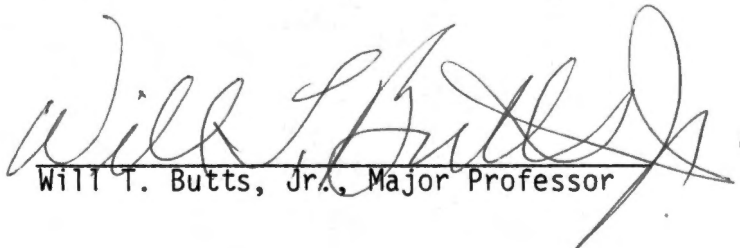


To the Graduate Council:

I am submitting herewith a dissertation written by Nancy Ella Sanders Greene entitled "Estimated Genetic Parameters of Measures of Partial Nutritional Efficiency of Cow-Calf Pairs." I have examined the final copy of this dissertation for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Animal Science.


Will T. Butts, Jr., Major Professor

We have read this dissertation
and recommend its acceptance:

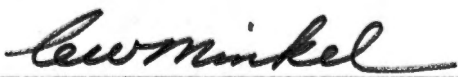
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ESTIMATED GENETIC PARAMETERS OF MEASURES OF PARTIAL
NUTRITIONAL EFFICIENCY OF COW-CALF PAIRS

A Dissertation
Presented for the
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Nancy Ella Sanders Greene

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ABSTRACT

Estimates of heritability (h^2) of the partial nutritional efficiency of cow-calf pairs during the lactation period (ratio of estimated total digestible nutrients (ETDN) consumed by the cow and calf during lactation to calf weight at weaning (LWEFF)) and over the entire 365-d period (ratio of 365-d ETDN consumed by the cow and calf to calf weight at weaning (365-d WEFF)) were obtained from intake and performance records of 146 cows by 56 sires raising 266 calves by 46 sires. Intake data on 113 cow-calf pairs were from individual feeding on a grass silage diet. Intake data on 153 cow-calf pairs were from weekly, inert marker estimates of forage intake of pairs grazing fescue or fescue-clover pastures. In addition to cow-calf pair efficiency, estimates of h^2 of cow-calf pair forage ETDN intake during the lactation period (LETDN), 365-d ETDN intake of the pair and mean daily milk intake were obtained by paternal half-sib analyses (sire of cow) by Henderson's Mixed-Model Procedure. The structures of the genetic influences on LWEFF, 365-d WEFF, LETDN intake, 365-d ETDN intake and calf mean daily milk intake were examined by sequential addition, as covariables, phenotypic traits of the cow-calf pair, to models estimating sire components of variance. From records adjusted for year-treatment, sex of calf and age of calf, estimates of h^2 obtained by Henderson's Mixed-Model Procedure of LWEFF, 365-d WEFF, LETDN intake, 365-d ETDN intake and calf mean daily milk intake were $.70 \pm .260$, $.69 \pm .260$, $.13 \pm .214$, $.09 \pm .210$ and $.83 \pm .267$,

respectively. After the addition of terms for cow weight and fat thickness, recorded at weaning of her previous calf, cow weight change during the year, calf weight at weaning and mean daily milk intake (where applicable) the estimates of h^2 of LWEFF, 365-d WEFF, LETDN intake, 365-d ETDN intake and calf mean daily milk intake were $.13 \pm .221$, $.08 \pm .216$, $.30 \pm .238$, $.07 \pm .215$ and $.32 \pm .238$, respectively. From records adjusted for year-treatment, sex of calf and calf weaning age, estimates of genetic correlations between LWEFF and mean daily LETDN intake, mean daily milk intake, cow weight, cow fat thickness and 365-d WEFF were $.13 \pm .332$, $-.70 \pm .221$, $.26 \pm .244$, $.25 \pm .309$ and $1.03 \pm .028$, respectively.

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CHAPTER I

INTRODUCTION

The efficiency of cow-calf production systems can be defined in many different ways. Emphasis may be placed on a particular segment of the life cycle of the cow-calf pair, or the life cycle may be considered as a whole which could include the entire life of the cow and calf and, possibly, more than one calf. The relationship of a particular biological process with a cow-calf production characteristic may be of interest, or the relationships of many biological processes to many cow-calf production characteristics may need to be considered as interrelated. Feed represents a major cost in the cow-calf production system, and, with the availability of land decreasing and equipment and transportation costs increasing, animal feed will remain a major cost in the future. One way of defining the partial efficiency of the cow-calf pair to weaning would be the ratio of the forage intake (considered as estimated total digestible nutrient intake) of the cow-calf pair until weaning of the calf to the weaning weight of the calf. Researchers have found small differences in the nutritional efficiencies of cow-calf pairs measured in this way. Some of the variation in nutritional efficiencies of cow-calf pairs has been explained on the basis of variation in weight and condition of the cow, in sex of calf and in weaning weight of the calf. The age of the calf and the amount of milk intake have been found to be predictors of calf weight at weaning and are related to the partial

nutritional efficiency of the cow-calf pair to weaning through the weight of the calf. The partial nutritional efficiency of the cow-calf pair to weaning has been found to be related also to the amount and quality of forage consumed.

Means of improving the partial nutritional efficiency of the cow-calf pair are to select for nutritionally efficient cows (either directly or indirectly by selecting on the basis of known components of efficiency) and to use bulls that would promote nutritional efficiency of the cow-calf pair, or to alter the environmental conditions in such a manner as to promote nutritional efficiency of cow-calf pairs. Before the selection of nutritionally efficient cows and before mating schemes can be developed to promote nutritional efficiency of cow-calf pairs, the degree to which genetic differences contribute to differences in partial nutritional efficiency of cow-calf pairs to weaning must be determined. Since it is known that the partial nutritional efficiency of the cow-calf pair to weaning is related to traits of the cow and calf and to cow-calf pair forage intake, it is important to know to what degree these factors are under genetic control.

The objectives of the present study were to estimate the genetic parameters of the partial nutritional efficiency of the cow-calf pair to weaning, the cow-calf pair estimated total digestible nutrient intake, calf weight at weaning and the average milk intake of the calf. The estimates of variance components were obtained by Henderson's Method III, a maximum-likelihood method and Henderson's

Mixed-Model Procedure. Various traits of the cow and calf were considered covariables, and the genetic structure of the estimates of the variance components were studied. The genetic and phenotypic coefficients of correlation of the partial efficiency of the cow-calf pair to weaning with traits of the cow and calf were estimated.

CHAPTER II

REVIEW OF LITERATURE

Many researchers have studied the efficiency of cow-calf production systems, in particular, the relationships of cow and calf feed consumption to weight of calf produced at weaning. Some workers have studied single lactations in which only one calf was involved, while, others have studied lifetime efficiencies which take into consideration reproductive rates and possible salvage value of the cow. Morris and Wilton have published two reviews (Morris and Wilton, 1976; Morris and Wilton, 1977) summarizing much of the work done in this area of study, particularly, in relating cow body size to cow-calf efficiency. Dickerson (1970, 1978) and Fitzhugh (1978) have similarly published extensive discussions of cow-calf efficiency.

This literature review will be divided into two major sections. The first section will contain reviews of studies which have been conducted on cow-calf efficiency to weaning and its relationships with nutritional factors and traits of the cow and calf. The second section will deal briefly with the methodology of estimating variance components and genetic parameters.

1. COW-CALF PAIR EFFICIENCY

Estimates of Measures of Partial Efficiency

Studies involving cow-calf pair efficiency to weaning have been conducted in South Dakota, Wisconsin, Texas, Canada and Tennessee,

utilizing a variety of breeds, crosses, sizes of cows, diets, both individually-fed and pasture, and including data from one or more lactations.

Marshall et al. (1976) collected data over a 3-year period from 73 individually-fed 2-, 3- and 4-year old Angus, Charolais and reciprocal cross cows and their calves. They calculated efficiency as the ratio of total digestible nutrient (TDN) intake of the cow plus nonmilk TDN intake of the calf to calf weight at weaning and reported a mean value of 11.47 ± 1.21 . These cows were fed varying amounts of a diet relatively high in energy in an attempt to simulate the weight-change pattern of similar cows maintained on improved pastures.

Melton et al. (1967) used 30 Hereford and 15 Charolais cows selected to include the smallest and largest of each breed in the station herd. Cows and calves were individually-fed, and efficiency ratios were calculated by the same method as used by Marshall et al. (1976). The mean efficiency values for pairs involving small, medium and large Hereford cows and small and large Charolais cows were 8.6, 8.6 and 9.1 and 7.4 and 8.9, respectively. These cows were fed a 56.3 percent TDN diet in amounts needed to maintain body weight.

Butts et al. (1984), using data from the same individually-fed Angus cow-calf pairs which provided data for the present study, measured weaning efficiency as the ratio of total forage TDN intake of the cow and calves until weaning to calf weight at weaning and reported means of 11.1 and 12.1 for steer and heifer calves,

respectively, with an identical standard deviation of 2.4 for each of these values and a residual standard deviation of 1.5 after adjustments were made for year and sex of calf.

Holloway and Butts (1983), using data from the pastured Angus cow-calf pairs which provided data also for the present study, measured weaning efficiency as the ratio of total forage digestible dry matter intake of the cow and calf to calf weight gain to weaning. Data were collected over a 4-year period in which cow-calf pairs were maintained on either fescue or fescue-legume pastures, and mean efficiency values were 11.90, 13.82, 11.82 and 17.36 for the 4 years for cow-calf pairs pastured on fescue-legume pastures, and 11.43, 10.66, 10.07 and 13.49 for the 4 years for cow-calf pairs pastured on fescue pastures. After adjusting for year, sex of calf, birth date, pasture type and year x pasture type interaction, the residual standard deviation was 1.896. In each of the studies mentioned above, a smaller value represents greater efficiency.

Kress et al. (1969) and Davis et al. (1983a,b) reported life-cycle (that is, until the animals were removed from the study) cow-calf pair efficiency values, measured as the ratio of outputs (progeny weaning weights plus cow salvage weight) to inputs (progeny creep feed plus the cow's lifetime feed consumption). Kress et al. (1969) reported mean efficiency values for 1 lactation, 2 lactations and 3 lactations to be .101, .102, and .112, respectively, where larger values indicate greater efficiency. No research providing estimates of genetic parameters of cow-calf pair weaning efficiency has been reported.

The efficiency of cow-calf pairs has usually been measured as a function of two factors, the feed consumption of the pair and the weight of the calf produced. Marshall et al. (1976) reported that weaning weight alone and in combination with calf age accounted for 62 percent and 68 percent, respectively, of the variation in cow-calf weaning efficiency. Butts et al. (1984) reported similar results. After adjusting for year and sex of calf, 64 percent of the variation in cow-calf pair efficiency was explained. Adding initial cow weight and fat thickness along with cow weight change explained an additional 4 percent of the variation, and adding calf age and weaning weight to the model explained an additional 16 percent of the variation. Holloway and Butts (1983) reported a phenotype-by-nutritional-environment-interaction effect on cow-calf pair efficiency due to the type and amount of forage consumed by the cow as related to her weight and condition and the products she produced.

Many estimates of heritability of weaning weight have been reported. Woldehawariat et al. (1977) reported an extensive review of all of the estimates of heritability of weaning weight that had been reported prior to the review. Vesely and Robison (1971), after adjusting for the fixed effects of lactation, year, sex of calf, age of dam, sires nested within year and regressing weight at weaning on date of birth and age at weaning, estimated heritability of weaning weight to be $.50 \pm .10$. Thrift et al. (1981) estimated the genetic parameters of calf weaning weight from data collected from three Southern Region Stations. After adjustments for the fixed

effects of cow age, breed-station-year combination and, sire within breed-station-year combination and weaning age, the estimates of heritability were calculated for each line (select-yearling weight or control) and sex of calf combination. The results were $.27 \pm .11$ and $.39 \pm .21$ for select and control males, respectively, and $.16 \pm .11$ and $.39 \pm .21$ for select and control females, respectively. Nelson and Kress (1979) reported estimates of heritability of calf weaning weight calculated from Angus and Hereford field data. Estimates were calculated by the paternal half-sib method with estimates of variance components obtained by Harvey's least-squares procedure. After adjustments were made for herd, year within herd, sire within year within herd, sex, age of dam, herd x sex interaction and sex x age of dam interaction and calf weaning age, the estimate of heritability of weaning weight, based on the Angus data, was $.35 \pm .06$ and, based on the Hereford data, was $.43 \pm .09$ (bulls only).

Fewer estimates of genetic parameters of cattle feed consumption have been reported. Estimates of the heritability of feed consumption by mature cows have not been reported. A few studies have reported estimates of heritability of consumption by calves during the post-weaning growth period. Brown and Gifford (1962) estimated heritability of feed consumption to be .76 in Angus and Hereford bulls fed 154 days in post-weaning tests in Arkansas. This estimate was based on paternal half-sib analysis. Brown and Gacula (1964) later reported an estimate of heritability of feed consumption of .43 from data from the same calves by the weighted-regression technique, using regression of

offspring record on sire record. Koch et al. (1963), studying Angus, Hereford and Shorthorn calves fed different types of diets, estimated heritability of feed consumed to be .64 after adjustments were made for difference in live weight. Swiger et al. (1965) reported heritability of daily TDN intake to be .64 from data from 480 calves including 9 breeding groups of combinations of Hereford, Angus and Shorthorn straightbreds and crossbreds. Bogart and England (1971) estimated the heritability of post-weaning feed consumption of Angus and Hereford calves fed to gain 136.2 kg or until they reached 313.2 kg of body weight to be $.38 \pm .15$.

Factors Affecting Components of Cow-Calf

Efficiency

Cow size. The effect of cow size on cow-calf efficiency should be expressed either as an effect on the feed consumption of the pair or as an effect on the calf weaning weight. Larger animals consume more feed than do smaller animals, mainly because of the increased maintenance requirements. Maintenance requirements are based on metabolic body weight to the .75 power (MW), and beef cow maintenance requirements increase from 10.8 Mcal metabolizable energy per day (ME/d) at 350 kg to 14.1 Mcal ME/d at 500 kg of body weight (NRC, 1976). Turner et al. (1974) partitioned TDN utilization into maintenance, body weight change and milk production, utilizing large cows averaging 555 kg in weight and small cows averaging 407 kg in weight. Their results indicated that maintenance requirements

increased proportionately to MW, and requirements were .036 kg of TDN per kg MW. Cow body size has been the factor most commonly studied to determine its effect on cow-calf weaning efficiency.

There have been conflicting results concerning the relationship between cow size and cow-calf efficiency. The effect cow size has on cow-calf efficiency may be a result of a relationship between cow size and cow forage intake or a relationship between cow size and calf weight at weaning or a combination of the two relationships.

Kress et al. (1969) calculated efficiency measures that either took into account the salvage weight of the cow or did not. If salvage weight was not considered and age at calving held constant, lighter cows were more efficient (as cows have more lactations, the salvage value of the cow becomes less important). However, further study indicated that adding height at withers to a regression model in which age at calving was held constant, showed that cows with greater height at withers tended to be more efficient. Perhaps a heavier cow weight indicated a fatter cow, and, thus lighter cows were more efficient from carrying less fat rather than from having a large skeletal size.

Melton et al. (1967) studied the relationships between the size of Charolais and Hereford cows and their milk yield and the effect cow size had on calf gain. They found that smaller Hereford cows gave more milk and had faster gaining calves than larger Hereford cows, with medium cow size having an intermediate effect on milk yield and lowest calf gain. The larger Charolais cows had a slight advantage over the smaller ones in milk yield, but calves from the

smaller cows gained considerably more than those from the larger cows. Overall, the smaller cows of both breeds were considered to have a slight advantage in efficiency over the larger cows.

Davis et al. (1983b) reported that weights, heights and weight:height ratios taken at 240 days of age were not correlated significantly with subsequent efficiency of calf production, indicating that selection for these traits to improve indirectly lifetime cow efficiency at an early age would be ineffective. Correlations of efficiency with weight of dam at calving and at weaning were negative and generally highly significant. Height at withers also was negatively correlated with efficiency.

Butts et al. (1984) reported that initial cow weight, considered by itself, was unrelated to pair efficiency, but, when considered together with calf weaning weight, it had an unfavorable effect on pair efficiency. However, initial cow weight was positively associated with calf weaning weight. Dinkel and Brown (1978) reported results similar to those of Butts et al. (1984). They found calf weight at weaning to be the most important predictor of cow-calf efficiency with a .81 coefficient of determination and cow weight to be a less important predictor with only accounting for an additional 3 percent of the variation in calf weight at weaning.

Song and Wilton (1980), in an effort to develop equations for predicting cow-calf efficiency to weaning, fitted a model which included sex of calf, sire and group within sire as fixed effects, accounting for 23.2 percent of the variation in weaning efficiency. The prediction

equation including fixed effects, cow weight and calf weaning weight yielded a coefficient of determination of .70. The prediction equation including fixed effects, and the ratio of calf weight to cow weight yielded a coefficient of determination of .67. The prediction equation including fixed effects, cow weight, milk production, cow weight x milk production interaction, heart girth, height, shoulder-to-hip, hip-to-hook and calf weaning weight had a coefficient of determination of .77. Calf weaning weight and the ratio of calf weaning weight to the weight of the cow proved to be the most important variables in predicting cow-calf weaning efficiency.

Knox (1957) reported data comparing large and compact type Herefords and found that large type cattle consistently weaned heavier calves. However, when this comparison was made on a unit-of-cow-weight basis, there were no significant differences between the types. The average annual production of the two types showed a 13 percent advantage in favor of the large-type cows which were superior in reproductive rate. Vaccaro and Dillard (1966) reported that cows that were heavier 90 days prior to calving tended to produce heavier calves throughout the lactation period. Godley et al. (1970) found Hereford cow weight at the beginning of the breeding season to have a significant positive effect on preweaning weight per day of age of Hereford calves but did not observe this effect in their Angus data. Hawkins et al. (1965) found that Hereford cows with the heaviest pre-calving and early pasture weights had fewer calves born per cow bred and produced calves with lower 205-day weights. The same was

true for post-calving weights in that cows weighing less at calf weaning, weaned more calves and more total pounds of calf. Carpenter et al. (1972b) in a study of performance records of calves raised from cows that were fed to maintain an average condition (in other words, fatter cows were fed less and thinner cows were fed more), observed a tendency for calves from smaller cows to be heavier at weaning. This was thought to be due to the heavier milk production, possibly due to extra feeding and the fact that these calves had a higher pre-weaning feed consumption. The cow-calf pairs from smaller cows tended to be more efficient even though the difference was not significant, probably due to the increased feed consumption of the smaller, thinner cows. Olson et al. (1982) studied the effects of cow size on cow productivity and performance, studying cows divided into four size categories. The ratios of adjusted weight of calf weaned/cow exposed to cow MW were 1.63, 1.39, 1.51 and 1.15 for small, medium, large and very large cows. Compared to herd average, small, medium, large and very large cows weaned -1.5, 3.6, 11.2 and 6.7 percent weight of calf/cow exposed. In this study, the very large cows were the fattest, and the small cows were the thinnest. Clark et al. (1958) and Brinks et al. (1962) reported small correlations of .11 and .12, respectively, between previous fall weight of the cow and the adjusted weaning weight of the calf. Urlick et al. (1971) reported relationships between the weights of Charolais, Hereford and Angus cows and the weaning weight of their calves. They found correlations between actual cow weight and weaning weight and 205-day weaning weight of

the calf to be .16 and .21, respectively. However, a large negative correlation (-.56) between cow weight with calf weight per 45.4 kg of cow weight indicates an inverse relationship of calf and cow weights, with smaller cows having the larger calf weights per unit of cow weight. The relationship of calf and cow weights appeared essentially linear ($P < .01$). The test for curvilinearity was not significant, but there was some evidence of a downward trend in calf weight from cows in the heavier classes. Hohenboken et al. (1973) reported that the size of the dam at calving and at weaning of calf was positively correlated with progeny size. Hays and Brinks (1980) reported small positive genetic correlations of $.25 \pm .22$, $.31 \pm .23$ and $.09 \pm .23$ between weight taken in the spring, summer and fall and adjusted calf weaning weight, respectively. Rahnefeld et al. (1980) found that cows heavier the previous October prior to parturition produced faster gaining and heavier calves at weaning. Correlations of cow weight in the previous October with weaning weight and pre-weaning average daily gain (ADG) were $.28 \pm .05$ and $.25 \pm .05$, respectively. Correlations of weaning weight with cow weight at parturition, in June and in October following parturition were $.42 \pm .04$, $.40 \pm .04$ and $.41 \pm .04$, respectively. Singh et al. (1970) found cow weight not to have a significant ($P > .05$) effect on calf weaning weight or calf ADG; but, heavier cows tended to wean heavier calves, and cows of intermediate weight at parturition produced calves that grew faster. In general, most of these findings indicate a small positive relationship between cow weight and calf weaning weight.

