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I am submitting herewith a thesis written by William Francis Brown entitled "Body Composition and Weight Changes of Mature Grazing Angus 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
J. W. Holloway, Major Professor

We have read this thesis and
recommend its acceptance:

Will L. Bull Jr.
Gordon W. Davis
Wm. R. Bachus

Accepted for the Council:

Levans Cook
Vice Chancellor
Graduate Studies and Research

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BODY COMPOSITION AND WEIGHT CHANGES
OF MATURE GRAZING ANGUS COWS

A Thesis
Presented for the
Master of Science
Degree
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William Francis Brown

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ABSTRACT

In vivo body composition was estimated by both direct and indirect methods 33 times on 18 mature Angus cows grazing either high or low quality pasture. The direct method consisted of deuterium oxide in a deuterium oxide dilution technique employing a two compartment open model.

Body composition variables estimated were: empty body weight (EBWT); empty body water (EBW); empty body fat (EBFAT); percent water (PERH_2O); percent fat (PERFAT); gross energy (GE); and gross energy per body weight (GEPBW). Water kinetics variables estimated were: flow rate of water between gut and nongut compartments (FAB); flow rate of water between nongut and gut (FBA); and, flow rate of water from the body (FOA).

As cow weight increased, water flow rates between gut and nongut compartments decreased for cows grazing high quality pastures ($P < .04$) but not for cows grazing low quality pasture type ($P > .23$). Flow rate from the body was not related to weight and fatness. Cows grazing high quality pastures had larger PERH_2O ($P < .05$), PERFAT ($P < .05$), GE ($P < .03$) and GEPBW ($P < .05$).

Forty mature lactating Angus cows were selected to represent the variation in mature fall weight and milk production of Angus cows. Cows were allotted to either high or low quality pasture.

Weight and ultrasonic estimate of fat thickness were taken every two weeks from the time of calving until a low weight was attained and then once per month until weaning. Certain cow and calf measurements

were obtained to provide information useful in explaining animal variation in cow weight and fatness change during the year.

The Gauss-Newton iterative process was employed to determine the least squares estimates of the Fourier coefficients from data for each cow.

Results indicate that cows with large fall heights, fall weights, fall fat thickness and dry matter intakes had large mean weights during the year. Fall height ($P < .13$), fall weight ($P < .10$), milk production ($P < .01$), digestible dry matter intake ($P < .003$), dry matter intake ($P < .06$) and digestibility of the pastures ($P < .03$) were observed to influence the shape of the cow weight change curve. Fall weight was the only variable noted to influence the periodicity of the cow weight change curve ($P < .005$).

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CHAPTER I

INTRODUCTION

The visual appraisal or commercial grading of live cattle and carcasses is an evaluation of the conformation, finish and quality of the animal or carcass. These factors are influenced by the relative amounts of bone, muscle and fat tissue, which are greatly affected by feeding and breeding.

Body weight changes are usually employed as the criteria of response in most feeding experiments with ruminants. There are many limitations to the use of body weight change as a criterion to estimate the proportion of bone, muscle and fat tissue present in an animal. Some of these limitations include: (1) a change in the amount of ingesta which might be peculiar to a particular ration could result in erroneous estimates of body tissue change (the amount of ingesta in the GI tract of ruminants is large and variable ranging from 5 to 30 percent of the total body weight), (2) a change in body weight is incorrectly assumed to represent body tissue of constant chemical composition and energy value, therefore the same change in body weight resulting from different rations does not necessarily reflect equivalent effects (Reid et al., 1963).

It has been recognized that changes in the proportion of fat, protein and carbohydrates in the body reflect energy storage, and if these factors could be measured in the animal body they could be

employed as criterion of the energy value of feeds for maintenance, growth and fattening. Early methods utilized to determine the above criterion involved desiccation, ether extraction and nitrogen determination of the carcass. Later, the specific gravity technique was used to determine percent body fat, percent body water and percent body protein.

A disadvantage of the above two methods is that animals must be sacrificed in order for the determinations to be made. It would be an advantage for these body parameters to be determined in the live animal. Most methods for determining in vivo body water, fat and protein content are based on the degree of dilution of a foreign substance after its intravenous injection. This is called a dilution technique and is based upon the concept that the constituents of the fat free body mass are in constant proportion to each other. For measurement of these in vivo body parameters a substance should possess the following characteristics: (1) even and rapid distribution throughout the body; (2) nontoxic; (3) slow transformation in and slow excretion from the body; (4) accurate and convenient estimation of its concentration in the blood plasma or serum (Soberman et al., 1949; Soberman, 1950).

The purpose of this experiment was to estimate in vivo body composition of mature Angus cows grazing either high or low quality pasture, and to develop prediction equations to estimate water kinetics and body composition parameters from weight and fat thickness. Also to study the weight change patterns of mature Angus cows grazing either high or low quality pasture, and to determine the influence of certain cow and calf measurements upon the weight change pattern.

CHAPTER II

REVIEW OF LITERATURE

Most estimates of body composition are determined through live animal or carcass techniques. The more important live animal techniques include the in vivo dilution techniques: antipyrine, N-acetyl 4-amino-antipyrine, deuterium oxide and tritium oxide. Varying and contradictory results have been reported concerning the validity, distribution, rate of transformation, calculations, sampling times and problems involved in these techniques. Other live animal techniques include untrasonics, photogrammetry, whole body analysis and ^{40}K . Carcass techniques which have been utilized include specific gravity and tissue separation. Other carcass techniques include partial carcass analyses.

I. MEASUREMENT OF LIVE ANIMAL COMPOSITION

Antipyrine Dilution Technique

Validity of the antipyrine technique. Varying conclusions are observed in the literature concerning the validity of the antipyrine dilution technique in the estimation of body composition in the live animal. Most of this variation occurs between species; however, varying results are found within species.

Soberman (1949), Soberman (1950), Reid et al. (1958) and Panaretto (1962), working with rabbits, determined that the mean antipyrine space (74.1, 73.3, 72.6 and 62.4 percent of body weight, respectively) was in

close agreement with total body water determined by desiccation (73.8, 73.3, 73.5 and 62.3 percent of body weight, respectively), and concluded that the antipyrine technique provides an accurate estimate of total body water in this species.

Brodie et al. (1949), Soberman et al. (1949), Osserman et al. (1950), Steele et al. (1950) and Hurst et al. (1952) determined that the degree of dilution of antipyrine provides an accurate estimate of body water in man due to its even distribution throughout body water and ease and accurate determination in plasma samples. Osserman et al. (1950) and Steele et al. (1950) calculated the mean antipyrine space in man as 70.7 and 49.0 percent of body weight respectively. The values of Steele et al. (1950) are lower than others reported in the literature due to different segments of the population studied. Hurst et al. (1952) determined the mean antipyrine space to be 54.6 percent and the mean deuterium oxide space to be 64.2 percent of total body weight in man. The observation that the antipyrine space is somewhat lower than the deuterium oxide space was not explained. Soberman (1940) suggested that the difference may be due to failure to correct for small amounts of antipyrine that become protein bound. However, Moore (1946) suggested that a similar error may be present for the deuterium oxide technique due to the possibility of some deuterium exchanging with available ordinary hydrogen in the body.

Brodie et al. (1949), Soberman et al. (1949), Kraybill et al. (1951) and Herrold and Sapirstein (1952) have questioned the usefulness of the

antipyrine technique in the determination of body water in the dog.

Although antipyrine is present in all tissues and organs in the amounts proportional to their water content, it is destroyed at a rate some five times greater than the corresponding decrease in man. It was thought that injected antipyrine would be destroyed in the dog before equilibrium had occurred. However, Herrold and Sapirstein (1952) determined that the rate of equilibration of antipyrine in the dog was so rapid that it compensated for its rapid destruction and made possible the determination of body water in this species by the antipyrine technique.

Kraybill et al. (1953) and Hansard (1964) concluded that the determination of total body water by the antipyrine technique was not accomplished as easily in swine as with other species. Due to the binding of antipyrine to plasma proteins, and its rapid transformation in the body, the antipyrine technique was found to be an unreliable estimate of body water in swine.

Kraybill et al. (1951), working with cattle, found good agreement between the antipyrine and specific gravity techniques in the measurement of total body water. Wellington et al. (1956) working with cattle, and Panaretto and Till (1963) working with goats, reported close agreement between the antipyrine space (68.0 and 60.2 percent of body weight, respectively) and empty body water (67.9 and 60.5 percent of empty body weight respectively). The observations of Kraybill et al. (1951), Wellington et al. (1956) and Panaretto and Till (1963) have no significant meaning because the antipyrine space was measured as a percentage of live weight while empty body water was measured as a percentage of empty body weight (Panaretto and Till, 1963).

Garrett et al. (1959), Panaretto and Till (1963) and Panaretto and Reid (1964) concluded that body water estimated by the antipyrine technique is too variable to have a direct application in nutritional investigations with ruminants. MacFadden and Richards (1956) concluded that due to erratic results observed in determining body water in cattle by the antipyrine technique, a study should be conducted to determine the effect of "degree of fill" on body water values obtained by this method.

Distribution of antipyrine in the body. Injected antipyrine has been shown to be equally distributed in all body fluids, and present in proportion to the water content of cattle (Soberman, 1950; Kraybill et al., 1951; Wellington et al., 1956; Reid et al., 1957; Whiting et al., 1960); man (Soberman et al., 1949); dog (Herrold and Sapirstein, 1952); rabbit (Soberman et al., 1949); sheep (Garrett et al., 1959; Bensadoun et al., 1963), and goats (Panaretto and Reid, 1964).

Soberman et al. (1949) and Soberman (1950) determined that the concentration of antipyrine in a tissue is proportional to the water content of that tissue, low in the lung and high in the kidney. Except for these two organs, there is relatively equal distribution of antipyrine in the water of tissues.

Equilibration of antipyrine in the body. Time required for uniform distribution of antipyrine in body water varies with species, with equilibrium occurring faster in small animals, and with physical condition of the subject.

Soberman et al. (1949), Osberman et al. (1950), Soberman (1950) and Kraybill et al. (1951) determined that equal distribution of antipyrine

in cattle and normal man occurred between 2 and 2.5 hours after injection. Hurst et al. (1952), on the other hand, found that approximately 24 hours were required for antipyrine to become uniformly distributed in edematous patients. Herrold and Sapirstein (1952) observed that antipyrine equilibrates with body fluids in the dog in less than ten minutes.

Transformation rate of antipyrine. The rate of breakdown and excretion of antipyrine in the body varies widely among species. Kraybill et al. (1951), MacFadden and Richards (1956) and Hansard (1964) determined the average fall in blood level antipyrine due to degradation and excretion in cattle to be 28, 25, and 23 percent per hour respectively. An approximate two fold increase (53 percent per hour) was observed in goats (Panaretto and Reid, 1964). However, Hansard (1964) calculated a value of 28 percent per hour as the mean decrease in blood antipyrine in sheep.

Soberman (1950) and Herrold and Sapirstein (1952) calculated the rate of transformation in the dog to range from 20 to 60 percent per hour with a mean of 31 percent per hour.

Kraybill et al. (1953) and Hansard (1964) reported the rate of transformation of antipyrine in swine to be 36 and 45 percent per hour respectively. The rate of transformation of antipyrine was found to be 40 percent per hour in rabbits (Soberman, 1949) and 6 percent per hour in man (Soberman et al., 1949).

Calculation of body water and fat. The falling level of antipyrine in the plasma can be corrected for by calculating the zero time plasma concentration (the concentration of antipyrine at the time of injection if uniform distribution was instantaneous, and if none of the substance

had been metabolized) by plotting the plasma levels on semilogarithmic paper as a function of time, and extrapolating the straight portion of the time concentration curve to the time of injection (Soberman et al., 1949; Soberman, 1949; Soberman, 1950; Kraybill et al., 1951; Reid et al., 1957; Reid et al., 1958). Since intravenous administered antipyrine is distributed relatively uniformly throughout body water, and the antipyrine concentration in all body tissue and organ water is for all practical purposes equal to that in plasma water, then body water can be calculated as:

$$\text{Percent Body Water} = \frac{\text{mg. of antipyrine injected}}{\text{mg. of antipyrine per liter of serum water at zero time}} \div \frac{\text{body weight}}{\text{kg.}}$$

(Soberman, 1949; Soberman et al., 1950; Kraybill et al., 1951; Faller et al., 1955; MacFadden and Richards, 1959; Reid et al., 1958; Panaretto and Till, 1963).

Messinger and Steele (1949) and Panaretto (1962) determined a method for the calculation of percent body fat given the water content:

$$\text{Percent Body Fat} = \frac{100 - \text{Percent Water}}{0.735}$$

This formula is based upon the assumptions that the fat free lean body mass contains all body water including that in the gut, and that the fat free tissues contain 73 percent water. Osberman (1950) used a similar formula to calculate body fat; however, they assumed the percent water in the fat free tissues to be 71.8:

$$\text{Percent Body Fat} = 100 (\text{body weight kg.} - (\text{body water kg.}/0.718)).$$

Sampling times. A large range in sampling times is observed in the literature with most starting at the point of equilibrium of antipyrine with body water, and therefore varying with species.

Soberman (1949) and Panaretto (1962) working with rabbits, obtained blood samples 50, 75 and 100 and 60, 75 and 100 minutes after injection respectively. Due to the rapid equilibration of antipyrine with body water in the dog, Herrold and Sapirstein (1952) obtained blood samples 10, 20, 40, 60 and 90 minutes following injection in this species. Osberman et al. (1950) compared two time sequences for obtaining blood samples in man; one at 2, 3, 5 and one at 3, 4, 5 hours post injection. Sampling at 3, 4, and 5 hours after injection was found to be best because in some rare cases there was inadequate distribution 2 hours after injection. Hurst et al. (1952) also concluded that 3 hours post injection was the best time to obtain the first blood sample in man. Kraybill et al. (1953) working with swine, Panaretto and Reid (1964) working with sheep and goats, obtained blood samples at times 90 to 280 minutes after injection.

Problems of the antipyrine technique. Wellington et al. (1956) have indicated that a source of error involved in all dilution techniques is the failure to deliver completely the intended dosage of the tracer substance into the jugular vein. This can be prevented by injecting the tracer substance through a previously inserted venous catheter.

Soberman et al. (1949), Kraybill et al. (1951), Brodie et al. (1951), Kraybill et al. (1953), Faller et al. (1955), Huckabee (1956), MacFadden and Richards (1956) and Hansard (1964) have observed that the main error in the antipyrine technique lies in antipyrine's binding with plasma proteins to an extent of ten percent. It has been suggested that this compensatory binding in tissues accounts for antipyrine's ability to

diffuse throughout the body in close proportion to the water content (Brodie et al., 1951).

Assuming that antipyrine is uniformly distributed in the body water of an animal and is metabolized at a constant rate, a probably source of error in the ruminant is that associated with dilution into the relatively large but variable amount of water in the GI tract (Garrett et al., 1959). In ruminants, the empty body has become the reference structure in order to avoid this error. Observations derived from study of the empty body cannot be applied to living animals since simple and accurate techniques for measurement of gut water volume apart from total body water have not been developed.

Bensadoun et al. (1963) have concluded that in order to convert empty body water to terms of percent water in the empty body some estimate of empty body weight must be made. In order to obtain estimates of empty body weight, some workers have fasted experimental animals 6 to 24 hours prior to injection, and assumed that the animals weight at injection approached the empty body weight (Garrett et al., 1959; Panaretto and Reid, 1964; Kraybill et al., 1951; Bensadoun et al., 1963; MacFadden and Richards, 1956). MacFadden and Richards (1956), Garrett et al. (1959) and Panaretto and Reid (1964) have indicated that conditions of fasting an animal prior to injection of antipyrine have a considerable effect on the antipyrine space, and yield it an unreliable estimate of body water. MacFadden and Richards (1956) concluded that this effect may be due to the degree of fill in the GI tract but changes in tissue water levels may also occur.

