.89	5	3.27	3.1	185.98
Small	415	387.83	7	4.19	4.3	215.46
Small	758	407.79	6	5.15	1.9	265.36
Small	1661	437.72	8	4.49	3.6	249.48
Small	1701	435.91	5	3.89	4.3	249.48
Small	1989	395.99	4	4.00	4.1	233.60
Small	9630	451.79	11	5.79	1.3	201.85

TABLE 7. INDIVIDUAL COW FOURIER COEFFICIENTS OF COWS GRAZING FESCUE-LEGUME-PASTURES[a]

Pasture	Cow No.	A_0	A_1	A_2	A_3	A_4
Large	40	2.562	0.074	0.097	0.362	- .121
Large	180	2.703	- .026	0.272	0.680	- .076
Large	206	2.907	- .023	- .036	0.267	- .315
Large	335	2.535	- .016	0.191	0.406	- .231
Large	386	3.394	- .006	0.047	0.116	- .482
Large	1286	2.625	- .070	0.130	0.420	- .259
Large	1337	2.480	0.082	0.199	0.283	- .322
Large	1516	2.630	- .075	0.126	0.330	- .174
Large	1668	2.343	- .149	0.204	0.346	0.026
Large	2497	2.602	- .151	0.091	0.544	- .147
Small	25	3.134	0.013	0.335	- .118	- .027
Small	28	3.273	- .128	0.130	0.454	- .513
Small	85	2.693	- .153	0.258	0.471	- .273
Small	429	2.956	- .198	0.313	0.276	- .180
Small	445	2.882	0.047	0.471	0.344	- .441
Small	1436	3.365	- .250	0.207	0.278	- .057
Small	1561	2.972	- .370	0.047	0.538	- .136
Small	2477	3.441	- .149	0.007	0.258	0.152
Small	3100	3.062	- .179	0.340	0.464	- .240
Small	5106	2.717	- .173	0.264	0.285	- .228

[a]Derived from fecal chromium concentration.

TABLE 8. INDIVIDUAL COW FOURIER COEFFICIENTS OF COWS GRAZING FESCUE PASTURES[a]

Pasture	Cow No.	A_0	A_1	A_2	A_3	A_4
Large	35	3.519	- .195	0.236	0.083	- .363
Large	140	3.705	- .011	0.072	0.590	- .611
Large	448	3.142	- .047	0.151	0.469	0.059
Large	577	3.389	- .102	0.672	- .176	- .366
Large	836	3.970	- .110	0.162	0.423	- .071
Large	845	4.099	- .603	0.178	0.498	- .203
Large	890	3.556	- .218	0.189	0.802	- .080
Large	1040	3.980	- .158	0.363	0.218	0.003
Large	1127	3.509	0.055	0.134	0.063	- .099
Large	1659	3.989	- .340	0.124	0.320	- .289
Small	48	4.052	- .285	0.073	0.511	- .411
Small	70	3.277	- .138	0.135	0.310	- .351
Small	201	3.832	- .178	0.329	0.433	- .153
Small	305	4.754	- .263	- .024	0.157	- .373
Small	415	3.886	- .023	- .119	0.148	- .491
Small	758	3.365	0.013	0.159	0.470	- .069
Small	1661	3.512	- .074	0.574	0.275	0.290
Small	1701	3.579	- .174	0.042	0.186	- .242
Small	1989	4.004	- .264	0.362	0.129	- .285
Small	9630	2.714	- .729	- .092	0.128	- .430

[a]Derived from fecal chromium concentration.

TABLE 9. PERCENTAGE OF TIME COWS SPENT GRAZING

Time	Fescue-Legume				Fescue			
	Large Cow		Small Cow		Large Cow		Small Cow	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
8AM-12	73.07[a]	12.17	76.93	8.11	26.67	9.46	16.15	8.47
12 - 4PM	14.38	4.22	35.63	9.34	11.88	6.22	24.38	9.06
4PM- 8PM	65.63	12.24	63.13	18.51	61.25	8.23	66.25	11.86
8PM-12	34.38	5.31	41.25	4.37	38.13	9.06	34.38	4.42
12 - 4AM	45.00	10.54	15.00	4.37	36.88	9.52	28.75	7.34
4AM- 8AM	43.75	14.73	37.50	0.00	2.50	3.23	44.38	5.47
8AM-12	53.75	6.04	39.38	3.02	20.63	7.25	32.50	7.68
12 - 4PM	7.50	4.93	11.88	3.55	19.38	7.48	11.25	8.74
4PM- 8PM	48.13	12.86	46.25	5.27	42.50	5.74	41.88	3.02
8PM-12	40.00	3.23	16.88	6.62	38.75	6.45	16.25	12.22
12 - 4AM	42.50	7.68	18.13	6.88	51.88	6.62	40.63	10.31
4AM- 8AM	40.63	5.31	25.00	0.00	13.75	6.45	30.00	7.10

[a]Average of two days.

