Components of Growth in Holstein Heifers Fed Either Alfalfa or Corn Silage Diets to Produce Two Daily Gains

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ABSTRACT

Growth components were compared in an experiment with a 2 × 2 factorial design. Eight replicates of Holstein heifers were fed diets based on either alfalfa or corn silage for daily gain of either 725 or 950 g from 181 to 334 kg of body weight (BW). Mean daily gains from corn diets were greater than gains from alfalfa diets for BW, udder, empty body, fat, fat-free matter, protein, H_2O, C, and energy but were less than gains from alfalfa for gut contents and ash. High daily gain produced higher mean values for all of these variables than did lower daily gain. The percentage of protein in fat-free matter was not affected by either main effect. The percentage of fat in empty body gain was increased as daily gain increased. Energy concentration of fat-free matter that was gained was not affected by either diet or daily gain. Energy concentration of empty body gain increased as daily gain increased. The percentage of gut contents in daily BW gain was higher for heifers fed the alfalfa diet than for those fed the corn diet. Energy concentration in daily BW gain was affected by diet and daily gain. Variations of fat and gut contents in daily BW gain must be considered when requirements or expected growth are described.

(**Key words**: cattle, energy deposition, protein deposition, fat deposition)

Abbreviation key: **ADG** = average daily gain, **ADL** = acid detergent lignin, **ARN** = autoclaved ruminal fluid insoluble N, **CEL** = cellulose, **DE** = digestible energy, **EBG** = empty body gain, **EBW** = empty BW, **EE** = ether extract, **FFM** = fat-free matter, **HEM** = hemicellulose, **HWIN** = hot water insoluble N, and **ME** = metabolizable energy.

INTRODUCTION

An integrated study was planned to assess the effects of prepubertal growth rates of replacement US Holstein heifers on milk production potential as has been described for Danish dairy replacement heifers (8, 9). In this study, a group of heifers was slaughtered at the end of the experimental feeding period for use in morphological and chemical analyses of mammary glands. Another small group of heifers was slaughtered prior to the experimental feeding period to provide data on mammary growth and to enable conventional calculation of slaughter balance parameters. These calculations of changes in body composition would allow better definition of requirements for the growth of US Holsteins that are used as dairy replacements. The current NRC (16) requirements for raising dairy replacements are based primarily on extrapolations of the current NRC (15) beef requirements and do not explicitly reference research on US Holsteins.

Mammary growth and mammogenic hormones during the experimental feeding have been discussed previously (6).

MATERIALS AND METHODS

This study was conducted over 2 yr. Data for forage harvests, animal randomization groups, and feeding periods were considered separately for each year.

Silages

In 1984, alfalfa herbage was harvested on May 14 and 15 in the bud stage at 18.5% DM and received 0.135% formic acid and 0.118% formaldehyde on a fresh-weight basis at ensiling. Similarly, corn was harvested for silage on September 5 and 6 at 37.4% DM. In 1985, alfalfa herbage was harvested at the bud stage on May 7 through 9 at 21.3% DM and received 0.158% formic acid and 0.127% formaldehyde on a fresh-weight basis at ensiling. The corn silage used was that which had been processed for general feeding of the dairy herd.

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Heifers

In 1984, 64 Holstein heifers were randomly assigned from 15 time sequence blocks. In 1985, 60 Holstein heifers were randomly assigned from 14 time sequence blocks. Time sequence blocks were based on attainment of 175 kg of BW. For each year, all blocks contained at least 4 heifers for the four experimental feeding treatments, and four blocks contained 5 heifers, 1 for initial slaughter and 4 for slaughter after the four experimental feeding treatments.

The four experimental feeding treatments were either alfalfa silage or corn silage plus protein, vitamins, and minerals. Each diet was fed to produce either 725 or 950 g of average daily gain (**ADG**). The alfalfa silage was fed as the sole diet. The feeding treatments that were based on corn silage were 78% corn silage and 22% soybean meal, vitamins, and minerals (DM basis). The corn silage diet was calculated to provide 15% CP and to meet NRC (14) requirements for vitamins and minerals. All heifers were fed individually, and trace-mineralized salt was available during the daily exercise period of approximately 2 h. Heifers were fed once daily between 0900 and 1000 h. Supplemental lighting was provided to give 16 h of light at 100 lx from 0600 to 2200 h.

The experimental feeding period lasted until each heifer reached 325 kg of BW and had two or more estrous cycles. Determination of estrus was based on plasma concentrations of progesterone from samples that were collected twice weekly by jugular venipuncture. At the end of the experimental feeding period, one-half of the heifers were scheduled for slaughter during estrous phase, and the other half was scheduled for slaughter during the luteal phase. The experimental feeding period began and ended when heifers had reached equivalent BW, which resulted in a feeding period of variable length. Decisions were made weekly to determine the initiation and end of dietary treatments and to determine adjustments to the quantity of feed offered based on DM changes and deviations from expected ADG.

The 44 heifers in 1984 and the 40 heifers in 1985 in the nonslaughter blocks were raised for subsequent trials. During each year, a group of 4 heifers was used in a 4 × 4 Latin square that was balanced for residual effects to determine digestibility and N balance using 7 d of total excreta collection. In 1985, an additional group of 4 heifers was used in a 4 × 4 Latin square to determine energy and N balance in respiration chambers at Beltsville, Maryland. Similarly, the four experimental feeding treatments were either alfalfa silage or corn silage plus protein, vitamins, and minerals. Each diet was fed at intakes similar to those in the production groups to produce either 725 or 950 g of ADG.