Wellington et al. (1956) noted that the supernatant resulting after the precipitation of the serum protein should be filtered through

Whatman No. 42 filter paper in order to remove any traces of a flocculent precipitate which fails to drop during centrifugation. This precipitate will interfere with the spectrophotometric analysis for antipyrine. Garrett et al. (1959) recentrifuged the decanted supernatant which accomplished the same thing as filtering.

Brodie et al. (1951) determined that a correction must be applied for the antipyrine transformed during the period of measurement. This involves the analysis of three consecutive plasma levels. Furthermore, the analysis for antipyrine requires the use of an ultraviolet spectrophotometer and timed readings of samples analyzed one at a time. This method is insensitive and difficulties of turbidity and protein particles are encountered. Also, when it is necessary to analyze whole blood or tissue samples, a cumbersome chloroform extraction procedure must be used.

Garrett et al. (1956) concluded that the variability in body water as determined by the antipyrine technique is probably not due to one factor alone, but due to a combination of uncontrolled circumstances inherent in the application of this technique.

N-Acetyl 4-Aminoantipyrine Dilution Technique

Brodie et al. (1951) discovered in the study of the intermediary metabolism of antipyrine a metabolite N-Acetyl 4-Aminoantipyrine (NAAP). When injected intravenously, the concentration of NAAP in tissue water is almost identical with that of plasma water, which indicates that NAAP achieves a uniform distribution with all body water. It was determined that equilibrium of NAAP occurs within three hours after injection in normal humans (Brodie et al., 1951).

It is believed that NAAP has certain advantages over antipyrine in the determination of total body water. In contrast to antipyrine, NAAP is negligibly bound to plasma proteins, less than 3 percent (Brodie et al., 1951). Reid et al. (1957) working with rabbits, Reid et al. (1958) working with cattle and Brodie et al. (1951) working with man recorded recovery rates of 99.5 ± 1.79 , 100.7 ± 3.01 and 92 ± 1.34 percent of injected NAAP respectively. The disappearance of NAAP from the body can be almost entirely accounted for by its renal excretion, with only a minor fraction metabolized over a three hour period. Therefore, the NAAP space can be calculated from a single plasma sample and a urine sample, whereas three consecutive accurately timed blood samples must be analyzed to calculate the antipyrine space. Brodie et al. (1951) pointed out that the analysis of NAAP does not require an ultraviolet spectrophotometer as does analysis of antipyrine.

Brodie et al. (1951) determined a method for calculating the percent body water as:

$$\text{Percent Body Water} = \frac{\text{mg. of antipyrine injected} - \text{mg. NAAP excreted}}{\text{mg./l of NAAP in plasma water}} \div \frac{\text{body weight}}{\text{kg.}}$$

It was noted by Reid et al. (1958) that NAAP overestimated total body water by 1.9 percent of total body weight when compared with desiccation. Panaretto and Till (1963) on the other hand, determined that the NAAP space underestimated empty body water by a mean of 6.3 percent of empty body weight, and concluded that NAAP estimates were biased and not in good agreement with body water as determined by antipyrine.

Simultaneous Use of Antipyrine and NAAP

Reid et al. (1957), Reid et al. (1958) and Panaretto and Till (1963) determined that antipyrine and NAAP injected simultaneously were compatible in solution and each could be determined in the presence of the other in blood, urine or digesta samples of cattle, rabbits and goats.

NAAP has been shown to enter the rumen in much smaller quantities than simultaneously injected antipyrine. This suggests that antipyrine is distributed in total body water, while NAAP is distributed in empty body water (Brodie et al., 1951; Reid et al., 1957; Whiting et al., 1960; Bensadoun et al., 1963; Panaretto and Reid, 1964). Reid et al. (1957) suggested the possibility of measuring in vivo gut water by subtracting the NAAP space from the simultaneously determined antipyrine space.

Panaretto and Till (1963) and Panaretto and Reid (1964) have determined that there was large variability in the antipyrine and NAAP spaces, and concluded that antipyrine and NAAP underestimated total and empty body water respectively.

Deuterium Oxide Dilution Technique

Validity of the deuterium oxide technique. Moore (1946) stated that the ideal method with which to measure total body water is by the dilution of a "tracer" for one of the normal constituents of body water, an isotope of either hydrogen or oxygen. Longworth (1937), Swift (1939), Moore (1946), Scholerb et al. (1950), Edelman (1952), Hurst et al. (1952) and Faller et al. (1955) determined that deuterium oxide (D_2O) is an ideal substance for the determination of total body water since it is an isotope of the normal constituent water, forms an ideal solution with

water and rapidly equilibrates throughout the entire body fluids within a relatively short time. Brooks (1935) and Parpart (1935) however, concluded that D_2O penetrates the erythrocyte 44 percent more slowly than water, due to the lower mobility and higher viscosity of D_2O , although later research demonstrated that the rate of penetration of D_2O into cells is the same as that of ordinary water (Govaerts and Lambrechts, 1946). Therefore there is no significant physical difference between these two fluids to effect a difference in their rate of cell penetration under the force of osmotic pressure.

Haig and Schnieden (1956) reported that D_2O causes none of the radiation effects possible with tritium oxide since it is a stable isotope of water, nor did it combine with plasma proteins like antipyrine.

Deuterium oxide technique for one pool systems. Flexner et al. (1942) concluded that the mixing of D_2O with blood in the guinea pig is at least 95 percent complete at the end of one minute, and 100 percent complete at the end of three minutes after injection.

McDougal et al. (1934), Moore (1946), Scholerb et al. (1950), Hutchinson et al. (1954), Gotch et al. (1957) and Bradbury (1961) determined that D_2O reached equilibrium with total body water in the normal human and rabbit in two or at the most three hours after injection. Hutchinson et al. (1954) hypothesized that due to the increased water pool during pregnancy more time would be required for equilibration of D_2O . However, it was found that the time necessary to establish equilibrium did not differ between pregnant and nonpregnant women. Faller et al. (1955) and O'Meara et al. (1957) determined that 4.5 to 6 hours were required for D_2O to equilibrate in edematous patients.

Equilibration could have been prolonged due to increased mean diffusion distances or because of decreased surface to volume ratios in various regions of the body (edematous patients have higher total body water expressed per kilogram of body weight than in normal subjects). Also, blood flow per unit volume of tissue water might be reduced sufficiently to produce some delay in uniform distribution of D_2O (O'Meara et al., 1957).

Moore (1946) and Flexner et al. (1947) calculated body water volume as:

$$V_2 = \frac{C_1 V_1}{C_2}$$

where V_2 = volume of water in liters into which injected D_2O diffuses at equilibrium, C_1 = concentration of injected D_2O (g/l), V_1 = volume of D_2O injected, corrected to 37 degrees C and C_2 = serum concentration of D_2O at equilibrium. Scholerb et al. (1950) and Edelman (1952) subtracted the amount of D_2O excreted in the urine before equilibrium in the calculation of body water volume:

$$V_2 = C_1 V_1 - C_u V_u / C_2$$

where C_u = concentration of D_2O in the urine prior to equilibrium and V_u = volume of D_2O excreted in the urine prior to equilibrium. Faller et al. (1955) calculated total body water as:

$$\text{Total Body Water (l)} = \frac{\text{g. of } D_2O \text{ injected}}{\text{g./l. of } D_2O \text{ at equil.}}$$

Deuterium oxide technique for multipool systems. Hevsey and Hoffer (1934), McDougal et al. (1934), Flexner et al. (1942), Moore (1946) and Hurst et al. (1952) have indicated that there is a very

rapid dilution of D_2O with total body water. Other research has indicated that there are two, not clearly defined, sets of capillaries in the body, a fast group and a slow group which determine the two rate constants, and the two pools of body water (Flexner et al., 1942). Scholerb et al. (1950), however, concluded that the rate constants could be explained by water transfer across cell membranes as well as across capillaries. Later work placed both rate limiting processes for water distribution as being between extra and intracellular fluid at the cell wall rather than at the capillary (Edelman and Moore, 1951; Edelman, 1952). Therefore, the rapid exchange is between D_2O and extracellular fluid, and the slower rate reflects cellular water exchange. This indicates that extracellular and intracellular water make up the two pools of body water.

Pinson (1942), Scholerb et al. (1950) and Edelman (1952) calculated the concentration of D_2O in blood serum at time t as:

$$C_t = C_{eq} + Ae^{-k_1t} + Be^{-k_2t}$$

where C_t = concentration in volume percent of D_2O in blood serum at time t , C_{eq} = concentration in volume percent of D_2O in blood serum at equilibrium, A = zero time intercept of the initial fast rate, B = zero time intercept of the second slow rate and k = rate constant for water distribution in fraction per minute.

Edelman et al. (1952), Edelman et al. (1954), Cizek (1954), Gotch et al. (1957) and Byers (1979) have concluded that the concept of the anatomy of body water distribution as a two compartment system consisting of extra and intracellular water is inadequate. Intraluminal gut water has been shown to be a significant subdivision of body water. Therefore, the fast rate constant reflects distribution of D_2O within

the nongut water pool, and the slow rate constant reflects movement of D_2O from the nongut to the gut water pool.

Byers (1979) used the formula of Pinson (1942), Scholerb et al. (1950) and Edelman (1952) to calculate the concentration of D_2O in blood serum at time t . However, Byers (1979) also calculated water kinetics estimates and pool sizes from the two pool kinetics model as follows:

$$Q_a = \text{mg. } D_2O \text{ injected} / (A+B) (\text{mg/kg})$$

$$Q_b = FAB / KAB$$

$$FAB = KAA (\text{amount } D_2O \text{ injected} / (A+B))$$

$$FBA = KBA (\text{amount } D_2O \text{ injected} / (A+B))$$

$$FOA = KOA (\text{amount } D_2O \text{ injected} / (A+B))$$

where Q_a = size of the nongut pool, Q_b = size of the gut pool, FAB = flow rate of water from the nongut to gut pool, FBA = flow rate of water from the gut to the nongut pool and FOA = flow rate of water from the body.

In order to derive the rate of movement of water it must be assumed that the amount of D_2O lost from the blood per unit time is proportional to: (1) the number of millimeters of water which moves from blood to extravascular fluid, and (2) the amount of D_2O present in each millimeter of this water. Part of the D_2O which escapes into the extravascular fluid will return to the blood, and the amount which returns per unit time is proportional to: (1) the rate of movement of water from extravascular fluid to blood, and (2) the concentration of D_2O in the extravascular fluid (Flexner et al., 1942).

Edelman (1952) noted that while the distribution curve can be adequately described by two major rate constants, each of the major

rates is composed of a series of rates which while similar are not identical. In the case of the D_2O distribution curve, these many different rates group themselves so that a single exponential term fits the curve.

Estimates of D_2O space. Desiccation studies have shown that the D_2O space corresponds closely to total body water (McDougal, 1934; Moore, 1946; Pace et al., 1947). Total body water in man as determined by the D_2O dilution technique ranges from 53.8 to 74.6 percent of body weight (Hevesey and Hofer, 1934; Flexner et al., 1947; Scholerb et al., 1950; London and Ritterberg, 1950; Edelman, 1952; Hurst et al., 1952; Faller et al., 1955; O'Meara et al., 1957; Bradbury, 1961).

Flexner et al. (1947) and Edelman and Moore (1951), working with humans, have determined that extracellular water makes up approximately 15 percent of body weight. Gotch et al. (1957) has determined that gastrointestinal water makes up 12 percent of body weight in man. It is possible that the calculated gastrointestinal and extracellular water could be incorrectly assumed to be each other. Byers (1979) using IV and oral administered D_2O in cattle observed that ruminal D_2O concentration increased at the same time that blood D_2O concentration decreased. This indicates that nongut and gut water make up the two pools of body water.

Problems of the D_2O technique. Scholerb et al. (1950) pointed out that due to the small volume of injected tracer substance, and the large dilution factor, a small error in administration, collection or analysis of the tracer will introduce a large error in the final result.

The major source of error involved in the D_2O technique is that deuterium atoms will exchange with exchangeable hydrogen atoms of organic molecules. This exchange occurs in molecules where hydrogen is bonded to atoms other than carbon. In pure fat, all hydrogen atoms are attached directly to carbon by stable linkages; therefore, none of these hydrogen atoms should be replaced by deuterium. In protein and carbohydrate, however, approximately 20 percent of the hydrogen is in labile form. Due to these exchanges, the injected D_2O will be diluted into a volume larger than that of total body water alone, resulting in an equilibrium concentration lower than that which would be observed in the same volume of water in vitro, and therefore an overestimate of total body water in vivo. Total exchangeable hydrogen has been calculated to be 0.5 to 1.5 percent of body weight (Smith et al., 1936; Schonheimer and Rittenberg, 1940; Pinson, 1942; Moore, 1946; Scholerb et al., 1950; Faller et al., 1955; Reid et al., 1958; Bradbury, 1961).

Moore (1946), on the other hand, reported that hydrogen atoms of the water molecule are readily exchangeable with deuterium, while only a fraction of the hydrogen atoms in organic compounds are exchangeable. Therefore, it can be said that body water hydrogen constitutes approximately 95 percent of the total mass of exchangeable hydrogen in the body.

Scholerb et al. (1950) and Faller et al. (1955) observed that during the period of equilibrium, some of the administered D_2O was excreted in the urine, and it must be assumed that some is expired through the lungs and transpired from the skin. This loss was estimated to be 0.4 percent of the dose.

Oral administration of D_2O . As one phase of evaluating the D_2O technique, it is desirable to determine whether the renal tubule is capable of distinguishing between water and D_2O . If no distinction is made then D_2O and water will be reabsorbed by the tubule in the same ratio. In this case, at any given time, the blood D_2O to water ratio would equal the urine D_2O to water ratio. The average urine to blood ratio, after equilibrium has been reached, has been shown to be 1.00, indicating that the kidney does not distinguish between water and D_2O , and therefore total body water estimations may be based upon analysis of urine as well as upon blood (Longsworth, 1937; Swift, 1939; Scholerb et al., 1950; Hurst et al., 1952; Faller et al., 1955).

Faller et al. (1955) working with man, compared oral and intravenous administration of D_2O and concluded that estimates of total body water did not differ significantly between these two methods.

Faller et al. (1955) have indicated an advantage of using orally administered D_2O is that venous puncture is omitted completely. Urine samples do not have to be treated until analysis, and since there is no significant change in urine D_2O concentration between three and five hours after injection, accurate timing of sample collection is not necessary.

Scholerb et al. (1950), Hurst et al. (1952) and Faller et al. (1955) determined that equilibration of ingested D_2O follows the same pattern as injected D_2O , and that equilibrium occurs within three to four hours after ingestion.

Tritium Oxide Dilution Technique

Validity of the tritium oxide technique. The tritium oxide (TOH) water space has been shown to yield an accurate and unbiased estimate of total body water in the ruminant (Panaretto and Till, 1963). Moore (1946), Pace et al. (1947), Scholerb et al. (1950), Reid et al. (1958), Kay and Jones (1962) and Pitts (1963) found the TOH space in rabbits and pigs to be in close agreement with desiccation values, and concluded that TOH may be used for estimation of total body water within ten percent of the true value in these species.

An inherent limitation in D_2O studies is the relatively narrow range between the highest concentration of D_2O that may be safely administered to an animal, and the lowest concentration which can be analytically distinguished from the normal D_2O present. This limitation has been found to be less stringent when using TOH. The analyzable concentration of TOH is several orders of magnitude greater than for D_2O ; therefore, a wide range of dilution over which the tritium activity of labeled tissue constituents may be followed is obtained. This permits the detection of components of slow turnover rate which would have gone unnoticed in similar experiments using D_2O (Thompson, 1952, 1953, 1954).

Brues et al. (1952), Thompson (1954), Langham et al. (1956) and Foy and Schnieden (1960) determined that in spite of its radioactivity, TOH is safe to use since it only emits beta particles.