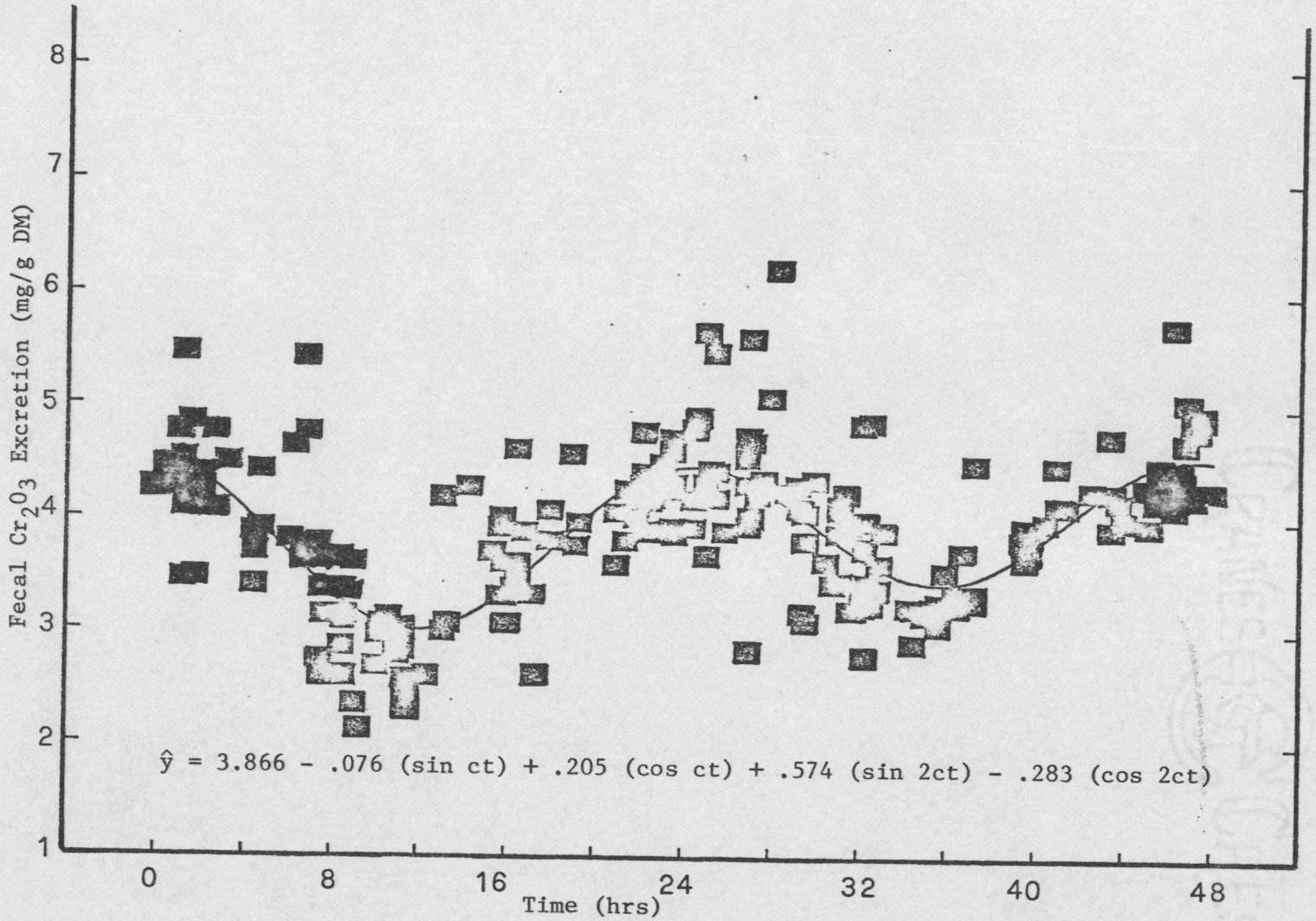


Figure 3. Chromic oxide excretion pattern of large cows grazing fescue-legume pasture.