Some investigators have studied the effect of cow size on feed consumption and have found this effect to range from positive to no effect. Stonaker et al. (1952) compared the hay consumption of large, intermediate and small breeding females of different age groups and found that, within an age group, the amount of hay eaten per unit of body weight maintained was independent of cow size. This indicates that there was a difference in the hay consumption of cows weighing less than 455 kg and that of cows weighing more than 455 kg. Carpenter et al. (1972a) discussed the relationship between feed consumption and mature size of beef cows. They found that mature size did not significantly affect the feed consumption of the cows, however, they were feeding their cows to maintain average conditions. Melton et al. (1967), comparing large and small Charolais cows to small, medium and large Hereford cows found that, in both the Charolais and Hereford, an increase of approximately .27 pounds of TDN daily was required for each 45.45 kg increase in cow weight. Fulgoni (1983) reported that cow body weight was positively related to digestible dry matter (DDM) intake, but body width was negatively related to DDM intake.

Cow weight change and cow condition. Some workers have found cow weight change to play an important part in explaining the variation in cow-calf efficiency and its direct components, pair feed consumption and calf weaning weight. Gregory et al. (1950) calculated negative coefficients of correlation between calf gain from birth to weaning and cow gain from calving to weaning, using data collected from two

different experiment stations. The data from the North Platte Station yielded a correlation of $-.12$, and the data from the Valentine Station yielded a correlation of $-.34$. These correlations indicated that cows making the smallest gains during lactation produced calves which made the largest gains. These results agree with Brinks et al. (1962) who reported a small negative correlation ($-.17$) between cow weight change and calf weaning weight. Singh et al. (1970) found that cow weight change during lactation influenced ($P < .01$) pre-weaning ADG and calf weaning weight. Each percent loss in a cow's weight added $.14$ to 1.09 kg to her calf's weaning weight. Hohenboken et al. (1973) reported that cow weight gain during lactation was negatively correlated with calf pre-weaning gain. Butson and Berg (1978) reported that $.1$ -kg increase in average daily gain of the cow from calving to weaning was associated with a decrease of 1.3 kg in calf weight at weaning.

Cow winter weight loss did not appear to have an effect on calf weight at weaning. Hays and Brinks (1980) reported a large negative genetic correlation ($-.60 \pm .42$) between cow weight change from spring to fall and calf weaning weight. Rahnefeld et al. (1980) did not find any of the cow weight changes studied to have a significant effect on calf weaning weight. Butts et al. (1984) reported that a positive cow weight change from the previous October prior to calving to calf weaning had an unfavorable effect on cow-calf weaning efficiency and weaning weight. Wilton and Song (1980) regressed cow weight change on lactation dry matter consumed and creep dry matter

consumed and reported regression coefficients of 1.39 and .10, respectively. In general, cow weight change during the lactation period as well as weight change during the 365-d period had a negative relationship with calf weaning weight.

Klosterman et al. (1968) estimated fatness by a visual condition score and by a weight:height ratio and found that these two variables had a significant correlation of .89. They studied changes in body weight and condition of different sizes of non-pregnant, non-lactating Charolais and Hereford cows fed a diet based on their weight. The level of energy fed appeared adequate for maintenance. Very small differences were observed in body weight, with a tendency for fatter cows to gain weight and thinner cows to lose weight. Kress et al. (1969) measured cow fatness by the weight:height ratio and found differences ($P < .01$) in efficiency of cows in the first lactation (age at calving held constant), suggesting that efficiency is negatively related to fatness. Davis et al. (1983b) reported that weight:height ratios were negatively related to efficiency. Lemenager et al. (1980) developed equations for predicting the relative TDN needs (kg/d) of cows during late gestation and lactation. They found that visual body condition score combined with weight appeared to predict relative TDN requirements of pregnant cows during late gestation more accurately than did weight alone. Similarly, condition score, when used with weight and estimated milk production, appeared to predict relative TDN needs more accurately during early lactation than did weight and milk production alone. Butts et al. (1984) did not find

initial cow fat thickness measured ultrasonically to have a significant effect on cow-calf efficiency. Ending cow fat thickness approached having a significant undesirable effect on cow-calf efficiency.

Milk production. Marshall et al. (1976) reported that milk production alone accounted for 23 percent of the variation in cow-calf efficiency and had a moderate correlation with it (-.52, smaller efficiency values being desirable). However, when cow-calf efficiency was regressed on calf weight at weaning, 62 percent of the variation in pair efficiency was explained by weaning weight alone, and, if milk production was added to the model with calf weaning weight, calf age and cow weight, only an additional 10 percent of the variation was explained with the smallest standard partial coefficient of regression being that of efficiency on milk production. Butts et al. (1984) reported very similar results. When pair efficiency was regressed on initial traits of the cow and milk production, milk production had a highly ($P < .001$) significant effect, but when calf weaning weight was added to the model, milk production was no longer significant and played only a minor role in explaining the variation in pair efficiency values.

Rutledge et al. (1971) reported that, on a within herd-sex-year basis, approximately 60 percent of the variance in 205-day calf weight could be attributed to the direct influence of the dam's milk yield. Butson and Berg (1978) found a simple correlation between milk and component yields and calf weaning weight of .6 and reported

that a 1-kg increase in daily milk yield was associated with a 7.7-kg increase in calf weight at weaning. Robison et al. (1978) found a phenotypic correlation of .63 between milk production and calf weaning weight. Melton et al. (1967), studying the relationships of milk yield with calf gain and size of Charolais and Hereford cows, found that smaller Hereford cows gave more milk and had faster gaining calves than did larger Hereford cows and that medium cow size had an intermediate effect on milk yield and was associated with the lowest calf gain. The larger Charolais cows had a slight advantage over the smaller ones in milk yield, but calves from the smaller cows gained considerably more than those from the larger cows. Wilton and Song (1980) regressed change in cow milk yield on lactation dry matter consumption and creep dry matter consumption and found regression coefficients of .086 and -.009, respectively. Hohenboken et al. (1973) reported cow weight change during lactation to be negatively correlated with milk production and calf pre-weaning gain. Milk production and butterfat production were moderately correlated with calf gain and weaning weight.

Lownam et al. (1979) studied the effects of three planes of nutrition in early lactation on the performance of beef cows. The cows were divided into three groups and fed either .89, 1.21 or 1.63 times the estimated allowance of metabolizable energy (.5 MJ/kg cow MW) and were maintained on these diets for the total lactation period. Increasing the plane of nutrition significantly ($P < .05$) increased the 150-day cumulative milk yield. The small 150-day-cumulative-milk

yield response (32.8 kg/10 MJ ME and 62 g digestible crude protein/day) demonstrated the limitation of feeding beef cows for increased milk production as opposed to feeding the calf directly. Fulgoni (1983) found that digestible dry matter intake was positively related to milk production in light-weight cows but was negatively related in heavy-weight cows.

Phenotype by environment interaction. A few researchers have attempted to tie all of these variables together to discover how each variable, cow size, feed consumption, type of forage consumed, cow weight change, cow condition, calf weaning weight and milk production affects cow-calf pair efficiency in an overall scheme. The general result is a phenotype by environment interaction in which under different nutritional environments, cow phenotypes react differently and may be more efficient in one environment but less efficient in another. Holloway and Butts (1983) published a description of a classical example of this phenomenon. Mature Angus cows of various sizes and types were assigned to either fescue-legume or fescue pastures. Cows grazing fescue-legume pastures consumed 1.7 kg/d more dry matter that was 4.6 percent more digestible than was the case in cows grazing straight fescue pasture. They in turn produced .4 kg/d more milk and weaned 23.8 kg more calf. However, this increased production required an additional intake/cow-calf unit of 2.3 kg of digestible dry matter for each additional kg of calf weaning weight. Cows grazing fescue-legume pastures gained 33.3 kg more

weight and 1.82 mm more fat cover than did cows grazing fescue. The result was that cows grazing fescue-legume pastures were less efficient than were cows grazing fescue pastures. One difference to note is the fact that structural size did not affect efficiency of cows grazing fescue-legume pastures since this quality of forage was sufficient to support a structurally large cow, and her milk production potential was fully expressed. Among cows grazing fescue pasture, smaller cows or cows that had smaller amounts of fat were more efficient since this quality of forage was not adequate to allow a larger cow or a cow that tended to fatten to be an efficient producer of calf weight. Milk production was positively related to digestible dry matter consumption in cows grazing both pasture types, but level of milk production was negatively related to weight maintained during mid- to late-lactation in cows grazing fescue and positively related in those grazing fescue-legumes.

Parkins et al. (1977) used two equations to calculate the metabolizable (ME) and net energy (NE) requirements (modified versions of Zulberti and Reid, 1972) for ME and an adapted version of Lofgreen and Garrett (1968, for NE), in creep feed for calves and total energy requirements of cow-calf pairs using information from cows with three levels of milk production and of three sizes. For calves weaned at a constant weaning weight within a given cow size, the total energy required to produce a weaned calf increased with increased milk yield above 5 kg/day. Increases in total energy costs between milk yields of 5 and 15 kg/day to produce a 182-kg weaned calf from a 400-kg cow

were 8 and 14 percent for NE and ME methods of calculation, respectively. The increases in total energy costs between milk yields of 5 and 15 kg/day to produce a 274-kg weaned calf from a 600-kg cow were 11 and 13 percent, respectively, for the NE and ME methods of calculation. The 600-kg cows producing 5 kg milk were the most efficient and the 400-kg cows producing 15 kg of milk were the least efficient. The results of this study indicated a difference of 17-29 percent in efficiency in terms of total energy (including energy for cow maintenance, pregnancy, milk production and creep feed)/kg weaned calf between the two extremes. At a given level of milk production, efficiency of energy use to produce a weaned calf increased with increasing cow size, and, within a cow size, efficiency decreased as milk yield increased above 5 kg/day. Their results indicated also that for any given live weight gain of calf, it is more efficient to give creep feed to the calf than to give extra feed to the dam to obtain from her the additional milk required.

Vicini et al. (1982a) compared the effects of forage species and creep grazing on the forage intakes of cows and calves. In the first treatment, cows and calves were allowed to graze native pastures consisting of a mixture of Kentucky bluegrass and white clover. In the second treatment, cows were allowed to graze a tall fescue pasture while calves were allowed free access to the tall fescue pasture and a creep pasture consisting of Kentucky bluegrass and white clover. In the third treatment, cows and calves were allowed access to a tall

fescue pasture. Forage intakes and digestibilities were estimated by the same methods that Holloway and Butts (1983) used. Mean daily dry matter and metabolizable intake by the cows on the native, fescue-creep and fescue pastures were 11.9 kg and 25.9 Mcal, 10.6 kg and 22.2 Mcal and 9.9 kg and 20.7 Mcal, respectively. These results agree well with the results of Holloway and Butts (1983) in which cows grazing a high quality fescue-legume pasture consumed 1.7 kg/d more dry matter that was 4.6 percentage units more digestible than was the case with cows grazing a low quality fescue pasture. Overall, forage consumption by the cows was greatest in the spring, with that from the native pastures greater than that from the other pastures. Mean forage consumptions by the calves over the entire grazing season were 2.6, 2.4 and 2.2 kg/head/day, respectively, on the native, fescue-creep and fescue pastures. When forage intakes by calves were expressed as g/kg MW, fescue-creep (59.7) was superior ($P < .05$) to "native" treatment (57.2) which was superior to the "fescue" treatment (54.3). Forage dry matter intake by the calves averaged 1.6, 2.1 and 3.5 kg/head/day during the spring, summer and fall grazing periods, respectively. Cows and calves were assigned to pastures an average of 60 days postpartum. No indication of correcting calf intake for calf age was given. Vicini et al. (1982b) reported cow and calf production results from the same study. Cows on all three treatments lost weight during the lactation period, but there were no significant differences in these losses due to treatment. On the native, fescue-creep and fescue pastures, respectively, average milk productions

were 6.1, 3.8 and 5.1 kg/day with higher ($P < .10$) production on the native pastures. The 205-day adjusted weights of the calves on the "native," "fescue-creep" and "fescue" treatments were 211, 193 and 182 kg, respectively, with ADG highest ($P < .10$) in calves on the native pastures and lowest ($P < .10$) in calves on fescue pastures. This also is in agreement with Holloway and Butts (1983) who reported that cows grazing fescue-legume pastures produced .4 kg/d more milk and weaned 23.8 kg more calf than did cows grazing fescue pastures. These results and those of Vicini et al. (1982a) suggest that the superiority of the "native" treatment over the "fescue-creep" treatment in supporting calf ADG was due to enhanced milk production by the cows, while the superiority of the "fescue-creep" treatment over the "fescue" treatment was due to increased forage consumption by the calves. Cow-calf efficiency values from this study were not reported.

Boggs et al. (1980) studied the effects of milk and forage intake on the performance of calves born within one of three periods of time (March 1-20, March 21-31 or April 1-May 2). Calves born during the second period consumed more milk than did those born within period one or period three, probably because this period of time coincides with the time when poor winter forage available to the cow was replaced by higher-quality spring forage. Improved cow condition was related to decreased milk production during the first four months. Each additional kg of milk per day added 7.20 kg of 205-day adjusted calf weaning weight. Calves born during period three consumed less dry matter than did those born during period one or period two, probably

due to their being younger calves during the summer months when the forage was of lower quality.

Davis et al. (1983a) reported that dams receiving low-energy diets generally had lifetime efficiencies equal to or superior to those of cows fed high-energy diets in spite of older ages at calving. Dams on high-energy diets had greater salvage value but did not wean calves of additional weight to offset their increased ME intake.

Long et al. (1975) listed variation in size of cow, mating system, growth and development pattern, nutritional requirement, market conditions and management practice as some of the variables responsible for variation in productive efficiency of beef production systems. By using actual cow-calf data collected at Texas A&M, supplemented with estimates of genetic and phenotypic parameters of variables of interest and various other information, they were able to simulate actual production situations. Systems utilizing small cows produced more live weight and gross income but were more expensive to operate than were systems using larger cows. In a drylot management system, where the major expense was cow feed, the increased income from small cows was more than offset by increased expenses, making systems using larger cows more profitable. However, under pasture management, where cows were maintained more cheaply, systems utilizing small cows were more profitable. Statements of Klosterman (1972) are in agreement with this philosophy.

Summary

Researchers have reported small differences in cow-calf weaning efficiencies and have searched for factors to explain these differences. The factors that have been found to affect cow-calf efficiency are cow body size, cow weight change, milk production, calf weight at weaning and cow-calf pair feed consumption. All of these factors are interdependent upon each other and upon the environmental conditions to which the animals are subjected. Under all conditions, no particular cow size, level of milk production or level of feed consumption is optimum, but, under limited conditions, there are certain optimum characteristics that improve efficiency. Cartwright (1979) drew this conclusion concerning cow size; cow size is important, and there is an optimum size above and below which there are sizes which cause herd efficiency to decrease. However, through proper management of the calves and taking milk production into consideration simultaneously with cow size, there is a broad range around optimum cow size within which efficiency changes little for a given set of conditions. Klosterman (1972) stated that a need will continue to exist for cattle populations which vary in size and rate of maturing and that no single size will be most efficient under all conditions. These workers are referring more specifically to cow size, but the research shows these conclusions to apply to all factors affecting cow-calf pair efficiency.

2. METHODOLOGY FOR ESTIMATING VARIANCE COMPONENTS AND GENETIC PARAMETERS

Methods of Estimating Variance Components

C. R. Henderson (1953) published three methods of variance component estimation and for many years, even unto the present, his Method III was the predominant method used in animal breeding work (Henderson, 1953). His methods were modeled after the balanced ANOVA methods of estimation. Method I was devised to be used with a completely random model, and the procedure is to compute sums of squares as in the standard analysis of variance of orthogonal data, then to equate these sums of squares to their expectations and solve for the unknown variances. Method II allows for including fixed effects by obtaining least-squares estimates of fixed effects, then adjusting the data for these fixed effects and then using the adjusted data in place of the original data and proceeding as in Method I. Method III allows for including fixed and random effects and non-orthogonal data. Mean squares are computed by least-squares analysis of non-orthogonal data and then equated to their expectations to solve for the unknown variances.

Method I leads to biased estimates if certain elements of the model are fixed or if some of the variables are correlated. Method II is free of the bias due to fixed effects but, as with Method I, correlated data cannot be validly used. Method II does not allow for fixed and random interactions to be used in the models. Method III

yields unbiased estimates but does not allow for adjustments for relationships among sires and adjustments of the error variance for external variation that may be affecting it (Henderson, 1984).

Henderson's Methods I, II and III do not prevent the estimates of variance components, other than the error variance, from becoming negative. Some researchers believe that these are not truly estimates because they do not lie in the parameter space, but, to obtain unbiased estimates, they believe one must be prepared to accept such solutions. Some researchers truncate negative values to zero, others drop the offending variable from the model and re-estimate the parameter. Henderson (1984) stated that if values are truncated to zero, they no longer can be considered unbiased.

Searle (1978) stated that the next major breakthrough in variance component estimation was made by Hartley and Rao (1967) when they described maximum-likelihood (ML) procedures based on the assumption of normality of the random effects. Searle (1971) summarized maximum-likelihood estimation as the process of taking the logarithm of the likelihood function of the dependent (y) variable, and then, after differentiating with respect to the parameters of interest (the variance components of the random effects), setting the derivatives equal to zero and solving these equations for the parameters. This is an iterative solution that is allowed to iterate until convergence and, because of the nature of maximum-likelihood estimators, the variance components obtained cannot be negative. The research efforts of Hartley and Rao (1967) and others paved the way for the Restricted

Maximum-Likelihood (REML), Minimum Norm Quadratic Unbiased Estimation (MINQUE) and Minimum Variance Quadratic Unbiased Estimation (MIVQUE) methods.

Henderson and Henderson (1979) described a procedure for estimating variance components using general mixed-model equations, and it will be referred to here as Henderson's Mixed-Model Procedure. This procedure can use unbalanced data with fixed and random effects, the interactions of the fixed and random effects and continuous co-variables. This procedure allows for adjusting the variances of the random effects. The sire component of variance can be adjusted for relationships among the sires, and the error component of variance can be adjusted for external sources that are contribute to it. The variances of the random effects are assumed to be known, and, if they are not known, they must be estimated by an independent method and substituted into the procedure. This procedure is an iterative procedure that produces best linear unbiased estimates (BLUE) of the fixed effects and best linear unbiased predictors (BLUP) of the random effects.

Estimation of Genetic Parameters

All estimates of heritability are attempts to measure the extent to which relatives resemble each other more than do non-relatives. The following summary came largely from discussions of Falconer (1982) and Dickerson (1969).

Heritability in the narrow sense can be defined as the proportion of the total phenotypic variance which is due to additively genetic

variance (or variance due to regression of phenotype on genotype). Total phenotypic variance contains additively genetic variance, variance due to deviations from the regression of phenotype on genotype, deviations caused by dominance, interaction between non-allelic genes and environment. Estimates of heritability are the regression of offspring on midparent, doubled regression of offspring on one parent, quadrupled correlation between paternal or maternal half-sibs, doubled full-sib correlation and twice the ratio of the difference between the average offspring of high-half mates and low-half mates to that between the averages of high-half mates and low-half mates ("high-half" and "low-half" being a phenotypic division of mates of each sire).

The regression of offspring on midparent (mean of parents) is the most nearly unbiased estimate, the variance in the numerator containing almost no variance other than additively genetic variance. It is subject to bias from additive x additive interactions, correlations of direct and maternal dominance deviations and environmental correlations with maternal effects. This estimate is applicable when each individual or litter has a sire and dam different from those of other individuals or litters.

The doubled regression of offspring on dam (intra-sire) is subject to over-estimating heritability compared to the regression of offspring on midparent. The numerator contains increased maternal additive variance, dominance interactions and environmental-maternal correlation effects to the extent that these exist. The double

regression of offspring on sire underestimates the heritability compared to the regression of offspring on midparent because of smaller maternal additive and interaction effects. Variance from sex-linked genes will be included twice in the doubled regression of mammalian female offspring on sire and not at all in the doubled regression of mammalian male offspring on sire.

