Limit Feeding of Gravid Holstein Heifers: Effect on Growth, Manure Nutrient Excretion, and Subsequent Early Lactation Performance

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ABSTRACT

A study was conducted to evaluate the effect of limit feeding on growth, feed efficiency, and manure excretion in Holstein heifers and subsequent milk production. Fifty-four gravid Holstein heifers were randomly assigned to replicate pens and fed 1 of 3 experimental diets for 111 d. Experimental diets included an ad libitum-fed control diet containing 11.3% crude protein (CP) and 2.46 Mcal/kg of metabolizable energy (ME). Two limit-fed diets of increased nutrient density were formulated to contain 12.7 and 14.2% CP and 2.55 and 2.68 Mcal/kg of ME, respectively. Feed intakes of limit-fed diets were limited to 90 and 80% of the control diet. Nutrient intake, growth, manure excretion, blood metabolites, behavior, and 150-d lactation performance were evaluated. Heifers fed 80 and 90% of the control diet consumed less dry matter (8.3 and 9.0 vs. 9.7 kg/d), but similar amounts of net energy for gain (9.5 and 9.4 vs. 9.4 Mcal/d) and CP (1.17, 1.15 vs. 1.10 kg/d) as compared with control diet-fed heifers. The weight gain and skeletal growth of heifers were not different, but heifers limit fed at 80 and 90% of the control had improved feed efficiency. Heifers limit fed at 80 and 90% of ad libitum intake excreted 0.86 and 0.36 kg/d less dry matter, respectively, as compared with control diet-fed heifers, but all heifers excreted similar amounts of N and P. Limit feeding did not affect calf birth weight, dystocia, or lactation performance. Limit feeding gravid heifers improved feed efficiency and reduced manure dry matter excretion without negative effects on lactation performance.

Key words: heifers, limit feeding, growth, feed efficiency

INTRODUCTION

The goals of a dairy replacement management program are to rear heifers at a low economic and environmental cost without compromising future lactation per-

formance. To meet these objectives, gravid heifers are commonly fed diets containing low-cost, high-fiber forages (MidWest Plan Service, 2003), which are commensurate with the low energy requirement (NRC, 2001) of gravid replacement heifers. Feeding gravid heifers low-energy, high-fiber forages effectually controls caloric intake and helps minimize overconditioning at calving, which can be detrimental to lactation performance (Hoffman et al., 1996). However, caloric intake could also be controlled by limit feeding a more nutrient-dense diet. Controlling caloric intake through limit feeding may also reduce feed cost and nutrient excretion, both of which are becoming of greater concern in the dairy industry. Driedger and Loerch (1999) limit fed a diet containing 63.4% corn, as compared with feeding 69.0% forage ad libitum, to nonlactating dairy cows. Diets were formulated and fed to supply an equal intake of energy, protein, vitamins, and minerals. Limit feeding resulted in a 15.0% greater DM digestibility, a reduction in DM and N excretion, and a reduction in feed cost without compromising lactation performance. Lammers et al. (1999) used a limit-feeding strategy to control growth rates of prepubescent Holstein heifers and observed no negative carryover effects on first-lactation performance. Limit feeding of gravid heifers, as compared with prepubescent heifers, may yield greater economic and nutrient management benefits because gravid heifers have higher feed intakes (NRC, 2001) and excrete more manure DM (Wilkerson et al., 1997). Limit-feeding strategies have been used successfully with other livestock species. Species-appropriate animal performance has been observed in limit-fed beef cows (Loerch, 1996), ewes (Susin et al., 1995), and beef heifers (Wertz et al., 2001). The objective of this study was to investigate whether a limit-feeding regimen used on gravid Holstein heifers would have an effect on lactation performance.

MATERIALS AND METHODS

Design and Treatments

Fifty-four gravid Holstein heifers (464 ± 45 kg; 17.5 ± 1.4 mo) were managed in 9 pens containing 6 heifers per pen, with 3 replicate pens randomly assigned to 1

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Table 1. Ingredient and nutrient composition of treatment diets