Slaughter and Sampling

The heifers that were scheduled for slaughter were weighed without feed withdrawal before being taken to the abattoir. All heifers were killed by exsanguination, following a stun to the head from a captive bolt gun. All blood was collected, weighed, and incorporated into the noncarcass fraction at grinding. All segments of the gastrointestinal tract were emptied, washed, and drip-dried before weighing. In 1984, the noncarcass fraction included hide, head, feet, tail, all internal organs, and kidneys, but the mammary gland was excluded. In 1985, the gastrointestinal tract and associated omental fat was ground as a separate fraction for chemical analyses. The carcass was split longitudinally; each half was weighed to the nearest 0.05 kg, shrouded, chilled at 4°C for 2 or 3 d, and reweighed before grinding. Loss of weight during chilling was considered to be caused by H_2O loss. On the day of slaughter, the noncarcass fraction and incorporated blood were ground five times through a 20-cm grinder (Autio Co., Astoria, OR) using a plate with holes of 13-mm diameter. In 1985, the gastrointestinal tract and omental fat were ground separately on the day of slaughter. The right half of the carcass was ground later after chilling. A major function of the grinding process was mixing. Four samples of about 1 kg each were taken during the final grinding, weighed immediately to the nearest 0.1 g, stored frozen, and freeze-dried for determination of DM. Before analyses, these four samples were pooled with dry ice and were ground in a Wiley mill (2-mm screen; Arthur A. Thomas Co., Philadelphia, PA).

Chemical Analyses

All analyses of tissue of the carcass, noncarcass fraction, and gastrointestinal tract were run in quadruplicate with ashing at 600°C for 16 h. Total N was determined by macro-Kjeldahl method (3) that was modified to use boric acid in distillation, and fat was determined by ether extract (**EE**) (3) that was modified to use a sample of 5 to 7 g. Carbon in calorimetry data was determined by combustion (21), C in slaughter data by combustion (Leco CHN600 analyzer; Leco Corp., St. Joseph, MI), and gross energy by adiabatic calorimeter using a polyethylene bag of known energy content as primers. Samples of mammary gland were lost before analysis for DM, N, fat, and ash because of a freezer failure. Samples of diet and excreta were analyzed in duplicate using

TABLE 1. Composition of diets fed to Holstein heifers in growth and slaughter balance during both years.

	Alfalfa		Corn		SE	
Item[1]	1984	1985	1984	1985	1984[2]	1985[3]
Samples, no.	29	29	26	25	. . .	. . .
DM,[4] %	25.2	29.0***	42.7***	39.1	0.25	0.34
OM, % of DM	90.8	92.4	94.0***	94.3***	0.13	0.09
Energy, Mcal/kg of DM	4.87***	4.84***	4.47	4.59	0.023	0.017
N, % of DM	3.65***	3.52***	2.58	2.48	0.035	0.035
Ash, % of DM	9.16***	7.57***	6.04	5.73	0.135	0.090
NDF, % of DM	41.6***	38.9	37.1	39.0	0.42	0.40
ADF, % of DM	36.4***	31.5***	21.4	22.9	0.36	0.31
HEM, % of DM	5.2	7.4	15.7***	16.2***	0.42	0.35
CEL, % of DM	29.6***	26.0***	18.8	20.0	0.33	0.28
ADL, % of DM	6.74***	5.50***	2.63	2.92	0.087	0.068
HWIN, % of DM	1.33	1.49	1.50***	1.44	0.037	0.038
ARN, % of DM	1.39	1.61***	1.33	1.38	0.035	0.036
NH_3 N, % of DM	0.29	0.19	. . .	. . .	0.029	0.012

[1] HEM = Hemicellulose, CEL = cellulose, ADL = acid detergent lignin, HWIN = hot H_2O insoluble N, and ARN = autoclaved ruminal fluid insoluble N.

[2] Standard error is appropriate for n = 26, except for NH_3 N where n = 29.

[3] Standard error is appropriate for n = 25, except for NH_3 N where n = 29.

[4] For 1984, n = 48 for alfalfa, and n = 42 for corn and standard error; for 1985, n = 50 for alfalfa, and n = 42 for corn and standard error.

***$P < 0.001$.

undried samples. Dietary DM was analyzed using a 100°C forced-air oven and weekly composite samples. The NDF, nonsequential ADF, acid detergent lignin (**ADL**), $KMnO_4$ lignin, and hot H_2O insoluble N (**HWIN**) were determined by methods of Goering and Van Soest (12). NH_3 N was determined by distillation using MgO (3), and autoclaved ruminal fluid insoluble N (**ARN**) was determined by the method of Waldo and Goering (24). Hemicellulose (**HEM**) was calculated as NDF minus ADF, and cellulose (**CEL**) was calculated as ADF minus ADL. Using calorimetry, CEL was calculated as ADF minus $KMnO_4$ lignin, and soluble residue was calculated as neutral detergent solubles minus EE and CP. Plasma progesterone was assayed by radioimmunoassay (13, 18), and concentrations greater than 1 ng/ml were considered to indicate luteal function.

Data Derivation and Statistical Analyses

Empty BW (**EBW**) was the sum of carcass, noncarcass, and gastrointestinal tissues. Gut contents were calculated from the final BW minus the EBW. Initial gut composition of heifers that were fed experimental diets was based on individual initial BW times the proportional composition of the 4 heifers that were slaughtered prior to the experimental period each year. Data regarding dietary composition were analyzed by ANOVA as a completely random design; diet contrasts were tested by residual as error. Data on digestibility, energy balance, and N balance were analyzed as treatments. Individual degree of freedom contrasts were made of alfalfa versus corn silage, low versus high gain, the interaction of silage and gain, heifers, periods, and residual, used as the error term. Heifer BW and components were analyzed by ANOVA as individual degree of freedom contrasts of initial slaughter versus slaughter after experimental feeding, alfalfa versus corn diets, low versus high gain, and the interaction of diet and gain, blocks, and residual, which was used as the error term. The daily gain and its components were analyzed by ANOVA as individual degree of freedom contrasts of alfalfa versus corn diets, low versus high gain, the interaction of diet and gain, blocks, and residual, which was used as the error term. All ANOVA and regression analyses were done using the PROC GLM procedure of SAS (19).