When estimating heritability by quadrupled intra-sire correlation of paternal half-sibs, the direction and magnitude of the bias depends on the importance of genotype-environment interaction and the maternal influence, thus, it is possible for it to be less biased than the regression of offspring on midparent. In strain-cross matings, the sire component would be expected to contain an increasing proportion of dominance and non-allelic gene interaction variance as divergence of gene frequencies between strains is widened by reciprocal selection.

Doubled full-sib correlation overestimates heritability as compared to the regression of offspring on midparent because of greater dominance variance, additive x dominance interaction variance, dominance x dominance interaction variance, maternal x additive interaction variance, sex-linked variance and genotype-environment interaction variance being contained in the numerator. The estimate is useful only when the common environment of sibs can be measured independently or assumed to be negligible, and the fact that all genotype-environment interaction and part of any dominance and epistatic deviations are included can be accepted without great jeopardy to breeding decisions based on the estimate.

The method based on twice the ratio of the difference between the averages of offspring of high-half mates and of low-half mates to that between the averages of high-half mates and low-half mates measures the additively genetic variance and is biased in that it contains, in addition to additively genetic variance, a small amount of the non-allelic-gene interaction portion of the variance between dams mated to the same sire.

CHAPTER III

MATERIALS AND METHODS

1. INDIVIDUALLY-FED COW-CALF PAIRS

The data for this segment of the study were recorded over a 5-year period (1970-1974) from 60 individual mature Angus cows by 28 sires and raising 113 calves by 25 sires. These cows were selected from Tennessee Agricultural Experiment Station herds and were assumed to represent the variation in weight, body condition and maternal ability present in the herds. Prior to entering the experiment, cows were bred to bulls selected primarily for yearling weight. Cows were divided each year into three groups on the basis of their initial weight, and bulls used for breeding were selected to be comparable in size to these three groups of cows. Open cows were replaced each year with cows of similar size and maternal ability. Cows were bred to calve in March, April and May. Cows were calved on pasture, and the cow-calf pairs were assigned to individual feeding pens during the day (when calves were approximately three weeks of age). Cows and calves were turned out into one of three dirt exercise lots at night, according to weight group to restrict the cross-nursing of calves to cows within their weight group. Feeding pens were designed to allow the calf access to a creep feeder and the cow access to their diet but, in actuality, the calves were able to obtain feed from the cow's feeder, so, the estimated total digestible nutrient (ETDN) intakes presented are those of the cow-calf pair.

Cows were offered grass silage *ad libitum*. The silage was homogeneous within year since it was harvested from the same pasture all at the same time, but variation between years in species composition was observed as a result of yearly variation in environmental conditions. Grass silages fed consisted of orchard grass (IFN 3-03-454), timothy (IFN 3-04-916) and red clover (IFN 3-01-436). During the first year, sudan grass (IFN 3-04-499) was fed during lactation and the following dry period when perennial grass silage was not available. Calves were supplied alfalfa pellets (IFN 1-00-023) *ad libitum* during lactation as a creep feed and, when needed, these were supplied to the cows also to keep cow body condition and calf performance similar to those in cow-calf pairs on pasture.

The intake of the cow was estimated in three segments, the gestation period following the weaning of the previous calf until the birth of the subsequent calf, the 3-wk segment from the birth of the calf until the cow and her calf were individually penned and the period of time from individual penning until the calf was weaned. During the latter period, daily intakes of grass silage and alfalfa pellets were measured and summed for the entire period. Based on preliminary analyses, the daily cow intake during the 3-wk segment prior to individual feeding was assumed to be the same as the daily cow intake after individual feeding was begun and was estimated from the measured feed intake. The gestation period intake from the previous weaning date until calving date of the test year was estimated from the NRC (1970) daily requirements for cows of these

weights during the third trimester of pregnancy. Cows remaining on test from one year to the next were retained in the individual pens and offered amounts of grass silage that would allow them to attain a body condition suitable for the dry period. In order to standardize feed, NRC (1970) recommendations were used to convert the feed consumed to a common basis of ETDN. An in vitro digestion trial (Tilley and Terry, 1963) was performed on feed samples from the first year of the study. The ETDN values derived from this trial were similar to the NRC estimates. Bi-weekly feed consumption records were collected throughout lactation and gestation.

In one analysis, unit ETDN consumption was defined as kg of ETDN consumed by the cow during the 12-month period from one weaning date to the next, plus kg of ETDN consumed by the calf from creep feed (365-d ETDN). In another analysis, the unit ETDN was defined as kg of ETDN consumed by the cow during the lactation period plus kg of ETDN consumed by the calf from creep feeding (LETDN). An average daily LETDN intake (ADLETDN) was calculated from the LETDN by dividing LETDN by the calf age at weaning. The unit weaning efficiency (365-d WEFF) was calculated as the ratio of 365-d ETDN to calf weight at weaning, and the unit lactation weaning efficiency (LWEFF) was calculated as the ratio of LETDN to calf weight at weaning.

Milk production was estimated monthly during the first two years and bi-monthly during the last three years by the weigh-suckle-weight technique reported by Drewry et al. (1959). Total milk production was the sum of two segments of the lactation curve. The first segment

was a quadratic curve from calving to peak lactation (70 to 90 days). The second segment was a linear function from peak lactation to weaning (Cole and Johansson, 1933). Calves were weaned at the same time each year.

Bi-weekly weights of the cows and calves and bi-weekly ultrasonic fat measurements of the cows were recorded. The initial cow weight and fat thickness measurements were taken in the fall prior to entering the barn for the test period, and ending cow weight and fat thickness measurements were taken at calf weaning. Further information concerning this study were given by Onks (1976) and by Butts et al. (1984).

2. COW-CALF PAIRS MAINTAINED ON PASTURE

The data for this segment of the present study were collected during a 4-year (1977-1980) pasture study involving cow-calf pairs representing 86 mature Angus cows by 38 sires raising 153 calves by 23 sires. The study involved the use of four pastures of about 8.0 ha each. Two pastures contained high-quality forage consisting primarily of red clover (*Trifolium pratense* L.), ladino white clover (*Trifolium repens* L.), Korean and Kobe Lespedeza (*Lespedeza stipulacea* Maxim), Kentucky-31 tall fescue (*Festuca arundinacea* Schreb.) and bluegrass (*Poa pratensis* L.). The average species composition in the high-quality pastures from year to year was 60-70 percent tall fescue (and other grasses) and 30-40 percent legume, and these pastures will be referred to as treatment 1. The two low quality pastures (treatment 2)

consisted of Kentucky-31 tall fescue with a small contamination of Dallis grass (*Paspalum dilatatum* Poir) occurring the last year. Renovation of pastures occurred each spring, with the high-quality pastures being reseeded with red and ladino white clover. Stocking rate was maintained at about .8 ha/cow-calf pair. Cattle were grazed on their assigned pastures the entire year and, during the winter months when adequate forage was not available, were fed ad libitum hay, which was harvested from the assigned pasture in June of each year.

Cows were randomly assigned to one of the four pastures, with as many cows as possible being replaced each year (20 to 40 percent), and cows that remained on the study more than one year remained on the pasture of original allotment. Cows were bred to calve in January, February and March of each year, with cow size being confounded with pasture so that large cows could be mated to large bulls. Animals were rotated between their respective quality pastures to expose them to all species in the pasture treatment. Bull calves were castrated in April, and calves were weaned in mid-October of each year.

In order to estimate forage intake and forage digestibility in the cows, total fecal dry matter excretion was estimated for each cow for a period of 152 days (April 29-September 28) by the Cr_2O_3 dilution method. Cows were confined twice daily for approximately 10 minutes, at 0800 h and 1700 h and individually-fed Cr_2O_3 in 227 g of a pelleted carrier feed. A fecal sample was collected from each cow each week at 0800 h and 1700 h during the 152-day feeding period.

Fecal samples were analyzed for dry matter (60 C, AOAC, 1975), Chromium (Cr) (Williams et al., 1962), acid detergent fiber (ADF) and acid detergent lignin (ADL) (Van Soest, 1963). Equations describing diurnal excretion patterns of Cr_2O_3 (Hopper et al., 1978) were used to adjust 0800 h and 1700 h values for diurnal excretion. These adjusted values were regressed on Julian day and Julian day squared to estimate percentage of Cr_2O_3 in fecal dry matter for each cow during the grazing period (Holloway et al., 1979).

Morning and evening fecal ADL percentages for each cow did not differ ($P > .10$) and were averaged on a weekly basis to arrive at percentage of ADL in fecal dry matter. Average values were employed as a data set and were regressed on Julian day and Julian day squared to estimate percentage of ADL in fecal dry matter for each pasture during the grazing period (Holloway et al., 1979). Samples for pasture analyses were obtained by the cage-and-strip procedure described by Linehan (1952) and dry matter, ADF and ADL contents were determined. Contents of ADL in the forage were employed in the same regression equations as were the fecal ADL content to estimate percentage of ADL in consumed forage. Regression equations for estimating content of Cr_2O_3 and ADL in fecal dry matter and of ADL in forage dry matter were applied for each day of the experimental period in each year. Predicted values were used in calculations to estimate fecal production, dry matter digestibility and forage dry matter intake for each day of experiment. Regression equations were employed to describe seasonal changes in these variables, and then

an average forage dry matter digestibility per cow per day and an average forage dry matter intake per cow per day were calculated. Forage digestible dry matter (DDM) was converted to TDN by the equation of Heany and Pigden (1963):

$$\text{TDN}(\text{kg}/100\text{kg dm}) = 5.81 + .869 \times \text{DDM}(\text{kg}/100\text{kg dm})$$

These TDN percentage values were multiplied by average dry matter intake/day to obtain TDN intake in kg. Then the TDN intake was multiplied by the number of days that the cows were lactating to produce the total cow ETDN intake during lactation. Estimates of the forage intakes of individual cows for the non-lactating period from the previous weaning date until calving were estimated from NRC (1976) daily requirements for cows of these weights during the third trimester of pregnancy. The equations were:

$$\begin{aligned} \text{Non-lactating metabolizable energy (NLACME)} = \\ .132 \times (\text{cow fall wt., kg})^{.75} + 2.5 \end{aligned}$$

$$\text{Non-lactating Cow ETDN(NLCTDN)} = \text{NLACME}/3.6155$$

$$\begin{aligned} \text{Non-lactating ETDN intake}(\text{kg}/\text{cow}/\text{period}) = \\ \text{NLCTDN} \times \text{Non-lactating days} \end{aligned}$$

The appropriateness of using NRC requirements for this period was investigated by Neel (1973) on individually-fed cows selected from the same herd as the cows used in this study.

Three forage digestibility and intake trials were performed each year to estimate the forage intake of the calves. The trials were conducted in June (average Julian day 150), July (average Julian day 180) and September (average Julian day 240). Forage digestibility and intake were estimated by use of the Cr_2O_3 dilution method.

A 5-day preliminary period preceded the 5-day collection period. Calves were bolused with 2.5 g Cr_2O_3 at 0800 h and again at 1700 h each day of each trial. Also, fecal samples were taken at these times during the collection periods. Fecal samples (obtained by rectal grab) for each calf for all 5 days of each trial were composited on a wet basis and then dried at 60°C before analysis. Fecal samples were analyzed for dry matter (DM, AOAC, 1975), H_2SO_4 ADL (Goering and Van Soest, 1970) and Cr (Williams et al., 1962). Forage samples were obtained by selectively clipping forage subjectively estimated to be similar to that the calves were observed to be grazing. Samples consisted largely of leaves. Twenty samples were taken from each pasture type during each trial and analyzed in the same manner as the feces for DM and ADL. For comparison, these were analyzed also for in vitro dry matter digestibility by the two-stage technique of Tilley and Terry (1963). These values were quite similar and were highly correlated ($r=.87$) to those obtained by the lignin ratio technique. Forage digestible dry matter, forage dry matter intake and forage digestible dry matter intake were calculated by the methods of Crampton and Harris (1961):

Dry Matter Digestibility (DMD) =

$$100 - ((\%ADL \text{ (pasture)} / \%ADL \text{ (feces)}) \times 100)$$

Dry Matter Intake (DMI) = Fecal Output (kg) / (1 - DMD)

Fecal Output (kg) =

$$\text{Total Fecal Output (kg)} - [\text{milk intake (kg)} \times .10]$$

Digestible dry Matter Intake (DDMI) = DMI x DMD

Forage TDN (kg/100 kg DM) was calculated from the equation of Heany and Pigden (1963):

$$\text{Forage TDN (kg/100 kg DM)} = (5.8 + (.869 \times \text{DDM} \times 100)) / 100$$

Calf Forage TDN intake (kg/day) was calculated by the method described in Crampton and Harris (1961):

Calf Forage TDN Intake (CAFTDNI kg/d) =

$$\text{DMI} \times \text{Forage TDN}$$

Boggs et al. (1980), in a study to evaluate milk and forage utilization of calves, found that, as lactation progressed, the replacement of milk with forage increases, resulting from a decrease in milk production and an increase in the utilization of forage. In the first two months of lactation, forage intake was negatively correlated with average daily gain (-.19) but at 60 to 150 days, additional forage tended to improve gain with each additional kg of forage, making possible a .02 kg/day increase in gain. Based on this

research, we have assumed that calves did not consume enough forage prior to 90 days to consider it in our estimation of calf forage consumed. Since calves were born over a possible three-month span of time and calves were of different ages and stages of maturity when the digestion trials were conducted, calf intake was adjusted for age of calf.

Regression equations were constructed by year and trial with CAFTDNI as the dependent variable and calf weaning age and calf weaning age squared as the independent variables. These regressions produced "average" intake curves for each year-trial combination. The estimated coefficients of regression were used to predict the forage ETDN intakes of the calves at the average time of a digestion trial in each year. The midpoint (midpoint 1) between 90 days of age and the average time of trial 1 (150 Julian days) was calculated (see Figure 1). The coefficients of regression were used to predict the forage ETDN intakes of the calves at their respective midpoint 1. The ratio of the predicted intake at midpoint 1 to the predicted intake at the time of trial 1 was used to adjust the actual intake measurement estimated from digestion trial 1 to the midpoint between 90 days of age and trial 1. This process was continued for trial 2 and trial 3 for each separate year, utilizing the respective coefficients of regression. Figure 2 outlines the trials and locates the respective midpoints. For each trial, the actual intake measurement is adjusted to its respective midpoint. The intervals of time were interval 1, the day each individual calf was 90 days of age to midpoint 2; interval 2, the

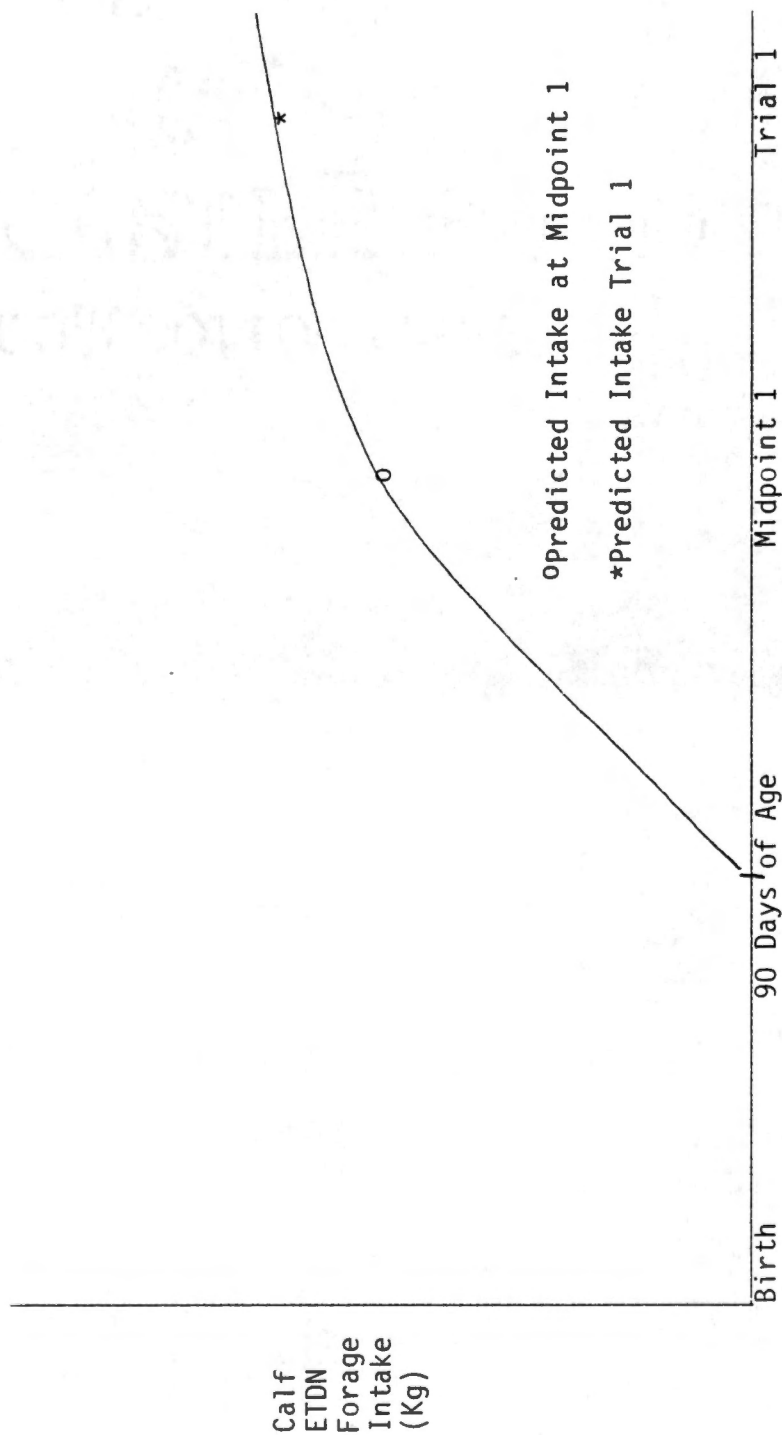


FIGURE 1. Calf ETDN forage intake, Trial 1.

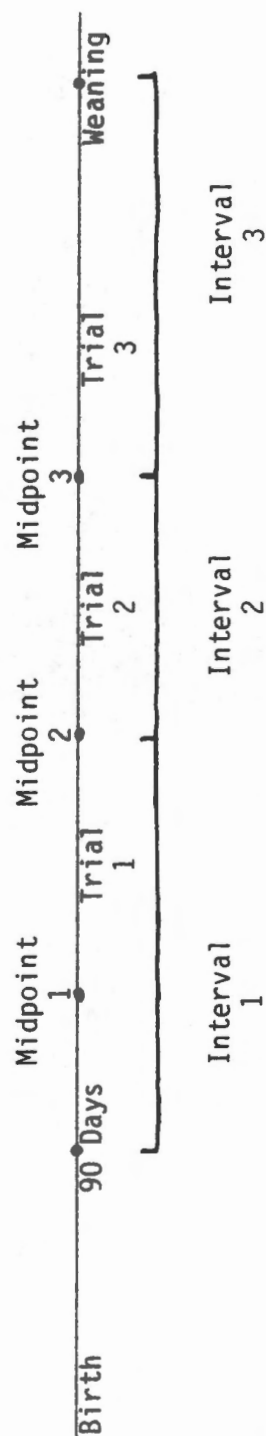


FIGURE 2. Location of trials and midpoints.

interval of time between midpoint 2 and midpoint 3; and interval 3, the interval of time from midpoint 3 to the age of the calf at weaning. The estimated forage TDN intakes of the calves at midpoint 1 were multiplied by the number of days in interval 1, the estimated forage TDN intakes of the calves at midpoint 2 were multiplied by the number of days in interval 2, and the estimated forage intakes of the calves at midpoint 3 were multiplied by the number of days in interval 3. These three consecutive values were summed to obtain an estimate of what the calf was consuming during the period from 90 days of age until weaning.

The total cow ETDN intake during lactation was combined with the calf forage ETDN intake to form the lactation ETDN intake of the cow-calf pair (LETDN). The LETDN was divided by the calf age at weaning to form average daily ETDN intake (ADLETDN) of the cow-calf pair. The LETDN intake was added to the non-lactating ETDN intake to form the 365-d ETDN. The partial nutritional efficiency of the cow-calf pair at weaning based on the lactation ETDN (LWEFF) was calculated by the ratio of the LETDN intake of the pair to calf weight at weaning. The partial nutritional efficiency of the cow-calf pair at weaning based on the 365-d ETDN intake of the pair was calculated as the ratio of 365-d ETDN intake of the cow-calf pair to calf weight at weaning (365-d WEFF).