Item	Treatment diet ¹			SEM ²
	C100	L90	L80	
Ingredient	—— (% of DM) ——			
Small-grain silage (oatlage)	47.0	39.6	30.5	—
Corn silage	47.3	40.7	32.2	—
Shelled corn	2.1	11.5	23.5	—
Soybean meal	2.0	6.4	11.7	—
Urea	0.51	0.52	0.51	—
Calcium carbonate	0.32	0.43	0.61	—
Sodium bicarbonate	0.11	0.14	0.19	—
Magnesium sulfate	0.39	0.43	0.49	—
Vitamin premix ³	0.18	0.20	0.22	—
Mineral premix ⁴	0.13	0.15	0.17	—
Nutrient composition ⁵				
DM	40.2	43.0	51.2	0.5
CP	11.3	12.7	14.2	0.2
NDF	47.3	41.8	35.6	0.5
NDF-CP	1.9	2.1	2.0	0.1
ADF	29.3	26.0	21.7	0.3
ADF-CP	0.62	0.64	0.61	0.01
IV NDFD, ⁶ % NDF	60.9	59.1	59.7	0.6
NFC	34.0	38.2	42.9	0.5
Ether extract	2.3	2.3	2.5	0.1
P	0.27	0.29	0.31	0.01
Ca	0.40	0.45	0.49	0.01
K	1.7	1.6	1.5	0.01
Mg	0.18	0.19	0.20	0.01
Ash	7.1	7.0	6.9	0.21
Energy calculations ⁷				
Total digestible nutrients	67.5	70.0	73.9	—
ME, Mcal/kg	2.46	2.55	2.69	—
NE _g , Mcal/kg	0.97	1.04	1.15	—
NE _m , Mcal/kg	1.41	1.48	1.57	—

¹C100 = Control heifers fed ad libitum; L90 = limited to 90.0% of intake; L80 = limited to 80.0% of intake.

²Includes sampling and laboratory error.

³Contained 2,200,000 IU/kg of vitamin A and 308,000 IU/kg of vitamin D.

⁴Contained 4.3% Zn, 4.3% Mn, 7,800 mg/kg of Cu, 830 mg/kg of I, 320 mg/kg of Co, 220 mg/kg of Se, 5,500,000 IU/kg of vitamin A, 1,375,000 IU/kg of vitamin D, and 18,700 IU/kg of vitamin E.

⁵All ingredients and nutrients are expressed on a DM basis unless otherwise specified.

⁶In vitro NDF digestibility after a 48-h incubation.

⁷Calculated according to NRC (2001).

of 3 diets in a randomized replicated pen design. A control diet (**C100**), based on NRC (2001) recommendations for a 450-kg heifer, containing 11.3% CP and 2.46 Mcal of ME/kg of DM was formulated for ad libitum feeding. Two treatment diets were formulated for limit feeding at 90 (**L90**) and 80% (**L80**) of the DMI of C100. The L90 and L80 diets contained 12.7 and 14.2% CP and 2.55 and 2.69 Mcal of ME, respectively. The L90 and L80 diets were formulated to provide similar daily intakes of CP, energy, vitamins, and minerals as compared with feeding C100 ad libitum. A description of ingredients and nutrient composition of the diets is presented in Table 1. Diets were fed as TMR once daily at 0800 h for 111 d. The amount of each experimental

diet offered and orts from C100 were recorded daily. The amount of experimental diet offered to heifers fed L90 and L80 was adjusted daily based on C100 intakes. Orts from L90 and L80 were negligible and were not recorded or sampled. Heifers were housed in 4.5 × 9.0 m pens with a 30-m² resting area bedded with sawdust and had access to 0.75 m of bunk space/heifer. Body weight and frame measurements were taken on d 1, 38, 78, and 111 of the experimental period. Duplicate BW were taken prior to feeding by weighing, removing heifers from the scale, and then immediately reweighing all heifers in a given replicated pen using a cattle chute (Real Tuff, Clearbrook, MN) fitted with an electronic scale (Tru-Test Inc., Mineral Wells, TX). Frame measurements included hip height, heart girth, and BCS (Wildman et al., 1982).

Blood was collected from each heifer via the jugular vein into serum separator tubes (BD Vacutainer Systems, Franklin Lakes, NJ) on d 60 of the experimental period. After collection, blood samples were immediately cooled and centrifuged at 1,074 × *g* for 20 min. Blood serum was evaluated for glucose, alkaline phosphatase, total protein, albumin, urea N, P, and Ca content (Marshfield Laboratories, Marshfield, WI). On d 30, 60, and 90 of the experimental period, each replicated pen of heifers was moved to a clean manure collection pen identical in size and configuration to their normal housing pen and fed the corresponding experimental diet. The manure collection pens were bedded with approximately 35 kg of clean wood shavings, evenly distributed over the concrete pen floor, and manure and urine was allowed to accumulate in the pen for 24 h. The sides of pens were bridged to eliminate cross-contamination of urine and feces between pens. After 24 h, heifers were returned to their original pen. All feces, urine, and bedding from the manure collection pen were weighed, vigorously mixed by hand, and sampled 3 times for nutrient analysis. Duplicate samples of wood shavings were taken on d 30, 60, and 90 for nutrient analysis.

