Life cycle efficiency of beef production: IX. Relationship between residual feed intake of heifers and cow efficiency ratios based on harvest, carcass, and wholesale cut weight outputs

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ABSTRACT: Data were collected from 1953 through 1980 from identical and fraternal twin beef and dairy females born in 1953, 1954, 1959, 1964, and 1969, from crossbred females born as singles in 1974, and their progeny. Numbers of dams that weaned at least one calf and were included in the first analysis were 37, 45, and 56 in the 1964, 1969, and 1974 data sets, respectively. Respective numbers of dams that weaned three calves and were included in a second analysis were 6, 8, 8, 22, 33, and 33 in the 1953, 1954, 1959, 1964, 1969, and 1974 experiments. Individual feed consumption was measured at 28-d intervals from the time females were placed on the experiment at 240 d of age until three calves were weaned or the dams had reached 5 yr of age. Residual feed intake (**RFI**) and residual BW gain (**RG**) of heifers that subsequently became dams were determined based on ADG and DMI from 240 d of age to first calving. Various measures of cow efficiency were calculated on either a life cycle or actual lifetime basis using ratios of progeny and dam weight outputs to progeny and dam feed inputs. The correlation between RFI and DMI was large and positive ($r = 0.67$; $P < 0.0001$), and RG was highly correlated with ADG ($r = 0.75$; $P < 0.0001$). Correlations of RFI with cow efficiency ratios that included harvest weight, carcass weight, or weight of trimmed wholesale cuts as measures of output ranged from –0.05 ($P > 0.10$) to −0.17 ($P < 0.10$), indicating that heifers with better (i.e., more negative) RFI values tended to become slightly more efficient cows. Correlations of RG with life cycle and actual lifetime cow efficiency ratios ranged from 0.08 ($P > 0.10$) to 0.23 ($P < 0.05$), demonstrating that heifers with better (i.e., more positive) values for RG were somewhat more efficient as cows. The correlations were stronger when cow salvage value was included in the measures of cow efficiency. Correlations of DMI and mid-test metabolic BW (**MMW**) with life cycle cow efficiency ratios that did not include cow salvage value as output ranged from −0.15 ($P < 0.10$) to −0.22 ($P < 0.01$). Correlations of DMI and MMW with actual lifetime cow efficiency ratios varied from −0.20 ($P < 0.05$) to −0.36 ($P < 0.001$). Therefore, smaller heifers that consumed less feed had superior cow efficiency ratios. Correlations of RFI with carcass grade, backfat thickness, marbling score, and kidney fat of progeny indicated that heifers with superior RFI would tend to produce leaner offspring.

Key words: cattle, feed efficiency, lifetime production, residual feed intake, residual gain

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INTRODUCTION

A major goal of the beef cattle industry is to improve the efficiency of acceptable edible meat production. Because much of the beef produced

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in the United States is segmented into two separate enterprises, the cow–calf producer and the cattle feeder, it is important to partition efficiency of beef production into preweaning and postweaning components. Few studies have combined efficiency of calf production with postweaning feed efficiency to estimate efficiency of production to the harvest end point (Holloway et al., 1975; Wagner, 1978; Brown and Dinkel, 1982). Koch et al. (1963) first proposed the concept of residual feed intake (**RFI**), which is defined as the difference between actual feed intake and predicted feed intake required for maintenance of live weight and measures of production such as observed rate of weight gain. Similarly, residual BW gain (**RG**) is defined as the difference between actual and predicted daily BW gain (Crowley et al., 2010). The objective of this study was to determine the relationship of postweaning RFI and RG in heifers with subsequent life cycle efficiency of cows when output is based on harvest weight, carcass weight, or trimmed wholesale cut weight, as well as to explore the relationships of RFI and RG with various traits of the progeny.

MATERIALS AND METHODS

Approval of an animal care and use committee was not required at the time these data were collected at the University of Wisconsin in the 1950s, 1960s, and 1970s.

Source of Data

Data were collected from identical and fraternal twin heifers purchased between 8 and 224 d of age in 1953, 1954, 1959, 1964, and 1969, and from crossbred heifers born as singles and purchased before 168 d of age in 1974, and their progeny (Christian et al., 1965; Kress et al., 1969,1971a,b; Kress, England et al. 1971; Hohenboken et al., 1972, 1973; Towner, 1975; Baik, 1980). Thirty-seven, 45, and 56 dams from the 1964, 1969, and 1974 data sets, respectively, produced at least one progeny that survived to the harvest end point and were included in the first analysis (analysis I). Numbers of dams from the 1953, 1954, 1959, 1964, 1969, and 1974 experiments that produced three calves that survived to the harvest end point and were included in a second analysis (analysis II) were 6, 8, 8, 22, 33, and 33, respectively. The 1953, 1954, and 1959 twins were included only in analysis II, because in these data sets, feed consumption was available only for those dams completing three lactations (Table 1). Breed composition and numbers of dams, along with single vs. twin status of the dams used in each of the six experiments, are shown in Table 1.

Feeding and Management Systems

Diets differed for the 1953, 1954, and 1959 birth year groups, but the same diet was fed to all females within a group (Christian et al., 1965). Throughout the 1964, 1969, and 1974 experiments, dams received either a high- or a low-energy diet (Kress et al., 1971a; Towner, 1975, Baik, 1980). Females on the high-energy diet received a chopped mixed hay and concentrate diet, whereas those on the low-energy diet were fed chopped mixed hay. Individual feed offered was recorded daily and accumulated over 28-d periods from the time females were placed on the experiment until three calves were weaned or

Table 1. Source of data for analysis I and analysis II

Experiment	Breed composition	*N*	Singles/Twins	Analysis I	Analysis II
1953	Hereford	6	Twins	No	Yes
1954	Hereford	8	Twins	No	Yes
1959	Hereford	8	Twins	No	Yes
1964	Hereford	33	Twins	Yes	Yes
	Hereford x Guernsey	1	Twins	Yes	Yes
	Hereford x Shorthorn	1	Twins	Yes	Yes
	Hereford x Holstein	1	Twins	Yes	Yes
	Hereford x Brown Swiss	1	Twins	Yes	Yes
1969	Hereford	17	Twins	Yes	Yes
	Hereford x Shorthorn	2	Twins	Yes	Yes
	Hereford x Charolais	2	Twins	Yes	Yes
	Holstein	24	Twins	Yes	Yes
1974	Hereford x Holstein	14	Singles	Yes	Yes
	Angus x Holstein	14	Singles	Yes	Yes
	Simmental x Holstein	15	Singles	Yes	Yes
	Chianina x Holstein	13	Singles	Yes	Yes

they reached 5 yr of age. Orts were weighed at 28-d intervals. Feed consumption for each 28-d period was the difference between feed that was offered and the orts. Estimates were made of the ME consumed by dams from birth to the beginning of the experiments (Davis et al., 1983).