Milk production was estimated by the weigh-suckle-weigh technique (Drewry et al., 1959), starting in April and proceeding through October, with six estimates obtained in 1978 and 1979 and

seven estimates each in 1977 and 1980. Milk production was measured at different times from the digestion trials in June, July and August to facilitate more natural and accurate estimates of both milk production and calf intake. Calves were separated from their dams at 1800 h on the day preceding the day of estimation, with calves being held in a central holding area while cows were returned to pasture. At 0600 h the following day, calves were weighed and then allowed to nurse their dams. After nursing, calves were again separated from their dams and reweighed and the difference in weight was assumed to be the 12-hour milk production. This procedure was repeated again the following evening and morning, and the two 12-hour estimates were totaled to obtain an estimate of 24-hour milk production. From these milk production estimates, the lactation curve of each cow was then described by the model of Wood (1977):

$$Y_n = a d^b e^{c d}$$

where Y_n is the milk consumption at time d , d is calf age in days, e is the base of natural logarithms and a , b and c are coefficients describing the milk intake curve. This model fit the weigh-suckle-weigh data well (average R -Squared $> .90$ with no lack of fit detected in residual plots). The milk production of each individual cow was calculated from this curve for each day of lactation and summed to estimate the total milk production for the lactation period; and then an average milk intake/day was calculated, and these values were used in later analyses.

Cow weights and ultrasonic fat measurements were taken in the fall before the cows went on test and then bi-monthly until a minimum weight was obtained and then once per month until the calves were weaned. Cow weight was regressed on time in Julian days in the Gauss-Newton iterative process to determine the least-squares estimates of the Fourier Coefficients (Bliss, 1967) for data from each cow. The following model was used:

$$Y = A + A_1 \sin (ct) + A_2 \cos (ct) + A_3 \sin (2ct) + A_4 \cos (2ct)$$

where Y = predicted cow weight in kilograms at time t ; A = mean cow weight during the year in kilograms; A_1 , A_2 , A_3 and A_4 are coefficients, the effects of which cannot be described but which measure the shape of the cow's weight change curve, c = the fundamental period or length of the cycle in radians per day, and t = time in days. Polynomials were used to describe the change in fatness over time, and linear and quadratic effects of time were found to be important. Cow weight and cow fat thickness at weaning were predicted for each cow from the respective curves. Cow weight change was calculated as the difference between cow weight at weaning and cow weight at weaning the previous fall. Further information concerning these data can be obtained from Worley (1981), Holloway et al. (1979), Holloway et al. (1982) and Holloway and Butts (1983).

3. STATISTICAL ANALYSES

Regression analyses were performed with 365-d WEFF, LWEFF, 365-d ETDN intake, LETDN intake, average daily LETDN intake, calf

weight at weaning and average daily milk intake as dependent variables and the same combinations of independent variables presented in equations by Butts et al. (1984). These analyses were performed separately on the data from the individually-fed pairs, and those from the pastured pairs and then on the combined data set. The fixed effects included in all models were sex of calf, treatment (pairs maintained on fescue-legume pastures were considered treatment 1, pairs maintained on fescue pastures were considered treatment 2, and individually-fed pairs were considered treatment 3) and year within treatment. Initial cow weight and fat thickness, calf weaning age and weight, average daily milk intake and ending cow weight and fat thickness were covariables used in various combinations to study their contribution to the explanation of the variation observed in the dependent variables. The results of the regression analyses performed on the combined data sets are shown on pages 58, 60, 62, 63, 65, 66, and 68, and the results of the regression analyses performed on the data set consisting of individually-fed cow-calf pairs and the data set consisting of pastured pairs, separately, are shown in the Appendix, pages 107-120. The results of the regression analyses performed on the separate data sets were similar with minor differences; and, to provide a larger number of observations, the two data sets were combined, and the effect of treatment was removed.

Three methods of estimating variance components have been used and reported. They are Henderson's Method III (Henderson, 1953), a method for computing maximum-likelihood estimates (Hartely and Rao,

1967) and Henderson's Mixed-Model Procedure for use when variances are unknown (Henderson and Henderson, 1979) with adjustment for relationships among the sires of the cows and, in a few analyses, adjustment for repeated occurrences of cows across years.

To estimate variance components by Henderson's Method III, the dependent variables (except calf weaning weight) were regressed on the fixed effects which included sex of calf, year-treatment combinations, sire of the cow and various combinations of covariables. Mean squares were computed by least-squares analyses and equated to their expectations, and the components of variances due to error and to differences in sire of cow were estimated. To estimate variance components by the maximum-likelihood method, the VARCOMP procedure of SAS (1982) was used. This procedure does not allow for continuous variables on the right-hand side of the regression equations; so, to facilitate the addition of covariables to the models, the dependent variables were first regressed on the fixed effects, and covariables and residuals were obtained. Then the VARCOMP maximum-likelihood procedure was used, regressing the residuals of the dependent variables on sire of cow (except calf weaning weight which was regressed on sire of calf), and estimates of the variance components were obtained. This procedure has a built-in limit on the variance components so that they cannot become negative, and the procedure is an iterative procedure which iterates until convergence.

The general mixed model described by Henderson and Henderson (1979) and applied to these data is:

$$Y = XB + Zu + e$$

where Y represents the dependent variable of interest (365-d WEFF, LWEFF, LETDN intake, average daily LETDN intake, 365-d ETDN intake, calf weight at weaning or average daily milk intake). X is a known $n \times p$ matrix with rank $\leq p$, where n is the number of observations (266) and p is the number of columns designated to represent all levels of the fixed effects and a column for each covariable added to the model. B is an unknown fixed $p \times 1$ vector of parameters that are estimated by the mixed-model equations. Z is a known $n \times q$ matrix where n is the number of observations and q represents the number of columns (56) designated to represent each sire. U is a $q \times 1$ vector of non-observable parameters that can be estimated from the mixed-model equations.

The variance of U and e is equal to the matrices G and R

$$(\text{Var} \begin{bmatrix} u \\ e \end{bmatrix} = \begin{bmatrix} G & 0 \\ 0 & R \end{bmatrix})$$

which are known and non-singular. G is the variance-covariance structure associated with the random effects of cow sires and is equal to a 56 by 56 matrix of sire relationships. R is the variance-covariance structure associated with the error variance and may be assumed equal to $I\sigma_e^2$. In a few analyses, the effects of the repeated occurrences of cows across years on the estimates of the variance components were studied. To facilitate this, R was allowed to equal a 266 by 266 variance-covariance matrix multiplied by σ_e^2 . Prior to constructing

this matrix, a correlation analysis was performed on data from the individually-fed and pastured pairs, separately, to see if similar correlations existed among the dependent variables measured on the pairs when the same cows were used across years. The only variable to have similar correlations across years was 365-d WEFF. The variance-covariance matrix that is multiplied by σ_e^2 to form R was constructed using the estimates of variance made from a pooled analysis across years, but within the same group (individually-fed or pastured pairs), and estimates of covariances were obtained by estimating the intra-class correlation among cows.

The general mixed model is expanded to:

$$\begin{bmatrix} X'R^{-1}X & X'R^{-1}Z \\ Z'R^{-1}X & Z'R^{-1}Z+G^{-1} \end{bmatrix} \begin{bmatrix} \hat{B} \\ \hat{U} \end{bmatrix} = \begin{bmatrix} X'R^{-1}Y \\ Z'R^{-1}Y \end{bmatrix}$$

In all analyses performed by Henderson's Mixed-Model Procedure, the variance components were adjusted for relationships among sires by using the G matrix, and this application of the Mixed-Model Procedure will be referred to in the text as Application 1. In most analyses, R is assumed equal to $I\sigma_e^2$. In a few analyses involving 365-d WEFF, the R matrix was formed using the variance-covariance structure described above to adjust for repeated occurrences of cows across years, and this application of the Mixed-Model Procedure will be referred to as Application 2. The estimates of variance due to differences between sires (σ_e^2) obtained by this application were very small after the

adjustments for the fixed effects, initial cow traits and cow weight change (see page 126). As the remaining covariables of calf age and weight at weaning, average milk intake and ending cow traits were included in the model, the estimate of σ_S^2 became negative, so, we assume that the estimate of h^2 after these adjustments are made is essentially zero.

Henderson's Mixed-Model Procedure assumes the variance components of the random effects, σ_S^2 and error (σ_e^2) to be known; and, if they are unknown, they must be estimated from an independent source (method) and then substituted for these values in the equations. The components of variance of the random effects, σ_S^2 and σ_e^2 , were estimated by Henderson's Method III and then substituted for the values in the mixed-model equations. The next step was to obtain the inverse of:

$$\left[Z'R^{-1}Z + G^{-1} \right]^{-1} = \left[T \right]$$

To solve for the new estimates of σ_e^2 and σ_S^2 obtained after adjustment for relationships among sires and, in a few cases, the repeated occurrences of cows across years, one must solve the following equations:

$$\hat{\sigma}_e^2 = (Y'Y - \hat{B}'X'Y - \hat{u}'Z'Y)/n$$

and

$$\hat{\sigma}_S^2 = \hat{u}'\hat{u} + \hat{\sigma}_e^2 \text{tr}(T)/q_S$$

where $\hat{\sigma}_e^2$ is the new estimate of σ_e^2 and $\hat{\sigma}_S^2$ is the new estimate of σ_S^2 ,

n is the number of observations and q_s is the number of sires. These estimates can be resubstituted into the mixed-model equations, and new estimates of the parameters can be obtained, with this procedure continuing until convergence.

The estimates of heritability (h^2) of 365-d WEFF, LWEFF, 365-d ETDN intake, LETDN intake, average daily LETDN intake and average daily milk intake were obtained by the paternal half-sib method

$$(h^2 = 4 \frac{\hat{\sigma}_s^2}{\hat{\sigma}_e^2 + \hat{\sigma}_s^2})$$

using the component of variance due to the differences in sire of cow and the error variance component derived by each of the three methods. The estimate of heritability of calf weight at weaning was obtained by using the component of variance due to differences in sire of calf derived by Henderson's Method III and the maximum-likelihood method. The estimates of the standard errors of the estimates of heritability were made according to the following formula presented by Hazel and Terrill (1945):

$$4 \frac{\hat{\sigma}_s^2 (\hat{\sigma}_s^2 + (K \hat{\sigma}_e^2))}{(\hat{\sigma}_s^2 + \hat{\sigma}_e^2 \sqrt{.5 (K-1) Kn}}$$

where K is the disproportionality constant and n is the number of sires.

Preliminary analyses were performed to obtain estimates of heritability of calf age at weaning. These analyses produced very

low estimates of heritability of calf age at weaning and, calf age were considered a random environmental effect that should be considered as a covariable and, adjustments should be made for calf age at weaning prior to estimating heritability of the traits of the cow-calf pair.

The genetic and phenotypic correlations of 365-d WEFF and LWEFF with one another and with average daily LETDN intake, average daily milk intake, initial cow weight, initial cow fat, ending cow weight and ending cow fat were estimated. The procedures for estimating the genetic correlations and phenotypic correlations and their respective standard errors is described by Becker (1984). The formula for the genetic correlations is:

$$r_G = \frac{4 \hat{COV}_S(xy)}{\sqrt{4\hat{\sigma}_S^2(x) \hat{\sigma}_S^2(y)}}$$

The formula described by Becker (1984) for solving for the standard error of r_G is lengthy but with it one solves for the var $\hat{r}_G$ and the standard error of $\hat{r}_G = \sqrt{\text{Var } \hat{r}_G}$. The formula for the phenotypic correlation is:

$$r_P = \frac{\hat{COV}_W(xy) + \hat{COV}_S(xy)}{\sqrt{(\hat{\sigma}_W^2(x) + \hat{\sigma}_S^2(x)) (\hat{\sigma}_W^2(y) + \hat{\sigma}_S^2(y))}}$$

and the standard error of $\hat{r}_P$ is calculated by the formula described by Becker (1984).

CHAPTER IV

RESULTS AND DISCUSSION

1. MEANS AND STANDARD DEVIATIONS OF COW-CALF TRAITS

Unadjusted means and standard deviations of traits of the cow-calf pairs by treatment group and sex of calf are shown in Table 1. Across treatment groups, initial cow weight, initial cow fat and average daily milk intake and calf age at weaning were similar. The cow-calf pairs included in treatment 1 (grazing fescue-legume pastures) tended to be heavier and fatter at the time of calf weaning relative to those included in treatment 2 or 3 (grazing fescue pastures or individually-fed). The pairs were estimated to consume more TDN over a 365-day period and over the lactation period. The cow-calf pairs in the second and third treatment groups were more efficient during the lactation period and over the entire 365-day period than were the pairs in the first treatment group. Variation in cow weight was similar across treatment groups but variation in calf weight at weaning and in pair ETDN intake tended to be greater in the individually-fed pairs. This may be a result of stress due to confinement, relative to the pasture environment, to which the calves and the pairs differed in response.

Marshall et al. (1976) reported a mean average cow weight of 431.5 kg and an average actual calf weight at weaning of 218 kg. they reported an average total 365-d TDN intake of 2469 kg, a value

TABLE 1. Means and Standard Deviations of Cow and Calf Traits

Traits	Treatment 1		Treatment 2		Treatment 3	
	Steers	Heifers	Steers	Heifers	Steers	Heifers
	Mean	SD	Mean	SD	Mean	SD
Number	33	43	31	46	63	50
Initial Cow Weight, kg ^b	479	49	475	49	460	54
Initial Cow Fat, mm	7.2	3.8	5.1	2.5	7.9	4.6
Ending Cow Weight, kg ^c	483	50	474	49	453	54
Ending Cow Fat, mm	7.9	4.6	6.1	3.4	5.9	3.7
Cow Weight Change, kg ^d	4	13.1	-2	16.0	-7	53.5
Calf Age at Weaning, d	251	21	248	19	253	36
Calf Weight at Weaning, kg	242	38	218	29	221	41
Average Daily Milk Intake, kg	7	1.5	6	1.4	6	1.2
Pair 365-day ETDN Intake, kg	2891	347	2333	199	2389	380
Pair Lactation ETDN Intake, kg	2045	406	1471	229	1770	402
Pair Average Daily ETDN Intake, kg (Lactation Period)	8	1.3	6	.8	7	1.2
Pair 365-Day Efficiency at Weaning ^e	12.1	1.9	10.9	1.6	11.1	2.4
Pair Lactation Efficiency ^f	8.5	1.5	6.8	1.0	8.1	1.6

^aResidual standard deviation from the model $\bar{Y} = \text{sex} + \text{year} - \text{treatment combinations}$. Means and standard deviations for steers and heifers, by treatment are unadjusted.

^bWeight at weaning in October the previous year.

^cWeight at weaning in October of the test year.

^dEnding cow weight minus initial cow weight.

^ePair 365-d ETDN intake/calf weight at weaning.

^fPair ETDN intake during lactation/calf weight at weaning.

very similar to the present study total TDN intake of the pairs on treatment 2 and treatment 3 but lower than the total TDN intake of the pairs on treatment 1. They reported a mean value of partial 365-d efficiency at weaning of 11.47, very similar to the values reported here. Milk productions reported by Marshall et al. (1976) were much higher than the values obtained in this study, but the difference in milk production was not reflected in the calf weights at weaning. The cows used by Melton et al. (1967) were somewhat larger, and the total 365-d TDN intake was less, probably due to their limited feeding regime to maintain body weight. The calf weights at weaning were similar to those reported in this study, and subsequently, the pairs were more efficient to weaning.

2. PHENOTYPIC RELATIONSHIPS BETWEEN MEASURABLE TRAITS OF COW-CALF PAIRS

Calf weight at weaning was related positively (Table 2) to initial cow weight ($P < .05$), calf age at weaning ($P < .001$) and milk production ($P < .001$) in the complete model. Calf weight at weaning was negatively related to initial cow thickness ($P < .10$) and to cow weight change ($P < .01$). Substituting ending cow weight and fat thickness for initial cow weight and fat thickness in the complete model resulted in an increase in the negative relationship of calf weight at weaning with cow weight change ($P < .001$) and with the measure of cow fat thickness ($P < .05$) and an increase in the positive relationship between calf weight at weaning and cow weight ($P < .01$). Deleting

TABLE 2. Partial and Standard Partial Coefficients of Regression of Calf Weaning Weight on Traits of the Cow and Calf

Error df	Cow Weights		Initial		Cow FES		Cow Weight Change		Weaning Calf We		With Production		Cow Milk		Ending		R ²
	Partial	Standard	Partial	Standard	Partial	Standard	Partial	Standard	Partial	Standard	Partial	Standard	Partial	Standard	Partial	Standard	
251									.76***								.22
251	.13***	.18															.03
250	.18***	.25	-1.43*	-.15													.04
249	.16***	.22	-1.69**	-.17			-.28***	-.27									.06
248	.10**	.14	-1.25*	-.13			-.13*	-.12	.70***	.53							.23
248	.13**	.17	-1.23*	-.13			-.31***	-.30			11.62***	.42					.20
247	.07*	.10	-.80†	-.08			-.15**	-.15	.70***	.52	11.52***	.41					.37
247							-.20***	-.19	.69***	.52	11.33***	.40	.09**	.13	-1.12*	-.13	.37

†All models contained terms for sex of calf, treatment group and year within treatment group, sequentially accounting for 9% (P<.001), 4% (P<.001) and 24% (P<.001), respectively, of variation in calf weight at weaning. Tabled R² values reflect additional variation in calf weight at weaning explained by independent variables shown.

†P<.10.

**P<.05.

***P<.01.

****P<.001.

from the model calf age at weaning and/or milk production results in an increase in the positive relationship between calf weight at weaning and initial cow weight. The magnitude of the negative relationship of calf weight at weaning with initial cow fat thickness and cow weight change fluctuated, depending on whether calf age at weaning was considered jointly with milk production in the model.

The positive relationship of initial and ending cow weight with calf weight at weaning supports the positive correlations found by Hohenboken et al. (1973), Hays and Brinks (1980) and Rahnefeld et al. (1980). The association between calf weight at weaning and milk production was similar to that reported by Melton et al. (1967) and Marshall et al. (1976). Brinks et al. (1962), Hohenboken et al. (1973), Butson and Berg (1978) and Hays and Brinks (1980) reported negative correlations of calf weight at weaning with cow weight change during the lactation period.

The LETDN intake of the cow-calf pair was positively related (Table 3) to initial cow weight ($P < .001$), calf age at weaning ($P < .001$) and calf weight at weaning ($P < .001$) in the complete model as well as in all models considered. Initial cow fat thickness was negatively related to LETDN intake of the cow-calf pair, however, the relationship was not significant in models which contained calf age and weight at weaning also. Substituting ending fat thickness for initial cow fat thickness in the complete model resulted in a small positive ($P > .10$) relationship between LETDN intake and ending cow fat thickness. The LETDN intake of the cow-calf pair was positively

TABLE 3. Partial and Standard Partial Coefficients of Regression of Pair Estimated Total Digestible Nutrient Intake During Lactation^a on Traits of the Cow and Calf

Error df	Initial			Cow Weight Change			Weaning			Milk Production			Cow Weight			Ending			R ²
	Cow Weight Partial	Standard Partial	Cow Wt Partial	Cow Weight Change Partial	Standard Partial	Cow Wt Partial	Cow Weight Change Partial	Standard Partial	Cow Wt Partial	Milk Production Partial	Standard Partial	Milk Production Partial	Cow Weight Partial	Standard Partial	Cow Wt Partial	Ending Partial	Standard Partial	Ending Partial	
251									7.85***										.22
251	1.93***	.26																	.05
250	2.34***	.31	-11.48*																.06
249	2.26***	.30	-12.25*																.06
248	1.67***	.22	-7.54*																.25
247	1.34***	.18	-3.58																.28
246	1.40***	.19	-3.09																.22
248	1.15***	.29	-10.60*																.08
247	1.56***	.21	-5.95																.26
247	1.30***	.18	-3.20																.23
246	1.35***	.18	-3.57																.26
246																			.26

^a Regressed total digestible nutrient (TDN) intake of the cow measured during lactation plus nominal TDN intake of the calf to weaning.

^b All models contained terms for sex of calf, treatment group and year within treatment group, sequentially accounting for <1% (P<.10), 22% (P<.001) and 33% (P<.001) of the variation in pair TDN intake during lactation. Tabled R² values reflect additional variation in pair TDN intake during lactation explained by independent variables shown.