A matrix of times was constructed between 0600 and 1800 h by 15-m increments, with 3 random times chosen daily, and the behavior of each heifer was observed at those times. The behavior of each heifer was recorded 3 times daily as a standing, lying, or eating event. Thirty observations of behavior were also made between 1800 and 0600 h. We observed that approximately 90% of heifers were recumbent, 5% were standing, and 5% were eating. Time spent in forced behavior because of barn cleaning, blood sampling, and weighing was not recorded; therefore, behavioral data represent an estimate of voluntary behavior of the heifers. A total of 18,102 heifer behavioral observations were made. Daily weighted averages of heifer behavior were constructed

from observations collected between 0600 and 1800 h and a constant 90% lying, 5% standing, and 5% eating between 1800 and 0600 h. The purpose of the behavioral observations was to investigate possible relative treatment differences in animal behavior and not define heifer behavior on a congruent time basis.

After the heifer growth phase of the experiment, 5 nonpregnant heifers were culled from the experiment; the remaining heifers were transported to the Arlington Agricultural Research Station (Arlington, WI) and fed a common diet for approximately 75 d prepartum. Heifers calved in individual maternity pens, where the dystocia index (Cole et al., 2005), calf BW, and postpartum BW were recorded. The resulting primiparous cows were housed in tie stalls and milked twice daily, with daily milk weight recorded for 150 d. Three heifers did not complete the lactation phase of the experiment because of death ($n = 1$) or severe trauma ($n = 2$) related to calving. Forty-six cows completed the lactation phase of the experiment, with 15, 16, and 15 cows remaining assigned to C100, L90, and L80, respectively.

Milk fat and protein were evaluated monthly by near infrared spectroscopy (Ag Source, Verona, WI). Primiparous cows were fed a single diet as a TMR formulated to requirements (NRC, 2001) for a 550-kg cow producing 40 kg of milk containing 3.8% fat. The nutrient composition of the lactation diet was not evaluated or recorded. All animal handling and experimental procedures were approved by the Research Animal Resource Committee at the University of Wisconsin–Madison.

Sampling and Statistical Analysis

Experimental diets during the heifer growth phase of the experiment were sampled each week, immediately dried at 55°C for 48 h, and then ground through a Wiley mill (Arthur H. Thomas, Philadelphia, PA) fit with a 1-mm screen. The final DM determination was conducted using AOAC procedures (AOAC, 1990). Samples were evaluated for CP, fat, ash (AOAC, 1990), ADF, and NDF (Goering and Van Soest, 1970), with modifications by Mertens (1992). The ADF-CP and NDF-CP contents of the diets were ascertained by an initial nonsequential determination of ADF or NDF using the aforementioned procedures, with the exception that no sodium sulfite was used in the NDF procedure to avoid removal of CP from the NDF. Determination of CP in the ADF and NDF residues was derived by Kjeldahl procedures (AOAC, 1990). Calcium, K, and Mg were determined using atomic absorption spectroscopy (GBC Scientific, Gilberts, IL) and P by colorimetric methods (Coleman Instruments, Inc., Maywood, IL). The total digestible nutrients, ME, NE_G , and NE_M of experimental diets

were estimated using summative equations (NRC, 2001).

The DM, N, and P contents of pen manure (urine plus feces plus bedding) samples were determined by the aforementioned methods, with the exception that N was determined prior to sample drying to minimize N volatilization. We were unable to control N volatilization during the collection phase; therefore, N excretion in manure and body N retention data are apparent. The DM, N, and P content of the wood shavings used for bedding were determined by the aforementioned procedures, and fecal DM, N, and P excretions were calculated by the difference. The mean pen N and P intake for 2 d prior to fecal collection was used to estimate apparent N and P retention.