Distribution and equilibrium of TOH. Thompson (1953, 1954) have shown that TOH is distributed rapidly and uniformly throughout all body

fluids. Pace et al. (1947) reported that the rate of equilibrium of TOH in mammals is related to body size. Time required for complete mixing of TOH in humans has been reported to range from one to three hours (Pace et al., 1947; Prentice et al., 1952; Langham et al., 1956; Pinson, 1957; Till and Downes, 1962). TOH was observed to equilibrate in the body water of the rat in 2.5 hours (Foy and Schnieden, 1960), while only one hour was required in the rabbit (Reid et al., 1958). Shumway et al. (1956), Till and Downes (1962) and Aschbacher (1965) reported values of three to six hours required for complete mixing of TOH in ruminants.

Problems of the TOH technique. The TOH technique has been shown to be promising but a half life of 12 years renders tritium's human application potentially hazardous, and its three fold mass increment makes it suspect as a tracer for hydrogen due to its large isotope effects (Schloerb et al., 1950; Thompson, 1954).

Thompson (1952) has indicated that the TOH technique is limited by the maximum radiation which an organism will tolerate, and by the sensitivity of the method employed for the determination of tritium activity. Pace et al. (1947) has stated that much of the error is attributable to the uncertainty in the measurement of activities one half to two times the background value.

The main source of error in the TOH technique is that the TOH water space overestimates the total body water due to exchange with labile hydrogen atoms and water loss during the equilibration period. Values for exchangeable hydrogen space have been reported to vary from 1/2 to 5 percent of body weight. Many workers have reduced

the estimated TOH water space by 3 percent liveweight to correct for this labile hydrogen pool (Scholerb et al., 1950; Prentice et al., 1952; Thompson, 1952; Thompson, 1954; Pace et al., 1957; Reid et al., 1958; Foy and Schnieden, 1960; Panaretto and Till, 1963; Aschbacher et al., 1965). Prentice (1952) and Foy and Schnieden (1960) determined that the uncorrected tritiated water space in rats and man exceeded the total body water measured by desiccation by 4 percent of body weight. Panaretto and Till (1963) found that the corrected TOH space overestimated the total body water by a mean of 0.8 percent body weight.

Langham et al. (1956) and Leibman et al. (1960) concluded that yellow pigments and serum proteins found in human blood depressed the counting rate and must be removed. Also, cooling of samples below freezing caused the sample to become turbid and resulted in a falsely high reading.

Ultrasonics

Hazel and Kline (1959) concluded that accurate methods for measuring fatness in live animals are needed in order to study tissue changes during growth and fattening, and for measuring fatness at market weights of animals that cannot be killed for detailed carcass examination. Watkins et al. (1967) demonstrated that ultrasonics have potential as a nondestructive and accurate method for determining fatness in the live animal.

The main objective of research using ultrasonics with live animals has been the estimation of subcutaneous fat thickness and rib eye muscle area (Watkins et al., 1967). Hazel and Kline (1959), Stouffer et al.

(1959), Hendrick et al. (1962) and Watkins et al. (1967) have determined that fat thickness and rib eye area can be accurately estimated in beef cattle and swine with ultrasonic equipment as shown by a close relationship between a plotted outline made ultrasonically in the live animal, and a tracing from between the twelfth and thirteenth rib of the carcass. Hendrick et al. (1962) found that ultrasonic measurements of fat thickness in the live animal five months prior to slaughter were significantly related to measurements taken from tracings in the carcass.

Some biological and technical factors that affect the use of ultrasonic techniques include: sound frequency, air trapping, type of tissue, transducer pressure, operator variation and postmortem changes. Also, unless the animal remains still while the measurements are being taken, it is difficult to obtain accurate and reliable results (Hazel and Kline, 1959; Hendrick et al., 1962; Watkins et al., 1967).

K⁴⁰

Some research has indicated that the radioactivity of a naturally occurring isotope of potassium (K⁴⁰) might be used to estimate body composition of the live animal (Kirton et al., 1961). Potassium-40 has been shown to be present in a constant ratio in naturally occurring potassium, while potassium is known to be a relatively constant proportion of muscle tissue (Mounib and Evans, 1960).

Woodard et al. (1956) and Zobrisky et al. (1959) have indicated that potassium-40 gamma activity might be used to estimate the muscle mass of humans and swine. However, Kirton et al. (1961) found no significant correlation between carcass composition of sheep and

potassium-40 activity of the carcasses due to insensitive counting by the whole body scintillation counter.

Photogrammetry

Photogrammetry has been used in biological fields to estimate variables such as size, shape and surface of objects. Reference targets are placed along the center line of the back and on the navel of livestock. Stereophotographs are taken using stereometric measuring cameras and the points are recorded using stereo plotting machines in an X, Y, Z coordinate system. The points are then used to compute the desired distances (Leydolph, 1954; Brinks et al., 1964).

Brinks et al (1964) found that all distance measurements were positively correlated with the weight of a particular wholesale cut being predicted. He pointed out, however, that additional accuracy accounted for by using distance measurements combined with live weight alone, added only slightly to the accuracy of live weight alone.

Leydolph (1954) concluded that stereophotographs may be used in many ways. Studies of animal development by growth or change in shape may be observed. Stereophotogrammetry yields a better impression of an animal's shape than is given by visual appraisal. Leydolph (1954) also pointed out some of the problems involved in this technique. It is difficult to photograph small animals as well as nervous cattle and horses because certain research requires animals to be in the same position. For a satisfactory estimation of volume, the animal must be photographed in a horizontal plane with its weight distributed evenly on all legs.

II. MEASUREMENT OF CARCASS COMPOSITION

Specific Gravity Technique

For mature animals, the concept of the body composed of a fat free body mass of constant gross composition, and a variable quantity of fat has been established. It is expected then that the density of this constant portion of the body, consisting essentially of muscle and bone, must also be relatively constant. Hence fat with a low density (0.92) as compared with that of muscle (1.06) and bone (1.50) can be regarded as chiefly responsible for deviations of body specific gravity from a basal value. Therefore, estimation of body density affords a measure of body fat (Moulton, 1923; Welham and Behnke, 1942; Rathburn et al., 1945; Messinger and Steele, 1949; Osserman et al., 1950; Kraybill et al., 1952).

A close relationship has been shown between specific gravity and percent fat in the eviscerated body of the rat (DaCosta and Clayton, 1950); guinea pig (Rathburn and Pace, 1945); swine (Brown et al., 1951); cattle (Kraybill et al., 1952); sheep (Barton and Kirton, 1956); and human (Messinger and Steele, 1949; Keys and Brozek, 1953). Lofgreen and Garrett (1954) determined that the specific gravity technique is more accurate than mechanically separating the fat due to the difficulty of obtaining complete separation of fat from other tissues.

Specific gravity is determined, in most cases, on the kidney-free carcass after chilling for approximately 18 hours after slaughter. The carcass is weighted in air and then in 17 to 20 degree centigrade water

(Kraybill et al., 1952; Barton and Kirton, 1956). Specific gravity is then calculated by the formula:

$$\text{Specific Gravity} = \frac{\text{weight in air}}{\text{weight in air} - \text{weight in water}}$$

(Rathburn et al., 1945). Specific gravity can also be calculated by the following:

$$G = \frac{M}{F/D_f + M - F/D_1}$$

where G = whole animal specific gravity, M = body weight, F = weight of body fat, D_f = density of body fat and D_1 = density of fat free body mass (Kraybill et al., 1952; Kraybill et al., 1953).

An inverse relationship exists between body fat and body specific gravity, and a direct relationship between body water and body specific gravity (Rathburn et al., 1945; Messinger and Steele, 1949; Kraybill et al., 1952). Values for specific gravity range from 0.990 to 1.070, which yields a fat content of 53.1 to 13.6 percent.

Rathburn et al. (1945) and Kraybill et al. (1952) have reported that precise in vivo measurement of specific gravity on mammals other than man is difficult to obtain because of large errors created by residual air in the lungs, hair and abdominal viscera.

Whole Body Analysis

Many researchers using indirect methods of determining body composition have used whole body analysis as a standard (Soberman, 1950; Aschbacher et al., 1956; Klosterman et al., 1956).

Whole body determination is accomplished by first storing the carcass in a freezing chamber until frozen. The frozen carcass is then

divided down the center of the vertebral column and sliced into pieces one-eighth to one-fourth of an inch in thickness. These slices are then readily minced. This method is very effective in obtaining a uniform mince of all soft and hard tissues of the carcass. Representative samples are then taken for chemical analysis. Moisture is determined by drying in a vacuum oven at 70 degrees centigrade. Ether extraction, protein, and ash are then estimated (Forbes et al., 1953; Barton and Kirton, 1956; Liuzzo et al., 1958).

Forbes et al. (1953) and Clawson et al. (1955) have pointed out that direct analysis must be done on the carcass, and therefore, it cannot be applied at the beginning and end of a feeding period. Also in the grinding procedure, obtaining a uniform mixture of all parts of the body is difficult, and moisture loss can occur.

Partial Body Analysis

Lofgreen and Garrett (1954) concluded that the fat content of the ninth, tenth, eleventh rib cut of steer carcasses could be accurately estimated from the specific gravity of the whole cut. The separable fat of the ninth, tenth, eleventh rib cut has been used as an accurate indication of the fat of the entire carcass.

Pearson et al. (1956) and Price et al. (1957) determined that the specific gravity of the rough ham, loin and shoulder was closely associated with the specific gravity of the entire carcass, and concluded that these measures were suitable as measures of carcass leanness.

CHAPTER III

ESTIMATION OF IN VIVO BODY COMPOSITION OF MATURE LACTATING ANGUS COWS

I. SUMMARY

In vivo body composition of mature lactating Angus cows was estimated by both direct and indirect methods. The direct method consisted of deuterium oxide in a dilution technique employing a two compartment open model (Byers, 1979), whereas the indirect method consisted of weight and ultrasonic estimation of subcutaneous fatness. Thirty-three estimations were made during the lactations of 18 cows grazing either high or low quality pasture.

Body composition variables estimated were: empty body water (EBW), empty body weight (EBWT), empty body fat (EBFAT), percent water (PERH_2O), percent fat (PERFAT), gross energy (GE) and gross energy per body weight (GEPBW).

Cow weights and ultrasonic estimates of fat thickness over the twelfth-thirteenth rib using a sonoray were made at 14-day intervals from calving until a minimum weight was attained, and then at approximately 28-day intervals until their calves were weaned.

Regression procedures were employed to describe the changes in weight and fatness during lactation. These equations were evaluated to obtain estimates of weight and fatness at the times direct estimations of body composition were made. As cow weight decreased, water flow

rates between gut and nongut compartments increased for cows grazing high quality pastures ($P < .04$), but not for cows grazing low quality pasture type ($P > .23$). Flow rate from the body was not related to cow weight or fatness. Cows grazing different pasture quality had different PERH_2O ($P < .05$), PERFAT ($P < .05$), GE ($P < .03$), and GEPBW ($P < .05$).

Models were obtained predicting direct estimations of body composition from indirect estimations. The models with the highest R^2 and lowest standard errors consisted of pasture quality, weight, fatness, weight^2 , fatness^2 , $\text{weight} \times \text{fatness}$, $\text{weight} \times \text{fatness}^2$, $\text{weight}^2 \times \text{fatness}$ and $\text{weight}^2 \times \text{fatness}^2$. The R^2 for these models were .42 (EBW), .70 (EBWT), .51 (EBFAT), .34 (PERH_2O), .34 (PERFAT), .60 (GE) and .34 (GEPBW).

II. INTRODUCTION

In vivo estimation of body composition is a fundamental requirement for energetic efficiency evaluation of grazing, lactating cows. The only in vivo technique that has been employed with satisfactory precision and accuracy involves dilution of water soluble substances. This technique, however, is limited to intensive application.

The extensiveness of grazing situations requires development of extensive techniques for body composition estimation.

The purpose of this experiment was to estimate the in vivo body composition of mature Angus cows grazing high or low quality pastures, and to develop prediction equations to estimate water kinetics and body composition parameters from cow weight and ultrasonic fatness estimates.

III. MATERIALS AND METHODS

Thirty-three estimates of body composition were made over a period of three years during the lactations of 18 mature Angus cows grazing either high or low quality pastures.

Interdependencies in estimation of composition from the same cow more than once were not considered to be important, and were considered to be representative of mature lactating Angus cows grazing fescue-legume and fescue pastures.

The number, distribution and time when body composition was estimated is shown in Table 1. High quality pasture consisted of approximately 60 to 70 percent Kentucky-31 tall fescue (Festuca arundinacea Schreb), and approximately 30 to 40 percent red clover (Trifolium pratense L.), Korean and Kobe lespedeza (Lespedeza stipulacea Maxim.). Low quality pasture consisted primarily of tall fescue.

Direct estimations of in vivo body composition were made employing the dilution of deuterium oxide (D_2O) into body water by the method of Byers (1979). The right jugular vein of each cow was catheterized using a 10 gauge needle and approximately 25 cm. of 1.6 cm. diameter polyethylene tubing. After a 10 ml. blank blood sample was taken, approximately 160 ml. of warm D_2O (in 0.9 percent saline solution) was infused over a period of approximately one minute through the catheter into the jugular vein. Weight of D_2O infused was calculated by subtracting the weight of the injection apparatus after injection from the weight of the full apparatus.

Table 1
Number and Distribution of Cows Injected
with Deuterium Oxide

Year	Pasture Quality	
	High	Low
1976	11	0
1977	5	4
1978	6	7

Seventeen, 10 ml. blood samples were taken at timed intervals measured from the midtime of injection. The first five samples were taken every two minutes, the next five samples were taken every ten minutes, and the next three samples were taken every twenty minutes. Samples were also taken 24, 48 and 72 hours after injection. Blood samples were stored in bottles containing dried heparin at zero degrees centigrade until analysis.

Individual blood samples were lyophilized under a vacuum with water vapor being collected as ice in a vacuum trap surrounded by liquid nitrogen.

D₂O concentration was measured on the collected water at 4 μ in a Perkin-Elmer Model 337 Grating Infrared Spectrophotometer. Water samples were analyzed in duplicate in the order that they were obtained during sampling. D₂O standards were analyzed along with the water samples to remove variation due to temperature changes as analysis progressed.

Cows were weighed and estimates of fat thickness between the twelfth and thirteenth ribs using a Branson Model 12 sonar were taken every two weeks from the time of calving until the low-weight, and then once a month until their calves were weaned. Cow weights ranged from 342 to 582 kilograms with a mean of 474 kilograms. Cow fat thickness ranged from 2.4 to 21.1 millimeters with a mean of 9.4 millimeters. Regression analysis was then used to predict weight and fat thickness for each cow at the time of D₂O injection.

IV. STATISTICAL ANALYSIS

D₂O concentration was calculated from the lyophilized blood samples using linear regression analysis employing the model:

$$(1) \hat{Y} = b_0 + b_1x$$

where $\hat{Y}$ = predicted D₂O concentration, b_0 and b_1 = intercept and slope respectively obtained from the best fit D₂O standard line and x = percent absorbance at 4 μ .

A two compartment open model was employed to describe the dilution of D₂O into body water using nonlinear asymptotic regression (Barr et al., 1976; Hwang, 1977):

$$(2) \hat{Y} = Ae^{-k_1t} + Be^{-k_2t}$$

where $\hat{Y}$ = predicted D₂O space at time t , A = zero time intercept for the initial rapidly equilibrated compartment, B = zero time intercept after D₂O had equilibrated with total body water and k_1 and k_2 = rate constants for D₂O distribution. Flow rates from compartment to compartment were calculated using these estimates and equations 3-11.

$$(3) H_1 = \frac{A}{A + B}$$

$$(4) H_2 = \frac{A}{A + B}$$

$$(5) KAA = (H_1 \times K_1) + (H_2 \times K_2)$$

$$(6) KBB = K_1 + K_2 - KAA$$

$$(7) KBA = \frac{(KAA - KBB) - (K_1 - K_2)}{KBB}$$

$$(8) KOA = KAA - KBA$$

$$(9) FAB \text{ (mg/min)} = KAA \times \frac{\text{amount D}_2\text{O injected (mg)}}{A+B}$$

$$(10) \text{ FBA (mg/min)} = \text{KBA} \times \frac{\text{amount D}_2\text{O injected (mg)}}{\text{A} + \text{B}}$$

$$(11) \text{ FOA (mg/min)} = \text{KOA} \times \frac{\text{amount D}_2\text{O injected (mg)}}{\text{A} + \text{B}}$$

The model employed is illustrated graphically in Figure 1, where compartment A = the rapidly equilibrated compartment or the nongut body, compartment B = the gut contents, FAB = the flow rate of D₂O from compartment A to compartment B, FBA = the flow rate of D₂O from compartment B and compartment A and FOA = flow rate of D₂O from the body.