*P<.10.

**P<.05.

***P<.01.

***P<.001.

related ($P < .05$) to cow weight change when considered in the model jointly with calf age and calf weight at weaning and initial cow traits. Milk production considered in a model with initial cow traits and cow weight change or along with calf age at weaning was positively related ($P < .001$) to LETDN intake. When milk production was considered in a model containing calf weight at weaning, without calf age at weaning, it was negatively related ($P < .05$) to LETDN intake of the pair. When calf age at weaning was considered jointly with calf weight at weaning, milk production is not related ($P > .10$) to LETDN intake of the pair.

The results of the analysis of regression of cow-calf pair average daily LETDN intake on traits of the cow and calf (Table 4) were very similar to those of analyses of regression of pair LETDN intake on the same cow-calf traits (Table 3). The main differences were initial cow fat thickness was not related ($P > .10$) to average daily LETDN intake in any of the models fitted, cow weight change was positively related to average daily LETDN intake in all models fitted and the relationship increased in magnitude when calf weight at weaning was included in the model. The effect calf age at weaning has on the average daily LETDN intake was smaller since this average was calculated by dividing the total LETDN intake by the number of days in the period (equivalent to calf age at weaning).

The results of analysis of regression of cow-calf pair 365-d ETDN intake on traits of the cow and calf (Table 5) were similar to the results of the analysis of regression of cow-calf pair LETDN intake

TABLE 4. Partial and Standard Partial Coefficients of Regression of Pair Estimated Average Daily Total Digestible Nutrient Intake During Lactation^a on Traits of the Cow and Calf

Error df	Initial			Cow Weight Change			Weaning			With Production			Ending			R ² ^b
	Cow Weight Standard Partial	Cow FFE Standard Partial	Cow FFE Partial	Cow Weight Change Standard Partial	Cow Weight Change Standard Partial	Cow Weight Change Partial	Calf Age Standard Partial	Calf Age Standard Partial	Calf Weight Standard Partial	With Production Standard Partial	With Production Standard Partial	With Production Partial	Cow Weight Standard Partial	Cow Weight Standard Partial	Cow FFE Standard Partial	
251	.005***	.224														<.01
250	.006***	.261	-.025													.04
249	.007***	.270	-.022													.04
248	.006***	.259	-.020	.003	.074	.003										.05
247	.005***	.206	-.005	.005**	.142	.005**	.003†	.076								.10
246	.005***	.203	-.005	.005**	.158	.005**	-.005*	-.121	.012***	.374						.10
245	.005***	.251	-.016	.002	.064	.002			.010***	.305						.07
244	.006***	.240	-.014	.002	.064	.002	.003†	.074	.009***	.263	.168***	.181				.08
243	.005***	.205	-.005	.005*	.142	.005*	-.005*	-.103	.011***	.340	.167***	.181				.10
242	.005***	.206	-.005	.005*	.136	.005*	-.005*	-.105	.012***	.354	.040	.043	.004***	.175	.019	.11
241				<.001	.008											

^aAverage daily estimated total digestible nutrient intake of the cow during lactation plus the nowilk ETM intake of the calf.

^bAll models contained terms for sex of calf, treatment group and year within treatment group, sequentially accounting for 15 (P<.01), 325 (P<.001) and 331 (P<.001), respectively, of the variation in average daily ETM intake of the cow and calf during the lactation period. Tabled R² values reflect additional variation in pair average daily ETM intake measured during lactation explained by independent variables shown.

†P<.10.

*P<.05.

**P<.01.

***P<.001.

on the same cow-calf traits (Table 3). Cow weight change was more positively related ($P < .01$) to pair 365-d ETDN intake than to pair LETDN intake in models including calf age and/or calf weight at weaning. This is probably due to the fact that cow weight change and 365-d ETDN intake were both measured over the entire 365-d period and a change in cow weight would be a result of increased ETDN intake after adjusting for calf age and weight at weaning. Milk production was positively related to pair 365-d ETDN intake when considered jointly with calf age at weaning, and, without calf age at weaning in the model, milk production was not related to pair 365-d ETDN intake.

Average daily milk intake of the calf was positively related ($P < .001$) to calf weight at weaning and to cow weight change ($P < .05$) in the complete model (Table 6). Average daily milk intake was negatively related ($P < .001$) to calf age at weaning in the complete model. When calf age at weaning and cow weight change were not considered jointly with calf weight at weaning, they were not related ($P > .10$) to average daily milk intake of the calf.

The partial nutritional efficiency of the cow-calf pairs defined as the ratio of LETDN intake of the pair to calf weight at weaning (LWEFF) was related favorably to calf weight at weaning ($P < .001$) and unfavorably to initial cow weight ($P < .001$), cow weight change ($P < .05$) and calf age at weaning ($P < .001$) when these independent variables were considered jointly in the complete model (Table 7). Initial cow fat was not related to LWEFF in any of the models fitted.

TABLE 6. Partial and Standard Partial Coefficients of Regression of Estimated Calf Average Daily Milk Intake on Traits of the Cow and Calf

Error df	Initial			Cow Weight Change			Milk			Ending		
	Cow Weight Partial	Standard Partial	Cow Fat Partial	Cow Weight Partial	Standard Partial	Cow Fat Partial	Cow Weight Partial	Standard Partial	Cow Fat Partial	Cow Weight Partial	Standard Partial	Cow Fat Partial
251	.001	.042					.001	.013				<.01
250	.003	.097	-.041									<.01
249	.003	.105	-.039	-.112								<.01
248	.003	.104	-.039	-.111	.059							.01
246	-.001	-.022	-.004	-.011	.002	.062	<.001	.009				.01
247	<.001	-.014	-.002	-.006	.008*	.219	-.020***	-.425	.021***	.562		.20
247					.006*	.164	-.020***	-.425	.023***	.825		.28
					.006*	.171	-.020***	-.424	.023***	.818		.28

2431 models contained terms for sex of calf, treatment group and year within treatment group, sequentially accounted for <.15 (P<.10), 5% (P<.05) and 13% (P<.01) of the variation in estimated calf average daily milk intake. Tabled R² values reflect additional variation in estimated calf average daily milk intake explained by independent variables shown.

*P<.10.

**P<.05.

***P<.01.

****P<.001.

TABLE 7. Partial and Standard Partial Coefficients of Regression of Pair Weaning Efficiency During the Lactation Period^a on Traits of the Cow and Calf

Error df	Initial			Cow Weight Change			Weaning			Milk Production			Ending			R ² b
	Low Weight Partial	Standard Partial	Cow Fat Partial	Low Weight Partial	Standard Partial	Cow Fat Partial	Low Weight Partial	Standard Partial	Cow Fat Partial	Low Weight Partial	Standard Partial	Cow Fat Partial	Low Weight Partial	Standard Partial	Cow Fat Partial	
251	.005***	.147					.009**	.159								.02
250	.004**	.138	.009		.020											.02
249	.005**	.159	.016	.008*	.037											.03
248	.004**	.134	.022	.010**	.051	.167		.169								.04
247	.007***	.217	-.010	.007**	.023	.216	.010***	.169								.18
246	.007***	.226	-.007	.004	.002	.144	.028***	.475	-.582							.08
245	.006***	.181	.005	.008**	.013	.002	-.014***	-.310								.06
247	.005**	.156	.012	.010***	.028	.229	.010***	.171								.08
247	.007***	.224	-.008	.005	.016	.106	.029***	.493	-.248	-.261***	-.212					.09
246	.007***	.217	-.010	.006*	.137	.005*	.027***	.492	-.617	.052	.042					.18
246				<.001	.002		.029***	.492	-.603	.054	.044	.006***	.188	.021	.056	.18

^aRatio of pair ETRM intake measured during the lactation period of calf weight at weaning.

^bAll models contained terms for sex of calf, treatment group and year within treatment group, sequentially accounting for 33 (P<.001), 143 (P<.001) and 423 (P<.001), respectively, of the variation in pair lactation weaning efficiency. Tabled R² values reflect additional variation in pair lactation efficiency explained by independent variables shown.

*P<.05.

**P<.01.

***P<.001.

Substituting ending cow weight and fat thickness for initial cow weight and fat thickness in the complete model decreased the relationship between cow weight change and LWEFF. Cow weight change was not related ($P > .10$) to LWEFF when considered jointly with calf weight at weaning without calf age at weaning in the model. Milk production was negatively related ($P < .001$) to LWEFF when considered jointly with the initial traits of the cow, cow weight change and calf age at weaning. This negative relationship decreased in magnitude when calf weight at weaning was added to the model without calf age at weaning, and this relationship no longer existed when calf weight and age at weaning were considered jointly in the model with milk production and traits of the cow. The unfavorable relationship of calf age at weaning to LWEFF resulted from the definition of LWEFF as the ratio of LETDN intake to calf weight at weaning. Cow-calf pairs with older calves would have a larger LETDN intake because of the increased number of days involved, and, unless the weight of the calf compensated for this larger intake, the pair was less efficient. These relationships between LWEFF and calf weight at weaning and milk production suggest that milk production is related to LWEFF through its influence on calf weight at weaning.

The results of the analysis of regression of partial nutritional efficiency of cow-calf pairs defined as the ratio of 365-d ETDN intake of the pair to calf weaning weight (365-d WEFF, Table 8) were similar to those of the analysis of regression of LWEFF on the same cow-calf traits (Table 7). It was found that 365-d WEFF was related ($P < .001$)

TABLE 8. Partial and Standard Partial Coefficients of Regression of Pair 365-d Weaning Efficiency^a on Traits of the Cow and Calf

Error df	Initial			Cow Weight Change			Weaning			Milk Production			Cow Weight			Ending			R ^{2b}
	Cow Weight	Standard	Partial	Cow Fat	Standard	Partial	Calf Age	Standard	Partial	Calf Weight	Standard	Partial	Cow Weight	Standard	Partial	Milk Production	Standard	Partial	
251	.006**	.124					-.028***		-.343										.18
251			.124																.12
250	.005†	.104	.025	.041															.12
249	.006**	.140	.042	.069	.018***	.288													.14
248	.009***	.191	.024	.040	.012***	.188	-.029***	-.348											.22
247	.013***	.288	.029	.048	.007*	.103	.001	.015											.41
248	.013***	.289	.029	.048	.006*	.101			-.002***	-.681									.41
248	.008***	.168	.024	.040	.019***	.304													.41
247	.010***	.218	.006	.010	.013***	.205	-.029***	-.345								-.463***	-.267		.20
247	.013***	.289	.029	.048	.006*	.097			-.043***	.693						-.459***	-.265		.28
246	.013***	.289	.029	.048	.006*	.098	.002	.027	-.044***	-.713						.036	.021		.41
246						.098	.002	.027	-.044***	-.713						.050	.029		.41
246						.098	.002	.027	-.044***	-.713						.053	.031		.41
246						.098	.002	.027	-.044***	-.713			.011***	.253	.027				.051

^aRatio of pair 365-d ETDW intake to calf weight at weaning.

^bAll models contained terms for sex of calf, treatment group and year within treatment groups, sequentially accounting for 53 (P<.001), 85 (P<.001) and 102 (P<.001) percent of the variation in 365-d weaning efficiency. Tabled R² values reflect additional variation in pair 365-d weaning efficiency explained by independent variables shown.

†P<.10.

*P<.05.

**P<.01.

***P<.001.

favorably to calf weaning weight and unfavorably to initial cow weight ($P < .001$) and cow weight change ($P < .05$) when these independent variables were considered jointly in the complete model. Initial cow weight was unfavorably related to 365-d WEF in all models fitted, but the magnitude of the relationship was smaller when calf age and/or weight at weaning and/or milk production were not included in the models. Initial cow fat thickness was not related ($P > .10$) to 365-d WEF in any of the models fitted. Cow weight change was unfavorably related to 365-d WEF in all models in which the initial cow traits were included. The magnitude of the unfavorable relationship between cow weight change and 365-d WEF decreased when calf weaning weight was included in the model. Substituting ending cow weight and fat thickness for initial cow weight and fat thickness in the complete model decreased the relationship between cow weight change and 365-d WEF. Calf age at weaning was favorably related ($P < .001$) to 365-d WEF when calf weight at weaning was not included in the model and was no longer related ($P > .10$) to 365-d WEF when calf weight at weaning was included in the model. Milk production was related ($P < .001$) favorably to 365-d WEF when calf weight at weaning was not in the model; and, when calf weight at weaning was considered jointly in the model, milk production was no longer related ($P > .10$) to 365-d WEF. These relationships between calf age at weaning, milk production, calf weaning weight and 365-d WEF suggest that calf age at weaning and milk production are related to 365-d WEF through their relationships to calf weaning weight.

3. ESTIMATES OF THE GENETIC PARAMETERS OF TRAITS OF THE COW AND CALF

Calf Weight at Weaning

The estimates of the sire component of variance (σ_s^2), error component of variance (σ_e^2), heritability (h^2) and standard error (S.E.) of the estimate of h^2 of calf weight at weaning are shown in Table 9. These estimates were obtained by Henderson's Method III and the maximum likelihood (ML) method, utilizing the sire of the calf ($n=46$). After adjustments were made for the fixed effects of sex of calf and year-treatment combinations and calf age at weaning, the estimate of h^2 was .65 by Henderson's Method III and .40 by the ML method. The estimate of h^2 by the ML method is smaller due to the smaller σ_s^2 in relation to the σ_e^2 . This is true for all of the estimates of σ_s^2 for calf weight at weaning obtained by the ML method.

The variation due to certain covariables was removed prior to estimating the genetic parameters, and these covariables were selected on the basis of the regression analyses described previously. After additional adjustments for the initial cow traits, cow weight change and average milk intake, the estimates of σ_s^2 and σ_e^2 were further reduced, resulting in estimates of h^2 of .76 and .34 obtained by Henderson's Method III and the ML method, respectively. Substituting ending cow weight and fat thickness for initial cow weight and fat thickness resulted in very little change in the estimates of heritability. The additional adjustment for the initial cow traits

TABLE 9. Estimates of Genetic Parameters of Calf Weaning Weight by Two Methods, ^a After Adjustments for Fixed Effects and Traits of the Cow and Calf

Model	Method III			Maximum-Likelihood			
	σ_s^2	σ_e^2	Estimates h^2	S.E.	σ_s^2	Estimates σ_e^2	S.E.
F.E. ^b	230	760	.93	.296	89	793	.40
F.E. + Calf Weaning Age	106	540	.65	.282	57	521	.40
F.E. + Initial Cow Traits ^c + Cow Weight Change + Calf Weaning Age	91	530	.59	.282	51	500	.37
F.E. + Initial Cow Traits + Cow Weight Change + Calf Weaning Age + Average Milk Intake	83	334	.79	.296	34	330	.38
F.E. + Ending Cow Traits + Cow Weight Change + Calf Weaning Age + Average Milk Intake	79	334	.76	.295	31	331	.34

^aMethod III, Henderson (1953); Maximum-Likelihood, Hartley and Rao (1967).

^bFixed effects include sex of calf and year-treatment combinations.

^cInitial cow traits include cow weight and cow fat.

and cow weight change removed a slightly higher proportion of variation from σ_S^2 which resulted in a reduction in h^2 . After adjusting for the variation due to average milk intake, considered jointly with calf age at weaning, initial cow traits and cow weight change, the estimate of σ_e^2 obtained by Henderson's Method III was reduced more than the estimate of σ_S^2 , which resulted in the increased estimate of h^2 .

The estimates of h^2 obtained by the ML method after adjusting for fixed effects and calf age at weaning agree well with estimates reported by Nelson and Kress (1979), $35 \pm .06$ from Angus data and $.43 \pm .09$ from Hereford data, after adjustments for similar effects. The estimate of h^2 reported by Vesely and Robison (1971) after adjustments for fixed effects and calf age at weaning was intermediate between the estimates obtained by Henderson's Method III and the ML method after adjusting for fixed effects and calf age at weaning.

ETDN Intake of the Cow-Calf Pair

The estimates of σ_S^2 , σ_e^2 and h^2 for LETDN intake, obtained by Henderson's Method III, the ML method and Henderson's Mixed-Model Procedure, application 1, using the sire of the cow ($n=56$) are shown in Table 10. After adjusting for the fixed effects of sex of the calf and year-treatment combinations, and calf age at weaning, the estimates of h^2 obtained by the three methods ranged from .13 to .52. Adjusting for calf age at weaning removes variation from the σ_e^2 but has different affects on the estimate of σ_S^2 , depending upon which

TABLE 10. Estimates of Genetic Parameters of Cow-Calf Pair Estimated Total Digestible Nutrient Intake During Lactation by Three Methods,^a After Adjustments for Fixed Effects and Traits of the Cow and Calf

Model	Method III			Maximum-Likelihood			Mixed-Model Procedure		
	σ^2_s	σ^2_e	h^2	σ^2_s	σ^2_e	h^2	σ^2_s	σ^2_e	S.E.
F.E. b	3288	66296	.19	3883	61998	.24	2780	62974	.17
F.E. + Calf Meaning Age	4618	31122	.52	3725	30012	.44	1094	32258	.13
F.E. + Intake Cow Traits ^c + Cow Weight Change + Calf Meaning Age	1650	29616	.21	1596	27541	.22	601	28456	.08
F.E. + Initial Cow Traits + Cow Weight Change + Calf Meaning Age + Average Milk Intake	1144	27635	.16	1279	25434	.19	1237	25512	.18
F.E. + Initial Cow Traits + Cow Weight Change + Calf Meaning Weight	5367	30129	.60	4575	28677	.55	6323	27642	.74
F.E. + Initial Cow Traits + Cow Weight Change + Calf Meaning Age + Calf Meaning Weight	2170	23166	.34	1850	21739	.31	1576	21946	.27
F.E. + Initial Cow Traits + Cow Weight Change + Calf Meaning Age + Calf Meaning Weight + Average Milk Intake	2144	23251	.33	1869	21675	.32	1794	21738	.30
F.E. + Ending Cow Traits + Cow Weight Change + Calf Meaning Age + Calf Meaning Weight + Average Milk Intake	2037	23282	.32	1649	21789	.28	1513	21888	.26

^aMethod III, Henderson (1953); Maximum-Likelihood, Hartley and Rao (1967); Mixed-Model Procedure, Application 1 (adjustment for sire relationships), Henderson and Henderson (1979).

^bFixed effects include sex of calf and year-treatment combinations.

^cInitial cow traits include cow weight and cow fat.

method was used. The estimates of σ_S^2 and h^2 obtained by the Mixed-Model Procedure, application 1 are lower than those obtained by the other two methods.

After additional adjustments of initial cow traits, cow weight change, calf weaning weight and average milk intake, the estimates of h^2 of LETDN intake obtained by the three methods were very similar, ranging from .30 to .33. Substituting ending cow traits for initial cow traits resulted in slight reductions in the estimates of h^2 of LETDN intake. Considering the initial cow traits and cow weight change along with calf age at weaning removes a greater proportion of variation from σ_S^2 than from the estimate of σ_e^2 which results in a lower estimate of h^2 . Initial cow traits would be expected to be a source of variation in LETDN intake as was seen in the regression analyses presented in Table 3, page 60, and one would expect the component of variance due to differences in sires of cows to contain much of the variation associated with cow weight, fat thickness and cow weight change.

Adjusting for average milk intake considered along with the traits of the cow and calf age at weaning has very little effect on estimates of σ_S^2 and σ_e^2 for LETDN intake obtained by Method III and the ML method. The estimate of σ_S^2 obtained by the Mixed-Model Procedure was increased by adding average milk intake, which results in an increased estimate of h^2 . Adjusting for calf weight at weaning considered with the traits of the cow results in a large increase in the estimate of σ_S^2 obtained by all three methods which, in turn increases the estimate of h^2 . Jointly considering calf weight and

age at weaning reduces the estimates of σ_S^2 and h^2 obtained by each method. These results suggest that a relationship exists between calf age and calf weight at weaning in the effects that they have on the estimate of LETDN intake. Adjusting for average milk intake considered along with the cow traits and calf age and weight at weaning has very little effect on the estimates of σ_S^2 , σ_E^2 and h^2 obtained by the three methods.

Estimates of σ_S^2 , σ_E^2 and h^2 of average daily LETDN intake of the cow-calf pair were obtained by the three methods are shown in Table 11. Calf age at weaning was not considered a covariable in these analyses since the average was obtained by dividing LETDN intake by calf age at weaning, and the variation due to calf age at weaning should be negligible. The estimates of h^2 of average daily LETDN intake obtained by the three methods after adjusting for the fixed effects were larger than those of LETDN intake after adjusting for fixed effects.