For statistical analysis, the experimental unit was the pen replicate rather than the individual heifer. Intake, growth, blood, nutrient excretion, and parturition data were compressed to treatment $\times$ pen replicate means and analyzed using the GLM procedures of SAS (SAS Institute, 1999). During lactation, cows were fed and managed individually, but lactation data were likewise compressed to pen replicate means to retain the effect of pen on lactation performance during the growth phase. Thus, pen replicate was retained as the experimental unit for statistical evaluation of the lactation data. Growth, parturition, and lactation data were determined by the model

$$Y_{ij} = \mu + D_i + R_j + e_{ij}$$

where μ is the overall mean, D_i is the effect of diet ($i = 1$ to 3), R_j is the effect of the replicate ($j = 1$ to 3), and e_{ij} is the random residual. First-order (linear) and second-order (quadratic) contrasts and a contrast of C100 vs. L90 and L80 were planned. No quadratic relationships were detected for any measurement. Behavioral data were analyzed as repeated measurements in a split-plot arrangement (Littell et al., 1991). The model included treatment, pen within treatment, and week as independent variables. The effects of treatments were tested using pen nested within treatment as the error term. Significance was declared for $P \leq 0.10$.

RESULTS AND DISCUSSION

Nutrient compositions of the diets are presented in Table 1. Diets were not designed to be isocaloric or isonitrogenous on a percentage of DM basis. As compared with C100, the CP and ME contents of L90 and L80 were increased to offset the decrease in feed offered, facilitating the pretrial design of all experimental diets providing similar daily intakes of protein and energy

Table 2. Effect of limit feeding on the nutrient and energy intake of replacement heifers

Item	Treatment ¹			SEM	Effect (<i>P</i> >)		
	C100	L90	L80		Treatment	Linear	C vs. L ²
Nutrient intake							
DM, kg/d	9.66	9.03	8.30	0.18	0.01	0.003	0.006
CP, kg/d	1.10	1.15	1.17	0.01	0.07	0.03	0.03
ADF, kg/d	2.83	2.34	1.80	0.05	0.0002	0.0001	0.0001
NDF, kg/d	4.56	3.76	2.95	0.07	0.0003	0.0001	0.0002
Digestible NDF, ³ kg/d	2.77	2.22	1.76	0.04	0.0002	0.0001	0.0001
NFC, kg/d	3.29	3.45	3.56	0.08	—	0.07	0.09
Fat, kg/d	0.22	0.21	0.21	0.01	—	—	—
Ash, kg/d	0.68	0.63	0.56	0.01	0.004	0.002	0.003
P, g/d	25.9	26.3	26.3	0.5	—	—	—
Ca, g/d	39.0	40.9	40.4	0.5	—	—	0.08
K, g/d	160.3	143.9	121.7	2.3	0.001	0.000	0.001
Mg, g/d	17.7	17.3	16.3	0.5	0.03	0.02	0.05
Energy intake ⁴							
TDN, kg/d	6.53	6.30	6.12	0.14	—	0.08	0.09
ME, Mcal/d	23.8	23.0	22.3	0.4	—	0.07	0.09
NE _G , Mcal/d	9.4	9.4	9.5	0.2	—	—	—
NE _M , Mcal/d	13.7	13.3	13.0	0.2	—	—	—

¹C100 = Control heifers fed ad libitum; L90 = limited to 90.0% of intake; L80 = limited to 80.0% of intake.

Treatment means expressed on a per heifer basis.

²C = Control (C100) vs. L = limited (L90, L80). Entries without values are not significant (*P* > 0.10).

³In vitro digestible NDF as determined by a 48-h incubation.

⁴TDN = total digestible nutrients.

to the heifers. Dietary NDF decreased by 5.5 and 11.7 percentage units for L90 and L80, respectively, as compared with C100, to accommodate increasing protein and energy density. Concentrations of Ca, P, and Mg were increased in the limit-fed diets, again to offset decreases in feed offered in the treatment regimen, but K decreased in the limit-fed diets. Because forages generally contain higher levels of K as compared with grains (NRC, 2001), C100 logically contained more K because it contained more forage; however, all treatment diets were in excess of K for 450-kg gravid heifers.

Nutrient and energy intakes of heifers fed the experimental diets are presented in Table 2. There was a linear decrease (*P* = 0.003) in DMI, which was in direct relationship to the limit-feeding strategy of the trial (C100 vs. L90 vs. L80). Trial design, diet formulation, and DM limitations schemes did not result in isonitrogenous intakes. Compared with C100, the intake of CP increased linearly (*P* = 0.03) as the DM offered decreased. Heifers fed L90 and L80 consumed 50 and 70 g more CP/d than did heifers fed C100. Although CP intakes were different between heifers fed C100, L90, and L80, the differences in CP intake were numerically small relative to CP requirements. The estimated dietary requirement for a 450-kg Holstein heifer with a target gain of 800 g/d is 1,088 g/d of CP (NRC, 2001). The experimental diets (C100, L90, and L80) supplied 1,100, 1,150 and 1,170 g of CP/d, meeting NRC (2001) requirements for dietary CP. Likewise, the calculated

(NRC, 2001) MP requirement of a 450-kg Holstein heifer with a target gain of 800 g/d is approximately 635 g/d. Mean MP supplied by the experimental diets was 875 g/d (NRC, 2001), suggesting that the MP supply in all diets was adequate.