Body composition parameters were calculated from equations 12-22:

$$(12) \text{ Empty body water (kg)} = \left(\frac{\text{amount D}_2\text{O injected (mg)} \times 1.038}{\text{A} + \text{B}} \right) - 17.918$$

$$(13) \text{ Empty body weight (kg)} = (\text{cow weight (lb)} \times .4536 \text{ kg/lb}) - \frac{\text{FAB} \times .84}{.88} \frac{\text{KBB}}{.88}$$

$$(14) \text{ Empty body protein (kg)} = \text{EBW} \times 0.3017$$

$$(15) \text{ Empty body mineral (kg)} = \text{EBW} \times 0.0689$$

$$(16) \text{ Empty body fat (kg)} = \text{EBWT} - (\text{EBPRO} + \text{EBMIN} + \text{EBW})$$

$$(17) \text{ Percent water (\%)} = \frac{\text{EBW} \times 100}{\text{EBWT}}$$

$$(18) \text{ Percent fat (\%)} = \frac{\text{EBFAT} \times 100}{\text{EBWT}}$$

$$(19) \text{ Percent fat (\%)} = \frac{\text{EBFAT} \times 100}{\text{EBWT}}$$

$$(20) \text{ Percent mineral (\%)} = \frac{\text{EBMIN} \times 100}{\text{EBWT}}$$

$$(21) \text{ Gross energy (kcal)} = (\text{PREFAT} \times \text{COW WEIGHT} \times 453.6 \times 9 \times .01) + (\text{PERPRO} \times \text{COW WEIGHT} \times 453.6 \times 5.65 \times .01) \times .001$$

$$(22) \text{ Gross energy per body weight (kcal/kg)} = \frac{\text{GE}}{\text{Cow weight}}, \text{ (Byers, 1979).}$$

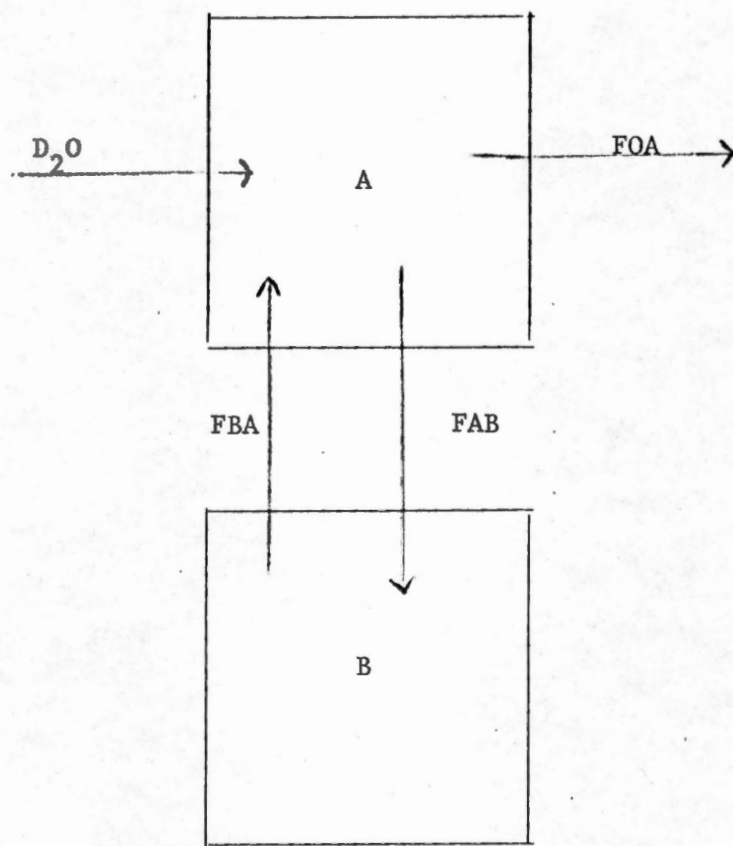


Figure 1. Graphic description of the two compartment open model employed.

Regression procedures (Barr et al., 1976) were employed to develop models to determine relationships between water kinetic variables, intensive estimates of body composition and the extensive estimates of weight and ultrasonic fat thickness.

V. RESULTS AND DISCUSSION

Water kinetics. Individual cow water kinetics estimates are presented in Tables A-1 and A-2.

Means of the water kinetics estimates by pasture quality are presented in Table 2. Cows grazing high quality pastures tended to have more rapid flow rates between compartments, and more rapid flow rates from the system than those cows grazing low quality pastures. This is consistent with faster rates of passage expected with high quality forage.

Models predicting water kinetics estimates from cow weight and fatness estimates, their standard error of the estimates and their R^2 values are shown in Table 3. As indicated by the low R^2 values and large standard error of the estimates, precise equations were not found that would estimate these flow rates, but a trend existed for larger, fatter cows to have slower flow rates.

For cows grazing high quality pastures, those that were heavier and fatter had slower flow rates between the gut and nongut ($P < .07$), and also slower flow rates from the system ($P < .12$). For cows grazing low quality pastures, however, no relationship was detected between weights, fatness and water kinetics. For cows grazing high quality

Table 2
Least Squares Means of Water Kinetics Variables
by Pasture Quality^a

Pasture Quality	Water Kinetics Variables		
	FAB(mg/min)	FBA(mg/min)	FOA(mg/min)
High	4.29	4.21	.087
Low	2.58	2.51	.075

^aModel: $\hat{Y} = \text{Pasture quality} + \text{stage of lactation} + \text{pasture quality} \times \text{stage of lactation}$

Table 3
Regression Models Estimating Water Flow Rates
from Cow Weight and Fatness

Variable	FAB(mg/min)	FBA(mg/min)	FOA(mg/min)
Intercept	127.815	127.392	0.423
Cow weight	-0.2359	-0.2343	-0.0017
Cow weight ²	0.0001	0.0001	0.000001
Fatness	-34.8770	-34.9841	0.1071
Fatness ²	0.9662	0.9917	-0.0255
Cow weight × fatness	0.0649	0.0650	-0.00005
Cow weight × fatness ²	-0.0018	-0.0019	0.00004
Cow weight ² × fatness	-0.00003	-0.00003	-0.00000008
Cow weight ² × fatness ²	0.00000086	0.00000087	-0.00000001
R ²	.27	.27	.36
S _{y·x}	2.50	2.51	0.05

pastures, FAB and FBA decreased by .09 mg/min and .085 mg/min per kilogram increase in weight. Also for cows grazing high quality pastures, FAB and FBA decreased by 14.12 mg/min and 13.98 mg/min per millimeter increase in fat thickness.

Body composition. Individual cow body composition estimates are presented in Tables A-3 and A-4. Values for percent empty body water range from 36.5 to 69.0 with a mean of 52.7. Values for percent empty body fat range from 5.4 to 49.9 with a mean of 27.6. These values are in agreement with Byers (1979) who calculated empty body water as 53.9 percent of empty body weight in cattle.

Estimates of body composition parameters expressed in the form of means by treatment are presented in Table 4. Cows grazing high quality pastures had larger EBWT ($P < .07$), EBFAT ($P < .002$), PERFAT ($P < .01$), GE ($P < .001$) and GEPBW ($P < .01$) than cows grazing low quality pastures. Cows grazing low quality pastures had larger EBW ($P < .08$) and $PERH_2O$ ($P < .01$). These differences are due to the presence of legume in the high quality pastures causing the cows in these pastures to become heavier and fatter.

Models predicting body composition parameters from cow weight and fatness estimates, their standard error of the estimates and their R^2 values are shown in Table 5. As indicated by the low R^2 values and large standard error of the estimates, precise equations were not found that would estimate these body composition parameters.

For cows grazing high quality pastures, those that were heavier had larger EBWT ($P < .0002$), EBFAT ($P < .005$), PERFAT ($P < .05$),

Table 4

Least Squares Means of Body Composition Variables by Pasture Quality^a

Pasture Quality	EBW(kg)	EBWT(kg)	EBFAT(kg)	PERH ₂ O(%)	PERFAT(%)	GE(kcal)	GEPBW(kcal/kg)
High	213.98	380.98	87.70	56.18	22.99	1512.62	1.37
Low	220.81	344.55	41.91	63.39	13.11	968.42	1.02

^aModel: $\hat{Y}$ = Pasture quality + stage of lactation + pasture quality × stage of lactation.

Table 5

Regression Models Estimating Body Composition from Cow Weight and Fatness

Variable	EBW(kg)	EBWT(kg)	EBFAT(kg)	PERH ₂ O(%)	PERFAT(%)	GE(kcal)	GEPBW(kcal/kg)
Intercept	1838.268	2796.901	277.370	114.261	-56.606	-2798.346	-1.427
Cow weight	-2.7444	-3.9736	-0.2122	-0.1193	0.1635	7.7300	0.0057
Cow weight ²	0.001	0.0015	-0.00003	0.00007	-0.00009	-0.0038	-0.0000003
Fatness	-579.6497	-1024.5523	-230.0844	6.1810	-8.4717	-442.8101	-0.2980
Fatness ²	22.4061	52.6399	21.9301	-1.8836	2.5817	118.0117	0.0908
Cow weight × fatness	0.9886	1.7344	0.3795	-0.0078	0.0107	0.5690	0.0003
Cow weight ² × fatness ²	-0.0379	-0.0906	-0.0386	0.0033	-0.0045	-0.2090	-0.0001
Cow weight ² × fatness	-0.0004	-0.0906	-0.0001	-0.000001	-0.000002	-0.00009	-0.00000006
Cow weight ² × fatness ²	0.00002	0.00003	0.00002	-0.000001	0.000002	-0.00009	0.00000007
R ²	.42	.70	.50	.34	.34	.60	.34
S _{y·x}	33.78	26.85	27.65	6.32	8.66	259.75	0.31

GE ($P < .0005$) and GEPBW ($P < .05$), and smaller EBW ($P < .17$) and PERH₂O ($P < .05$). The relationship observed between cow weight and EBWT was due to a part-whole relationship and was not a true relationship. For cows grazing low quality pastures, no relationship was detected between weight and body composition.

A problem involved with the direct method of determining body composition is associated with the temperature changes of the infrared analyzer. Even though the D₂O standards were analyzed along with the unknown water samples, some researchers have maintained the temperature to within ± 0.004 degrees centigrade (Byers, 1979).

Rumsey et al. (1979) have indicated that necrotic fat lesions may develop in cattle grazing highly fertilized fescue pastures. These lesions were not found in subcutaneous fat, but were found in abdominal fat depots. Due to these necrotic lesions, it is possible that ultrasonic estimates of fat thickness are not a good indirect estimate of body composition.

CHAPTER IV

EFFECT OF CERTAIN COW AND CALF MEASUREMENTS UPON COW WEIGHT AND FATNESS CHANGE DURING THE YEAR

I. SUMMARY

Forty mature lactating Angus cows were selected to represent the variation in mature fall weight and milk production of Angus cows for each of three years. Cows were allotted to either high or low quality pasture.

Ultrasonic measurement of cow fat thickness at the twelfth rib, and cow weight were taken every two weeks from the time of calving until a low weight was attained, and then once per month until weaning. Certain fall measurements, productivity measurements and digestibility and intake characteristics were obtained to provide information useful in explaining animal variation in cow weight and fatness change during the year.

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

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

These Fourier coefficients were then employed as dependent variables to determine the influence of the cow and calf measurements upon the shape of the cow weight and fatness curve.

Results indicate that cows having large fall heights ($P < .05$), fall weights ($P < .06$), fall fat thickness ($P < .003$) and dry matter intake ($P < .07$) had large mean weights during the year. Fall height ($P < .13$), fall weight ($P < .10$), milk production ($P < .01$), digestible dry matter intake ($P < .003$), dry matter intake ($P < .06$) and digestibility of the pastures ($P < .03$) were observed to influence the shape of the cow weight change curve. Fall weight was the only variable noted to influence the periodicity of the cow weight change curve ($P < .005$).

II. INTRODUCTION

The knowledge of the energetic efficiency of a cow during the year is necessary for the determination of energy requirements for maintenance and lactation. It is known that dairy cattle lose a large amount of weight during lactation; however, no research has been conducted to observe the change in weight during the lactation period of beef cows.

The purpose of this experiment was to observe weight change patterns of mature grazing Angus cows, and to determine the effects of certain fall measurements, productivity measurements and digestibility and intake characteristics upon the weight change patterns.

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. Mature cow fall weight, milk production and progeny weaning weights were employed to randomly allot cows to two types of pasture quality. High

quality pasture consisted of approximately 60 to 70 percent Kentucky-31 tall fescue (Festuca arundinacea Schreb), and approximately 30 to 40 percent red clover (Trifolium pratense L.), Korean and Kobe lespedeza (Lespedeza stipulacea Maxim). Low quality pasture consisted primarily of tall fescue.

Within each pasture quality cows were allotted to two 20 acre pastures (10 cows with calves/pasture) according to cow fall weight. Within pasture quality, cow weight was intentionally confounded with pasture so that large cows could be mated to large bulls.

Means of dry matter intake, digestibility and digestible dry matter intake by pasture quality are presented in Table 6. Estimates of forage intake, forage digestibility and fecal output were made by the Cr_2O_3 dilution and lignin ratio techniques as explained by Hopper (1977).

Measurements of cow fat thickness at the twelfth rib using a Branson Model 12 sonar, and cow weight were taken every two weeks from the time of calving (beginning the day after calving) until a minimum weight was attained, and then once per month until weaning. Certain cow calf measurements were taken to provide information useful in explaining animal variation in weight change patterns. Cow milk productions were estimated monthly during lactation for a total of seven estimates by the calf-suckle technique (Drewery et al., 1959). These milk productions were averaged to obtain a mean milk production per cow. Total milk collections were taken during the fourth, fifth and sixth months of lactation with a milking machine after the intramuscular injection of 10 IU of oxytocin. Butterfat was estimated with the Mark III

Table 6
Least Squares Means of Cow Intakes and Digestibilities
by Pasture Quality^a

Item	Pasture Quality		
	High	Low	Standard Deviation
Dry Matter Intake (kg)	10.12	8.29	0.79
Digestibility	0.60	0.56	0.14
Digestible Dry Matter Intake (kg)	6.11	4.68	0.49

^aModel: $\hat{Y} = \text{year} + \text{pasture quality} + \text{year} \times \text{pasture quality}$.

Milk-O-Tester. The calves were weaned at a mean age of about 240 days. Cow weight, structural size and fatness were estimated during the fall preceding the year of intensive cow evaluation. Measurements obtained were weight (COWFW), ultrasonic estimate of fat thickness (COWFFAT), height at withers (FLHT) and length from the point of the shoulder to the hooks. Height and length measurements were taken from slides made while the cows were confined in a grid chute. The means of these cow and calf characteristics are shown in Table 7.

IV. STATISTICAL ANALYSIS

Cow weight was plotted against time in days and the Gauss-Newton iterative process employed to determine 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 $\hat{Y}$ = predicted cow weight in kilograms at time t , A_0 = mean cow weight during the year in kilograms, A_1 = the semiamplitude, or one-half the range in cow weight from maximum to minimum, A_2 = coefficient that affects the shape of the first harmonic, A_3 and A_4 = coefficients that affect the shape of the second harmonic, and allows the second harmonic to be different from the first harmonic, C = the fundamental period or length of the cycle in radians per day and t = time in days (day 1 = January 1). The six parameters A_0 , A_1 , A_2 , A_3 , A_4 , and c were estimated from data for each cow.