The estimates of h^2 of average daily LETDN intake obtained by the three methods after adjustments for the fixed effects, initial cow traits, cow weight change, calf weight at weaning and average milk intake were very similar ranging from .25 to .27. These estimates of h^2 of average daily LETDN intake are slightly smaller than the estimates of h^2 of LETDN intake which, after similar adjustments, ranged from .30 to .33. Substituting ending cow traits for initial cow traits resulted in slight reductions to the estimates of h^2 of average daily LETDN intake. The major reduction in the estimates

TABLE 11. Estimates of Genetic Parameters of Cow-Calf Pair Estimated Average Daily Total Digestible Nutrient Intake During Lactation by Three Methods,^a After Adjustments for Fixed Effects and Traits of the Cow and Calf

Model	Method III			Maximum-Likelihood			Mixed-Model Procedure		
	σ_e^2	Estimates σ_e^2	h^2	σ_e^2	Estimates σ_e^2	h^2	σ_e^2	Estimates σ_e^2	h^2
F.E. ^b	.067	.487	.48	.245	.055	.469	.42	.240	.483
F.E. + Initial Cow Traits ^c + Cow Weight Change	.025	.458	.21	.225	.025	.426	.22	.227	.430
F.E. + Initial Cow Traits + Cow Weight Change + Average Milk Intake	.023	.419	.21	.227	.025	.387	.24	.230	.389
F.E. + Initial Cow Traits + Cow Weight Change + Calf Meaning Weight	.026	.372	.26	.231	.019	.352	.21	.226	.350
F.E. + Initial Cow Traits + Cow Weight Change + Calf Meaning Weight + Average Milk Intake	.027	.368	.27	.234	.022	.344	.25	.231	.342
F.E. + Ending Cow Traits + Cow Weight Change + Calf Meaning Weight + Average Milk Intake	.024	.368	.25	.231	.017	.346	.19	.226	.343

^aMethod III, Henderson (1953); Maximum-Likelihood, Rao and Hartley (1967); Mixed-Model Procedure, Application 1 (with adjustment for sire relationships), Henderson and Henderson (1979).

^bFixed effects include sex of calf and year-treatment combinations.

^cInitial cow traits include cow weight and cow fat.

of h^2 of average daily LETDN intake obtained by the three methods occurred after the adjustments for initial cow traits and cow weight change. Similar reductions occurred in the estimates of h^2 of LETDN intake after adjustments for the same cow traits. Very little change was observed in the estimates of h^2 of average daily LETDN intake with additional adjustments of calf weaning weight and average milk intake. The estimates of σ_S^2 , σ_E^2 and h^2 of 365-d ETDN intake of the cow-calf pair (Table 12) differ from the estimates of σ_S^2 , σ_E^2 and h^2 of LETDN intake and average daily LETDN intake. This difference is particularly large for the estimates obtained by the Mixed-Model Procedure. The estimates of σ_S^2 of 365-d ETDN intake obtained by the Mixed-Model Procedure are very small compared to the estimate of σ_E^2 . Small changes occur in these estimates due to adjusting for the different covariables, however, the estimates of h^2 are similar throughout the analyses.

After adjusting for fixed effects and calf age at weaning, the estimates of h^2 of 365-d ETDN intake obtained by Method III and the ML method were .66 and .54, respectively. These estimates of h^2 of 365-d ETDN intake are similar to the estimates of h^2 of LETDN intake and average daily LETDN intake after adjusting for similar effects. Since 365-d ETDN intake considers the entire year, the age of calf at weaning would not be expected to be as great a source of variation in the cow-calf pair intake as in the intake of the pair considering only the lactation period. This is the reason the adjustment of calf age at weaning reduces the estimate of σ_E^2 for LETDN intake by

TABLE 12. Estimates of Genetic Parameters of Cow-Calf Pair Estimated 365-d Total Digestible Nutrient Intake by Three Methods, a After Adjustments for Fixed Effects and Traits of the Cow and Calf

Model	Method III			Maximum-Likelihood			Mixed-Model Procedure Application 1				
	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2
	Estimates	Estimates	Estimates	Estimates	Estimates	Estimates	Estimates	Estimates	Estimates	Estimates	Estimates
	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2
	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2
	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2
	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2
	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2
	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2
	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2
	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2
	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2
	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2
	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2
	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2
	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2
	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2
	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2
	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2
	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2
	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2
	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2
	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2
	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2
	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2
	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2
	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2
	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2
	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2
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	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2
	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2
	σ^2	σ^2	σ^2	σ^2	σ^2	σ^2					

^aMethod III, Henderson (1953); Maximum-Likelihood, Hartley and Rao (1967), Mixed-Model Procedure, Application 1 (adjustment for sire relationships), Henderson and Henderson (1979).

^bFixed effects include sex of calf and year-treatment combinations.

^cInitial cow traits include cow weight and cow fat.

such a large amount, whereas, the same adjustment does not reduce the estimate of σ_e^2 of 365-d ETDN intake nearly so much.

The estimates of h^2 of 365-d ETDN intake of the pair and LETDN intake of the pair, obtained by Method III and the ML method were similar after adjusting for fixed effects, initial cow traits, cow weight change, calf weaning age, calf weaning weight and average milk intake, whereas, the estimate of h^2 of 365-d ETDN intake obtained by the Mixed-Model Procedure was smaller. The major reduction in the estimate of h^2 of 365-d ETDN intake occurred when the initial cow traits and cow weight change were considered jointly with the fixed effects and calf age at weaning. This same change occurred in the analyses estimated h^2 of LETDN intake. The estimates of h^2 of 365-d ETDN intake after the additional adjustment for average milk intake were reduced slightly (Method III and ML methods). The adjustment for calf weight at weaning, considered jointly with the traits of the cow, did not result in as large of an increase in the estimate of h^2 of 365-d ETDN intake as was observed in the estimate of h^2 of LETDN intake after adjusting for the same effects.

Cow-Calf Pair Efficiency to Weaning

The estimates of σ_s^2 , σ_e^2 and h^2 of cow-calf pair efficiency during the lactation period (LWEFF) are shown in Table 13. These estimates were obtained by Henderson's Method III, the ML method and Henderson's Mixed-Model Procedure (application 1) and are based on the sire of the cow. The estimates of h^2 of LWEFF after adjusting

TABLE 13. Estimates of Genetic Parameters of Cow-Calf Pair Lactation Weaning Efficiency by Three Methods, a After Adjustments for Fixed Effects and Traits of the Cow and Calf

Model	Method III				Maximum-Likelihood				Mixed-Model Procedure			
	σ_s^2	σ_e^2	h^2	S.E.	σ_s^2	σ_e^2	h^2	S.E.	σ_s^2	σ_e^2	h^2	S.E.
F.E. ^b	.197	.992	.66	.257	.175	.961	.62	.255	.228	.925	.79	.264
F.E. + Calf Weaning Age	.174	.969	.61	.254	.149	.939	.55	.250	.193	.908	.70	.260
F.E. + Initial Cow Traits ^c + Cow Weight Change + Calf Weaning Age	.166	.909	.62	.259	.148	.861	.59	.257	.199	.829	.78	.268
F.E. + Initial Cow Traits + Cow Weight Change + Calf Weaning Age + Average Milk Intake	.093	.876	.39	.244	.065	.836	.29	.235	.088	.819	.39	.244
F.E. + Initial Cow Traits + Cow Weight Change + Calf Weaning Weight	.104	.858	.43	.246	.092	.805	.41	.244	.144	.772	.63	.260
F.E. + Initial Cow Traits + Cow Weight Change + Calf Weaning Age + Calf Weaning Weight	.018	.655	.11	.218	.023	.602	.14	.222	.018	.606	.11	.218
F.E. + Initial Cow Traits + Cow Weight Change + Calf Weaning Age + Calf Weaning Weight + Average Milk Intake	.020	.653	.12	.220	.025	.597	.16	.224	.021	.600	.13	.221
F.E. + Ending Cow Traits + Cow Weight Change + Calf Weaning Age + Calf Weaning Weight + Average Milk Intake	.017	.653	.10	.218	.021	.599	.14	.221	.017	.601	.11	.219

^aMethod III, Henderson (1953); Maximum-Likelihood, Hartley and Rao (1967); Mixed-Model Procedure, Application 1 (with adjustment for sire relationships), Henderson and Henderson (1979).

^bFixed effects include sex of calf and year-treatment combinations.

^cInitial cow traits include cow weight and cow fat.

for the fixed effects and calf age at weaning, obtained by Henderson's Method III, the ML method and by Henderson's Mixed-Model Procedure were .61, .55 and .70, respectively.

The estimates of h^2 of LWEFF obtained by the three methods were very similar after adjustments were made for fixed effects, initial cow traits, cow weight change, calf age and weight at weaning and average milk intake. They ranged from .13 to .16. Substituting ending cow traits for initial cow traits reduced the estimates of h^2 of LWEFF slightly. Throughout the analyses to examine the genetic structure of LWEFF, the estimates of h^2 obtained by the three methods followed the same trends, but the changes caused by adjustments and varying combinations of independent variables differed in magnitude. The major reduction in the estimates of h^2 of LWEFF obtained by the three methods occurred when average milk intake was added to the model with fixed effects, initial cow traits, cow weight change and calf weaning age. Replacing average milk intake with calf weaning weight in the model without considering calf age at weaning resulted in slight increases in the estimates of h^2 of LWEFF. Joint consideration of calf weaning age and weight reduced the estimates of h^2 of LWEFF, but the addition of average milk intake had very little effect on them. Calf age at weaning and average milk intake were shown in the regression analyses (Table 2, page 58), to be predictors of calf weight at weaning. Here again, this is illustrated by similar trends in these analyses.

The estimates of σ_s^2 , σ_e^2 and h^2 of 365-d WEFF, obtained by the three methods based on the sire of the cow are shown in Table 14. These estimates of h^2 of 365-d WEFF after adjusting for the fixed effects and calf age at weaning, obtained by Henderson's Method III, the ML method and Henderson's Mixed-Model Procedure are .64, .47 and .69, respectively. The estimates of h^2 of 365-d WEFF obtained by the three methods were very similar and small after adjustments for fixed effects, initial cow traits, cow weight change, calf age and weight at weaning and average milk intake. The estimates of h^2 of 365-d WEFF were reduced when average milk intake was considered jointly with the fixed effects, initial cow traits, cow weight change and calf age at weaning. A larger reduction occurred in the estimates of h^2 when calf weight at weaning was added to the model including fixed effects and initial cow traits and cow weight change, and they remained small when calf age at weaning and average milk intake were added to the model. The estimates of h^2 of LWEFF and 365-d WEFF follow similar trends as the adjustments are made for the covariables. The major difference is observed when adjustment is made for calf weight at weaning. Adjusting for calf weight at weaning without simultaneously considering calf age at weaning in the analysis performed on LWEFF results in moderate estimates of h^2 ranging from .41 to .63, depending on the method used. Adding calf age at weaning to the model along with calf weight at weaning reduces the estimates of h^2 to values ranging from .11 to .14. In the analyses performed on 365-d WEFF, the estimates of h^2 are reduced by adjusting for calf weight at weaning

TABLE 14. Estimates of Genetic Parameters of Cow-Calf Pair 365-d Weaning Efficiency by Three Methods, a After Adjustments for Fixed Effects and Traits of the Cow and Calf

Model	Method III				Maximum-Likelihood				Mixed-Model Procedure			
	σ_s^2	σ_e^2	h^2	S.E.	σ_s^2	σ_e^2	h^2	S.E.	σ_s^2	σ_e^2	h^2	S.E.
F.E. ^b	.222	2.459	.33	.232	.119	2.418	.19	.219	.123	2.413	.19	.220
F.E. + Calf Weaning Age	.358	1.891	.64	.256	.245	1.841	.47	.246	.374	1.786	.69	.260
F.E. + Initial Cow Traits ^c + Cow Weight Change + Calf Weaning Age	.367	1.693	.71	.264	.311	1.619	.64	.260	.409	1.564	.83	.270
F.E. + Initial Cow Traits + Cow Weight Change + Calf Weaning Age + Average Milk Intake	.184	1.548	.42	.247	.121	1.487	.30	.236	.134	1.479	.33	.239
F.E. + Initial Cow Traits + Cow Weight Change + Calf Weaning Weight	.019	.923	.08	.214	.016	.862	.07	.212	.018	.862	.08	.213
F.E. + Initial Cow Traits + Cow Weight Change + Calf Weaning Age + Calf Weaning Weight	.019	.927	.08	.215	.011	.866	.05	.212	.017	.862	.08	.215
F.E. + Initial Cow Traits + Cow Weight Change + Calf Weaning Age + Calf Weaning Weight + Average Milk Intake	.019	.928	.08	.216	.013	.862	.06	.214	.017	.860	.08	.216
F.E. + Ending Cow Traits + Cow Weight Change + Calf Weaning Age + Calf Weaning Weight + Average Milk Intake	.020	.929	.08	.216	.016	.860	.07	.215	.018	.861	.08	.216

^aMethod III, Henderson (1953); Maximum-Likelihood, Hartley and Rao (1967); Mixed-Model Procedure, Application 1 (with adjustment for sire relationships), Henderson and Henderson (1979).

^bFixed effects include sex of calf and year-treatment combinations.

^cInitial cow traits include cow weight and cow fat.

without simultaneously considering calf age at weaning, and very little change is observed in the estimates when calf age at weaning is added to the model containing calf weight at weaning.

Average Daily Milk Intake

The estimates of σ_S^2 , σ_E^2 and h^2 of average daily milk intake obtained by Henderson's Method III, the ML method and Henderson's Mixed-Model Procedure, using the sire of the cow, are shown in Table 15. The estimates of h^2 obtained by the three methods were large, (ranging from .68 to .83) after adjustments for the fixed effects of sex of calf and year-treatment combination, and for calf age at weaning. The estimates of h^2 of average milk intake after adjustments for fixed effects, initial cow weight, cow weight change and calf age and weight at weaning ranged from .14 to .32. Substituting ending cow traits for initial cow traits resulted in very little change in the estimates of h^2 of average milk intake. Reductions in the estimates of h^2 of this trait occurred after adjustments for calf weight at weaning considered at the same time as fixed effects, initial cow traits and cow weight change. A further reduction occurred after adjusting for calf age at weaning, considered jointly with fixed effects, initial cow traits, cow weight change and calf weight at weaning. Based on the regression analyses (Table 6, page 65) performed on average milk intake, one would expect calf weight at weaning, or calf weight and age at weaning considered jointly to have a major effect on estimates of h^2 . The estimates of h^2 prior to adjusting

TABLE 15. Estimates of Genetic Parameters of Average Daily Milk Intake of the Calf By Three Methods, a After Adjustments for Fixed Effects and Traits of the Cow and Calf

Model	Method III			Maximum-Likelihood			Mixed-Model Procedure		
	σ^2_{ϵ}	σ^2_{ϵ}	$\ln^2$	S.E.	σ^2_{ϵ}	$\ln^2$	S.E.	σ^2_{ϵ}	S.E.
F.E. b	.296	1.253	.76	.263	.245	1.219	.67	.301	1.185
F.E. + Calf Weaning Age	.305	1.250	.78	.265	.247	1.217	.68	.308	1.180
F.E. + Initial Cow Traits ^c + Cow Weight Change + Calf Weaning Age	.297	1.259	.76	.267	.223	1.220	.62	.287	1.179
F.E. + Initial Cow Traits + Cow Weight Change + Calf Weaning Weight	.162	1.015	.55	.255	.113	.982	.41	.152	.954
F.E. + Initial Cow Traits + Cow Weight Change + Calf Weaning Age + Calf Weaning Weight	.083	.942	.32	.238	.034	.914	.14	.076	.882
F.E. + Ending Cow Traits + Cow Weight Change + Calf Weaning Age + Calf Weaning Weight	.087	.937	.34	.241	.035	.912	.15	.078	.880

^aMethod III, Henderson (1953); Maximum-Likelihood, Hartley and Rao (1967); Mixed-Model Procedure, Application 1 (with adjustment for sire relationships), Henderson and Henderson (1979).

^bFixed effects include sex of calf and year-treatment combinations.

^cInitial cow traits include cow weight and cow fat.

for calf weight at weaning or calf weight and age at weaning were large compared to the range of accepted values of estimates h^2 of milk production in dairy cattle (.20 to .30). After adjusting for calf weight at weaning or for calf weight and age at weaning, in the same analyses, the estimates of h^2 were reduced and resemble more closely the accepted values in dairy cattle. There is some published evidence that milk production may be more highly heritable in beef cattle than in dairy cattle. Christian et al. (1965) reported their estimate of h^2 of 305-day milk yield in Hereford identical and fraternal twins to be .52. Dillard et al. (1978) estimated the heritability of the sum of three observations (per cow) of milk production to be $.44 \pm .13$ with a repeatability of $.46 \pm .03$.

4. ESTIMATES OF GENETIC AND PHENOTYPIC CORRELATIONS OF COW-CALF PAIR EFFICIENCY WITH TRAITS OF THE COW

The estimates of the genetic and phenotypic correlations of the two measures of cow-calf efficiency with average daily LETDN intake, milk intake and initial and ending cow weight and fat thickness are presented in Table 16. LWEFF and 365-d WEFF are very highly correlated (genetic and phenotypic) as would be expected. Small positive genetic correlations were found between average daily LETDN intake and both measures of cow-calf efficiency to weaning with larger positive phenotypic correlations. This result bears out the expected unfavorable relationship that exists between the ETDN intake of the pair and measures of efficiency. Large negative genetic correlations and smaller

TABLE 16. Estimates of Genetic and Phenotypic Correlations^a of Cow-Calf Pair 365-d Weaning Efficiency and Cow-Calf Pair Lactation Weaning Efficiency with Traits of the COW

Traits	365-Day Weaning Efficiency			Lactation Weaning Efficiency		
	r_G	S.E.	r_P	r_G	S.E.	r_P
365-day Weaning Efficiency						
Lactation Weaning Efficiency	1.03	.028	.92	1.03	.028	.92
Average Daily LEIDN Intake	.11	.327	.23	.13	.332	.43
Average Daily Milk Intake	-.65	.209	-.36	-.70	.221	-.29
Initial Cow Weight	.17	.244	.26	.26	.244	.18
Initial Cow Fat	.09	.312	.15	.25	.309	.12
Ending Cow Weight	.21	.231	.30	.23	.234	.25
Ending Cow Fat	.46	.218	.32	.57	.217	.27

^aEstimates of genetic and phenotypic correlations were obtained by Henderson's Method III, Henderson (1953) and the equations presented by Becker (1984).

b_{r_G} = Genetic Correlation, adjusted for sex of calf, year-treatment combinations and calf age at weaning.

c_{r_P} = Phenotypic correlation, adjusted for sex of calf, year-treatment combinations and calf age at weaning.

phenotypic correlation were found between average daily milk intake and the measures of cow-calf efficiency. This agrees well with the regression analyses performed on LWEFF and 365-d WEFF (Table 7, page 66, and Table 8, page 68) where average milk intake was favorably related to efficiency and as predictors of calf weight at weaning (Table 2, page 58). Small positive genetic and somewhat larger phenotypic correlations were found between cow-calf pair efficiency and initial and ending cow weight. These results agree well with the regression analyses performed on LWEFF and 365-d WEFF (Table 7, page 66, and Table 8, page 68) in which initial and ending cow weight was unfavorably related to the efficiency of the cow-calf pair to weaning. The genetic and phenotypic correlations of initial cow fat thickness with the measures of cow-calf efficiency are smaller than the correlations of ending cow fat thickness with these. This result indicates that cows which become fatter during the lactation period are less efficient and probably is related to the negative effect that ending cow fat thickness has on calf weight at weaning (Table 2, page 58).

5. CONCLUSIONS

The results from this study support the conclusions of other researchers that the efficiency of cow-calf systems to weaning are a dynamic function of traits of the cow, traits of the calf and the nutritional environment. In the regression analyses, calf weight at weaning was affected by the weight, fat thickness and weight change

of the cow, and average milk intake and calf age at weaning were found to be predictors of calf weight at weaning. The regression analyses of LETDN intake, average daily LETDN intake and 365-d ETDN intake on traits of the cow and calf were characterized by generally similar relationships. Initial cow weight and calf weight at weaning were found to be positively associated with cow-calf pair intake. In the analyses performed on LETDN intake, calf age at weaning was found to be a very important factor, as would be expected; but, in the analyses performed on 365-d ETDN intake, calf age at weaning was important only when calf weight at weaning was not in the model. The affect that average milk intake has on cow-calf pair forage intake follows the same trend; it is important when calf weight at weaning is not in the model. Cow weight change is positively related to 365-d ETDN intake and average daily LETDN intake when considered jointly in a model with calf weight at weaning.