RESULTS AND DISCUSSION

Diet Description

Composition. In both years, concentrations of energy, N, ash, ADF, CEL, and ADL were greater ($P < 0.001$) in alfalfa diets than in corn diets (Table 1); similarly, OM and HEM concentrations were lower

($P < 0.001$) in alfalfa diets than in corn diets. In 1984, NDF concentration was greater ($P < 0.001$) in alfalfa diets than in corn diets, but HWIN concentration was less ($P < 0.001$) in alfalfa diets than in corn diets. In 1985, ARN concentration was greater ($P < 0.001$) in alfalfa diets than in corn diets. The NH_3 N concentration was below the maximum, but HWIN concentration and ARN concentration were also below the minimums suggested for well-preserved haycrop silages (7). The treatments in 1985 using slightly higher concentrations of formic acid and formaldehyde might have contributed to increased proportions of total N as HWIN and ARN and a decreased proportion of NH_3 N relative to 1984.

Digestibility and N balance. Even though slightly less DMI was required from the corn diet than from the alfalfa diet to attain the intended ADG, no difference ($P > 0.05$) occurred in either year (Tables 2 and 3). The alfalfa diet had lower ($P < 0.001$) digestibilities of DM, OM, and energy but greater ($P < 0.01$) digestibility of CEL than did the corn diet in both years. The alfalfa diet had lower ($P < 0.01$) digestibility of HEM than did the corn diet in both years. The corn diet had greater ($P < 0.05$) digestibility of ADL than did the alfalfa diet in 1985. The alfalfa diet had greater ($P < 0.05$) digestibility of ADF than did the corn diet in 1984. No differences ($P > 0.05$) were observed between alfalfa and corn silage diets for ash and NDF digestibilities and N balance. The DMI was greater ($P < 0.01$) as required for high ADG than for low ADG, but these rather small intake differences caused no digestibility differences.

Respiration calorimetry during the 2nd year. Two changes were made in the type of data presented and in chemical methods that were used in respiration calorimetry (Tables 4, 5, and 6). First, composition data were calculated for diets that were actually consumed rather than for diets that were offered, which did not alter results markedly when DMI was restricted. Second, lignin was oxidized from ADF by $KMnO_4$, which generally increases lignin and decreases CEL relative to the hydrolysis of CEL from ADF by 72% sulfuric acid. Concentrations of OM, HEM, and soluble residue were less ($P < 0.001$) in the alfalfa diet than in the corn diet, but concentrations of N, EE, ash, ADF, CEL, and $KMnO_4$ lignin were greater ($P < 0.001$) in the alfalfa diet than in the corn diet (Table 4). Concentration of C was greater ($P < 0.05$) in the alfalfa diet than in the corn diet. Concentrations of energy and NDF were not different ($P > 0.05$) between diets.

Digestibility of DM, OM, energy, EE, and C were lower ($P < 0.001$) for heifers fed the alfalfa diet than for those fed the corn diet (Table 5). Digestibility of N was less ($P < 0.05$), but N balance was greater ($P < 0.05$), for the heifers fed the alfalfa diet than for those fed the corn diet. No dietary differences ($P > 0.05$) occurred for digestibility of ash, NDF, ADF, HEM, CEL, or $KMnO_4$ lignin. As before, the DMI was greater ($P < 0.05$), as required for high ADG than for low ADG, but these comparatively small intake differences caused no digestibility differences.

Differences in calorimetric data (Table 6) included a greater ($P < 0.05$) intake of gross energy but lower

TABLE 2. Body weight, daily intake, digestibility, and N balance of Holstein heifers in growth and slaughter balance during 1984.

	Alfalfa		Corn			Diet		Daily gain	
Item[1]	Low	High	Low	High	SE[2]	Alfalfa	Corn	Low	High
Heifers, no.	4	4	4	4	. . .	8	8	8	8
BW, kg	311	315	303	315	3.4	313	309	307	315
DMI, $g/kg^{0.75}$	78.4	95.5	73.5	93.8	4.40	87.0	83.7	76.0**	94.7
DM, %	62.7	63.0	74.7	73.3	1.27	62.8***	74.0	68.7	68.1
OM, %	65.0	65.1	76.9	75.6	1.06	65.1***	76.2	71.0	70.3
Energy, %	64.6	64.6	75.6	74.2	1.05	64.6***	74.9	70.1	69.4
N, %	66.1	65.9	73.5	70.6	1.47	66.0**	72.1	69.8	68.3
Ash, %	39.3	42.2	40.5	37.2	4.20	40.7	38.9	39.9	39.7
NDF, %	51.4	54.0	58.6	56.3	3.06	52.7	57.4	55.0	55.1
ADF, %	56.3	58.5	50.6	48.8	3.06	57.4*	49.7	53.4	53.6
HEM, %	13.0	15.9	69.4	67.2	13.8	14.4**	68.3	42.7	40.1
CEL, %	67.6	69.6	55.9	53.4	2.61	68.6**	54.7	61.8	61.5
ADL, %	6.8	11.0	15.3	17.2	7.02	8.9	16.3	11.1	14.1
N Balance, g/d	22.4	27.0	22.3	20.1	6.23	24.7	21.2	22.4	23.6

[1] HEM = Hemicellulose, CEL = cellulose, and ADL = acid detergent lignin.

[2] Standard error is appropriate for n = 4.

*$P < 0.05$.

**$P < 0.01$.

***$P < 0.001$.

TABLE 3. Body weight, daily intake, digestibility, and N balance of Holstein heifers in growth and slaughter balance during 1985.