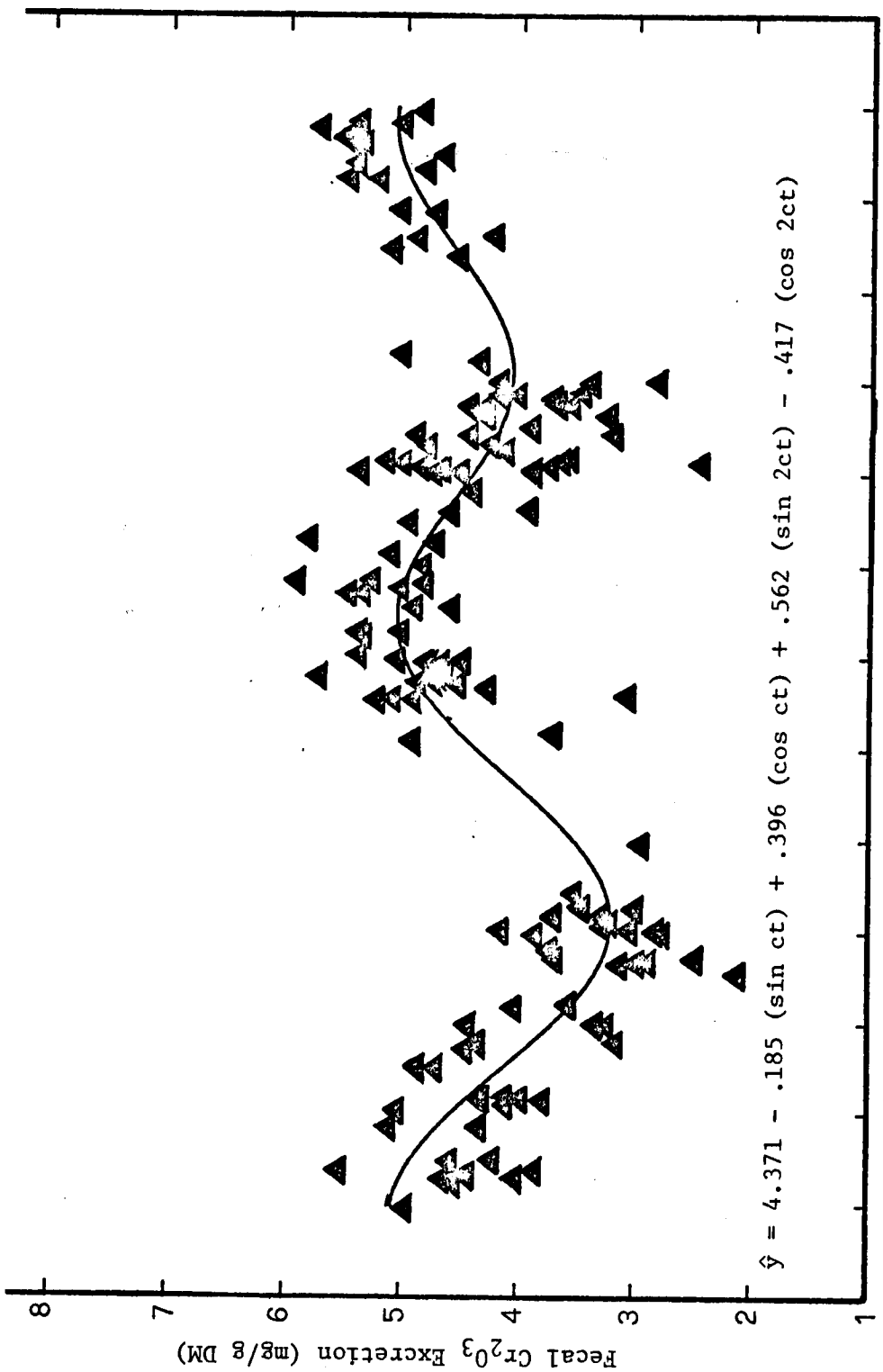


Figure 4. Chromic oxide excretion pattern of small cows grazing fescue-legume pasture.