The regression analyses performed on the two measures of cow-calf pair efficiency to weaning generally agree, the major difference is observed in the relationships with calf age at weaning. LWEFF is related to calf age at weaning in all models fitted, whereas, 365-d WEFF is related to calf age at weaning only if calf weight at weaning is not in the model. The regression analyses of average milk intake showed calf weight at weaning to be positively related to average milk intake. Calf age at weaning was negatively related to average milk intake when considered jointly with calf weight at weaning, indicating that if calf weight is held constant, older calves

will have a lower average milk intake over the lactation period than younger calves and will obtain more of their nutrient intake from available forage.

In general, the amounts and proportions of variation removed from the estimates of σ_S^2 and σ_E^2 of all the dependent variables, with the addition of covariables, agrees very well with the results of the regression analyses. In general, calf age at weaning is a source of variation that is primarily removed from the estimate of σ_E^2 and should be routinely removed in the same manner as is variation due to the fixed effect. Removing the variation associated with the traits of the cow (weight, fat thickness and weight change) tend to reduce slightly the estimate of σ_S^2 . Substituting ending cow traits for the initial cow traits has very little effect on the estimates of h^2 . Calf weight at weaning without calf age at weaning tends to have the largest affect on the estimates of σ_S^2 and h^2 and these affects are different, depending on which variable is being considered. Average milk intake tends to affect the estimates of σ_S^2 and h^2 in the same manner (to a much smaller extent) as does calf weight at weaning.

The estimates of h^2 of a particular variable, obtained by the three methods, in general, follow the same trends but vary in magnitude. Two notable exceptions were the estimates of h^2 of 365-d ETDN intake obtained by the Mixed-Model Procedure were smaller than the estimates of h^2 obtained by the other two methods, and the estimates of h^2 of calf weight at weaning obtained by the ML method were smaller than those obtained by Henderson's Method III. The standard errors of

all of the estimates of h^2 fall within the range of .20 to .30. Considering the small number of sires of the cows (56) and sires of the calves (46), these standard errors are not unreasonable.

The estimates of h^2 of calf weight at weaning, obtained by Henderson's Method III and the ML method, after adjusting for sex of calf, year-treatment combinations, traits of the cow, calf age at weaning and average milk intake were .76 and .34, respectively. Even though there is a large difference between these two estimates, they are in fair agreement with the estimates obtained by other researchers and indicate that calf weight at weaning is moderately to highly heritable. The estimates of h^2 of the three measures of cow-calf pair intake obtained by the three methods were similar after adjustments for sex of calf, year-treatment combinations, initial cow traits, cow weight change, calf age and weight at weaning and average milk intake. They ranged from .33 to .07 with only one estimate below .26, indicating that cow-calf pair ETDN intake is slightly to moderately heritable. The estimates of h^2 of LWEFF and 365-d WEFF, obtained by the three methods, after adjustments for sex of calf, year-treatment combinations, initial cow traits, cow weight change, calf age and weight at weaning and average milk intake were relatively low. They ranged from .16 to .06, indicating that the efficiency of cow-calf pairs to weaning is slightly heritable. It is important to realize that the fixed effects and the covariables considered in the complete model analyses explain much of the variation in cow-calf pair efficiency to weaning (77 percent for LWEFF and 84 percent for

365-d WEFF), so, the variation that remains as a part of the sire variance (σ_s^2) should approach being a true sire effect on cow-calf efficiency. The estimates of h^2 of average milk intake, obtained by the three methods, after adjustments for sex of calf, year-treatment combinations, initial cow traits, cow weight change and calf age and weight at weaning ranged from .15 to .34. These moderately low estimates agree fairly well with the range (.20 to .30) of accepted estimates of h^2 of milk production in dairy cattle, and fairly well with the estimates obtained by Christian et al. (1965) and Dillard et al. (1978) in beef cattle.

Cow-calf pair nutritional efficiency is hard to measure, so, selection schemes based on cow-calf pair nutritional efficiency would be impractical. Much of the genetic structure of cow-calf pair nutritional efficiency is explained by the traits of the cow and by calf weight at weaning which are heritable, and selection schemes could be developed to select for these traits to promote nutritional efficiency of cow-calf pairs.

In general, the genetic and phenotypic correlations of LWEFF and 365-d WEFF with each other and with the traits of the cow followed expected trends. LWEFF and 365-d WEFF were very highly genetically and phenotypically correlated. Genetic and phenotypic correlations between average daily LETDN intake and LWEFF or 365-d WEFF were relatively low. Average daily milk intake was highly genetically correlated with and moderately phenotypically correlated with LWEFF and 365-d WEFF. This would be expected since average milk intake

is a predictor of calf weight at weaning, a direct component of cow-calf pair efficiency to weaning. Small positive genetic and larger positive phenotypic correlations were found between initial and ending cow weight and the two measures of cow-calf efficiency to weaning. Based on the results of the regression analyses and the estimates of the genetic components, initial or ending cow weight have not been found to have a large effect on cow-calf efficiency to weaning, unless considered jointly with calf weight at weaning. Initial cow fat thickness was low to moderately genetically correlated with the measures of cow-calf efficiency to weaning, however, the genetic coefficients of correlation are relatively high for ending cow fat thickness and the measures of cow-calf efficiency to weaning. The phenotypic coefficients of correlation of ending cow fat thickness and the measures of cow-calf efficiency were not as high.

Results from this study suggest that heritability of the measures of partial nutritional efficiency studied were high in the population of Angus cattle from which this sample was drawn. This indicated genetic control of efficiency appeared to be exercised through genetic control of measureable traits associated with cow size and preweaning calf growth. Selection procedures and mating schemes directed toward desirable cow-calf weight relationships were concluded to be an effective method for improving these measures of partial efficiency. Heritability of intake during lactation was indicated to be moderate and was related to those animal size and growth traits associated with efficiency. However, in contrast to the situation

regarding measures of efficiency, moderate levels of residual heritability remained for intake after accounting for animal size and growth traits. This result was concluded to suggest that variation in relative intake may provide a partial explanation for other production responses, such as reproduction, not considered in the present study. Low estimates of heritability (Henderson's Mixed-Model Procedure), as opposed to the moderate level for intake during lactation, were concluded to reflect the somewhat controlled aspects of winter feeding and pre- and post-weaning compensations in cow intake associated with body compositional changes of the cow during lactation.

CHAPTER V

SUMMARY

Estimates of heritability (h^2) of the partial nutritional efficiency of cow-calf pairs during the lactation period (ratio of estimated total digestible nutrients (ETDN) consumed by the cow and calf during lactation to calf weight at weaning (LWEFF)) and over the entire 365-d period (ratio of 365-d ETDN consumed by the cow and calf to calf weight at weaning (365-d WEFF)) were obtained from intake and performance records of 146 cows by 56 sires raising 266 calves by 46 sires. Intake data on 113 cow-calf pairs were from individual feeding on a grass silage diet. Intake data on 153 cow-calf pairs were from weekly, inert marker estimates of forage intake of pairs grazing fescue or fescue-clover pastures. In addition to cow-calf pair efficiency, estimates of h^2 of cow-calf pair forage ETDN intake during the lactation period (LETDN), 365-d ETDN intake of the pair and mean daily milk intake were obtained by paternal half-sib analyses (sire of cow) by Henderson's Mixed-Model Procedure. The structures of the genetic influences on LWEFF, 365-d WEFF, LETDN intake, 365-d ETDN intake and calf mean daily milk intake were examined by sequential addition, as covariables, phenotypic traits of the cow-calf pair to models estimating sire components of variance. From records adjusted for year-treatment, sex of calf and age of calf, estimates of h^2 obtained by Henderson's Mixed-Model Procedure of

LWEFF, 365-d WEFF, LETDN intake, 365-d ETDN intake and calf mean daily milk intake were $.70 \pm .260$, $.69 \pm .260$, $.13 \pm .214$, $.09 \pm .210$ and $.83 \pm .267$, respectively. After the addition of terms for cow weight and fat thickness, recorded at weaning of her previous calf, cow weight change during the year, calf weight at weaning and mean daily milk intake (where applicable) the estimates of h^2 of LWEFF, 365-d WEFF, LETDN intake, 365-d ETDN intake and calf mean daily milk intake were $.13 \pm .221$, $.08 \pm .216$, $.30 \pm .238$, $.07 \pm .215$ and $.32 \pm .238$, respectively. From records adjusted for year-treatment, sex of calf and calf weaning age, estimates of genetic correlations between LWEFF and mean daily LETDN intake, mean daily milk intake, cow weight, cow fat thickness and 365-d WEFF were $.13 \pm .332$, $-.70 \pm .221$, $.26 \pm .244$, $.25 \pm .309$ and $1.03 \pm .028$, respectively. Results from this study suggest that heritability of the measures of partial nutritional efficiency studied were high in the population of Angus cattle from which this sample was drawn. The genetic control of efficiency appeared to be exercised through genetic control of measurable traits associated with cow size and preweaning calf growth. Selection procedures and mating schemes directed toward desirable cow-calf weight relationships should be an effective method for improving these measures of partial efficiency. Heritability of intake during lactation was indicated to be moderate, even after adjustments for cow and calf traits associated with efficiency.

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APPENDIX

TABLE A1. Partial and Standard Partial Coefficients of Regression of Calf Weaning Weight on Traits of the Cow and Calf (Pasture Cattle)

Error df	Initial			Cow Weight Change			Weaning Calf Age			Milk Production			Cow Weight			Ending			R ²
	Cow Weight	Standard	Partial	Cow Fat	Standard	Partial	Cow Weight Change	Standard	Partial	Weaning Calf Age	Standard	Partial	Milk Production	Standard	Partial	Cow Weight	Standard	Partial	
143	.03	.05								.53***	.37								.11
142	.13*	.18		-2.70**	-.28														<.01
141	.13*	.18		-2.70**	-.28		-.04	-.02											.03
140	.06	.12		-1.86†	-.19		.06	.03		.60***	.35								.13
140	.04	.06		-.83	-.08		-.25†	-.10					13.95***	.61					.31
139	.01	-.02		.13	.01		-.12	-.05		.64***	.37		14.33***	.62					.42
139							-.11	-.04		.64***	.37		14.29***	.62		-.01	-.02	<.01	.42

All models contained terms for sex of calf, treatment group and year within treatment group, sequentially accounting for 132 (P<.001), 65 (P<.001) and 132 (P<.001), respectively, of variation in calf weight at weaning. Tabled R² values reflect additional variation explained by independent variables shown.

†P<.10.

*P<.05.

**P<.01.

***P<.001.

TABLE A2. Partial and Standard Partial Coefficients of Regression of Calf Weaning Weight on Traits of the Cow and Calf (Individually-Fed Cattle)

Error of	Initial			Cow Weight Change			Weaning Calf Age			Milk Production			Cow Weight			Ending			R ^{2a}
	Cow Weight Partial	Standard Partial	Cow Fat Partial	Cow Weight Partial	Standard Partial	Cow Fat Partial	Cow Weight Partial	Standard Partial	Cow Fat Partial	Milk Partial	Standard Partial	Milk Partial	Cow Weight Partial	Standard Partial	Cow Fat Partial	Milk Partial	Standard Partial	Cow Fat Partial	
106							.84***												.32
106	.28***	.36																	.10
105	.29***	.37	-.40			-.04													.10
104	.23**	.30	-.79			-.08													.13
103	.15**	.19	-.77			-.08													.36
103	.23***	.30	-.92			-.09													.14
102	.15**	.19	-.88			-.09													.37
102																			.38

aAll Models Contained terms for sex of calf and year sequentially accounting for 71 (P<.001) and 343 (P<.001), respectively, of the variation in calf weaning weight. Tabled R² values reflect additional variation in calf weaning weight explained by independent variables shown.

*P<.10

**P<.05

***P<.01

****P<.001

TABLE A3. Partial and Standard Partial Coefficients of Regression of Pair Estimated Total Digestible Nutrient Intake During Lactation on Traits of the Cow and Calve (Pasture Cattle)

Error df	Initial			Cow Weight Change			Weaning			Milk Production			Ending			R ² b
	Cow Weight	Standard	Cow Fat	Partial	Standard	Partial	Calf Age	Standard	Partial	Partial	Standard	Partial	Cow Weight	Standard	Partial	
143	1.66***	.22					9.41***	.52								.23
142	2.31***	.31	-18.03*													.04
141	2.31***	.31	-18.19*													.06
140	1.60***	.21	-5.31	-1.53	.05		9.08***	.50								.26
139	1.34***	.18	.44	.35	.01		7.23***	.40	3.10***	.29						.31
140	1.66***	.22	-4.86	-1.33	-.05				4.93***	.47						.27
140	1.90***	.26	-11.52	-2.27	-.09						46.59**	.20				.09
139	1.22**	.16	2.33	-.43	-.02		9.25***	.51	5.97***	.57	55.09***	.23				.30
139	1.75***	.23	-6.58	-.79	-.03		7.01***	.43	2.24**	.21	-33.70*	-.14				.21
138	1.25***	.17	2.04	-.16	-.01		7.02***	.43	2.25**	.21	22.94	.09				.31
138				-1.30	-.05						23.34	.10	1.19**	.16	2.75	.31

a. Estimated total digestible nutrient (ETDN) intake of the cow measured during lactation plus nominal ETDN intake of the calf to weaning.

b. All models contained terms for sex of calf, treatment group and year within treatment group sequentially accounting for <15 (P<.10), 425 (P<.001) and 52 (P<.001) of the variation in pair ETDN intake during lactation. Tabled R² values reflect additional variation in pair ETDN intake during lactation explained by independent variables shown.

**P<.05.

***P<.01.

***P<.001.

TABLE A4. Partial and Standard Partial Coefficients of Regression of Pair Estimated Total Digestible Nutrient Intake During Lactation on Traits of the Cow and Calf (Individually-Fed Cattle)

Error df	Initial			Cow Weight Change			Weaning			Milk Production			Ending			g ^b
	Cow Weight	Partial	Standard Partial	Cow Weight	Partial	Standard Partial	Calf Age	Standard Partial	Calf Weight	Partial	Standard Partial	Milk Production	Partial	Standard Partial	Cow Fat	
106	2.37***	.30					6.88***	.60								.21
105	2.56***	.33	-5.78													.07
104	2.47***	.31	-6.39													.07
103	1.75***	.22	-6.22				6.45***	.57								.24
103	1.16**	.15	-3.15				3.45***	.30	3.58***	.40						.28
102	1.01*	.13	-1.42						6.30***	.63						.25
103	2.47***	.31	-6.91				6.43***	.57				19.36	.05			.08
102	1.76***	.22	-6.56						6.37***	.63		12.57	.03			.24
102	.99*	.13	-1.02				3.43***	.30	4.03***	.40		-4.42	-.01			.25
101	1.15**	.15	-3.00				3.13***	.27	4.49***	.45		-6.30	-.02			.28
101														.09	13.10*	.12

^aEstimated total digestible nutrient (EDN) intake of the cow measured during lactation plus month EDN intake of the calf to weaning.

^bAll models containing terms for sex of calf and year sequentially accounting for <1% (P<.10) and 41% (P<.001) of the variation in pair EDN intake during lactation. Listed R² values reflect additional variation in pair EDN intake during lactation explained by independent variables shown.

*P<.10.

**P<.05.

***P<.01.

****P<.001.

TABLE A5. Partial and Standard Partial Coefficients of Regression of Pair Estimated Average Daily Total Digestible Nutrient Intake During Lactation^a on Traits of the Cow and Calf (Pasture Cattle)

Error df	Initial			Cow Fat			Cow Weight Change			Calf Age			Weaning			Milk Production			Cow Weight			Ending			R ² b
	Partial	Standard	Partial	Partial	Standard	Partial	Partial	Standard	Partial	Partial	Standard	Partial	Partial	Standard	Partial	Partial	Standard	Partial	Partial	Standard	Partial	Standard	Partial		
143	.006***	.223								.012***					.186									.03	
142	.007***	.271	-.036	-.097																				.04	
141	.007***	.271	-.036	-.097																				.05	
140	.006***	.239	-.020	-.055			<-.001	-.001	-.001	.011***	.167													.07	
139	.005***	.200	.002	.007	.001	.011	.001	.011	.003	.054		.328												.13	
140	.006***	.206	.001	<.001	.004	.004	<.001	.004	.013***	.351			.012***			.207***	.238							.13	
140	.006***	.220	-.008	-.022			-.003	-.034	.012***	.177		.320				.214***	.246							.09	
139	.005***	.185	-.009	-.025	-.001	-.010	-.001	-.010	.012***	.320		.045				.039	.045							.12	
139	.005***	.202	.002	.005	<-.001	-.002	<-.001	-.002	.005	.094	.250	.090				.078	.090							.13	
138	.005***	.190	.008	.021	<.001	-.002	<.001	-.002	.005	.094	.094	.251				.079	.091		.005***	.190	.009		.031	.13	

^aAverage daily estimated total digestible nutrient intake of the cow during lactation plus the nominal ETDM intake of the calf.

^bAll models contained terms for sex of calf, treatment group and year within treatment group, sequentially accounting for 23 (P<.01), 485 (P<.001) and 153 (P<.001), respectively, of the variation in average daily ETDM intake of the cow and calf during the lactation period. Tabled R² values reflect additional variation in pair average daily ETDM intake measured during lactation by independent variables shown.

*P<.05.

***P<.001.

TABLE A6. Partial and Standard Partial Coefficients of Regression of Pair Estimated Average Daily Total Digestible Nutrient Intake During Lactation^a on Traits of the Cow and Calf (Individually-Fed Cattle)

Error df	Initial			Cow Weight Change			Meaning			Milk Production			Ending			R ^{2b}	
	Cow Weight	Cow Fat	Partial	Partial	Standard	Partial	Calf Age	Calf Weight	Partial	Partial	Standard	Partial	Cow Weight	Cow Fat	Partial		
106	.005***	.221					<-.001	<-.001								<.01	
105	.005***	.242		-.014	-.059											.04	
104	.005***	.275		-.009	-.034	.003										.04	
103	.006***	.283		-.009	-.034	.003	.131									.05	
103	.004**	.180		.002	.009	.005*	.015***	.543								.11	
102	.004**	.207		-.004	-.015	.005*	-.013***	.006**	.228							.07	
103	.006***	.276		-.011	-.040	.003						.070	.065			.05	
102	.006***	.295		-.011	-.041	.003	-.058	.006**	.220	.039	.036	.072	.066			.05	
102	.005**	.210		-.005	-.020	.005*	-.013***	.015***	.540	.009	.008	.009	.008			.11	
101	.004**	.181		-.002	-.008	<.001	-.014***	.016***	.593	<-.001	<-.001	<-.001	<-.001	.003†	.119	.052*	.174

^aAverage daily estimated total digestible nutrient intake of the cow during lactation plus the nonmilk ETM intake of the calf.

^bAll models contained terms for sex of calf and year, sequentially accounting for 18 (P=.10) and 655 (P<.001), respectively, of the variation in average daily ETM intake of the cow and calf during the lactation period. Tabled R² values reflect additional variation in pair average daily ETM intake measured during the lactation period explained by independent variables shown.

†P<.10.

* P<.05.