	Alfalfa		Corn			Diet		Daily gain	
Item[1]	Low	High	Low	High	SE[2]	Alfalfa	Corn	Low	High
Heifers, no.	4	4	4	4	. . .	8	8	8	8
BW, kg	260	265	259	268	3.96	263	263	260	266
DMI, g/kg$^{0.75}$	85.0	96.5	81.4	96.1	1.03	90.7	88.7	83.2***	96.3
DM, %	65.6	67.2	70.9	71.3	0.62	66.4***	71.1	68.3	69.3
OM, %	67.0	68.5	72.3	72.6	0.54	67.8***	72.4	69.6	70.6
Energy, %	64.8	66.4	71.1	71.9	0.50	65.6***	71.5	67.9	69.1
N, %	67.4	68.5	69.0	68.8	0.79	68.0	68.9	68.2	68.7
Ash, %	49.0	51.2	48.6	50.4	1.65	50.1	49.5	48.8	50.8
NDF, %	55.9	59.4	57.8	58.8	2.03	57.6	58.3	56.9	59.1
ADF, %	58.9	61.6	56.2	56.2	1.73	60.3	56.2	57.5	58.9
HEM, %	42.1	47.8	59.8	62.2	2.68	45.0***	61.0	51.0	55.0
CEL, %	70.0	72.3	60.3	60.9	1.24	71.1***	60.6	65.1	66.6
ADL, %	6.9	11.5	25.2	22.0	4.53	9.2*	23.6	16.0	16.8
N Balance, g/d	32.7	27.1	18.2	24.1	5.54	29.9	21.2	25.4	25.6

[1] HEM = Hemicellulose, CEL = cellulose, and ADL = acid detergent lignin.

[2] Standard error is appropriate for n = 4.

*$P < 0.05$.

***$P < 0.001$.

($P < 0.05$) production of methane energy for the alfalfa diet than for the corn diet. Intakes of digestible energy (**DE**), intakes of metabolizable energy (**ME**), losses as urine or heat energy, and deposition of tissue energy were not affected ($P > 0.05$) by diet. High gain required greater ($P < 0.05$) intakes of gross energy, DE, and ME to produce greater ($P < 0.05$) deposition of energy in tissue than did low gain, but methane, urinary, and heat energies were not affected ($P > 0.05$) by intake. The ME, expressed as a percentage of DE, was not affected ($P > 0.05$) by diet but was lower ($P < 0.05$) at low intake than at high intake; the experimental mean was 83.2%.

Components of BW

Amounts. The prefeeding heifers were slaughtered at 181 kg of BW prior to the initiation of the experiment, and the postfeeding heifers were slaughtered at 334 kg of BW (Table 7). The BW at initiation of the

TABLE 4. Composition of diets consumed by Holstein heifers in calorimetry during 1985.

	Alfalfa		Corn			Diet		Daily gain	
Item[1]	Low gain	High gain	Low gain	High gain	SE[2]	Alfalfa	Corn	Low	High
Heifers, no.	4	4	4	4	. . .	8	8	8	8
DM, %	28.8	29.0	38.2	38.3	0.58	28.9***	38.2	33.5	33.6
OM, % of DM	92.3	92.3	94.7	94.6	0.17	92.3***	94.6	93.5	93.4
Energy, Mcal/kg of DM	4.84	4.84	4.76	4.77	0.052	4.84	4.76	4.80	4.80
N, % of DM	3.60	3.60	2.34	2.38	0.070	3.60***	2.36	2.97	2.99
EE, % of DM	4.85	4.88	2.55	2.56	0.102	4.86***	2.55	3.70	3.72
Ash, % of DM	7.71	7.73	5.35	5.39	0.170	7.72***	5.37	6.53	6.56
C, % of DM	48.0	48.1	46.6	46.5	0.42	48.1*	46.6	47.3	47.3
NDF, % of DM	41.0	40.9	41.9	41.8	0.59	41.0	41.8	41.4	41.3
ADF, % of DM	30.8	31.5	23.8	23.8	0.46	31.1***	23.8	27.3	27.7
HEM, % of DM	10.2	9.4	18.1	17.9	0.44	9.8***	18.0	14.1	13.7
CEL, % of DM	24.0	24.1	19.6	19.6	0.29	24.0***	19.6	21.8	21.8
Soluble residue, % of DM	23.9	24.0	35.6	35.4	1.17	24.0***	35.5	29.8	29.7
$KMnO_4$ Lignin, % of DM	6.93	6.80	3.72	3.71	0.168	6.87***	3.72	5.33	5.26

[1] EE = Ether extract, HEM = hemicellulose, CEL = cellulose, and soluble residue = neutral detergent solubles − (EE + CP).

[2] Standard error is appropriate for n = 4.

*$P < 0.05$.

***$P < 0.001$.

TABLE 5. Intake, digestibility, and N balance of Holstein heifers in calorimetry during 1985.

	Alfalfa		Corn			Diet		Daily gain	
Item[1]	Low	High	Low	High	SE[2]	Alfalfa	Corn	Low	High
Heifers, no.	4	4	4	4	. . .	8	8	8	8
BW, kg	330	333	333	338	1.7	331*	335	331	335
DMI, g/kg$^{0.75}$	89.3	94.1	81.0	88.1	2.29	91.7*	84.6	85.2*	91.1
DM, %	66.5	66.5	70.8	71.7	0.46	66.5***	71.3	68.7	69.1
OM, %	68.8	68.9	72.9	73.6	0.38	68.8***	73.2	70.8	71.2
Energy, %	66.2	66.3	72.1	72.1	0.62	66.2***	72.1	69.2	69.2
N, %	66.8	65.8	68.4	70.0	0.77	66.3*	69.2	67.6	67.9
EE, %	57.9	58.8	71.3	74.4	1.96	58.3***	72.8	64.6	66.6
Ash, %	39.5	36.8	34.1	39.2	3.69	38.2	36.6	36.8	38.0
C, %	66.1	66.8	71.2	72.0	0.41	66.5***	71.6	68.6	69.4
NDF, %	56.1	54.7	55.9	56.4	0.76	55.4	56.1	56.0	55.5
ADF, %	55.7	54.2	52.8	53.6	1.10	54.9	53.2	54.2	53.9
HEM, %	57.1	54.9	59.9	60.0	3.52	56.0	59.9	58.5	57.5
CEL, %	67.8	65.9	64.9	63.8	1.82	66.8	64.3	66.3	64.8
$KMnO_4$ Lignin, %	31.3	30.0	18.9	24.3	5.40	30.6	21.6	25.1	27.2
Soluble residue, %	94.8	97.7	94.8	95.1	0.90	96.2	94.9	94.8	96.4
N Balance, g/d	23.3	41.0	12.5	21.2	5.51	32.1*	16.8	17.9	31.1

[1] EE = Ether extract, HEM = hemicellulose, CEL = cellulose, and soluble residue = neutral detergent solubles – (EE + CP).