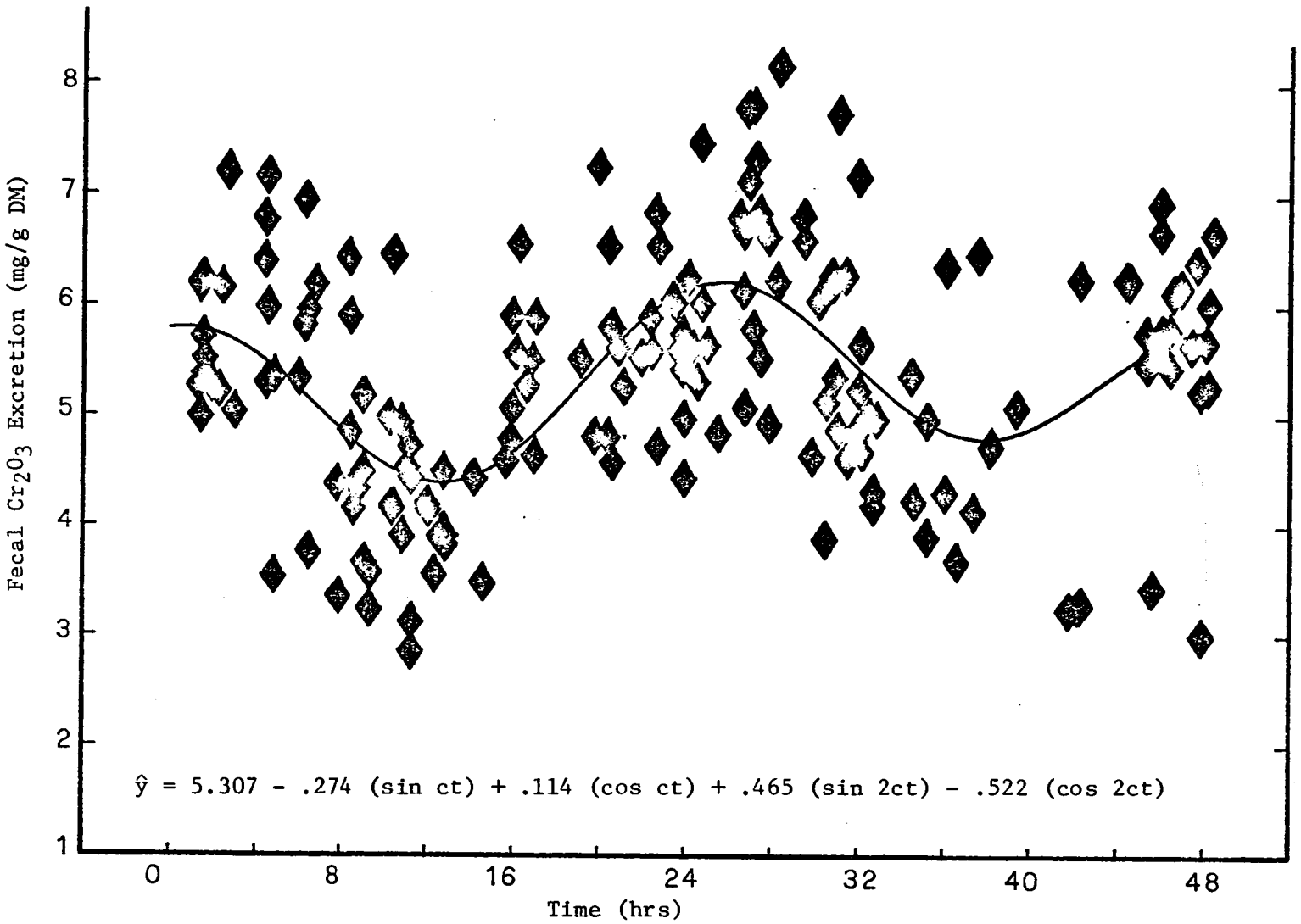


Figure 5. Chromic oxide excretion pattern of large cows grazing fescue pasture.