These Fourier coefficients were then employed as dependent variables in regression analysis (Barr et al., 1976) to determine the influence

Table 7
Description of the Sample Employed^a

Cow Characteristics	Pasture Quality		Standard Deviation
	High	Low	
Number of cows	60	60	
Cow weight (kg) ^b	486.2	466.4	50.9
Cow fat (mm) ^c	9.2	7.4	4.3
Calf weaning weight (kg) ^d	238.2	216.5	28.7
Milk production (kg) ^d	7.6	7.2	1.6
Butterfat content (%) ^d	.042	.040	.009
Cow fall weight (kg)	495.5	466.4	49.6
Cow fall fat (mm)	10.3	7.1	4.3
Cow fall height (cm)	45.7	45.3	1.4
Cow fall length (cm)	285.8	283.5	15.7

^aLeast squares means from model:

$$\hat{Y} = \text{year} + \text{pasture quality} + \text{year} \times \text{pasture quality}$$

^bAverage weight during lactation

^cAverage fatness during lactation

^dLeast squares means from the model:

$$\hat{Y} = \text{year} + \text{pasture quality} + \text{year} \times \text{pasture quality},$$

adjusted for sex

of cow and calf measurements upon the shape of cow weight and fatness curves (change of cow weight and fatness during the year).

Figure 2 shows the weight change pattern for an individual cow during the year.

V. RESULTS AND DISCUSSION

General characteristics. A large variation in curve shape was observed among cows due to variation in calving interval and individual weight change patterns; however, most followed the general pattern of that shown in Figure 3. The model obtained when all the data were pooled was: $\hat{Y} = 489.71 - 31.96 \sin(ct) + 20.82 \cos(ct) - 20.30 \sin(2ct) + 7.90 \cos(2ct)$, where $c = 0.014867$. Although the numerical value of A_0 has intrinsic meaning, the average cow weight through the year, the numerical value of the other parameters do not. In general terms, however, the other Fourier coefficients influence the shape of the curve. A_1 , on the semiamplitude, estimates the range in cow weights during the year.

Cows tended to lose weight until approximately April 1 (day 90 of each year). This weight loss was associated with season of the year, and not with stage of lactation as indicated by the relationship between minimum cow weight and day of the year, and the poor relationship between time of minimum cow weight and calving date. This weight loss was possibly due to the low quality forage available in January and February, and the low dry matter content of the very washy lush pasture available in March. Also during this time there was an increased nutrient

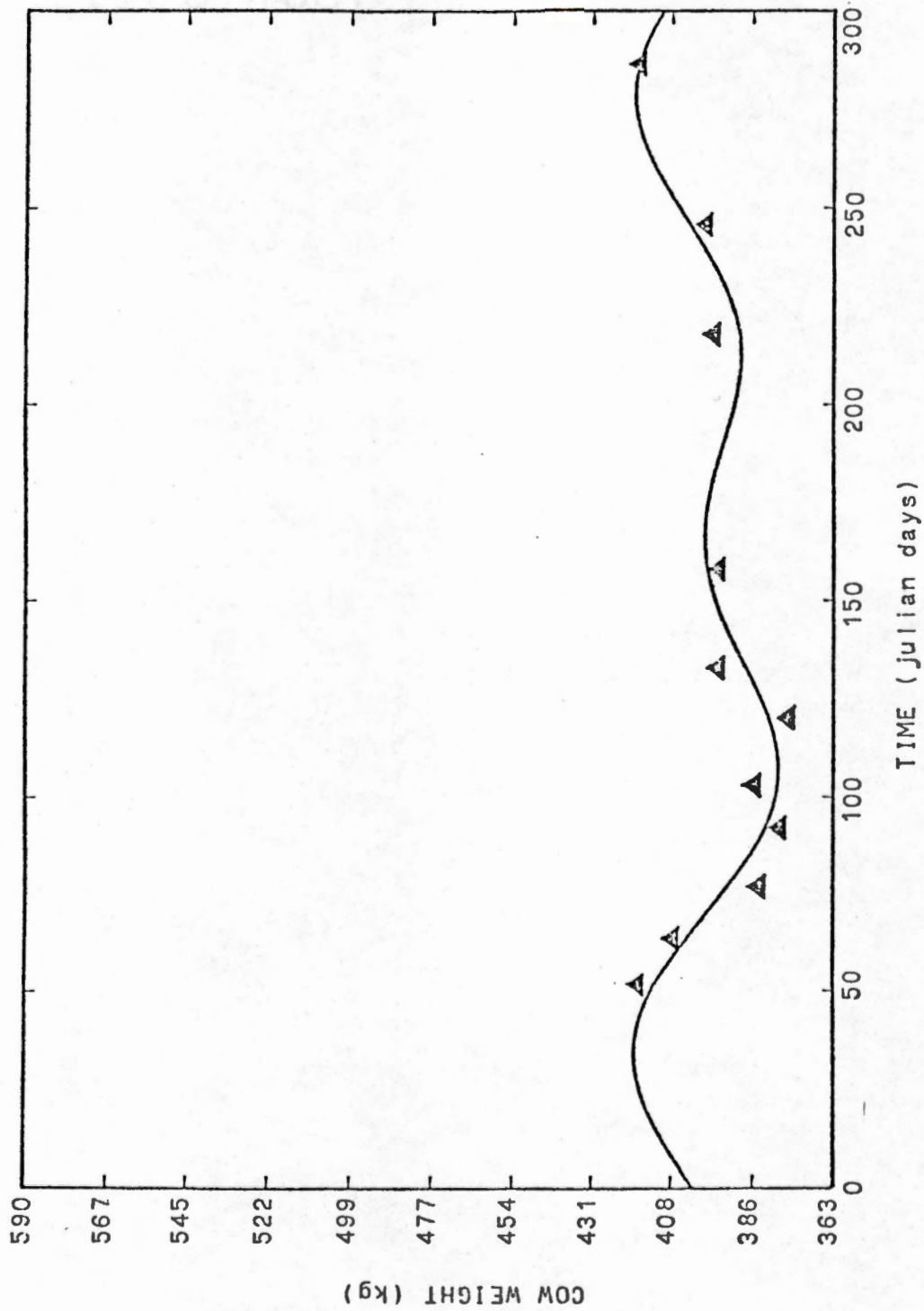


Figure 2. Weight change pattern during the year for an individual cow.

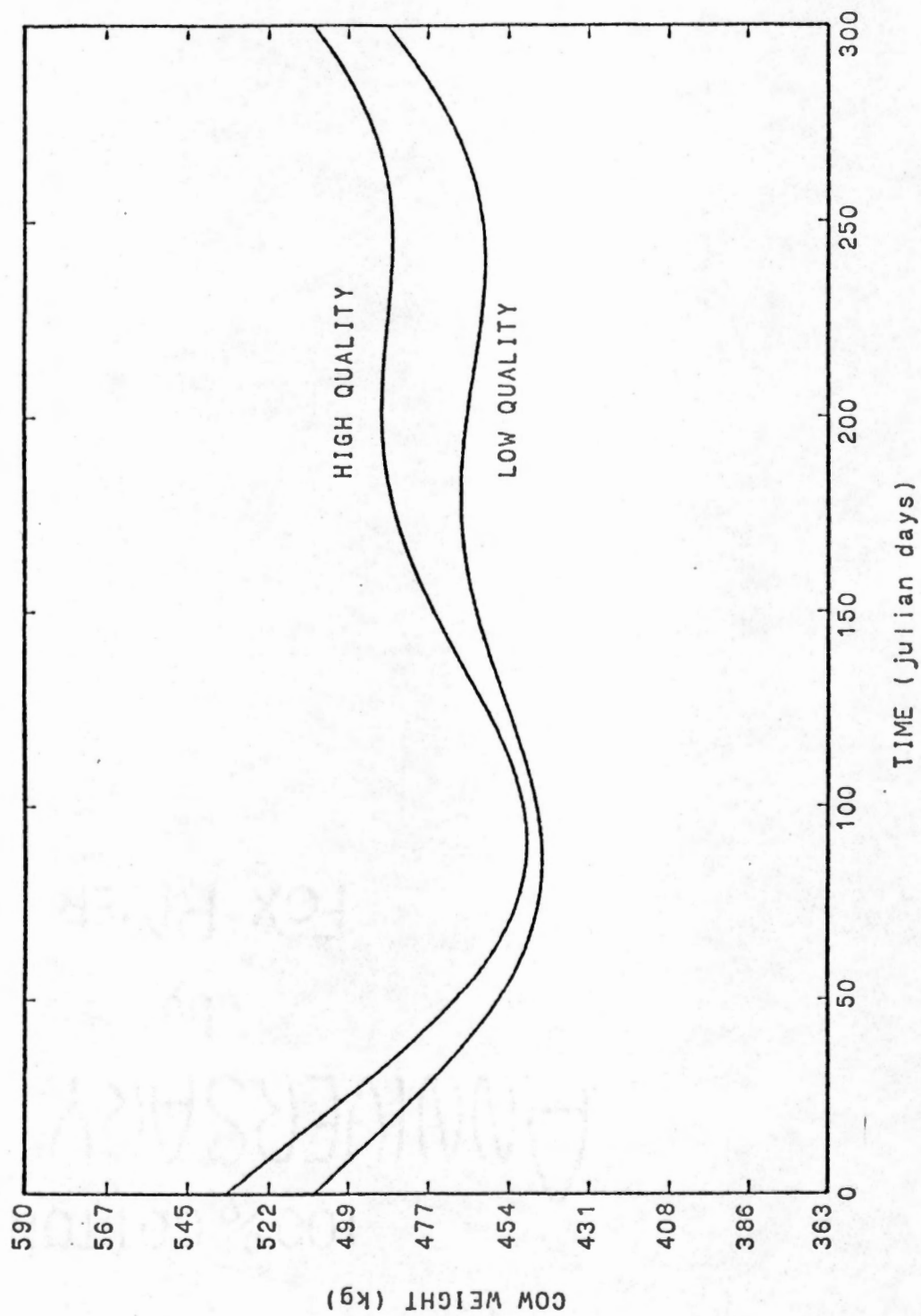


Figure 3. Cow weight change patterns during the year by pasture quality.

requirement due to lactation. The corresponding increase in weight from the end of April through June was possibly due to an increase in the dry matter content of the forage. The increase in weight during October and November was possibly due to termination of the lactation requirement associated with weaning of the calves on October 15. Also some cows were in the third quarter of pregnancy and some fetal development was taking place.

Cow weight change patterns by pasture quality are shown in Figure 3. Cows grazing high quality pastures were heavier than those grazing low quality pastures at the start of the experiment possibly due to a carry over effect of cows that were on high quality pastures the previous year, or this difference in weight could have been due to chance.

Cows on both pasture qualities followed the same general weight change pattern through the spring into the early summer, with differences in weight between pasture qualities being small. During the summer, however, when the legumes in the high quality pastures began to develop, cows grazing these pastures increased in weight at a faster rate than cows grazing low quality pastures. Cows grazing high quality pastures maintained this weight advantage over cows grazing low quality pastures throughout the rest of the year.

Change in cow fatness over time followed the same general trends as the changes noted for cow weight (Figures 3 and 4). Randomness in measurement of fatness, however, precluded the use of iterative methods for estimation of Fourier coefficients; therefore, a quadratic polynomial was employed. The resulting equations gave "smoother" appearing curves.

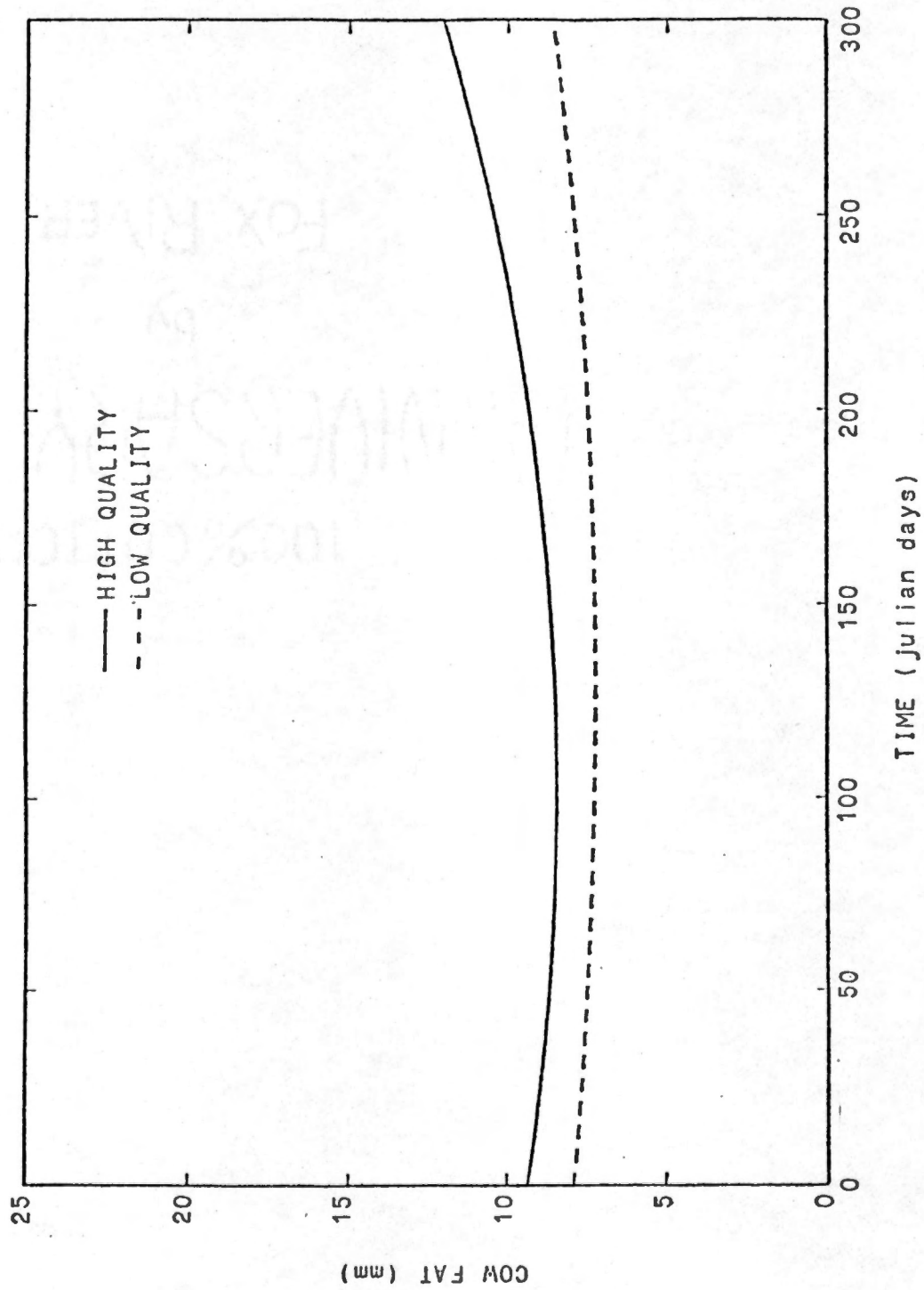


Figure 4. Cow fat thickness change during the year by pasture quality.

It is possible that cow fatness changes in a "smoother" manner than weight since weight measures both body and gut contents changes. Cows grazing high quality pastures were fatter than cows grazing low quality pastures at the start of the experiment for the same reasons as the differences in weight between the two pasture qualities at the start of the experiment. Cows grazing both pasture qualities showed a slight decrease in fat thickness at approximately day 90 of the year, which corresponds to the low point of the weight change pattern. During the summer, cows grazing high quality pastures increased in fat thickness at a faster rate than cows grazing low quality pastures due to the large advantages of the high quality pastures during the summer in terms of digestibility of forage consumed (Holloway et al., 1978).