[2] Standard error is appropriate for n = 4.

*$P < 0.05$.

***$P < 0.001$.

experimental period was greater than the intended 175 kg because decisions on scheduling heifers for slaughter were made at weekly weighings after heifers had reached 175 kg. The larger difference between the intended and observed BW at slaughter for the postfeeding heifers was caused by an occasional delay in reaching second estrus. All components for postfeeding heifers that were based on weight, as kilograms, and on energy, as megacalories, were greater ($P < 0.001$) than those components for the prefeeding heifers. Only the wet weight of the udder was included in these data because the samples were lost before analyses when a freezer failed. Heifers that were fed the alfalfa diet had less udder weight ($P < 0.01$) and body fat ($P < 0.05$), but more ($P < 0.01$) gut contents and ash than did heifers that were fed the corn diet. Heifers that were fed for low ADG had less ($P < 0.001$) fat; less ($P < 0.01$) udder, C, and energy; and less ($P < 0.05$) EBW than did heifers that were fed for high ADG. No interactions occurred.

Proportions. A description of body composition as proportional components gave additional insight into growth (17) and feed requirements (11). The fat-free matter (**FFM**) fraction had relatively constant proportions of protein, H_2O, and ash. A much more variable fat fraction completed the EBW. A final gut

TABLE 6. Energy metabolism of Holstein heifers in calorimetry during 1985.

	Alfalfa		Corn			Diet		Daily gain	
Item[1]	Low	High	Low	High	SE[2]	Alfalfa	Corn	Low	High
Heifers, no.	4	4	4	4	. . .	8	8	8	8
Gross energy, Mcal/d	33.18	35.14	30.01	33.07	0.965	34.16*	31.54	31.60*	34.11
DE, Mcal/d	21.99	23.36	21.64	23.87	0.546	22.68	22.75	21.81*	23.62
Methane, Mcal/d	2.08	2.07	2.27	2.39	0.091	2.08*	2.33	2.17	2.23
Urine, Mcal/d	1.80	1.58	1.48	1.56	0.081	1.69	1.52	1.64	1.57
ME, Mcal/d	18.11	19.71	17.89	19.92	0.455	18.91	18.90	18.00**	19.81
Heat, Mcal/d	14.64	14.85	14.20	15.08	0.277	14.74	14.64	14.42	14.97
Tissue, Mcal/d	3.47	4.86	3.68	4.83	0.385	4.17	4.26	3.58*	4.85
ME/DE, %	82.6	84.3	82.7	83.4	0.44	83.4	83.1	82.6*	83.8

[1] DE = Digestible energy; ME = metabolizable energy.

[2] Standard error is appropriate for n = 4.

*$P < 0.05$.

**$P < 0.01$.

content fraction of intermediate variation completed the BW. Prefeeding heifers had smaller ($P < 0.001$) proportions of protein and ash but a greater ($P < 0.001$) proportion of H_2O in FFM than did postfeeding heifers (Table 7). Prefeeding heifers had smaller ($P < 0.001$) proportions of fat in EBW than did postfeeding heifers. Concentration of energy in both EBW and BW was lower ($P < 0.001$) in prefeeding heifers than in postfeeding heifers. The alfalfa diet caused greater ($P < 0.05$) protein and ash but less ($P < 0.01$) H_2O in FFM than did the corn diet. The alfalfa diet produced less ($P < 0.05$) fat in EBW than did the corn diet. Gut contents were greater ($P < 0.01$) and energy was lower ($P < 0.05$) per unit of BW, for heifers that were fed alfalfa than for heifers that were fed corn. Diet did not affect ($P > 0.05$) energy concentration in EBW. High ADG produced greater ($P < 0.01$) fat and energy in EBW and in BW. Neither proportional composition of FFM nor percentage of gut contents in BW was affected ($P > 0.05$) by ADG. No interactions occurred. Based on fat, protein, and energy components of BW, multiple regression with no intercept apportioned energy into 9.293 ± 0.106 Mcal/kg of fat and 5.524 ± 0.0907 Mcal/kg of protein ($R^2 = 0.9999$ and n = 40). Both of these constants were lower than those commonly used (5).

Components of ADG

Amounts. Heifers that were fed the alfalfa diet had lower ($P < 0.001$) empty body gain (**EBG**); lower ($P < 0.01$) gains of udder, C, and energy; and lower ($P < 0.05$) gains of fat and H_2O than heifers fed the corn diet (Table 8). Greater ($P < 0.05$) gut contents and protein energy in total energy but lower ($P < 0.05$) fat energy in total energy were produced in heifers that were fed the alfalfa diet than in heifers that were fed the corn diet. The ADG and daily gains of FFM, protein, and ash were unaffected ($P < 0.05$) by diet. The ADG and daily gains of udder, EBG, fat, FFM, protein, H_2O, ash, C, and energy were lower ($P < 0.001$) in heifers that were fed for low ADG than in heifers that were fed for high ADG. Protein energy gain was a higher ($P < 0.01$) percentage and fat energy gain was a lower ($P < 0.01$) percentage of total energy in heifers that were fed the alfalfa diet

TABLE 7. Component weights and energy in total BW of Holstein heifers during both years.