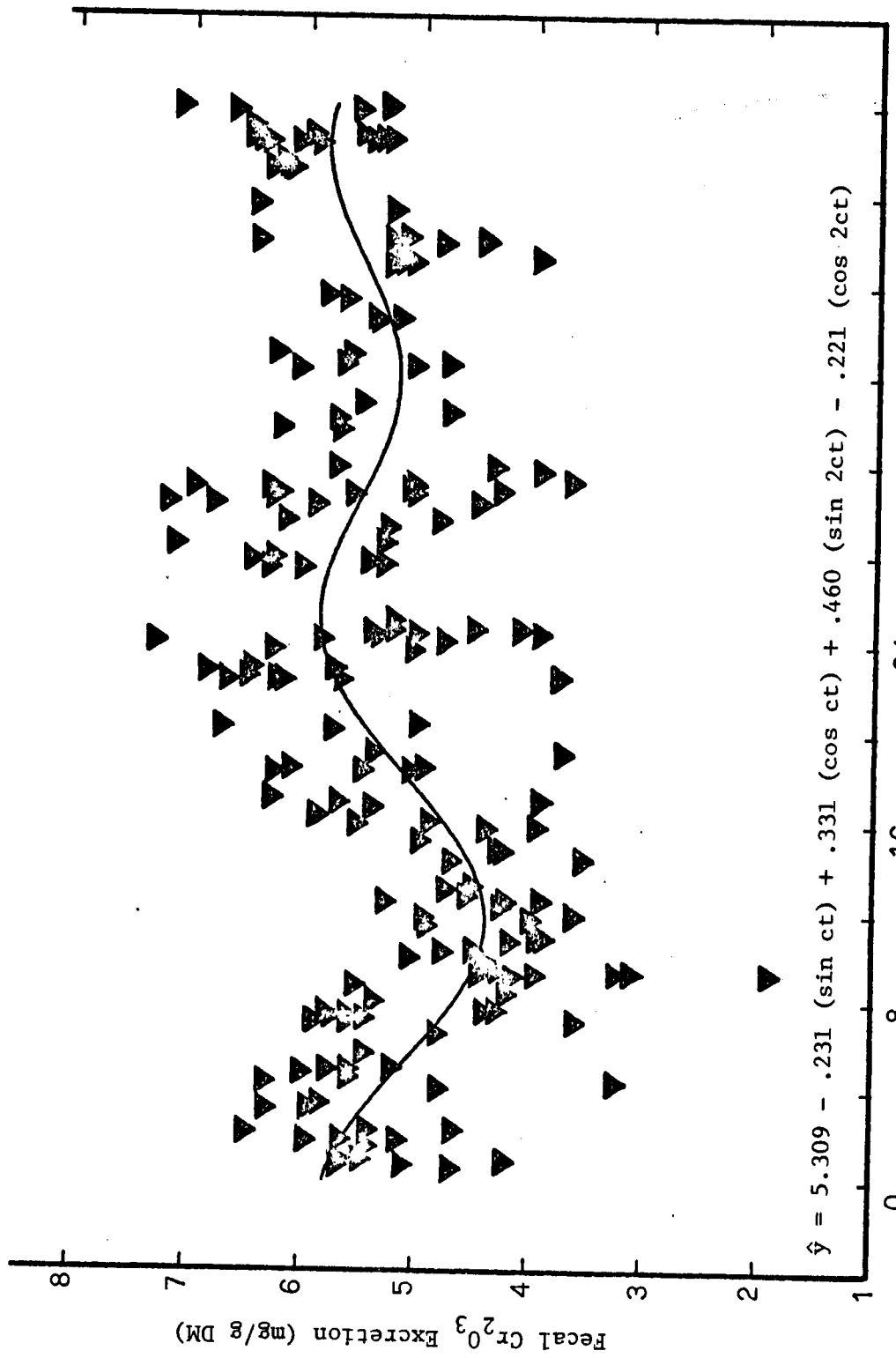


Figure 6. Chromic oxide excretion pattern of small cows grazing fescue pasture.

VITA

James Tigrett Hopper, son of Billy E. and Jane Chandler Hopper, was born May 10, 1953 at Jackson, Tennessee. He lived in Madison County throughout his elementary and secondary education. Upon graduation from Jackson-Central-Merry High School in 1971, he attended The University of Tennessee, Martin and obtained a Bachelor of Science degree in Animal Science in August 1975. Deciding to further his education in Animal Nutrition, he entered graduate school at The University of Tennesse, Knoxville and was granted the Master of Science degree in Animal Science in June 1977.