Limiting DMI of a more nutrient-dense diet resulted in heifers consuming (*P* = 0.0002) less NDF and more (*P* = 0.09) NFC. Minor differences in Ca, P, K, and Mg intake were observed, but mineral intakes were in excess of NRC (2001) requirements. Limit feeding resulted in linear decreases (*P* = 0.08) in daily total digestible nutrients and ME intakes by heifers, but intakes of NE_G and NE_M were not different. This nuance is explained by the mechanics of the net energy system (NRC, 1981) because the ability of a diet to promote energy retention is higher in a high-energy concentrate diet as compared with a low-energy forage-based diet because of differentials in gaseous, heat, urine, and surface energy losses (NRC, 1981). Based on retained energy potential (NE_G and NE_M), heifers fed L90 and L80 consumed similar amounts of energy as compared with heifers fed C100.

Effects of limit feeding on the body size and growth of gravid Holstein heifers are presented in Table 3. There were no differences in initial or final BW, hip height, heart girth, or BCS of heifers. Likewise, there were no differences in average daily gain, hip height gain, heart girth gain, or BCS gain in heifers that were limit fed as compared with heifers fed C100. These

Table 3. Effect of limit feeding on the body size and growth of replacement heifers

Item	Treatment ¹				Effect ² (<i>P</i> <)		
	C100	L90	L80	SEM	Treatment	Linear	C vs. L
Initial							
Weight, kg	469.9	463.1	458.6	9.5	—	—	—
Hip height, cm	137.7	138.7	139.4	0.8	—	—	—
Heart girth, cm	186.2	181.1	184.2	2.8	—	—	—
BCS	3.1	3.0	2.9	0.1	—	—	—
Final							
Weight, kg	553.4	559.7	552.0	8.6	—	—	—
Hip height, kg	142.2	143.0	143.3	0.8	—	—	—
Heart girth, kg	202.2	202.7	201.2	0.8	—	—	—
BCS	3.2	3.2	3.2	0.1	—	—	—
Growth							
ADG, g/d	753.6	871.7	835.4	63.6	—	—	—
Variance of gain, ³ g/d	99.9	104.4	122.6	13.6	—	—	—
Hip height, cm/111 d	4.6	4.3	3.8	0.8	—	—	—
Heart girth, cm/111 d	16.0	21.6	17.0	3.0	—	—	—
BCS, units/111 d	0.1	0.2	0.2	0.1	—	—	—
Feed efficiency, kg of DM/kg of gain	12.8	10.4	9.9	0.9	—	0.01	0.09

¹C100 = Control heifers fed ad libitum; L90 = limited to 90.0% of intake; L80 = limited to 80.0% of intake. Treatment means expressed on a per heifer basis.

²C = Control (C100) vs. L = limited (L90, L80). Entries without values are not significant (*P* > 0.10).

³Calculated as $\sqrt{(\text{mean pen average daily gain} - \text{individual heifer average daily gain})^2}$.

results are similar to the observations of Loerch (1990), who implemented a limit-feeding regimen with steers with experimental diets providing equal daily intakes of protein and energy. Similar to our observations, Loerch (1990) observed no appreciable difference in the growth of steers, but feed efficiency was improved by 10.0 and 43.0% by limit feeding more nutrient-dense diets. Likewise, we observed a similar improvement in feed efficiency through limit feeding. Feed efficiency was improved (*P* = 0.01) by 23.7 and 28.9% for heifers fed L90 and L80, respectively, as compared with heifers fed C100. These data are similar to other observed improvements in feed efficiency when growing animals are limit fed (Hicks et al., 1990; Loerch, 1990).