		Alfalfa		Corn			Diet		Daily gain	
Item[1]	Initial[2]	Low	High	Low	High	SE[3]	Alfalfa	Corn	Low	High
Heifers, no.	8	8	8	8	8	. . .	16	16	16	16
BW, kg	181***	335	338	329	333	2.9	336	331	332	336
Udder, kg	0.90***	2.03	2.24	2.33	3.04	0.160	2.13**	2.69	2.18**	2.64
Gut contents										
kg	25.7***	54.8	52.1	47.8	42.9	2.62	53.4**	45.3	51.3	47.5
% of BW	13.9	16.1	15.0	14.2	12.5	0.77	15.6**	13.3	15.1	13.7
EBW, kg	155***	279	285	280	289	2.6	282	284	280*	287
Fat										
kg	14.5***	39.8	45.1	42.7	50.3	1.71	42.5*	46.5	41.2***	47.7
% of EBW	9.4***	14.3	15.9	15.2	17.4	0.57	15.1*	16.3	14.7**	16.6
FFM, kg	140***	239	239	236	238	2.4	239	237	238	238
Protein										
kg	28.3***	52.1	51.3	50.7	51.0	0.53	51.7	50.9	51.4	51.1
% of FFM	20.2***	21.8	21.5	21.4	21.4	0.09	21.7*	21.4	21.6	21.5
H_2O										
kg	105***	173	174	173	174	1.8	174	174	173	174
% of FFM	74.8***	72.6	73.0	73.1	73.3	0.15	72.8**	73.2	72.9	73.2
Ash										
kg	6.9***	13.4	13.2	12.8	12.4	0.21	13.3**	12.6	13.1	12.8
% of FFM	4.94***	5.60	5.54	5.43	5.21	0.094	5.57*	5.32	5.51	5.38
C, kg	25.5***	56.1	60.3	58.3	62.9	1.25	58.2	60.6	57.2**	61.6
Energy										
Mcal	293***	656	705	679	745	16.1	680	712	667**	725
Mcal/kg of BW	1.62***	1.96	2.09	2.06	2.24	0.051	2.02*	2.15	2.01**	2.16
Mcal/kg of EBW	1.89***	2.35	2.48	2.42	2.58	0.048	2.41	2.50	2.39**	2.53

[1] EBW = Empty BW; FFM = fat-free matter.

[2] Significance indicated is initial versus all others.

[3] Standard error is appropriate for n = 8.

*$P < 0.05$.

**$P < 0.01$.

***$P < 0.001$.

than in heifers that were fed the corn diet. Gut contents were unaffected ($P < 0.05$) by ADG. No interactions occurred.

Proportions. Heifers that were fed the alfalfa diet had less ($P < 0.05$) H_2O, greater ($P < 0.05$) ash, and similar ($P > 0.05$) protein in FFM than did heifers that were fed the corn diet (Table 8). Diet did not affect ($P > 0.05$) either fat or energy in EBG of heifers. Heifers that were fed the alfalfa diet had greater ($P < 0.01$) gut contents in ADG and, consequently a lower ($P < 0.05$) energy concentration in ADG than heifers that were fed the corn diet. The proportional composition of FFM was not affected ($P < 0.05$) by ADG. Heifers that were fed for low ADG had lower ($P < 0.01$) fat concentration and, consequently, a lower ($P < 0.05$) energy concentration in EBG than did heifers that were fed for high ADG. Rate of ADG did not affect ($P < 0.05$) gut contents in ADG; therefore, the difference in energy concentration in EBG was retained as a lower ($P < 0.05$) concentration of energy in ADG of heifers that were fed for low ADG than of those that were fed for high ADG. No interactions occurred. Multiple regression with no intercept on components of EBG apportioned energy gain as 9.320 ± 0.136 Mcal/kg of fat and 5.378 ± 0.184 Mcal/kg of protein ($R^2 = 0.9998$ and n = 32). Again, both of these factors were lower than those suggested by Brouwer (5). Presumably, energy concentrations estimated from EBG would be more appropriate for use in feeding recommendations than would those estimated from empty body data.

Distribution of Retained Energy

The relative daily deposition of energy in fat and protein as functions of daily total deposition of energy is considered in Figure 1. Energy that was deposited as fat was calculated as 9.320 Mcal/kg of fat based on the earlier regression relationship of energy components of gain. Energy that was deposited as protein was calculated as total energy minus fat energy. The equation for fat was daily fat energy (megacalories per day) = 0.891 (± 0.025) × daily total energy – 0.46 ($R^2 = 0.98$; n = 32; $P < 0.001$). The equation for protein was: daily protein energy (megacalories per

TABLE 8. Daily gains and energy of growing Holstein heifers fed alfalfa or corn silages for two rates of gain during two years.

	Alfalfa		Corn			Diet		Daily gain	
Item[1]	Low	High	Low	High	SE[2]	Alfalfa	Corn	Low	High
Heifers, no.	8	8	8	8	. . .	16	16	16	16
ADG, g	766	974	792	1004	15.4	870	898	779***	989
Udder, g	5.63	8.41	7.54	14.24	1.168	7.02**	10.89	6.59***	11.33
Gut contents									
g	147	166	123	117	16.5	157*	120	135	142
% of ADG	19.0	17.1	15.1	11.2	1.64	18.1**	13.2	17.1	14.2
EBG, g	619	808	668	881	14.3	713***	774	643***	844
Fat, g	125	192	147	236	12.0	158*	192	136***	214
% of EBG	20.2	23.7	22.1	26.7	1.37	21.9	24.4	21.2**	25.2
FFM, g	495	615	518	645	14.0	555	582	507***	630
Protein									
g	119	143	120	150	3.0	131	135	120***	147
% of FFM	24.0	23.3	23.2	23.2	0.24	23.7	23.2	23.6	23.3
H_2O									
g	344	432	367	459	11.2	388*	413	355***	446
% of FFM	69.5	70.2	70.7	71.2	0.44	69.9*	70.9	70.1	70.7
Ash									
g	32.1	39.2	31.5	36.1	1.24	35.6	33.8	31.8***	37.6
% of FFM	6.50	6.41	6.10	5.61	0.24	6.45*	5.86	6.30	6.01
C, g	152	217	173	246	8.7	185**	210	162***	232
Energy									
Mcal	1.80	2.58	2.03	2.98	0.110	2.19**	2.51	1.91***	2.78
Mcal/kg of EBG	2.90	3.18	3.05	3.38	0.116	3.04	3.22	2.98*	3.28
Mcal/kg of ADG	2.35	2.64	2.58	2.99	0.127	2.49*	2.79	2.47*	2.81
Protein energy, % of total	35.9	30.3	32.1	27.5	1.56	33.1*	29.8	34.0**	28.9
Fat energy, % of total	64.5	69.1	67.3	73.2	1.55	66.8*	70.3	65.9**	71.2

[1] ADG = Average daily gain, EBG = empty body gain, and FFM = fat-free matter.