Twin heifers were bred at the first observed estrus after 15 mo of age and at each succeeding estrus until conception occurred. Crossbred heifers purchased in 1974 were bred at first detected estrus (puberty) and at each subsequent estrus until pregnant. Following each calving, all dams were bred at first estrus and at each subsequent estrus until conception occurred.

The 1953 and 1954 dams were all mated to the same Hereford bull to produce all three calves. The 1959 twins were artificially inseminated using eight Hereford bulls chosen at random from several bull studs, whereas the 1964 twins were bred artificially to one of four Polled Hereford bulls. Four Holstein bulls were used to artificially inseminate the 1969 Hereford twins. Holstein twins of the same year were mated artificially to one of four Hereford bulls. All matings in the 1974 experiment were monogamous; first calves were offspring of 1 of 56 Jersey bulls and second and third calves resulted from insemination with semen from 1 of 56 Charolais bulls.

Individual feed offered to progeny was recorded daily and accumulated by 28-d periods from 60 to 240 d of age (weaning) and from weaning to harvest. A postweaning diet containing 59.4% TDN was provided to progeny of 1950's and 1960's twins from weaning to 364 d of age (Towner, 1973). From 365 d of age until harvest, TDN content of the diet was 68.2%. Progeny of 1974 crossbred dams received the diet containing 68.2% TDN during the entire postweaning period (Baik, 1980). Orts were weighed at 28-d intervals. Feed consumption for each 28-d period was the difference between feed that was offered and the orts.

Progenies of 1953 and 1954 twins were harvested at what was then a live grade of average choice (average age at harvest = 520 d[SD = 35 d] and 566 d [SD = 63 d], respectively), whereas progenies of 1959 twins were harvested at a low-choice live grade (average age at harvest = 602 d; SD = 55 d). The USDA (1996) publication provides a history of USDA standards for grades of slaughter cattle and summarizes the changes in grade standards that were implemented in the 1950s. Progenies of 1964 and 1969 twins were harvested at a constant age of 532 d and that of 1974 crossbred dams were harvested at 364 d of age.

Progenies were removed from feed and allowed access to water for 24 h before harvest. Shrunk BW was recorded at the University of Wisconsin Meat Laboratory before harvest. Carcasses were chilled for 48 h, weighed, and processed into wholesale cuts that were trimmed to a fat thickness of 0.95 cm. The pretrimmed and trimmed weight of each wholesale cut for the right side of the carcass was recorded.

Adjustment of progeny creep feed consumption and weaning weights for the effect of sex was discussed by Davis et al. (1983). Similar procedures were used to obtain sex adjustment factors for postweaning feed consumption, shrunk slaughter weight, cold carcass weight, and weight of trimmed wholesale cuts. A more complete description of breeding procedures, diets, and management practices was given by Davis et al. (1983, 1984).

Estimation of Cow Efficiency

Cow efficiency ratios were calculated using two approaches, the first a life cycle approach (analysis I) and the second an actual lifetime approach for cows that produced three calves that survived to harvest (analysis II). Alternative efficiency ratios and components of input and output are defined in Table 2.

Assumptions and formulas used to estimate life cycle cow efficiency (analysis I) are the same as those discussed by Davis et al. (1983), aside from the inclusion of postweaning feed consumption of progeny as an additional input and the substitution of harvest outputs for weaning weight output. Life cycle cow efficiency, therefore, was expressed as the ratio of output to input, where output included relative values for shrunk harvest weight, cold carcass weight, or weight of trimmed wholesale cuts of progeny and weight of the dam, and input included preweaning and postweaning feed consumption of progeny and lifetime feed consumption of the dam (efficiency estimates R5, R7, and R9 in Table 2). Components of input and output were weighted by their expected occurrence in a theoretical herd consisting of 100 cows and 20 replacement heifers. Expected occurrence was a function of the age distribution of cows and percentage calf crop, assuming a 10% attrition rate at each age and an 80% calf crop (Davis et al., 1983). Values for the weighting factors were presented by Davis et al. (1983) and are repeated in Table 3 for the convenience of the reader.

Salvage equivalency basis of dam was determined by multiplying the average weight of the