Effects of limit feeding on apparent manure excretion and apparent nutrient retention are presented in Table 4. Pen manure collection methods resulted in appropriate daily manure DM and N excretion values, similar to those predicted by Wilkerson et al. (1997) for heifers weighing approximately 450 kg. There was a linear decrease (*P* = 0.10) in manure DM excretion because the amount of dietary DM offered was limited. Manure DM excretion was reduced by 12.9 and 34.6% for heifers fed L90 and L80, respectively, as compared with heifers fed C100. Driedger and Loerch (1999) observed a 67.8% reduction in fecal DM excretion when feeding a grain-based diet at a 30% DMI restriction, as compared with feeding nonlactating cows a high-forage diet ad libitum. The same authors also observed an increased efficiency of N utilization when nonlactating cows were limit fed. In this study, however, no enhancement in N efficiency

was observed in limited-fed heifers. We observed similar N intakes, apparent N excretions, and apparent N retentions in all diets (Table 4). However, these data should be interpreted with some caution because pen manure collection methods did not account for N volatilization during the 24-h collection period. Therefore, our methods likely underestimated N excretion and correspondingly overestimated N retention. This explanation appears valid because N retentions in this experiment were approximately 10 g/d higher than predicted by the NRC (2001) and were approximately 10 g/d higher than N retentions observed in other N balance studies conducted in our laboratory on Holstein heifers of similar weight (Hoffman et al., 2001). The intent of this study, however, was not to provide precise inferences on N retention in gravid heifers, which have previously been defined (Hoffman et al., 2001; NRC, 2001). We did not hypothesize a major change in N excretion or retention but did want to examine possible gross differences in N excretion among treatment diets because N utilization can be influenced by a number of dietary factors. That metabolic fecal N is positively related to DMI has been demonstrated (Hironaka et al., 1970). In addition, the carbohydrate-to-N ratio in the diet has been demonstrated to influence microbial N production in the rumen of heifers (Gabler and Heinrichs, 2003). Also, differences in protein type and degradability can shift N excretion between feces and urine in growing animals (Devant et al., 2000; Marini and Van Amburgh, 2003). Any or all of the aforementioned factors associated with

Table 4. Effect of limit feeding on manure excretion and blood profiles of replacement heifers

Item	Treatment ¹			SEM	Effect (<i>P</i> <)		
	C100	L90	L80		Treatment	Linear	C vs. L ²
Intake							
DM, kg/d	10.0	9.1	7.8	0.2	0.002	0.001	0.002
N, g/d	182.9	181.4	181.8	5.3	—	—	—
P, g/d	27.2	26.1	27.2	0.6	—	—	—
Apparent excretion ³							
DM, kg/d	3.5	3.1	2.6	0.3	—	0.10	0.10
N, g/d	140.2	141.7	146.8	9.7	—	—	—
P, g/d	24.7	25.2	24.3	2.3	—	—	—
Apparent retention ⁴							
N, g/d	42.4	39.5	35.2	11.9	—	—	—
P, g/d	2.5	1.1	2.8	2.3	—	—	—

¹C100 = Control heifers fed ad libitum; L90 = limited to 90.0% of intake; L80 = limited to 80.0% of intake.

Treatment means expressed on a per heifer basis.

²C = Control (C100) vs. L = limited (L90, L80). Entries without values are not significant (*P* > 0.10).

³Does not account for potential N volatilization during the 24-h collection period.

⁴Apparent retention (g/d) = Intake minus apparent excretion.

N utilization were present to some degree in our experimental diets, but nutrient excretion data suggest that no major changes in N utilization had occurred as a result of limit feeding gravid heifers.

Intake, apparent excretion, and apparent retention of P in heifers fed the experimental diets are also presented in Table 4. Heifers fed L90 and L80 consumed the same amount of P during the collection periods as heifers fed C100, and as a result, the excretion and retention of P of limit-fed heifers was not different from heifers fed C100. Because intake of P by the heifers was similar and P excretion is primarily influenced by P intake (Horst, 1986), no appreciable differences in P excretion and retention would be expected. These data, in combination with DM and N excretion data, are important because limit feeding DM to gravid heifers with diets that provide similar intakes of N and P effectively reduced the amount (DM) of manure produced but did not alter N or P excretion or retention. In total, the

data suggest that limit feeding did not alter N and P utilization in gravid replacement heifers.

The effects of limit feeding on blood profiles of gravid dairy replacement heifers are presented in Table 5. Limit feeding had no effect on blood glucose, total protein, albumin, P, and Ca but did increase BUN (*P* = 0.06) in gravid heifers. The linear increase (*P* = 0.07) in BUN likely corresponds to the increase in dietary CP intake (Table 2) in heifers fed L90 and L80. Studies have demonstrated a positive relationship between dietary CP intake and BUN in growing heifers (Hoffman et al., 2001; Marini and Van Amburgh, 2003).