[2] Standard error is appropriate for n = 8.

*$P < 0.05$.

**$P < 0.01$.

***$P < 0.001$.

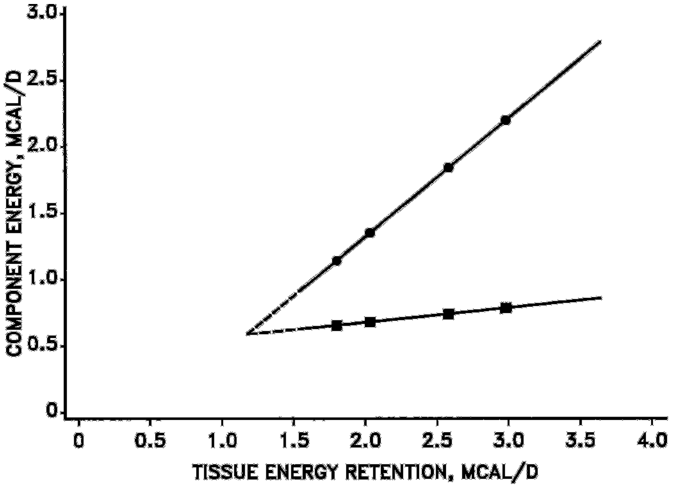

Figure 1. Daily retention of energy in protein (■) and fat (●) as a function of daily retention of total energy. Fat (fat energy = 0.891 (±0.025) × total energy – 0.46; n = 32; r^2 = 0.98; $P < 0.001$); protein (protein energy = 0.109 (±0.025) × total energy + 0.46; n = 32; r^2 = 0.38; $P < 0.001$). Solid lines represent the range for individual heifers, and broken lines represent an extrapolation to the point of equal energy deposition in fat and protein.

day) = 0.109 (± 0.025) × daily total energy + 0.46 (R^2 = 0.38; n = 32; $P < 0.001$). These lines intersected at 1.178 Mcal/d of total energy deposition, which implies equal deposition of energy as fat and protein at that rate of energy deposition. Deviations in daily total energy deposition lower than this rate decreased proportional fat and increased proportional protein. Deviations in daily total energy deposition higher than this rate increased proportional fat and decreased proportional protein. Increases in the daily total energy deposition increased daily protein deposition but decreased the concentration of protein that was required compared with the concentration of energy. The four treatment means fell on the two linear slopes for both protein and fat, which demonstrates the adequacy of dietary protein in all experimental treatments. In another study (23), inadequate dietary protein reduced the deposition of energy in protein and increased the deposition of energy in fat compared with deposition found with three other diets with adequate dietary protein. An estimation of protein deposition by slaughter balance in growing heifers (Figure 1) is a much more definitive documentation of protein adequacy than either plasma urea N or N balance data. In another study (25), Holstein steers of similar BW and ADG deposited energy in fat and protein at a ratio of 50:50 at a very similar total energy deposition, but the incremental deviations, or slopes, were essentially double the slope for protein (0.24) for heifers in the current study and showed a corresponding reduction relative to the slope for fat (0.76). It should be noted that all data from the study on steers were based on variable weight, fixed-time experiments. In contrast, data for heifers in the current study were based on fixed weight, variable-time experiments. Although Holstein heifers in the current study grew from about one-fourth to one-half of mature BW, the data were not greatly different from similar data, adjusted by covariance on ash, from dry and lactating Holstein cows (1). Changes in body fat represented about 93% of total body energy changes, and changes in body protein represented about 7% of total changes in body energy (1). These estimates of energy changes in the lactating cow were very consistent with the 8% contribution of protein to energy loss in early lactation that was determined by calorimetry (22) and with the 8% contribution of protein to the metabolism of fat adult sheep that occurred during feed withdrawal (4). The growth of broiler chicks (H. A. Boekholt, 1991, personal communication) showed similar linear relationships; all energy was deposited as protein at a daily rate of 180 kJ per unit of metabolic weight, and greater energy deposition up to 800 kJ per unit of metabolic weight was deposited, 84.9% (R^2 = 0.98) as fat and the remainder as protein. Any fundamental thinking about these relative changes in protein and fat pools that were reported in these studies must recognize that either the net deposition or the net loss during growth, lactation, or feed withdrawal is the algebraic sum of a dynamic synthesis and degradation.

Data on protein and fat deposition relative to EBW in the current study were compared with earlier data from Cornell experiments (2, 10, 20) (Figure 2). Curves were drawn after calculation of appropriate data for a in the allometric equation, $Y = aX^b$. Data for b was taken from Table 6, and data for X and Y were taken from Table 8 (10). In the Cornell study, the preexperimental group of 7 Holstein heifers was slaughtered at a mean EBW of 150 kg; 9 heifers that were fed for ad libitum intake were serially slaughtered at a mean EBW of 323 kg and a mean experimental EBG of 769 g; and 9 heifers that were fed either at 60 or 70% of ad libitum intake were serially slaughtered at a mean EBW of 238 kg and a mean experimental EBG of 378 g. In the current study, the preexperimental group of 8 heifers was slaughtered at a mean EBW of 155 kg, and each of the 8 heifers of the four groups that were fed experimentally were slaughtered at a mean EBW of 283 kg and a mean experimental EBG of 744 g. In the current study, ADG data were more similar to ADG data of Holstein heifers in the Cornell study that were fed for ad libitum intake than to data of heifers that were fed at 60 to 70% of ad libitum intake; however, protein and fat deposition data were more similar to data from Cornell for Holstein heifers fed at 60 to 70% of ad libitum intake. The cause for this compositional difference is unknown; however, it might represent genetic changes in mature body size and lactation potential per unit of body size in the Holstein breed from the time of the Cornell experiments, which were conducted from March 1972 to December 1974, to the time of the current study, which was conducted from October 1984 through August 1986.