Table 2. Definitions of symbols and acronyms

Items	Definition
PW_1, PW_2, and PW_3	Progeny weaning weights. Sex-adjusted weaning weight (240-d weight) of the first, second, and third calf from each cow.
$SLPW_1$, $SLPW_2$, and $SLPW_3$	Slaughter progeny weights. Sex-adjusted shrunk slaughter weight of the first, second, and third calf from each cow.
$CARCPW_1$, $CARCPW_2$, and $CARCPW_3$	Carcass progeny weights. Sex-adjusted sum of chilled weight of right and left half of carcass of first, second, and third calf from each cow.
$WHOLPW_1$, $WHOLPW_2$, and WHOLPW3	Wholesale progeny weights. Sex-adjusted sum of trimmed wholesale cuts (chuck, rib, plate, foreshank, brisket, flank, sirloin, shortloin, round, hindshank, and rump) of first, second, and third calf from each cow.
PF_1, PF_2, and PF_3	Progeny feed consumptions. Sex-adjusted feed consumption of the first, second, and third calf from 60 to 240 d of age.
PPF_1, PPF_2, and PPF_3	Postweaning progeny feed consumptions. Sex-adjusted feed consumption of the first, second, and third progeny from 240 d of age to slaughter.
DW_1, DW_2, and DW_3	Dam weights. Weight of the cow when her first, second, and third calf was weaned.
DF_0	An estimate of the feed consumed by the dam from her birth to 240 d of age.
DF_1, DF_2, and DF_3	Dam feed consumptions. Feed consumed by the cow from 240 d of age to the weaning of the first calf, from the weaning of the first calf to the weaning of the second calf, and from the weaning of the second calf to the weaning of the third calf.
k_1, k_2, and k_3	Weighting factors to accumulate first, second, and third (subscripts 1, 2, and 3) progeny weights on a life cycle basis.
l_1, l_2, and l_3	Weighting factors to estimate average weight of the dam on a life cycle basis where subscripts 1, 2, and 3 denote first, second, and third parity, respectively.
m_1, m_2, and m_3	Weighting factors to accumulate first, second, and third (subscripts 1, 2, and 3) progeny feed consumptions on a life cycle basis.
n_0, n_1, n_2, and n_3	Weighting factors to accumulate feed consumption of the dam on a life cycle basis where subscripts 0, 1, 2, and 3 denote periods from birth to 240 d and first, second, and third parity, respectively.
R5	Progeny and dam slaughter weight output divided by progeny and dam feed input computed on a life cycle basis (analysis I) as: $$\frac{\sum_{i=1}^{3} k_i \mathrm{SLPW}_i + (0.690)\sum_{i=1}^{3} l_i \mathrm{DW}_i}{\sum_{i=1}^{3} m_i \mathrm{PF}_i + \sum_{i=1}^{3} m_i \mathrm{PPF}_i + \sum_{i=0}^{3} n_i \mathrm{DF}_i}$$
R6	Progeny slaughter weight output divided by progeny and dam feed input computed on a life cycle basis (analysis I) as: $$\frac{\sum_{i=1}^{3} k_i \mathrm{SLW}_i}{\sum_{i=1}^{3} m_i \mathrm{PF}_i + \sum_{i=1}^{3} m_i \mathrm{PPF}_i + \sum_{i=0}^{3} n_i \mathrm{DF}_i}$$
R7	Progeny and dam carcass weight output divided by progeny and dam feed input computed on a life cycle basis (analysis I) as: $$\frac{\sum_{i=1}^{3} k_i \mathrm{CARCPW_i} + (0.439)\sum_{i=1}^{3} l_i \mathrm{DW}_i}{\sum_{i=1}^{3} m_i \mathrm{PF}_i + \sum_{i=1}^{3} m_i \mathrm{PPF}_i + \sum_{i=0}^{3} n_i \mathrm{DF}_i}$$
R8	Progeny carcass weight output divided by progeny and dam feed input computed on a life cycle basis (analysis I) as: $$\frac{\sum_{i=1}^{3} k_i \mathrm{CARCPW}_i}{\sum_{i=1}^{3} m_i \mathrm{PF}_i + \sum_{i=1}^{3} m_i \mathrm{PPF}_i + \sum_{i=0}^{3} n_i \mathrm{DF}_i}$$
R9	Progeny and dam trimmed wholesale cut output divided by progeny and dam feed input computed on a life cycle basis (analysis I) as: $$\frac{\sum_{i=1}^{3} k_i \mathrm{WHOLPW}_i + (0.289)\sum_{i=1}^{3} l_i \mathrm{DW}_i}{\sum_{i=1}^{3} m_i \mathrm{PF}_i + \sum_{i=1}^{3} m_i \mathrm{PPF}_i + \sum_{i=0}^{3} n_i \mathrm{DF}_i}$$
R10	Progeny trimmed wholesale cut output divided by progeny and dam feed input computed on a life cycle basis (analysis I) as: $$\frac{\sum_{i=1}^{3} k_i \mathrm{WHOLPLW}_i}{\sum_{i=1}^{3} m_i \mathrm{PF}_i + \sum_{i=1}^{3} m_i \mathrm{PPF}_i + \sum_{i=0}^{3} n_i \mathrm{DF}_i}$$

(Continued)

Table 2. (Continued)

Items	Definition
R11	Progeny and dam slaughter weight output divided by progeny and dam feed input computed on an actual lifetime basis for dams producing three calves (analysis II) as: $\frac{\sum_{i=1}^{3} \mathrm{SLPW}_i + (0.690)\mathrm{DW}_3}{\sum_{i=1}^{3} \mathrm{PF}_i + \sum_{i=1}^{3} \mathrm{PPF}_i + \sum_{i=0}^{3} \mathrm{DF}_i}$
R12	Progeny slaughter weight output divided by progeny and dam feed input computed on an actual lifetime basis for dams producing three calves (analysis II) as: $\frac{\sum_{i=1}^{3} \mathrm{SLPW}_i}{\sum_{i=1}^{3} \mathrm{PF}_i + \sum_{i=1}^{3} \mathrm{PPF}_i + \sum_{i=0}^{3} \mathrm{DF}_i}$
R13	Progeny and dam carcass weight output divided by progeny and dam feed input computed on an actual lifetime basis for dams producing three calves (analysis II) as: $\frac{\sum_{i=1}^{3} \mathrm{CARCPW}_i + (0.439)\mathrm{DW}_3}{\sum_{i=1}^{3} \mathrm{PF}_i + \sum_{i=1}^{3} \mathrm{PPF}_i + \sum_{i=0}^{3} \mathrm{DF}_i}$
R14	Progeny carcass weight output divided by progeny and dam feed input computed on an actual lifetime basis for dams producing three calves (analysis II) as: $\frac{\sum_{i=1}^{3} \mathrm{CARCPW}_i}{\sum_{i=1}^{3} \mathrm{PF}_i + \sum_{i=1}^{3} \mathrm{PPF}_i + \sum_{i=0}^{3} \mathrm{DF}_i}$
R15	Progeny and dam trimmed wholesale cut output divided by progeny and dam feed input computed on an actual lifetime basis for dams producing 3 calves (analysis II) as: $\frac{\sum_{i=1}^{3} \mathrm{WHOLPW}_i + (0.289)\mathrm{DW}_3}{\sum_{i=1}^{3} \mathrm{PF}_i + \sum_{i=1}^{3} \mathrm{PPF}_i + \sum_{i=0}^{3} \mathrm{DF}_i}$
R16	Progeny trimmed wholesale cut output divided by progeny and dam feed input computed on an actual lifetime basis for dams producing three calves (analysis II) as: $\frac{\sum_{i=1}^{3} \mathrm{WHOLPW}_i}{\sum_{i=1}^{3} \mathrm{PF}_i + \sum_{i=1}^{3} \mathrm{PPF}_i + \sum_{i=0}^{3} \mathrm{DF}_i}$
DMI	Daily dry matter intake of the cow from 240 d of age to first calving.
ADG	Average daily gain of the cow from 240 d of age to first calving.
MMW	Metabolic midweight of the cow from 240 d of age to first calving.
RFI	Residual feed intake of the cow from 240 d of age to first calving.
RG	Residual ADG of the cow from 240 d of age to first calving.