Cow Weight and Fat Change Patterns

Fall cow measurements. The relationship between patterns of cow weight change during the year and cow fall height by pasture quality is shown in Figures 5 and 6. Cows grazing both high and low quality pasture, having larger fall heights also had larger mean weights during the year ($P < .01$), with cows on high quality pastures having larger mean weights than cows on low quality pastures ($P < .05$). Fall height affected A_1 ($P < .13$), A_2 ($P < .03$) and A_3 ($P < .06$) of the cow weight change curve differently for the two pasture qualities. The relationship between fall height and weight for cows grazing low quality pastures appears to be flatter than this relationship for cows grazing high quality pastures. A curvilinear relationship existed between A_1

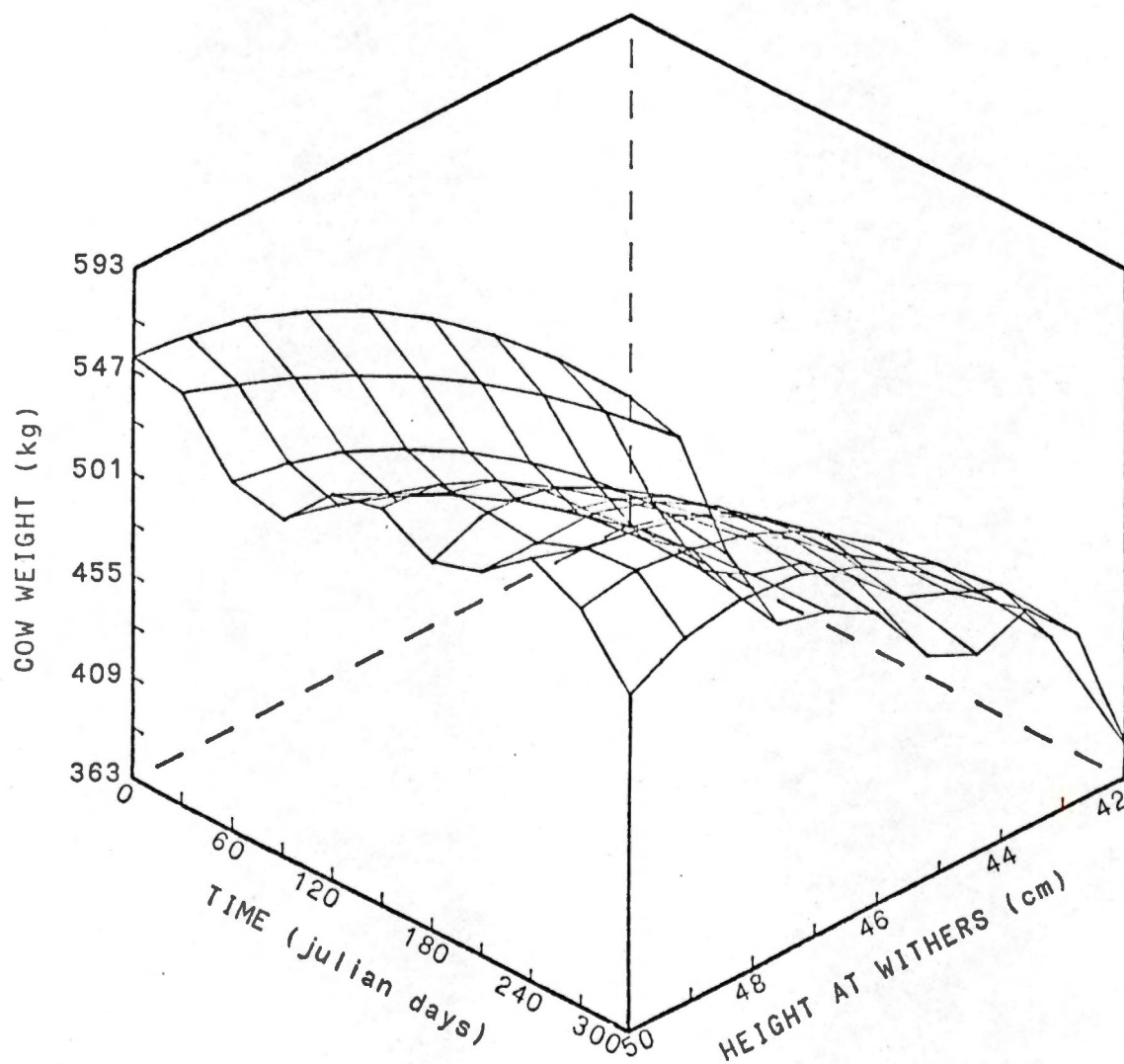


Figure 5. Relationship between cow weight change during the year and height at the withers for cows grazing high quality pastures.

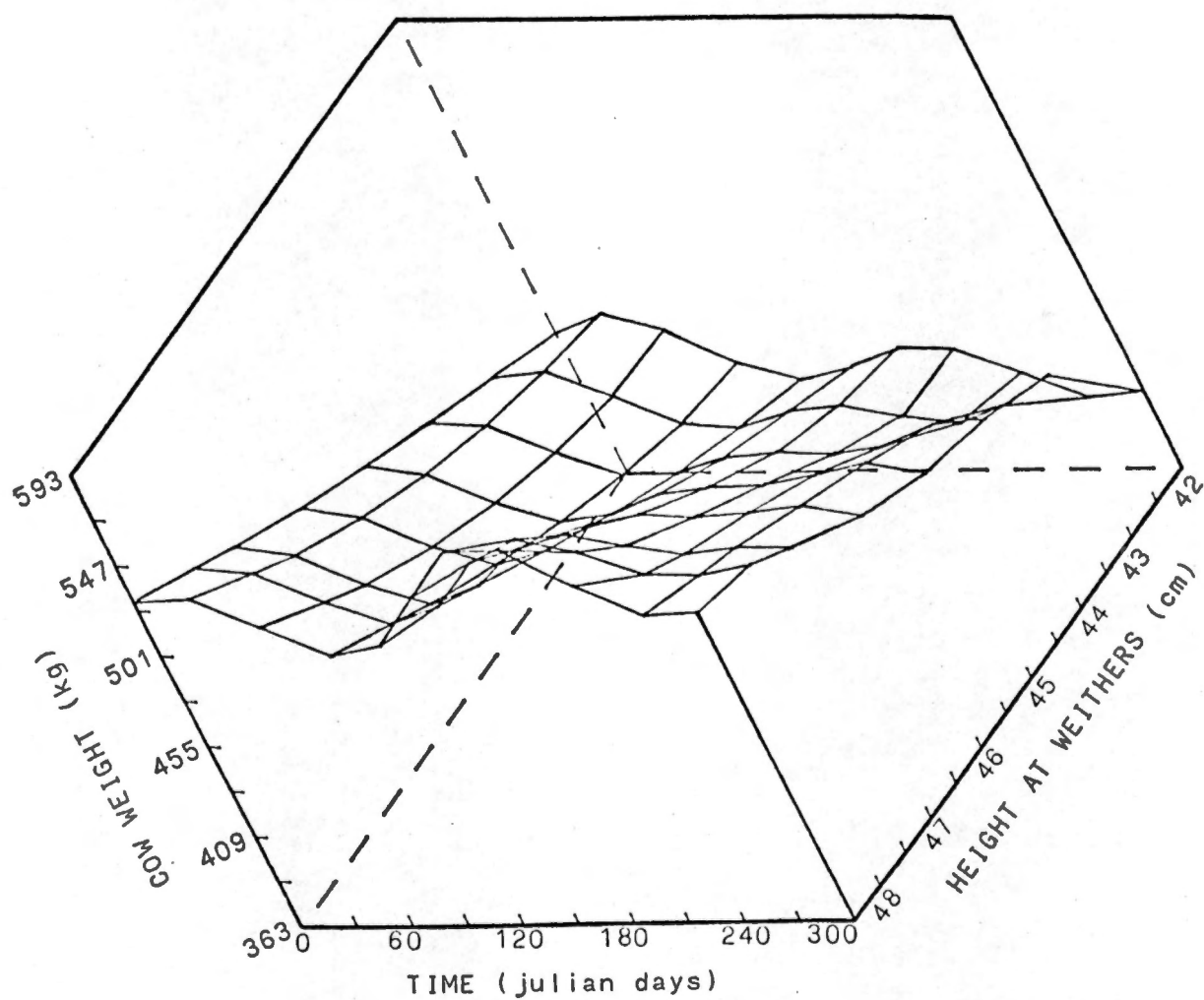


Figure 6. Relationship between cow weight change during the year and height at the withers for cows grazing low quality pastures.

and fall height for cows grazing high quality pastures, but not for cows grazing low quality pastures accounting for the curvilinearity observed in weight change patterns for cows grazing high quality pastures. Cows of small fall heights, grazing both high and low quality pastures seemed to have a more drastic weight change pattern than cows of large fall heights. It is possible that smaller cows must utilize more of their body tissue stores in order to meet lactation requirements than larger, fatter cows.

The relationship between cow fall weight and mean cow weight during the year was different for cows grazing different pastures qualities. Cows grazing high quality pastures which had larger fall weights, had larger mean weights during the year ($P < .06$). Fall weight had an influence on the shape of the cow weight change curve by affecting A_1 ($P < .04$) differently for the two pasture qualities. Fall weight also had an influence upon A_4 ($P < .10$) of the cow weight change curve. Cow fall weight affected the periodicity of the cow weight change curve differently for cows on different pasture qualities ($P < .005$).

Cow fall fat did not have as much an influence upon the Fourier coefficients of the weight change curve as did fall height and fall weight. Cows that were fatter the preceding fall, had larger mean weights during the next year ($P < .003$). Cows of different fall fat thickness within each pasture quality had an effect upon A_1 of the cow weight change curve ($P < .08$). Cow fall fat did not affect the periodicity of the cow weight change curve ($P > .30$).

Cow productivity measurements. The relationship between cow weight change during the year and milk production by pasture quality is shown in Figures 7 and 8. Cows grazing both high and low quality pastures, producing small amounts of milk, had larger mean weights during the year ($P < .03$). Milk production affected A_1 of the cow weight change curve differently for the two pasture qualities ($P < .01$), with cows grazing low quality pastures having a larger range in weight during the year than cows grazing high quality pasture. Cows on both pasture qualities producing small amounts of milk tended to lose more weight during the first part of the year than did cows producing large amounts of milk. Cows producing small amounts of milk were able to regain this lost weight later in the year, while cows producing large amounts of milk were not able to regain the lost weight. It is possible that larger cows producing small amounts of milk had to sacrifice more of their body tissue stores to meet lactation requirements during the first part of the year than did smaller cows producing large amounts of milk.

Milk production had no effect upon the periodicity of the cow weight change curve for either pasture quality ($P > .46$).

No relationship was noted between the butterfat content of the milk, and the mean cow weight during the year ($P > .30$). Also, the shape and periodicity of the cow weight change curve were not influenced by the butterfat content of the milk ($P > .30$).

No relationship was observed between calf weaning weight and average cow weight during the year or shape of the cow weight change curve ($P > .10$). Also, weaning weight had no influence upon the periodicity of the cow weight change curve ($P > .45$).

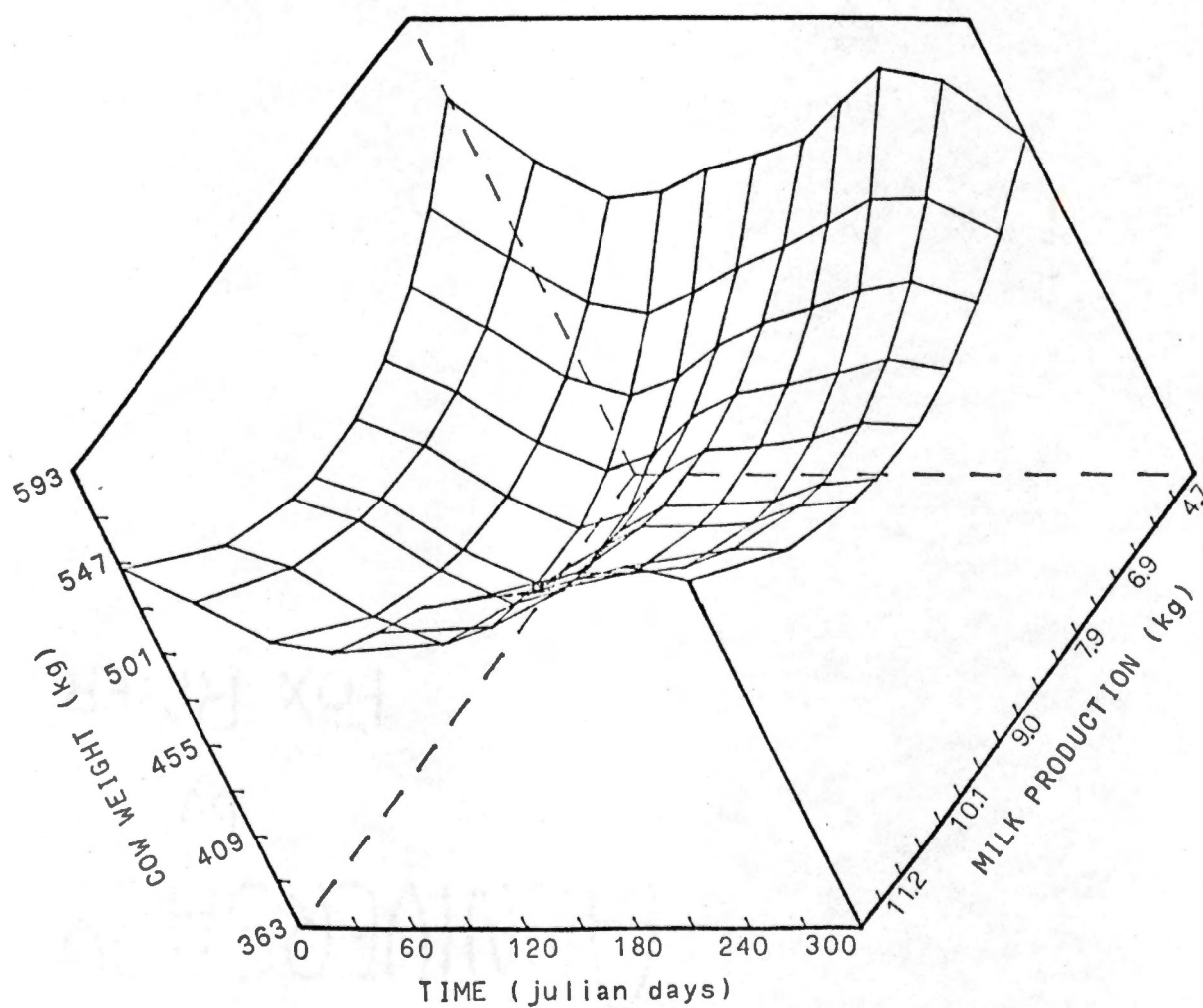


Figure 7. Relationship between cow weight change during the year and milk production for cows grazing high quality pastures.