Data for actual daily gains (Table 8) were compared with expectations derived from NRC (16) values using a BW of 181 kg. Expectations for heifers fed alfalfa silage for low gain were 108 g/d of protein and 2.05 Mcal/d of energy, and, for high gain, expectations were 136 g/d of protein and 2.65 Mcal/d for energy. Expectations for heifers fed a corn silage and soybean meal diet that was fed for low gain were 112 g/d of protein and 2.12 Mcal/d of energy, and, for high gain, expectations were 140 g/d of protein and 2.73 Mcal/d of energy. These expectations were lower than actual data for protein for all experimental treatments and higher than actual data for energy for all experimental treatments, except for the corn silage and soybean meal diet that was fed for high gain. The current NRC (16) assumes that gut fill represents 15% of ADG; however, gut fill in this study ranged from 12.2 to 19.0% of ADG. Observed differences in gut fill are an important factor in comparing the results of this study with expectations from NRC (16).

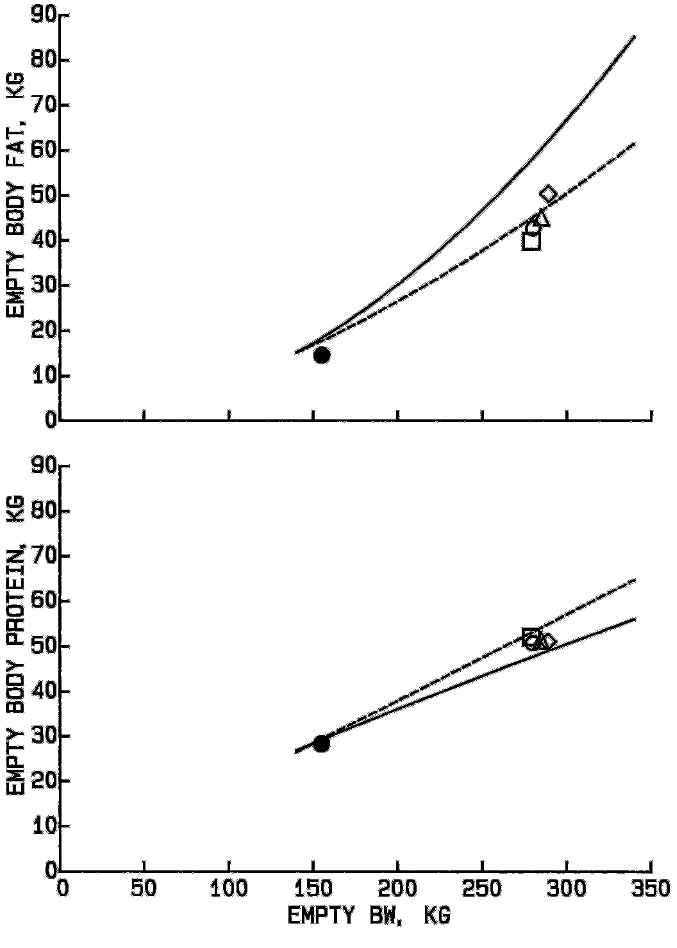

Figure 2. Comparison of data for protein and fat deposition in empty BW with similar data from Cornell (2, 10, 20) obtained on Holstein heifers about 12 yr earlier. Solid curves represent Cornell data for protein and fat deposition at ad libitum intakes. Broken curves represent Cornell data for protein and fat deposition at 60 or 70% of ad libitum intakes of the same diet. Data from the current study are points for prefeeding (●) slaughter and for slaughter following diets of either alfalfa to produce low (□) and high (△) daily gains or corn silage and soybean meal to produce similar low (○) and high (◊) daily gains.

Relationship of Requirements to Gain

The mean values for daily gain of FFM were 70.4% H_2O, 6.2% ash, and 23.4% protein. Percentage of protein, which is the only energy-containing component in FFM, was not affected by either diet or ADG. The daily EBG had a mean composition of 23.2% fat, which was affected by ADG; the remainder was FFM with a constant protein concentration, which implied a constant energy concentration. With an observed apportionment of energy to protein at 5.378 Mcal/kg, the relatively constant energy concentration of the FFM was 5.378×0.234 or 1.258 Mcal/kg. Similarly, with an observed apportionment of energy to fat at 9.320 Mcal/kg, the mean energy concentration in EBG was $9.320 \times 0.232 + 1.258 \times (1 - 0.232)$ or 3.13 Mcal/kg. The energy was accumulated as 69% in fat and 31% in protein. The mean values for ADG included 15.6% gut contents, which was affected by diet. Mean energy concentration in ADG was $3.13 \times (1 - 0.156)$ or 2.64 Mcal/kg.

CONCLUSIONS

The composition of deposited FFM was relatively constant at 70.4% H_2O, 6.2% ash, and 23.4% protein. The only component containing energy, protein, was not affected by diet or ADG. The relative daily deposition of energy as protein and as fat were linear functions of daily total deposition of energy. The distribution of energy was 50% protein and 50% fat when the daily energy deposition was 1.178 Mcal. As daily energy deposition increased above this intersection of equality, the incremental total energy was deposited as 89.1% to fat and 10.9% to protein. For example, the experimental mean daily energy deposition of 2.35

Mcal was deposited as 69% in fat and 31% in protein. Both fat percentage and energy concentration in EBW were increased by increasing ADG or increasing daily energy deposition. Variation in the contribution of gut contents to ADG was introduced by diet. Increasing gut contents caused further dilution of energy concentration in ADG relative to EBG.

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