Table 3. Weighting factors[a] for inputs and outputs used in the calculation of efficiency ratios

			Outputs						Inputs						
Parity			Progeny			Dam			Progeny			Dam			
1	2	3	k_1	k_2	k_3	l_1	l_2	l_3	m_1	m_2	m_3	n_0	n_1	n_2	n_3
1[b]	1	1	1	1	3.52	0.18	0.162	0.658	1	1	3.52	1	1	1	4.15
1	1	0	1	1	2.52	0.18	0.162	0.658	1	1	2.52	1	1	1	4.15
1	0	1	1	0	3.52	0.18	0.162	0.658	1	0	3.52	1	1	1	4.15
1	0	0	1	0	2.52	0.18	0.162	0.658	1	0	2.52	1	1	1	4.15
0	1	1	0	1	3.52	0.18	0.162	0.658	0	1	3.52	1	1	1	4.15
0	1	0	0	1	2.52	0.18	0.162	0.658	0	1	2.52	1	1	1	4.15
0	0	1	0	0	3.52	0.18	0.162	0.658	0	0	3.52	1	1	1	4.15

[a] See Table 2 for definitions of weighting factors.

[b] A "1" indicates that the cow weaned a calf. A "0" indicates that a cow failed to wean a calf.

dam on a life cycle basis by 0.690, 0.439, and 0.289 in the analyses that included slaughter weight, carcass weight, and weight of trimmed wholesale cuts, respectively, as output. These conversion factors were obtained by dividing the average price at harvest for commercial cows by the live price for Choice steers, wholesale carcass price, and retail price (USDA, 1980; Feuz, 1995; Feuz and Burgener, 2005).

Feed consumption was expressed in terms of megacalories of ME, while weights were expressed in kilograms. Thus, R5, R7, and R9, respectively, estimate kilograms of harvest weight, carcass weight, and trimmed wholesale cuts produced by a dam and her progeny per megacalorie of ME consumed by the dam and progeny. Differences in estimates of R5 could be due to differences in fertility, weaning weights, and postweaning gains of progeny, salvage weights of dams and feed consumption of dams and progeny. Differences in dressing percentage and carcass composition of progeny would further contribute to differences in estimates of R7 and R9. Cow salvage value was not included in life cycle cow efficiency estimates R6, R8, and R10 (Table 2). Therefore, these values represent kilograms of harvest weight, carcass weight, and trimmed wholesale cuts, respectively, from progeny per megacalorie of ME consumed by the progeny and their dam.

Actual lifetime cow efficiency was estimated for dams that produced three progenies that survived to harvest (analysis II) by dividing the sum of the live weight, carcass, and trimmed wholesale cut outputs from a dam and her progeny (R11, R13, and R15 in Table 2) by the sum of the feed inputs, where all components were weighted equally. Efficiency ratios R12, R14, and R16 were the same as R11, R13, and R15, respectively, except that salvage value of dam was not included in the numerators of the ratios (Table 2). Only dams with three progenies that survived to harvest were included in the calculation of R11, R12, R13, R14, R15, and R16. These efficiency estimates therefore do not include variation associated with the rate of reproduction and calf survival. Variation in age at first conception and calving interval are the only components of reproduction remaining to influence efficiency estimates in analysis II.

Cow efficiency to the harvest end point can be divided into two portions: 1) efficiency of weaning weight production as presented by Davis et al. (1983) and 2) efficiency of postweaning gains of progeny. The postweaning component of life cycle cow efficiency was estimated using weighted sums of gains and ME intakes:

$$\frac{\sum_{i=1}^{3} k_i(\mathrm{SLPW}_i - \mathrm{PW}_i)}{\sum_{i=1}^{3} m_i \mathrm{PPF}_i}$$

where symbols and coefficients are as defined in Table 2. The postweaning portion of actual lifetime cow efficiency was obtained for cows producing three progenies that survived to harvest by assigning equal weights to the postweaning gains and feed intakes:

$$\frac{\sum_{i=1}^{3} (\mathrm{SLPW}_i - \mathrm{PW}_i)}{\sum_{i=1}^{3} \mathrm{PPF}_i}$$

Statistical Analysis

To account for differences among years, study diets, and breeds, a year-diet-breed group variable was created based on year of birth and breed of heifers and energy density of the diet fed to heifers from 240 d to first calving. Hereford x Guernsey, Hereford x Holstein, and Hereford x Brown Swiss were grouped together in a Hereford x Dairy breed type, and Hereford x Shorthorn and Hereford x Charolais were grouped together as a Hereford x Beef breed type due to the small numbers of females of these breed crosses.

DMI was average daily feed intake of heifers from 240 d of age to first calving multiplied by dry matter percentage. ADG was computed as BW at first calving minus BW at 240 d of age divided by number of days from 240 d of age to first calving. Mid-test metabolic BW (MMW) was computed as the average of BW at first calving and 240 d of age raised to the 0.75 power. RFI was computed as the residual from mixed model regression (PROC MIXED; SAS Inst. Inc.) of DMI on ADG and MMW having random intercept and slopes for year-diet-breed group (Lancaster et al., 2009b). RG was computed as the residual from mixed model regression of ADG on DMI and MMW having random intercept and slopes for year-diet-breed group. The coefficients of determination for the DMI and ADG regression models to compute RFI and RG were 0.84 and 0.69, respectively, calculated by regressing an adjusted DMI or ADG trait (fixed effects plus residual; Lancaster et al., 2009b) on the appropriate independent variables.

All traits were adjusted to remove the random effect of year by diet group by breed using a mixed model (PROC MIXED). To accomplish this, dependent variables were analyzed using a one-way, random-effect treatment structure with year-diet-breed group as the random effect (Littell et al., 2006; Lancaster et al., 2009b). Phenotypic Pearson correlation coefficients (PROC CORR; SAS Inst. Inc.) were computed among adjusted traits along with RFI and RG.