Effects of limit feeding on the voluntary behavior of gravid heifers are presented in Table 6. Time spent eating, lying, and standing observed for gravid heifers fed C100 was similar to the behavioral data of lactating dairy cows (Albright, 1993). Because DMI was limited, a linear reduction (*P* = 0.0001) in the percentage of time spent eating was observed. Limit-fed heifers spent less

Table 5. Effect of limit feeding on blood profiles of replacement heifers

Item	Treatment ¹			SEM	Effect (<i>P</i> <)		
	C100	L90	L80		Treatment	Linear	C vs. L ²
Glucose, mg/dL	63.4	61.2	62.7	1.0	—	—	—
Alkaline phosphatase, units/L	130.9	156.3	167.3	7.4	0.06	0.03	0.03
Total protein, g/dL	6.8	7.0	6.9	0.1	—	—	—
Albumin, g/dL	3.8	3.8	3.8	0.1	—	—	—
BUN, mg/dL	15.2	16.9	17.2	0.6	—	0.07	0.06
P, mg/dL	5.1	5.4	5.9	0.3	—	—	—
Ca, mg/dL	9.9	9.9	9.7	0.1	—	—	—

¹C100 = Control heifers fed ad libitum; L90 = limited to 90.0% of intake; L80 = limited to 80.0% of intake. Treatment means expressed on a per heifer basis.

²C = Control (C100) vs. L = limited (L90, L80). Entries without values are not significant (*P* > 0.10).

Table 6. Effect of limit feeding on voluntary behavior of replacement heifers¹

Item	Treatment ²				Effect ³ (<i>P</i> <)		
	C100	L90	L80	SEM	Treatment	Linear	Trt × week
Eating, % of time	19.3	15.7	10.3	1.6	0.05	0.04	—
Standing, % of time	19.6	24.4	32.9	2.2	0.01	0.02	—
Lying, % of time	60.9	59.8	56.7	1.2	—	0.01	—
Vocalization, % of time	0.02	0.04	1.10	0.3	—	—	0.03
Eating, h/d	2.3	1.9	1.2	0.2	0.05	0.04	—
Standing, h/d	4.7	5.8	7.9	0.5	0.01	0.02	—
Nonrecumbent total, h/d	7.0	7.7	9.1	0.2	0.02	0.02	—
Lying, h/d	14.6	14.4	13.6	0.3	—	0.01	—

¹Time associated with involuntary behavior such as barn cleaning, blood sampling, and so on was not recorded; therefore, the percentage of time and hours of time will not equal 100 and 24, respectively.

²C100 = Control heifers fed ad libitum; L90 = limited to 90.0% of intake, L80 = limited to 80% of intake. Treatment means expressed on a per heifer basis.

³Entries without values are not significant (*P* > 0.10). Trt = treatment.

time lying (*P* = 0.0001) as compared with heifers fed C100. However, the primary compensatory change in voluntary behavior of the limit-fed heifers was to spend more time (*P* < 0.0001) standing (without eating). Heifers fed L80 spent an additional 3.2 h standing without eating, as compared with heifers fed C100. Limit feeding increased total nonrecumbent time by 0.7 and 2.1 h/d for heifers fed L90 and L80, respectively, as compared with heifers fed C100. When heifers are limit fed, the shift in behavior toward more total nonrecumbent time is of some concern, because greater time standing has been associated with a higher incidence of hoof disease in lactating dairy cows (Cook et al., 2004). Although not specifically evaluated, no lameness in the heifers was observed, but potential effects of increased standing time on hoof disease should be monitored in future

experiments. Heifers fed L80 vocalized 1.10% of time, but this time was not different from heifers fed C100 or L90. Vocalization was primarily confined to times just prior to feeding. However, a significant time by treatment interaction (*P* = 0.03) was observed for vocalization. Vocalization (data not shown) occurred in the first 5 wk after treatment allocation to L80 and subsided to negligible levels thereafter.

Effects on parturition and 150-d first-lactation milk yield of limit feeding gravid replacement heifers are presented in Table 7. Limit feeding heifers had no effect on dystocia, calf BW, or postpartum BW. Limit feeding also had no effect on milk yield, milk fat, or milk protein percentages from 0 to 150 DIM. Correspondingly, fat yield, protein yield, and yield of 3.5% FCM by primiparous cows were not affected when cows were limit fed

Table 7. Effect of limit feeding gravid replacement heifers on parturition and first-lactation milk production