**P<.01.

***P<.001.

TABLE A7. Partial and Standard Partial Coefficients of Regression of Pair 365-d Estimated Total Digestible Nutrient Intake^a on Traits of the Cow and Calf (Pasture Cattle)

Error df	Initial			Cow Weight Change			Calf Age			Weaning			Milk Production			Low Weight			Ending			R ^{2b}
	Cow Weight Partial	Standard Partial	Cow Fat Partial	Cow Weight Change Partial	Standard Partial	Cow Fat Partial	Calf Age Partial	Standard Partial	Calf Weight Partial	Standard Partial	Calf Weight Partial	Standard Partial	Milk Production Partial	Standard Partial	Cow Fat Partial	Low Weight Partial	Standard Partial	Cow Fat Partial	Ending Partial	Standard Partial	Cow Fat Partial	
143	2.66***	.37					2.19*			.13												.01
142	2.91***	.40	-7.07																			.12
141	2.91***	.40	-7.06	.08																		.12
140	2.78***	.38	-4.69	.43	.02		1.67*			.10												.13
139	2.51***	.35	1.21	.16	.01		-.23			-0.1	3.18***											.19
140	2.50***	.35	1.38	.21	.01						3.12***	.31										.18
140	2.55***	.35	.29	-.74	-.03								54.71***	.24								.17
139	2.40***	.33	3.05	-.37	-.01		1.04*			.10	2.52***	.25	55.81***	.24								.17
139	2.45***	.34	2.38	-.11	-.01		.33			.02	2.36**	.23	19.37	.06								.19
138	2.43***	.34	2.74	-.08	-.01		.33			.02	2.37**	.23	21.96	.09								.19
138				-2.49*	-.10								22.19	.10		2.38***	.34	3.03				.04

^aEstimated 365-d total digestible nutrient (EDM) intake of the cow plus nominal EDM intake of the calf to weaning.

^bAll models contained terms for sex of calf, treatment group and year within treatment group sequentially accounting for 25 (P<.01), 465 (P<.001) and 155 (P<.001), respectively, of the variation in pair 365-d EDM intake. Tabled R² values reflect additional variation in pair 365-d EDM intake explained by independent variables shown.

* P<.05.

**P<.01.

***P<.001.

TABLE A8. Partial and Standard Partial Coefficients of Regression of Pair 365-d Estimated Total Digestible Nutrient Intake on Traits of the Cow and Calf (Individually-Fed Cattle)

Error df	Cow Weight			Initial			Cow Weight Change			Calf Age			Weaning			Milk Production			Cow Weight			Ending			g ²
	Partial	Standard	Partial	Partial	Standard	Partial	Partial	Standard	Partial	Partial	Standard	Partial	Partial	Standard	Partial	Partial	Standard	Partial	Partial	Standard	Partial	Partial	Standard	Partial	
106	2.23***	.30								2.87***	.27														.04
105	2.67***	.36																							.07
104	2.81***	.38																							.08
103	2.56***	.35																							.09
102	1.99***	.27																							.11
101	1.96***	.27																							.15
102	2.82***	.38																							.15
101	2.58***	.35																							.09
102	2.02***	.27																							.15
101	1.90***	.27																							.16

*Estimated 365-d total digestible nutrient (ETDN) intake of the cow plus nonmilk ETDN intake of the calf to weaning.

†All models contained terms for sex of calf and year sequentially accounting for <15 (P<.10) and 605 (P<.001), respectively, of the variation in pair 365-d ETDN intake. Tabled R² values reflect additional variation in pair 365-d ETDN intake explained by independent variables shown.

†P<.10

**P<.05

***P<.01

***P<.001

TABLE A9. Partial and Standard Partial Coefficients of Regression of Estimated Calf Average Daily Milk Intake on Traits of the Cow and Calf (Pasture Cattle)

Error df	Initial			Cow Height Change			Calf Age			Weaning			Low Weight			Ending			R ²
	Partial	Standard Partial	Cow Fat	Partial	Standard Partial	Cow Fat	Partial	Standard Partial	Calf Weight	Partial	Standard Partial	Calf Weight	Partial	Standard Partial	Cow Fat	Partial	Standard Partial	Cow Fat	
143	.002	.054																	<.01
142	.007*	.211	-.138**																<.01
141	.007*	.212	-.138**																.05
140	.007*	.220	-.139**																.05
140	.003	.062	-.051																.46
139	.004†	.118	-.070*																.38
139																			.46

All models contained terms for sex of calf, treatment group and year within treatment group, sequentially accounting for 23 (P<.10), 53 (P<.01) and 115 (P<.01) degrees of freedom. The values in the table are estimated calf average daily milk intake. Tabular R² values reflect additional variation explained by independent variables shown.

†P<.10.

*P<.05.

**P<.01.

***P<.001.

TABLE A10. Partial and Standard Partial Coefficients of Regression of Estimated Calf Average Daily Milk Intake on Traits of the Cow and Calf (Individually-Fed Cattle)

Error df	Initial			Cow Weight Change			Calf Age			Meaning			Calf Weight			Low Weight			Ending			Low Fat			R ²
	Partial	Standard	Partial	Partial	Standard	Partial	Partial	Standard	Partial	Partial	Standard	Partial	Partial	Standard	Partial	Partial	Standard	Partial	Partial	Standard	Partial	Partial	Standard	Partial	
106	<.001	.032					.002																		<.01
105	<.001		.078		.110																				<.01
104	<.001	-.015	.027		.107																				<.01
103	<.001	-.020	.027		.107																				.01
101	<.002	-.005	.031		.125																				.03
102	<.002	-.098	.034		.137																				.04
102																									.04

All models contained terms for sex of calf and year, sequentially accounting for <1% (P>.10) and 20% (P<.001), respectively, of variation in estimated calf average daily milk intake. Tabled R² values reflect additional variation in estimated calf average daily milk explained by independent variables shown.

*P<.10

*P<.05.

TABLE A11. Partial and Standard Partial Coefficients of Regression of Pair Weaning Efficiency During the Lactation Period^a on Traits of the Cow and Calf (Pasture Cattle)

Error df	Initial			Cow Weight Change			Calf Age			Weaning			Calf Weight			Milk Production			Cow Weight			Ending			R ^{2b}
	Cow Weight			Cow Weight			Calf Age			Weaning			Calf Weight			Milk Production			Cow Weight			Ending			
	Partial	Standard Partial	Partial	Partial	Standard Partial	Partial	Partial	Standard Partial	Partial	Partial	Standard Partial	Partial	Standard Partial	Partial	Partial	Standard Partial	Partial	Standard Partial	Partial	Standard Partial	Partial	Standard Partial			
143	.008***	.222	.009						.025***	.304														.08	
142	.007**	.212	.008																					.04	
141	.007**	.212	.008						.025***	.301														.05	
140	.005*	.155	.044						.041***	.494														.12	
139	.008***	.222	.006						.023	.023														.29	
140	.010***	.275	.036						.003	.003														.12	
140	.010***	.276	.037						.000	.000														.11	
139	.008***	.219	.001						.042	.042														.18	
139	.010***	.289	.046						.005	.005														.13	
138	.007***	.207	.004						.045***	.537														.29	
138									.045***	.538														.29	
138									.005	.005														.026	
138									.007***	.203														.026	

^aRatio of pair ETD intake measured during the lactation period to calf weight at weaning.

^bAll models contained terms for sex of calf, treatment group and year within treatment group, sequentially accounting for 48 (P<.001), 215 (P<.001), and 253 (P<.001), respectively, of the variation in pair lactation weaning efficiency. Tabled R² values reflect additional variation in pair lactation weaning efficiency explained by independent variables shown.

*P<.10.

**P<.05.

***P<.01.

****P<.001.

TABLE A12. Partial and Standard Partial Coefficients of Regression of Pair Weaning Efficiency During the Lactation Perioda on Traits of the Cow and Calf (Individually-Fed Cattle)

Error df	Initial			Cow Weight Change			Calf Age			Weaning			Milk Production			Cow Weight			Ending			R ^{2b}
	Partial	Standard	Partial	Partial	Standard	Partial	Partial	Standard	Partial	Partial	Standard	Partial	Partial	Standard	Partial	Partial	Standard	Partial	Partial	Standard	Partial	
106	.001	.02																				.01
105	.001	.02	.006		.01																	.01
104	.003	.08	.019		.05																	.01
103	.002	.08	.019		.05	.009**		.29														.02
103	.005*	.15	.012		.03	.006*		.22		.19												.02
102	.005**	.17	.004		.01	.007*		.22		.209**												.05
103	.002	.08	.021		.05	.009**	.015***	.34		.019***	.23											.08
102	.002	.08	.021		.05	.009**	.001	.02			.49											.03
102	.005*	.15	.013		.03	.006*	.015***	.34		.009**	.22											.05
101	.005**	.17	.004		.01	.007	.014***	.31		.017***	.44											.08
101						.001		.05								.003†	.11		.071*	.17		.09

a. Gain of pair EDOM intake measured over the lactation period to calf weight at weaning.

b. All models contained terms for sex of calf and year, sequentially accounting for 35 (P < .001) and 612 (P < .001), respectively, of the variation in pair lactation weaning efficiency. Tabled R² values reflect additional variation in pair lactation weaning efficiency explained by independent variables shown.

†P < .10

*P < .05

**P < .01

***P < .001

TABLE A13. Partial and Standard Partial Coefficients of Regression of Pair 365-d Weaning Efficiency^a on Traits of the Cow and Calf (Pasture Cattle)

Error df	Initial		Cow Fat		Cow Weight Change		Calf Age		Meaning		Calf Weight		Milk Production		Low Weight		Ending		R ^{2b}
	Partial	Standard Partial	Partial	Standard Partial	Partial	Standard Partial	Partial	Standard Partial	Partial	Standard Partial	Partial	Standard Partial	Partial	Standard Partial	Partial	Standard Partial	Partial	Standard Partial	
143	.012***	.257																	.05
142	.008*	.172	.106 †	.171															.06
141	.009*	.172	.106 †	.171	.004	.026													.07
140	.010**	.218	.069	.111	-.001	-.008	-.026***	.243											.12
139	.014***	.306	-.018	-.030	.003	.017	.002	.014	-.047***	-.742									.42
140	.014***	.306	-.020	-.031	.002	.015			-.047***	-.736									.42
140	.012***	.256	.029	.047	.013	.000	-.028***	-.260					-.575***	-.394					.19
139	.014***	.308	-.013	-.021	.007	.045			-.051***	-.801			-.591***	-.406					.29
139	.014***	.301	-.013	-.021	<.001	.001	.006	.055	-.054***	-.846			.132	.091					.42
138	.013***	.292	-.006	-.010	-.001	.004	.006	.057	-.054***	-.846			.175*	.120	.013***	.290	.005	.011	.42
138					-.012†	-.075							.160*	.124					

^aRatio of pair 365-d ETON in:ake to calf weight at weaning.

^bAll models contained terms for sex of calf, treatment group and year within treatment groups, sequentially accounting for 52 (P<.001), 85 (P<.001) and 302 (P<.001), respectively, of the variation in 365-d weaning efficiency. †abled R² values reflect additional variation in pair 365-d weaning efficiency explained by independent variables shown.

†P<.10

*P<.05.

**P<.01.

***P<.001

TABLE A14. Partial and Standard Partial Coefficients of Regression of Pair 365-d Weaning Efficiency^a on Traits of the Cow and Calf (Individually-Fed Cattle)

Error df	Initial			Cow Weight Change			Weaning			Milk Production			Cow Weight			Ending			R ² b
	Cow Weight Partial	Standard Partial	Cow Fat Partial	Cow Weight Partial	Standard Partial	Cow Fat Partial	Cow Weight Partial	Standard Partial	Cow Fat Partial	Milk Production Partial	Standard Partial	Cow Weight Partial	Cow Weight Partial	Standard Partial	Cow Fat Partial	Milk Production Partial	Standard Partial	Cow Weight Partial	
106	-.003	-.06																	.12
105	-.002	-.04	-.034	-.017***	.37														<.01
104	.002	.05	-.009	-.012**	.26														<.01
103	.005†	.12	-.010	-.02**	.17														.04
102	.010***	.22	-.037	.008*	.17														.14
101	.010***	.22	-.034	.008*	.17														.20
100	.002	.05	-.006	-.017***	.37														.20
99	.005†	.11	-.007	-.012**	.26														.04
98	.010***	.22	-.039	.008*	.17														.14
97	.010***	.22	-.036	.008*	.17														.20
96				<.001	<.01														.20
95																			.20
94																			.20
93																			.20
92																			.20
91																			.20
90																			.20
89																			.20
88																			.20
87																			.20
86																			.20
85																			.20
84																			.20
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14																			.20
13																			.20
12																			.20
11																			.20
10																			.20
9																			.20
8																			.20
7																			.20
6																			.20
5																			.20
4																			.20
3																			.20
2																			.20
1																			.20

^aRatio of pair 365-d EIM intake to calf weight at weaning.

^bAll models contained terms for sex of calf and year, sequentially accounting for 45 (P<.001) and 605 (P<.001), respectively, of the variation in pair 365-d weaning efficiency. Tabled R² values reflect additional variation in pair 365-d weaning efficiency explained by independent variables shown.

†P<.10.

**P<.05.

***P<.01.

****P<.001.

TABLE A15. Estimates of Genetic Parameters of Calf Weaning Weight by Two Methods,^a After Adjustments for Fixed Effects and Traits of the Cow (Additional Models)

Model	Method III			Maximum-Likelihood		
	σ_s^2	σ_e^2	Estimates h^2	S.E.	σ_s^2	Estimates h^2
F.E. b + Initial Cow Weight	210	740	.89	.296	83	.759
F.E. + Initial Cow Weight + Initial Cow Fat	196	737	.84	.295	75	.752
F.E. + Initial Cow Weight + Initial Cow Fat + Cow Weight Change	184	712	.82	.295	65	.728
						.33
						.258

^aMethod III, Henderson (1953); Maximum-Likelihood, Hartley and Rao (1967).

^bFixed effects include sex of calf and year-treatment combinations.

TABLE A16. Estimates of Genetic Parameters of Cow-Calf Pair Estimated Total Digestible Nutrient Intake During Lactation by Three Methods, ^a After Adjustments for Fixed Effects and Traits of the Cow and Calf (Additional Models)

Model	Method III			Maximum-Likelihood			Mixed-Model Procedure					
	σ_s^2	Estimates		σ_s^2	Estimates		σ_s^2	Estimates		σ_s^2	Estimates	
		σ_e^2	h^2		S.E.	σ_e^2		h^2	S.E.		σ_e^2	h^2
F.E. b + Initial Cow Weight	299	60914	.02	.203	1427	56353	.10	.212	1086	56702	.08	.209
F.E. + Initial Cow Weight + Initial Cow Fat	130	60191	.01	.203	1266	55444	.09	.212	690	55966	.05	.208
F.E. + Initial Cow Weight + Initial Cow Fat + Cow Weight Change	66	60146	.00	.190	1207	55181	.09	.213	147	56191	.01	.204
F.E. + Initial Cow Traits + Cow Weight Change + Total Milk Intake	4129	42118	.36	.240	4052	39028	.38	.242	5975	37822	.55	.255
F.E. + Initial Cow Traits + Cow Weight Change + Average Milk Intake	1254	56561	.09	.215	2138	51770	.16	.222	3432	50878	.25	.231
F.E. + Initial Cow Traits + Cow Weight Change + Calf Weaning Weight + Average Milk Intake	4733	29978	.54	.256	3822	28567	.47	.250	5199	27722	.63	.261

^aMethod III, Henderson (1953); Maximum-Likelihood, Hartley and Rao (1967); Mixed-Model Procedure, Application 1 (adjustment for sire relationships), Henderson and Henderson (1979).

^bFixed effects include sex of calf and year-treatment combinations.

TABLE A17. Estimates of Genetic Parameters of Cow-Calf Pair Estimated Average Daily Total Digestible Nutrient Intake During Lactation by Three Methods, a After Adjustments for Fixed Effects and Traits of the Cow (Additional Models)

Model	Method III			Maximum-Likelihood			Mixed-Model Procedure			
	σ_s^2	σ_e^2	h^2	S.E.	σ_s^2	σ_e^2	Estimates	σ_s^2	σ_e^2	S.E.
F.E. ^b + Initial Cow Weight	.027	.460	.22	.224	.023	.436	.20	.222	.023	.438
F.E. + Initial Cow Weight										
+ Initial Cow Fat	.025	.459	.21	.225	.024	.430	.21	.225	.022	.434

^aMethod III, Henderson (1953); Maximum-Likelihood, Rao and Hartley (1967); Mixed-Model Procedure, Application 1 (with adjustment for sire relationships), Henderson and Henderson (1979).

^bFixed effects include sex of calf and year-treatment combinations.

TABLE A18. Estimates of Genetic Parameters of Cow-Calf Pair Estimated 365-d Total Digestible Nutrient Intake by Three Methods, a After Adjustments for Fixed Effects and Traits of the Cow and Calf (Additional Models)

Model	Method III			Maximum-Likelihood			Mixed-Model Procedure					
	σ^2_S	Estimates σ^2_E	h^2	S.E.	σ^2_S	Estimates σ^2_E	h^2	S.E.	σ^2_S	Estimates σ^2_E	h^2	S.E.
F.E. b + Initial Cow Weight	2441	39107	.24	.226	2315	36952	.24	.226	165	38918	.02	.203
F.E. + Initial Cow Weight + Initial Cow Fat	1975	38556	.20	.223	1927	36211	.20	.224	185	37813	.02	.205
F.E. + Initial Cow Weight + Initial Cow Fat + Cow Weight Change	1854	38621	.18	.223	1906	36033	.20	.225	183	37616	.02	.205
F.E. + Initial Cow Traits + Cow Weight Change + Total Milk Intake	1728	33761	.20	.225	1602	31527	.19	.225	587	32430	.07	.213
F.E. + Initial Cow Traits + Cow Weight Change + Average Milk Intake	1537	35925	.16	.223	1692	33284	.19	.226	660	34215	.08	.214
F.E. + Initial Cow Traits + Cow Weight Change + Calf Weaning Weight + Average Milk Intake	2212	29899	.28	.234	1878	28018	.25	.232	459	29233	.06	.213

^aMethod III, Henderson (1953); Maximum-Likelihood, Hartley and Rao (1967); Mixed-Model Procedure, Application 1 (adjusted for sire relationships), Henderson and Henderson (1979).

^bFixed effects include sex of calf and year-treatment combinations.

TABLE A19. Estimates of Genetic Parameters of Cow-Calf Pair Lactation Weaning Efficiency by Three Methods, ^a After Adjustments for Fixed Effects and Traits of the Cow and Calf (Additional Models)

Model	Method III				Maximum-Likelihood				Mixed-Model Procedure			
	σ^2_s	σ^2_e	h^2	S.E.	σ^2_s	σ^2_e	h^2	S.E.	σ^2_s	σ^2_e	h^2	S.E.
F.E. + Initial Cow Weight	.183	.960	.64	.258	.163	.921	.60	.255	.219	.886	.79	.266
F.E. + Initial Cow Weight + Initial Cow Fat	.182	.965	.64	.259	.161	.922	.60	.256	.217	.887	.78	.267
F.E. + Initial Cow Weight + Initial Cow Fat + Cow Weight Change	.190	.934	.68	.262	.171	.887	.65	.260	.235	.849	.87	.271
F.E. + Initial Cow Traits + Cow Weight Change + Total Milk Intake	.154	.935	.56	.256	.123	.895	.48	.250	.191	.852	.73	.266
F.E. + Initial Cow Traits + Cow Weight Change + Average Milk Intake	.113	.908	.44	.247	.084	.869	.35	.240	.119	.844	.50	.251
F.E. + Initial Cow Traits + Cow Weight Change + Calf Weaning Weight + Average Milk Intake	.085	.860	.40	.242	.069	.808	.32	.238	.112	.779	.50	.253

^aMethod III, Henderson (1953); Maximum-Likelihood, Hartley and Rao (1967); Mixed-Model Procedure, Application 1 (with adjustment for sire relationships), Henderson and Henderson (1979).

^bFixed effects include sex of calf and year-treatment combinations.

TABLE A21. Estimates of Genetic Parameters of Average Daily Milk Intake of the Calf by Three Methods,^a After Adjustments for Fixed Effects and Traits of the Cow (Additional Models)

Model	Method III				Maximum-Likelihood				Mixed-Model Procedure Application 1			
	σ_s^2	σ_e^2	h^2	S.E.	σ_s^2	σ_e^2	h^2	S.E.	σ_s^2	σ_e^2	h^2	S.E.
F.E. + Initial Cow Weight	.298	1.256	.77	.265	.236	1.226	.64	.258	.292	1.190	.79	.266
F.E. + Initial Cow Weight + Initial Cow Fat	.288	1.257	.75	.265	.227	1.219	.63	.258	.277	1.187	.76	.266
F.E. + Initial Cow Weight + Initial Cow Fat + Cow Weight Change	.286	1.263	.74	.265	.222	1.222	.61	.258	.274	1.188	.75	.266

^aMethod III, Henderson (1953); Maximum-Likelihood, Hartley and Rao (1967); Mixed-Model Procedure, Application 1 (with adjustment for sire relationships), Henderson and Henderson (1979).

^bFixed effects include sex of calf and year-treatment combinations.

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