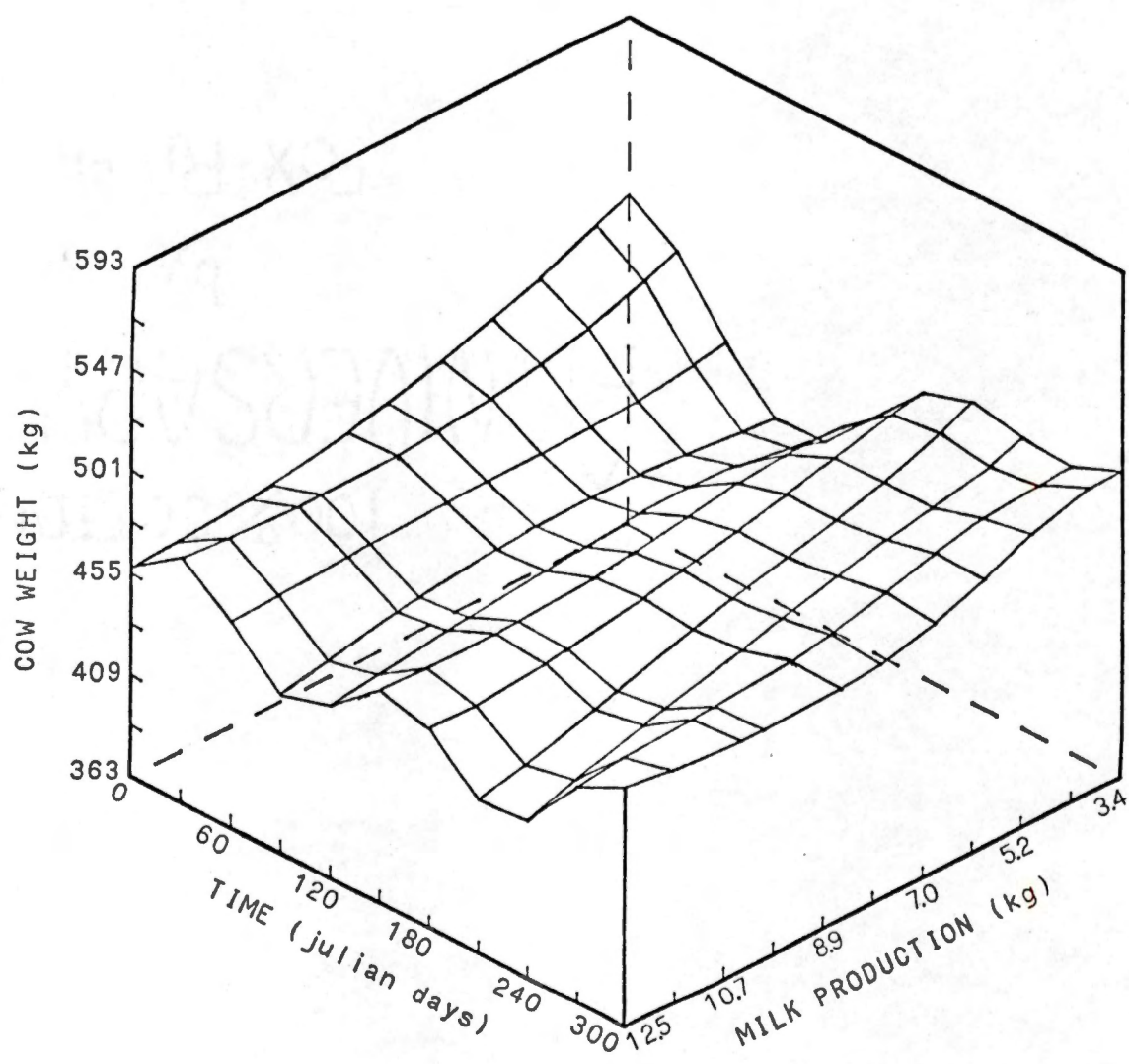


Figure 8. Relationship between cow weight change during the year and milk production for cows grazing low quality pastures.

The relationship between fat thickness change during the year and milk production, by pasture quality is shown in Figures 9 and 10. The relationship between milk production and fat thickness change during the year is similar to the relationship between milk production and weight change during the year. Cows grazing both high and low quality pastures producing small amounts of milk had larger fat thickness ($P < .01$). Cows grazing low quality pastures producing large amounts of milk were not able to regain in the latter part of the year, fat that they lost during the first part of the year. Cows grazing high quality pastures, however, were able to regain fat lost during the first part of the year due to the presence of legumes in the pastures. Cows grazing high quality pastures had a sharp decrease in fat thickness as milk production increased, while cows grazing low quality pastures decreased in fat thickness at a much slower rate as milk production increased.

Digestibility and intake characteristics. The relationship between cow weight change during the year and digestible dry matter intake is shown in Figures 11 and 12. Digestible dry matter intake appears to be more related to seasonal change in weight than to average weight during the year ($P > .40$). Digestible dry matter intake was observed to influence A_1 ($P < .003$) and A_3 ($P < .001$) of the cow weight change curve. Cows with small digestible dry matter intakes had a larger range in weight during the year than did cows with large digestible dry matter intakes. The periodicity of the cow weight change curve was not affected by digestible dry matter intake ($P > .30$).

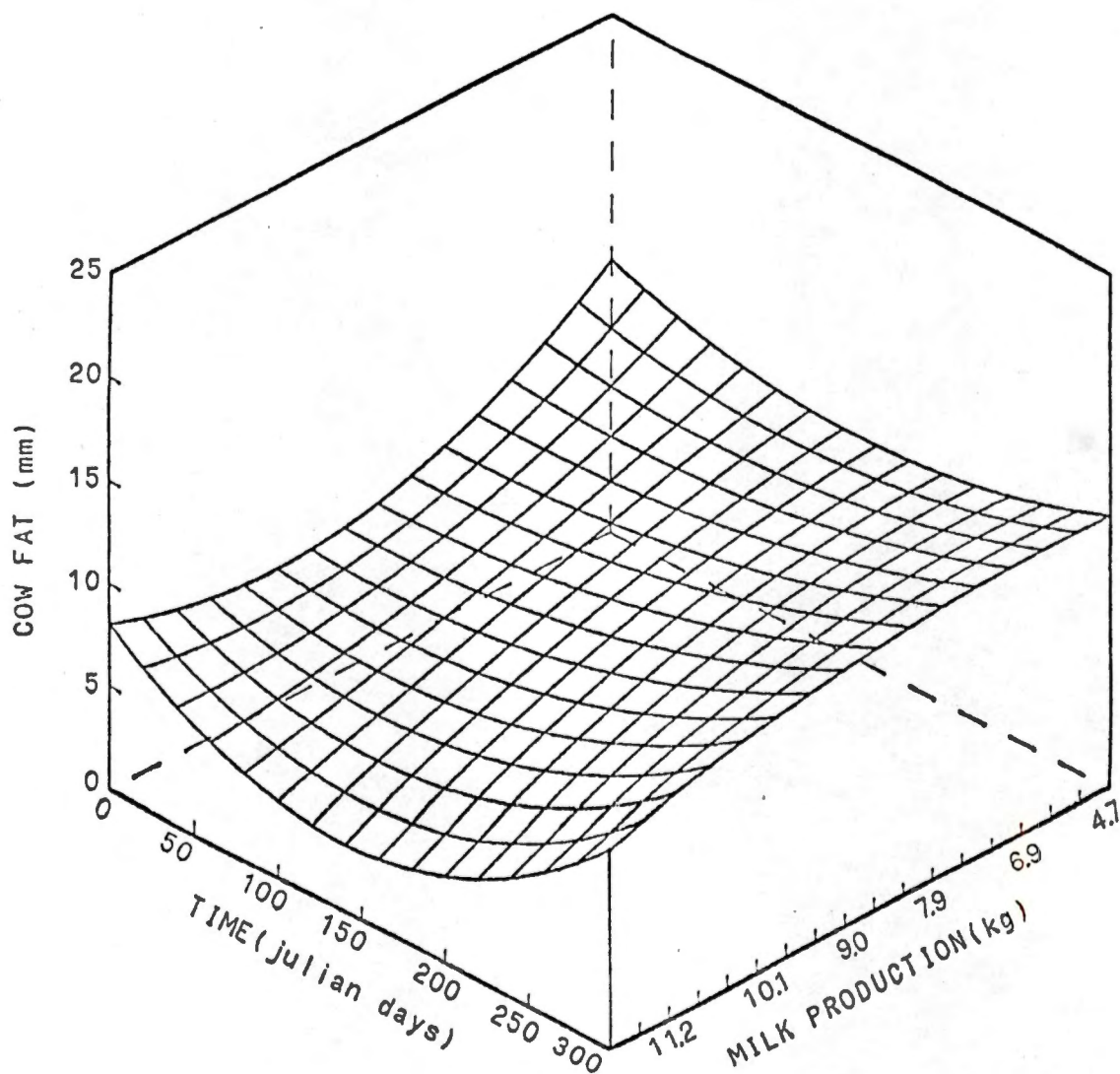


Figure 9. Relationship between cow fat change during the year and milk production for cows grazing high quality pastures.

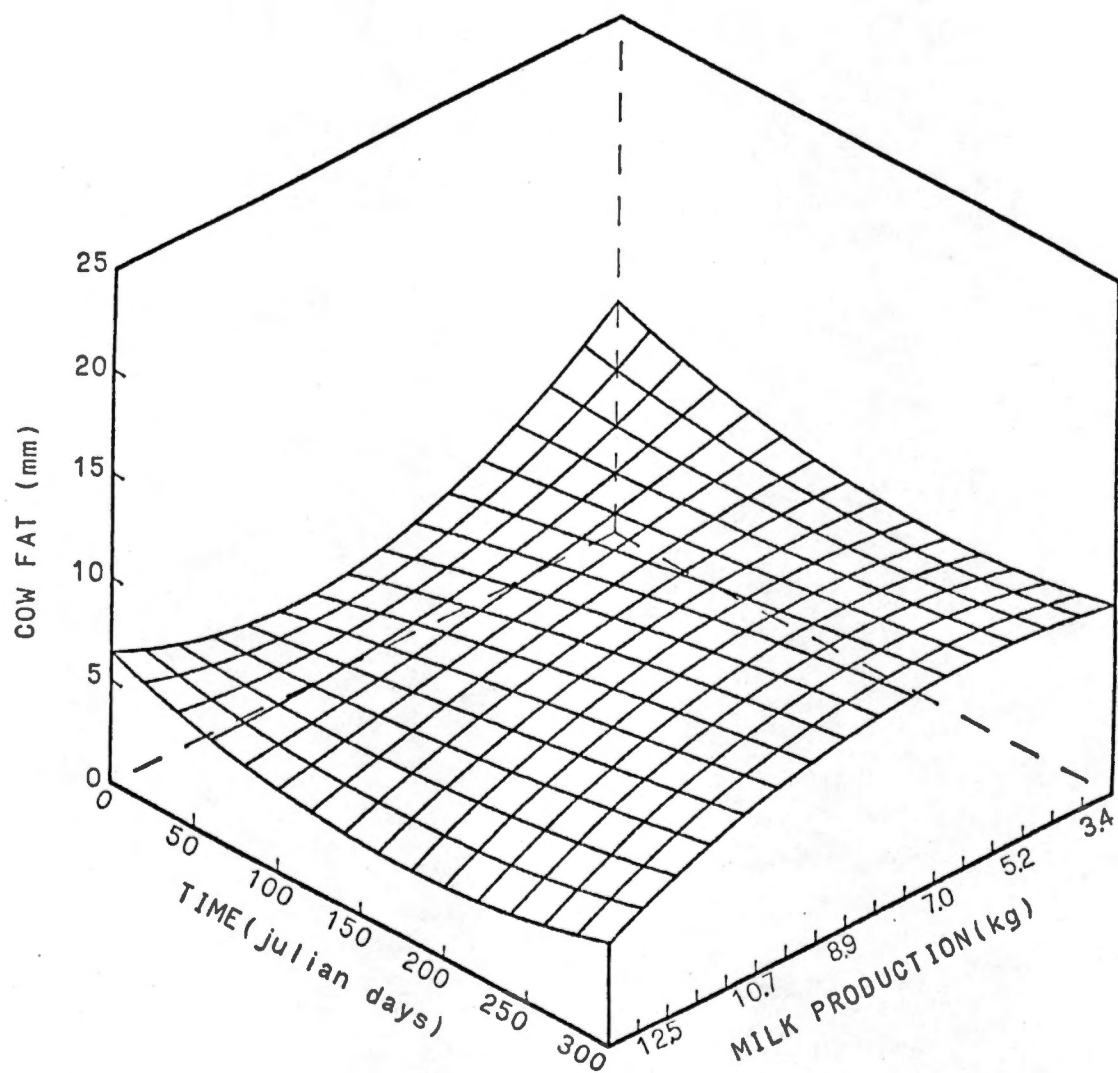


Figure 10. Relationship between cow fat change during the year and milk production for cows grazing low quality pastures.

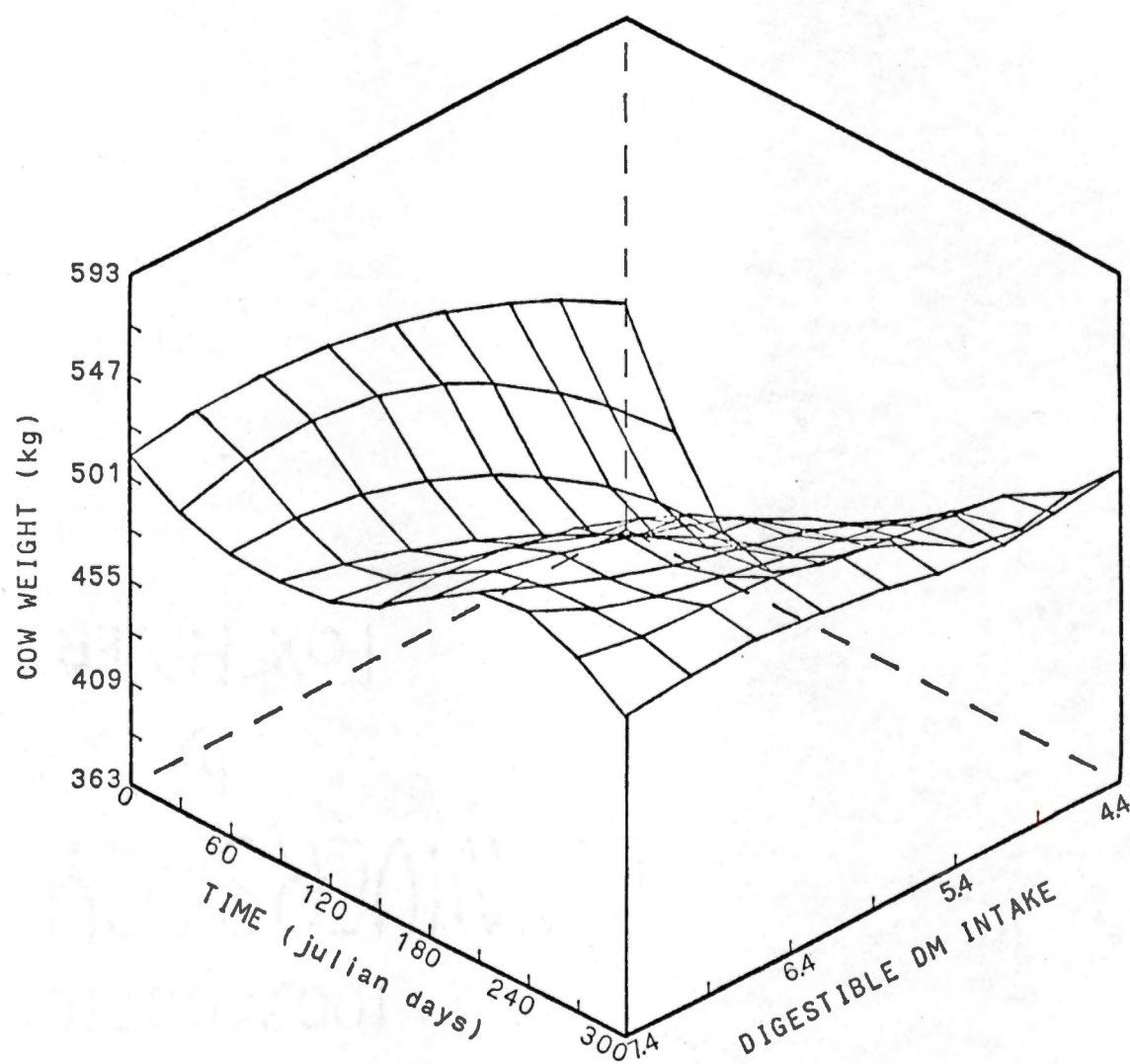


Figure 11. Relationship between cow weight change during the year and digestible dry matter intake for cows grazing high quality pastures.