RESULTS AND DISCUSSION

Numbers of observations, means, SD, and minimum and maximum values for each dependent variable are shown in Table 4. Means for RFI and RG equaled 0 (SD = 0.54 and 0.04, respectively), as expected. Individual values for RFI and RG ranged from −1.48 to 3.21 and from −0.13 to 0.15 kg/d, respectively.

Correlations among RFI, RG, DMI, ADG, and MMW are shown in Table 5. RFI was phenotypically independent of ADG and MMW, whereas the correlation between RFI and DMI was positive and highly significant ($r = 0.67$; $P < 0.0001$). These results were expected because the linear regression procedure used to compute expected DMI for estimation of RFI forces RFI to be phenotypically independent of the component traits. Basarab et al. (2007) reported a phenotypic correlation of 0.53 ($P < 0.001$) between RFI and DMI. Arthur and Herd (2012) examined genetic correlation estimates between RFI and feed intake in 11 different studies. With the exception of one negative estimate, values ranged from 0.41 to 0.81, indicating that cattle with low (desirable) RFI will produce offspring that consume less feed. Reduced DMI in more efficient RFI groups was also observed by Elzo et al. (2009), Lancaster et al. (2009a), Shaffer et al. (2011), and Basarab et al. (2011). RG was highly correlated with ADG ($r = 0.75$; $P < 0.0001$) and had near 0 correlations with DMI and MMW. A highly significant negative correlation was observed between RFI and RG ($r = −0.47$; $P < 0.0001$). Correlations among DMI, ADG, and MMW were also large and positive ($r > 0.45$; $P < 0.0001$). The large correlations of DMI with ADG and BW are indicative of high-quality data (Basarab et al., 2011).

Correlations of RFI, RG, DMI, ADG, and MMW with cow efficiency ratios based on various measures of output (i.e., harvest weight, carcass weight, or trimmed wholesale cut weight of progeny with or without the contribution of cow salvage value to output) are presented in Table 6. RFI of heifers exhibited small negative (i.e., favorable) correlations ($P \geq 0.07$) with life cycle and actual lifetime cow efficiency. These correlations were similar to those presented by Davis et al. (2016) when weaning weight was used as the measure of output. The correlations were stronger when cow salvage value was included in the numerators of the cow efficiency ratios (i.e., R5, R7, R9, R11, R13, and R15). Correlations of RG of heifers with subsequent cow efficiency ratios were positive and significant when cow salvage value was included as output, whereas the correlations were positive but nonsignificant when salvage value of the cow was ignored, likely due to the fact that RG was positively correlated with mature weight of the cows (Davis et al., 2016). In addition, correlations of RFI and RG with measures of cow efficiency were slightly stronger in the actual lifetime approach, which did not include variation associated with rate of reproduction and calf survival, than in the life cycle approach. We are not aware of other reports in the literature in which RFI of heifers was compared with their subsequent life cycle cow efficiency. However, several authors have compared RFI of heifers with RFI of the same females re-estimated in future years. Basarab et al. (2007) reported a phenotypic correlation of 0.30 ($P = 0.025$) between progeny RFI and cow RFI measured in the same year, which indicates that postweaning RFI and cow RFI are different traits. Black et al. (2013) reported that the phenotypic relationship between RFI measured in heifers and RFI measured in 3-yr-old lactating cows was not significant ($P = 0.30$). On the other hand, Arthur et al. (1999) obtained a phenotypic correlation of 0.36 ($P < 0.05$) between postweaning net feed intake (NFI) and NFI of 4- to 4.5-yr-old non-lactating cows, and Archer et al. (2002) reported a genetic correlation of 0.98 between postweaning RFI and RFI of the cow. Furthermore, heifers that were phenotypically superior for postweaning RFI on ad libitum feeding were also superior as lactating cows on medium-quality pasture and as dry cows on ad libitum feeding, but not on restricted feeding, in the study of Herd et al. (2011). Weight of calf weaned per cow exposed to the bull did not differ between high and low selection line Angus cows in Australia that were the result of 1 to 2.5 generations of selection (mean = 1.5 generations) for high vs. low RFI (Arthur et al., 2005). Dams that produced low, medium, and high RFI progeny were also similar in production efficiency (kilograms of calf

Table 4. Means, SD, and minimum and maximum values for dependent variables[a]

Trait	*N*	Mean	SD	Minimum	Maximum
$SLPW_1$, kg	123	411	34	319	497
$SLPW_2$, kg	152	451	42	277	575
$SLPW_3$, kg	160	459	34	370	590
CARCPW1, kg	123	245	23	185	309
CARCPW2, kg	152	271	29	163	349
CARCPW3, kg	160	277	23	219	376
WHOLPW1, kg	123	217	18	170	264
WHOLPW2, kg	152	241	24	152	307
WHOLPW3, kg	160	249	24	205	409
Postweaning gain, first calf, kg	123	154	23	100	220
Postweaning gain, second calf, kg	152	165	25	66	247
Postweaning gain, third calf, kg	160	165	24	67	281
PPF_1, Mcal	123	4,374	477	2,793	5,894
PPF_2, Mcal	152	4,507	533	2,561	6,159
PPF_3, Mcal	160	4,540	518	2,364	7,322
Postweaning feed efficiency, first calf	123	0.0346	0.0046	0.0195	0.0491
Postweaning feed efficiency, second calf	152	0.0369	0.0048	0.0177	0.0507
Postweaning feed efficiency, third calf	160	0.0369	0.0045	0.0243	0.0512
Life cycle postweaning feed efficiency	160	0.0365	0.0036	0.0270	0.0465
Actual lifetime postweaning feed efficiency	107	0.0362	0.0030	0.0279	0.0451
DMI, kg/d	160	7.82	0.89	5.41	13.82
ADG, kg/d	160	0.48	0.06	0.37	0.68
MMW, kg	160	75	5	58	94
RFI, kg/d	160	0	0.54	−1.48	3.21
RG, kg/d	160	0	0.04	−0.13	0.15
R5	160	0.0523	0.0027	0.0442	0.0608
R6	160	0.0276	0.0024	0.0205	0.0346
R7	160	0.0324	0.0017	0.0274	0.0375
R8	160	0.0166	0.0015	0.0123	0.0209
R9	160	0.0252	0.0014	0.0211	0.0299
R10	160	0.0148	0.0014	0.0108	0.0203
R11	107	0.0335	0.0016	0.0290	0.0387
R12	107	0.0259	0.0015	0.0221	0.0301
R13	107	0.0204	0.0010	0.0177	0.0236
R14	107	0.0156	0.0009	0.0133	0.0181
R15	107	0.0170	0.0009	0.0147	0.0197
R16	107	0.0138	0.0009	0.0117	0.0166
Loineye area, first calf, cm^2	101	66.8	8.5	50.5	94.2
Loineye area, second calf, cm^2	130	76.1	10.1	50.3	102.4
Loineye area, third calf, cm^2	125	78.9	10.1	55.4	110.0
Carcass conformation[b], first calf	101	8.7	1.4	6.0	13.0
Carcass conformation, second calf	130	10.4	1.3	5.5	13.1
Carcass conformation, third calf	124	10.7	1.1	5.8	13.0
Carcass grade[c], first calf	101	10.3	1.5	6.6	13.6
Carcass grade, second calf	130	10.3	1.4	5.1	13.1
Carcass grade, third calf	124	10.7	1.3	5.6	14.0
Marbling score[d], first calf	101	4.8	1.2	2.7	8.2
Marbling score, second calf	130	4.8	1.3	1.5	8.5
Marbling score, third calf	124	5.1	1.0	2.1	8.0
Fat thickness, first calf, cm	101	1.4	0.5	0.4	2.7
Fat thickness, second calf, cm	130	1.5	0.4	0.5	2.6
Fat thickness, third calf, cm	125	1.4	0.4	0.6	2.3
Kidney fat, first calf, kg	101	10.5	2.8	4.7	20.6
Kidney fat, second calf, kg	130	10.6	3.3	2.5	22.0
Kidney fat, third calf, kg	125	10.8	2.5	5.1	18.1

(Continued)

Table 4. (Continued)

Trait	*N*	Mean	SD	Minimum	Maximum
Dressing %, first calf	123	59.2	1.3	55.6	64.6
Dressing %, second calf	152	59.9	1.6	54.6	63.9
Dressing %, third calf	160	60.2	1.5	54.6	64.7

[a]See Table 2 for definitions of symbols and acronyms.

[b]Carcass conformation: 3 = utility, 4 = standard$^-$, 5 = standard, 6 = standard$^+$, 7 = good$^-$, 8 = good, 9 = good$^+$, 10 = choice$^-$, 11= choice, 12 = choice$^+$, 13 = prime$^-$, 14 = prime, 15 = prime$^+$.

[c]Carcass grade: 3 = utility, 4 = standard$^-$, 5 = standard, 6 = standard$^+$, 7 = good$^-$, 8 = good, 9 = good$^+$, 10 = choice$^-$, 11= choice, 12 = choice$^+$, 13 = prime$^-$, 14 = prime, 15 = prime$^+$.

[d]Marbling score: 2 = traces, 3 = slight, 4 = small, 5 = modest, 6 = moderate, 7 = slightly abundant, 8 = moderately abundant.

Table 5. Correlations[a] among RFI, RG, DMI, ADG, and MMW

Variables	RG	DMI	ADG	MMW
RFI	−0.47	0.67	0	−0.01
	<0.0001	<0.0001	0.99	0.94
RG		0	0.75	−0.05
		0.96	<0.0001	0.55
DMI			0.63	0.60
			<0.0001	<0.0001
ADG				0.47
				<0.0001

[a]Significance level for the test Prob > |r| under H_0: $\rho = 0$ is presented below the correlation coefficient.

Table 6. Correlations[a] of RFI, RG, DMI, ADG, and MMW with cow efficiency ratios[b]

Variables	RFI	RG	DMI	ADG	MMW
R5	−0.14	0.18	0.00	0.13	0.09
	0.08	0.03	0.97	0.10	0.25
R6	−0.07	0.09	−0.17	−0.07	−0.21
	0.35	0.28	0.04	0.37	<0.01
R7	−0.12	0.17	0.02	0.14	0.10
	0.13	0.03	0.84	0.08	0.19
R8	−0.05	0.08	−0.15	−0.07	−0.21
	0.50	0.34	0.06	0.40	<0.01
R9	−0.12	0.16	−0.05	0.08	0.01
	0.12	0.04	0.53	0.30	0.90
R10	−0.07	0.08	−0.17	−0.07	−0.22
	0.39	0.31	0.03	0.35	<0.01
R11	−0.17	0.21	−0.22	0.01	−0.23
	0.07	0.03	0.02	0.96	0.02
R12	−0.09	0.11	−0.25	−0.10	−0.35
	0.33	0.24	<0.01	0.29	<0.001
R13	−0.16	0.23	−0.20	0.03	−0.23
	0.10	0.02	0.04	0.74	0.02
R14	−0.07	0.13	−0.22	−0.08	−0.36
	0.44	0.18	0.02	0.44	<0.001
R15	−0.14	0.21	−0.21	0.02	−0.26
	0.16	0.03	0.03	0.86	<0.01
R16	−0.08	0.14	−0.22	−0.06	−0.35
	0.44	0.14	0.02	0.54	<0.001

[a]Significance level for the test Prob > |r| under H_0: $\rho = 0$ is presented below the correlation coefficient.

[b]See Table 2 for definitions of cow efficiency variables.

weaned per 100 kg of cow weight at weaning) and biological efficiency (ratio of calf weight at weaning to the sum of cow metabolic weight at weaning plus half of the calf's metabolic weight at weaning) in experiments performed by Basarab et al. (2007). Medium and high RFI heifers had greater means for cow RFI than low RFI heifers, indicating that heifers that consumed less feed than predicted during the postweaning period also ate less than predicted as 2-yr-old lactating cows in the study of Shike et al. (2014).

Bourg (2011) observed no relationship between postweaning RFI EPD and an energy efficiency index, which was expressed as the ratio of cow ME to calf weaning weight. A 15% advantage in efficiency of low RFI cows, expressed as the ratio of calf BW to cow feed intake, was seen using preliminary results of divergent selection for postweaning RFI (Herd et al., 2003). These preliminary results indicate that a phenotypic association exists between postweaning RFI of heifers and later efficiency of the cow/calf unit on pasture.