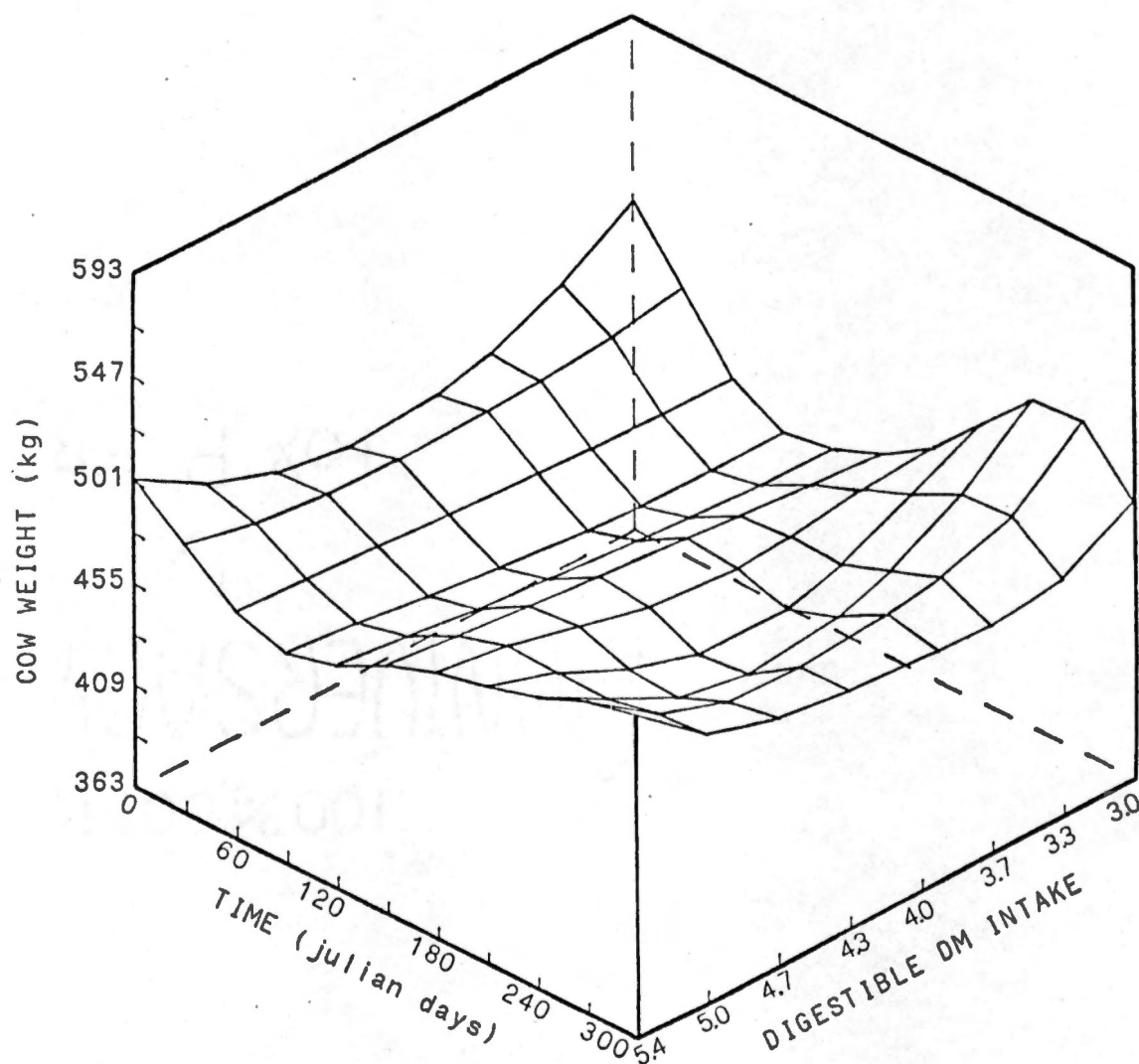


Figure 12. Relationship between cow weight change during the year and digestible dry matter intake for cows grazing low quality pastures.

For both pasture qualities, cows that consumed more digestible dry matter, had smaller seasonal cow weight change (Figures 11 and 12). It is possible that cows with small digestible dry matter intakes, had to use more of their digestible dry matter intake to meet lactation requirements than did cows with large digestible dry matter intakes, thus accounting for the drastic weight change patterns noted for cows with small digestible dry matter intakes.

The relationship between dry matter intake and mean cow weight during the year was different for cows grazing different pasture qualities, with cows grazing high quality pastures having higher dry matter intakes ($P < .07$). Dry matter intake had an influence upon the shape of the cow weight change curve by affecting A_1 ($P < .06$) and A_2 ($P < .03$) differently for the two pasture qualities. The periodicity of the cow weight change curve was not influenced by dry matter intake ($P > .30$).

Mean cow weight during the year was not influenced by the digestibility of the two pasture qualities. Digestibility of the pastures had an influence upon the shape of the cow weight change curve by affecting A_1 ($P < .03$) and A_3 ($P < .004$) differently for the two pasture qualities. Digestibility of the pastures had no influence upon the periodicity of the cow weight change curve ($P > .30$).

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APPENDIX

Table A-1
Individual Water Kinetics of Cows Grazing Fescue-Legume Pastures

Year	Cow Number	Stage of Lactation	Pasture	Injection Date (Julian Days)	A	B	K ₁	K ₂	FAB (mg/min)	FBA (mg/min)	FOA (mg/min)	Amount D ₂ O Injected (g)
1976	25	Calving	Small	50	386.2	613.2	-0.0285	-0.000264	1.98	1.90	0.0760	177.4
	25	Low-Weight	Small	106	92.8	562.2	-0.0500	-0.000392	1.73	1.62	0.1060	152.4
	206	Calving	Large	72	9.1	678.4	-0.0500	-0.000589	0.30	0.16	0.1448	166.9
	206	Weaning	Large	279	219.0	439.6	-0.0500	-0.000858	3.91	3.62	0.2893	149.6
	1286	Calving	Large	41	475.3	481.1	-0.0478	-0.000118	4.30	4.26	0.0422	172.9
	1286	Low-Weight	Large	106	475.1	480.8	-0.0340	-0.000249	2.98	2.89	0.0859	167.2
	1286	Weaning	Large	280	239.2	545.2	-0.0298	-0.000167	1.92	1.87	0.05	163.4
	1337	Calving	Large	45	324.2	388.6	-0.0465	-0.000207	4.83	4.75	0.0862	162.1
	1337	Low-Weight	Large	117	319.4	510.3	-0.0414	-0.000152	3.76	3.70	0.0576	194.2
	1436	Calving	Small	44	148.4	556.8	-0.0500	-0.000191	2.48	2.43	0.0561	163.9
	2477	Weaning	Small	281	357.4	517.8	-0.0288	-0.000245	2.12	2.05	0.0732	155.8
	180	Calving	Large	14	746.9	479.9	-0.0648	-0.000098	5.69	5.66	0.0321	176.8
1977	1516	Calving	Large	50	354.5	483.4	-0.0500	-0.000083	4.46	4.43	0.0267	176.3
	1668	Calving	Large	81	225.0	531.0	-0.0500	-0.000747	3.61	3.36	0.0247	176.9
	1668	Weaning	Large	280	325.8	348.7	-0.0243	-0.000198	2.27	2.20	0.0698	129.8
	3100	Calving	Small	49	430.6	592.0	-0.0552	-0.000130	4.06	4.02	0.0391	178.1
1978	1038	Low-Weight	Large	87	200.5	473.0	-0.0211	-0.000208	1.60	1.53	0.0733	167.2
	1337	Calving	Large	41	180.0	435.0	-0.0370	0.000012	2.99	2.99	0.0047	170.0
	1337	Weaning	Large	274	97.4	449.6	-0.2562	-0.000190	14.36	14.29	0.0725	171.7
	1668	Low-Weight	Large	86	424.8	518.3	-0.0925	-0.000377	7.78	7.65	0.1272	175.2
	1668	Weaning	Large	274	175.5	390.7	-0.0679	-0.000231	6.25	6.17	0.0989	167.5
	3199	Calving	Small	31	304.2	646.4	-0.0228	-0.000155	1.33	1.29	0.0410	171.2

Table A-2
Individual Water Kinetics of Cows Grazing Fescue Pastures

Year	Cow Number	Stage of Lactation	Pasture	Injection Date (Julian Days)	A	B	K ₁	K ₂	FAB (mg/min)	FBA (mg/min)	FOA (mg/min)	Amount	
												D ₂ O Injected(g)	D ₂ O Injected(g)
1977	305	Calving	Small	15	352.6	502.1	-0.0859	-0.000260	6.98	6.89	0.0865	167.6	
	448	Calving	Large	22	187.6	474.9	-0.0443	-0.000165	3.43	3.37	0.0621	179.3	
	836	Calving	Large	49	297.9	441.7	-0.0274	-0.000082	2.62	2.59	0.0323	175.2	
	9636	Calving	Small	21	371.3	497.6	-0.0610	-0.000142	5.31	5.26	0.0504	177.3	
1978	139	Calving	Small	48	544.7	553.5	-0.0685	-0.000108	5.42	5.39	0.0339	175.0	
	139	Low-Weight	Small	82	297.9	725.8	-0.0082	-0.000208	0.42	0.37	0.0483	169.9	
	494	Calving	Large	55	1000.0	457.4	-0.1301	-0.000391	10.43	10.29	0.1443	170.0	
	494	Low-Weight	Large	82	592.9	527.4	-0.0565	-0.000158	4.60	4.55	0.0513	172.0	
	494	Weaning	Large	275	0.086	535.1	0.0134	-0.000301	0.09	0.007	0.0948	168.3	
	600	Calving	Large	24	253.3	477.8	-0.0321	-0.000178	2.63	2.57	0.0635	171.3	
600	Low-Weight	Large	81	291.0	497.0	-0.0293	-0.000275	2.18	2.09	0.0860	156.2		

Table A-3
Individual Body Composition of Cows Grazing Fescue-Legume Pastures

Year	Cow Number	Stage of Lactation	Pasture	WT (lb)	COMWT (lb)	EBW (lb)	EBWT (lb)	EBPRO (lb)	EBMIN (lb)	EBFAT (lb)	PERH ₂ O (%)	PERPRO (%)	PERFAT (%)	PERMIN (%)	GE (kcal)
1976	25	Calving	Small	845.8	849.6	166.33	277.7	50.18	11.46	49.75	59.89	18.07	17.91	4.12	1014.72
	25	Low-Weight	Small	891.0	801.0	223.57	325.0	67.45	15.40	18.57	68.79	20.76	5.71	4.74	612.86
	206	Calving	Large	1074.3	1038.6	234.06	465.3	70.62	16.13	144.47	50.31	15.18	31.05	3.47	1720.51
	206	Weaning	Large	1239.0	1237.2	217.84	450.4	65.72	15.01	151.83	48.37	14.59	33.71	3.33	2165.29
	1286	Calving	Large	1045.0	1036.4	173.33	302.9	52.29	11.94	65.34	57.22	17.26	21.57	3.94	1371.20
	1286	Low-Weight	Large	964.7	964.4	163.66	272.4	49.38	11.28	48.11	60.08	18.13	17.66	4.14	1143.23
	1286	Weaning	Large	1003.3	999.0	198.31	365.0	59.83	13.66	93.20	54.33	16.39	25.53	3.74	1461.05
	1337	Calving	Large	1155.0	1203.8	218.14	364.7	65.81	15.03	65.70	59.82	18.05	18.02	4.12	1442.16
	1337	Low-Weight	Large	1125.5	1154.4	225.06	383.3	67.90	15.51	74.82	58.72	17.72	19.52	4.05	1444.07
	1436	Calving	Small	935.3	922.7	223.36	358.62	67.39	15.39	52.49	62.28	18.79	14.64	4.29	995.66
1977	2477	Weaning	Small	988.3	988.4	166.87	330.29	50.35	11.50	101.57	50.52	15.24	30.75	3.48	1626.99
	180	Calving	Large	1275.0	1266.0	131.67	360.42	39.73	9.07	179.94	36.53	11.02	49.93	2.52	2937.99
	1516	Calving	Large	1281.3	1302.8	200.49	443.52	60.49	13.81	168.73	45.20	13.64	38.04	3.11	2478.74
	1668	Calving	Large	1232.5	1240.5	224.97	465.341	67.87	15.50	157.00	48.35	14.59	33.74	3.33	2172.28
	1668	Weaning	Large	1225.5	1242.5	181.82	391.82	54.86	12.53	142.62	46.40	15.00	36.40	3.20	2292.07
	3100	Calving	Small	945.5	949.3	162.87	309.49	49.14	11.22	86.25	52.63	15.88	27.87	3.62	1466.32
	1038	Low-Weight	Large	975.3	993.2	239.80	348.14	72.35	16.52	19.47	68.89	20.78	5.59	4.74	755.75
	1337	Calving	Large	1267.5	1217.8	269.02	443.29	81.16	18.54	74.57	60.69	18.31	16.82	4.18	1407.77
1978	1337	Weaning	Large	1234.8	1239.5	307.92	497.14	92.90	21.22	75.11	61.94	18.69	15.11	4.27	1358.11
	1668	Low-Weight	Large	1018.5	1071.1	174.92	340.28	52.77	12.05	100.53	51.41	15.51	29.54	3.54	1717.58
	1668	Weaning	Large	1240.0	1247.3	289.19	438.17	89.25	19.93	41.81	66.00	19.91	9.54	4.55	1122.34
	3100	Calving	Small	956.3	953.4	169.03	350.65	51.00	11.65	118.98	48.21	14.54	33.93	3.32	1675.99

Table A-4
Individual Body Composition of Cows Grazing Fescue Pastures

Year	Cow Number	Stage of Lactation	Pasture	WT (lb)	COMWT (lb)	EBW (lb)	EBWT (lb)	EBPRO (lb)	EBMIN (lb)	EBFAT (lb)	PERH ₂ O (%)	PERPRO (%)	PERFAT (%)	PERMIN (%)	GE (kcal)
1977	305	Calving	Small	977.0	994.7	185.61	319.5	56.00	12.79	65.07	58.10	17.53	20.37	4.00	1273.93
	448	Calving	Large	1079.0	1070.0	263.01	382.50	79.35	18.12	22.02	68.76	20.75	5.76	4.74	820.33
	836	Calving	Large	1064.5	1064.5	227.99	332.08	68.78	15.71	19.60	68.65	20.71	5.90	4.73	825.16
1978	9636	Calving	Small	1005.0	1005.0	196.36	312.86	59.24	13.53	43.73	62.76	18.94	13.98	4.32	1061.83
	139	Calving	Small	891.7	891.7	147.49	242.64	44.50	10.16	40.49	60.79	18.34	16.69	4.19	995.79
	139	Low-Weight	Small	752.5	752.5	154.35	285.08	46.57	10.64	73.52	54.14	16.34	25.79	3.73	1146.44
	494	Calving	Large	896.5	896.5	103.16	158.56	31.12	7.11	17.16	65.06	19.63	10.82	4.48	834.86
	494	Low-Weight	Large	808.3	808.3	141.44	219.37	42.67	9.75	25.51	64.48	19.45	11.63	4.44	823.95
	494	Weaning	Large	998.3	998.3	308.50	447.01	93.07	21.26	24.18	69.01	20.82	5.41	4.76	742.49
	600	Calving	Large	1091.3	1091.3	225.30	400.12	67.97	15.52	91.33	56.31	16.99	22.82	3.88	1566.08
	600	Low-Weight	Large	926.5	926.5	187.86	334.80	56.68	12.94	77.32	56.11	16.93	23.10	3.87	1355.91

VITA

William Francis Brown, son of Peter W. and Stephanie W. Brown was born October 10, 1955, in Albuquerque, New Mexico. He grew up in Jacksonville, Florida, where he received his elementary and secondary education. Upon graduation from Samuel W. Wolfson High School in 1973, he attended The University of Florida and received the Bachelor of Science degree in agriculture in 1977. He was granted a graduate research assistantship from the Animal Science Department at The University of Tennessee, Knoxville, where he received the Master of Science degree in animal science in August 1979.