Correlations of DMI and MMW with R6, R8, R10, R12, and R14 ranged from −0.15 ($P = 0.06$) to −0.36 ($P < 0.001$), indicating that heifers that ate less and had smaller metabolic midweights from 240 d of age to first calving had superior cow efficiency ratios when cow salvage value was not considered as output (Table 6). Correlations of DMI and MMW with cow efficiency ratios in analysis I that included cow salvage value as output (i.e., R5, R7, and R9) were small and nonsignificant, whereas correlations with cow efficiency ratios in analysis II that included cow salvage value (i.e., R11, R13, and R15) varied from −0.20 ($P < 0.05$) to −0.26 (P < 0.01). Average daily gain was not significantly correlated with any of the measures of cow efficiency. Davis et al. (2016) reported stronger correlations of DMI, ADG, and MMW with measures of cow efficiency that were based on weaning weight outputs than were found in the current study with values ranging from −0.20 ($P < 0.05$) to −0.56 ($P < 0.0001$). Black et al. (2013) observed that ADG in heifers tended to be positively correlated with RFI in cows such that heifers that gained less weight had lower (more efficient) RFI values as cows. However, Arthur et al. (1999) reported a near zero correlation of postweaning ADG with NFI of cows. Based on studies conducted in Australia, Herd and Arthur (2012) observed phenotypic and genetic correlations ranging from 0.28 to 0.70 and from 0.72 to 0.98, respectively, between ADG, metabolic weight, feed intake, and RFI measured during the postweaning period and the same traits measured at maturity. The authors concluded that selection for improved feed efficiency in young growing animals is also expected to result in improved efficiency of mature cows.

Correlations of RFI, RG, DMI, ADG, and MMW with progeny output traits used in the estimation of cow efficiency ratios are presented in Table 7. RFI tended to be positively correlated with harvest weight, carcass weight, and wholesale cut weight of the first progeny ($P < 0.10$) but was not correlated with weight traits of the second and third progeny. RG was not correlated with harvest weight, carcass weight, or wholesale cut weight of first, second, or third progenies. Davis et al. (2016) observed nonsignificant correlations of RFI and RG with weaning weights of progeny. Correlations of DMI of heifers with measures of progeny output were positive and significant for first and second progenies and were positive but not significant for third progeny. ADG and MMW of heifers were positively correlated ($P < 0.05$) with SLPW2, SLPW3, CARCPW2, CARCPW3, and WHOLPW2. Therefore, heifers that consumed more feed, gained more weight, and were heavier during the postweaning period generally produced calves with greater harvest weights, carcass weights, and wholesale cut weights, a finding that is consistent with the strong positive correlations of DMI, ADG, and MMW with progeny weaning weights reported by Davis et al. (2016). RFI and RG were not significantly correlated with dam weight at weaning of the first, second, or third calf, whereas correlations of DMI, ADG, and MMW with dam weights were positive and highly significant (Davis et al., 2016).

Correlations of RFI, RG, DMI, ADG, and MMW with postweaning feed intake of progeny were positive, but nonsignificant, with the exception of a correlation of 0.18 ($P < 0.05$) between ADG and PPF1 (Table 7). RFI and DMI tended to be positively correlated with preweaning feed consumption of the first calf (Davis et al., 2016). RFI was positively correlated with feed consumed by the cow from 240 d of age to weaning of the first calf, whereas RG was negatively correlated with DF_0 and DF_1 (Davis et al., 2016). Dry matter intake, ADG, and MMW were positively correlated with feed consumption of the cows during different phases of the life cycle (Davis et al., 2016).

RFI, RG, DMI, ADG, and MMW generally exhibited positive, but nonsignificant, correlations with postweaning weight gain of the first, second,

Table 7. Correlations[a] of RFI, RG, DMI, ADG, and MMW with component traits of cow efficiency ratios[b]

Variables	RFI	RG	DMI	ADG	MMW
SLPW1	0.17	0.02	0.22	0.14	0.05
	0.06	0.81	0.01	0.13	0.56
SLPW2	−0.03	0.06	0.18	0.19	0.27
	0.71	0.45	0.02	0.02	<0.001
SLPW3	−0.07	0.12	0.10	0.19	0.19
	0.41	0.13	0.20	0.02	0.02
CARCPW1	0.17	0.04	0.18	0.12	−0.02
	0.05	0.64	0.04	0.17	0.84
CARCPW2	0.00	0.05	0.18	0.18	0.23
	0.97	0.53	0.03	0.03	<0.01
CARCPW3	−0.04	0.09	0.11	0.18	0.19
	0.64	0.24	0.16	0.02	0.02
WHOLPW1	0.16	0.05	0.22	0.16	0.06
	0.09	0.56	0.02	0.07	0.54
WHOLPW2	−0.03	0.07	0.19	0.20	0.26
	0.70	0.36	0.02	0.01	<0.01
WHOLPW3	−0.06	0.09	0.03	0.11	0.10
	0.47	0.27	0.67	0.16	0.22
PPF1	0.06	0.14	0.13	0.18	0.02
	0.49	0.14	0.14	0.04	0.83
PPF2	0.04	0.02	0.14	0.11	0.11
	0.65	0.76	0.09	0.18	0.17
PPF3	0.03	0.00	0.10	0.09	0.12
	0.67	0.97	0.23	0.28	0.13

[a]Significance level for the test Prob > |r| under H_0: $\rho = 0$ is presented below the correlation coefficient.

[b]See Table 2 for definitions of symbols and acronyms.

and third progenies (Table 8). Correlations with postweaning feed efficiency of the first, second, and third progenies and with life cycle and actual lifetime postweaning feed efficiency of progeny did not differ from zero. RFI, RG, DMI, ADG, and MMW had nonsignificant correlations with loineye area with the exception of a value of 0.21 ($P < 0.05$) between RG and loineye area of the third progeny (Table 8). In addition, correlations with carcass conformation were small and generally not significantly different from zero. Finally, RG, DMI, ADG, and MMW were not significantly correlated with carcass grade, backfat thickness, marbling score, kidney fat, or dressing percentage of future progeny. However, correlations of RFI with carcass grade, backfat thickness, marbling score, and kidney fat of progeny ranged from 0.11 ($P > 0.10$) to 0.20 ($P < 0.05$), indicating that heifers with superior RFI would tend to produce leaner offspring. Positive RFI heifers had more backfat as estimated by ultrasound and tended to have greater LM area per 100 kg of BW than negative RFI heifers at the beginning of the trial conducted by Shaffer et al. (2011). No differences in final subcutaneous fat thickness or intramuscular fat (**IMF**) were observed, whereas longissimus muscle area (**LMA**) per 100 kg of BW was significantly greater in positive than in negative RFI heifers. Small positive correlations of RFI with measures of body fat have been consistently reported in the literature (Basarab et al., 2003, 2011; Castro-Bulle et al., 2007; Nkrumah et al., 2007; Lancaster et al., 2009a, 2009b).

In summary, postweaning heifer RFI had small negative (i.e., favorable), but nonsignificant, correlations with cow efficiency ratios expressed on both a life cycle basis and an actual lifetime basis when harvest weights, carcass weights, and trimmed wholesale cut weights were used to measure output. Correlations of RG with life cycle and actual lifetime cow efficiency ratios also demonstrated that heifers with better (i.e., more positive) values for RG were somewhat more efficient as cows. The correlations for both RFI and RG were stronger when cow salvage value was included in the numerators of the measures of cow efficiency and when efficiency was estimated on an actual lifetime basis rather than on a life cycle basis. Correlations of heifer RFI and RG with progeny harvest weights, carcass weights, and trimmed wholesale cut weights generally were not significantly different from zero, nor

Table 8. Correlations[a] of RFI, RG, DMI, ADG, and MMW with traits of the progeny[b]

Variables	RFI	RG	DMI	ADG	MMW
Postweaning gain, first calf	0.12	0.10	0.15	0.15	−0.04
	0.19	0.29	0.10	0.10	0.67
Postweaning gain, second calf	−0.01	0.06	0.11	0.13	0.16
	0.88	0.48	0.16	0.12	0.05
Postweaning gain, third calf	−0.01	0.10	0.12	0.17	0.16
	0.86	0.20	0.14	0.04	0.04
Postweaning feed efficiency, first calf	0.01	−0.04	−0.01	−0.05	−0.04
	0.92	0.70	0.88	0.60	0.62
Postweaning feed efficiency, second calf	−0.04	0.07	0.02	0.07	0.07
	0.62	0.40	0.76	0.40	0.38
Postweaning feed efficiency, third calf	−0.06	0.10	−0.01	0.05	0.00
	0.48	0.19	0.86	0.57	0.98
Life cycle postweaning feed efficiency	−0.05	0.09	0.02	0.06	0.04
	0.55	0.27	0.84	0.46	0.64
Actual lifetime postweaning feed efficiency	−0.06	0.02	−0.01	0.00	0.05
	0.56	0.85	0.89	0.99	0.64
Loineye area, first calf	0.02	−0.03	−0.05	−0.06	−0.11
	0.81	0.77	0.64	0.57	0.29
Loineye area, second calf	−0.12	0.09	0.01	0.09	0.10
	0.19	0.30	0.92	0.29	0.26
Loineye area, third calf	−0.12	0.21	−0.04	0.12	−0.07
	0.19	0.02	0.62	0.19	0.43
Carcass conformation, first calf	0.22	−0.10	0.16	0.02	−0.02
	0.02	0.31	0.11	0.86	0.86
Carcass conformation, second calf	−0.04	0.13	0.10	0.16	0.10
	0.67	0.15	0.27	0.06	0.24
Carcass conformation, third calf	0.08	0.09	0.10	0.13	0.01
	0.36	0.33	0.25	0.14	0.93
Carcass grade, first calf	0.17	−0.02	0.02	−0.03	−0.20
	0.10	0.88	0.85	0.77	0.05
Carcass grade, second calf	0.11	−0.06	0.11	0.03	0.06
	0.20	0.53	0.20	0.73	0.50
Carcass grade, third calf	0.19	−0.07	0.13	0.03	0.03
	0.04	0.42	0.14	0.74	0.72
Marbling score, first calf	0.19	−0.06	0.08	−0.02	−0.11
	0.06	0.57	0.44	0.88	0.27
Marbling score, second calf	0.14	−0.06	0.11	0.02	0.03
	0.12	0.51	0.20	0.78	0.76
Marbling score, third calf	0.16	−0.06	0.11	0.02	0.00
	0.07	0.54	0.23	0.79	0.97
Backfat thickness, first calf	0.13	−0.06	0.04	−0.04	−0.08
	0.21	0.58	0.68	0.72	0.40
Backfat thickness, second calf	0.17	−0.11	0.09	−0.03	0.00
	0.06	0.22	0.31	0.75	0.99
Backfat thickness, third calf	0.15	−0.11	0.03	−0.07	−0.08
	0.09	0.21	0.77	0.41	0.40
Kidney fat, first calf	0.19	0.09	0.06	0.06	−0.25
	0.06	0.38	0.55	0.58	0.01
Kidney fat, second calf	0.16	−0.09	0.17	0.04	0.09
	0.06	0.29	0.06	0.68	0.29
Kidney fat, third calf	0.20	−0.11	0.12	0.01	0.02
	0.02	0.24	0.18	0.90	0.85
Dressing %, first calf	0.07	0.09	−0.06	0.00	−0.24
	0.43	0.33	0.49	0.97	<0.01

(Continued)

Table 8. (Continued)

Variables	RFI	RG	DMI	ADG	MMW
Dressing %, second calf	0.09	−0.03	0.08	0.04	0.02
	0.29	0.74	0.32	0.65	0.85
Dressing %, third calf	0.08	−0.06	0.07	0.02	0.04
	0.31	0.47	0.39	0.83	0.57

[a]Significance level for the test Prob > |r| under H_0: $\rho = 0$ is presented below the correlation coefficient.

were correlations with progeny postweaning feed consumption, gain, or efficiency. In addition, significant relationships were generally not observed between heifer RFI or RG and loineye area or carcass conformation of progeny. On the other hand, correlations of RFI with carcass grade, backfat thickness, marbling score, and kidney fat of progeny indicated that heifers with superior RFI would tend to produce leaner offspring. Thus, results of this study do not indicate any serious antagonisms of postweaning heifer RFI or RG with subsequent progeny postweaning performance traits or carcass traits, nor with life cycle or actual lifetime cow efficiency.

Conflict of Interest Statement. None declared.

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