Item	Treatment ¹				Effect ² (<i>P</i> <)			
	C100	L90	L80	SEM	Treatment	Linear	C vs. L	Trt × month ³
Parturition								
Dystocia index ⁴	2.2	2.1	1.9	0.3	—	—	—	NA
Calf BW, kg	41.5	42.4	43.2	1.4	—	—	—	NA
Postpartum BW, kg	562.7	565.9	579.5	9.5	—	—	—	NA
Lactation performance (0 to 150 DIM)								
Milk yield, kg/d	30.6	30.7	32.2	0.8	—	—	—	—
Milk fat, %	3.89	3.74	3.68	0.09	—	—	—	—
Milk fat, kg/d	1.17	1.13	1.17	0.03	—	—	—	—
3.5% FCM, kg/d	32.3	31.6	32.9	0.7	—	—	—	—
Milk protein, %	2.87	2.85	2.89	0.03	—	—	—	—
Milk protein, kg/d	0.88	0.87	0.92	0.02	—	—	—	—
3.5% FCM, kg/150 d	4,883.6	4,805.9	4,960.0	50.0	—	—	—	NA

¹C100 = Control heifers fed ad libitum; L90 = limited to 90.0% of intake; L80 = limited to 80.0% of intake.

Treatment means expressed as least squares means on a per heifer basis.

²C = Control (C100) vs. L = limited (L90, L80). Entries without values are not significant (*P* > 0.10).

³Trt = treatment; NA = not applicable.

⁴Dystocia index: 1 = no problem; 2 = slight problem; 3 = needed assistance; 4 = considerable force; and 5 = extremely difficult.

as heifers. The data suggest that limit feeding of gravid replacement heifers does not result in any carryover effect on milk production during the first 150 d of first lactation.

Comparative literature evaluating the effects of limit feeding of dairy heifers on subsequent lactation performance is limited. The results of Lammers et al. (1999) indicated that controlling prepubertal growth rates by limiting DMI to prepubertal heifers had no effect on first-lactation performance. Similarly, lactation performance was not diminished when multiparous nonlactating dairy cows were supplied with equal amounts of energy, protein, vitamins, and minerals prior to parturition in diets offered either restricted or ad libitum (Driedger and Loerch, 1999). Our results and those in the supporting literature suggest no carryover effects on subsequent lactation performance of limiting the DMI of heifers prior to parturition. However, because of the limited number of trials conducted to date, the effects of limit feeding heifers on future lactation performance observed in this trial should be considered preliminary.

CONCLUSIONS

Limit feeding is not a new concept for feeding livestock, but the practice is not often implemented on commercial dairy farms or custom heifer-rearing operations. Data from this experiment suggest that limit feeding more nutrient-dense diets to gravid dairy heifers may be an equally effective feeding management strategy to control caloric intake, as compared with feeding high-fiber forage diets. Limit feeding resulted in less total consumption of DM and increased feed efficiency, which could reduce the feed cost. In addition, no adverse effects on growth or subsequent lactation performance were observed when gravid heifers were limit fed more nutrient-dense diets. Although decreased manure DM excretion was observed, which is of benefit, no practical advantages associated with N and P excretion or utilization were observed. Additional investigations are warranted to investigate strategies to improve N and P utilization in limit-fed heifers. Finally, limit feeding does cause behavioral changes in gravid heifers and may not be advisable in all management situations, especially in situations in which bunk space and animal comfort may be compromised or in which edible bedding materials are required in the management system.

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REFERENCES

- Albright, J. L. 1993. Feeding behavior of dairy cattle. *J. Dairy Sci.* 76:485–498.
- Association of Official Analytical Chemists. 1990. *Official Methods of Analysis*. 15th ed. AOAC, Arlington, VA.
- Cole, J. B., R. C. Goodling, G. R. Wiggans, and P. M. VanRaden. 2005. Genetic evaluation of calving ease for Brown Swiss and Jersey bulls from purebred and crossbred calvings. *J. Dairy Sci.* 88:1529–1539.
- Cook, N. B., T. B. Bennett, and K. V. Nordlund. 2004. Effect of free stall surface on daily activity patterns in dairy cows with relevance to lameness prevalence. *J. Dairy Sci.* 87:2912–2922.
- Devant, M., A. Ferret, J. Gass, S. Calsamiglia, and R. Casals. 2000. Effects of protein concentration and degradability on performance, ruminal fermentation, and nitrogen metabolism in rapidly growing heifers fed high concentrate diets from 100 to 230 kg body weight. *J. Anim. Sci.* 78:1667–1676.
- Driedger, L. J., and S. C. Loerch. 1999. Limit-feeding corn as an alternative to hay reduces manure and nutrient output by Holstein cows. *J. Anim. Sci.* 77:967–972.
- Gabler, M. T., and A. J. Heinrichs. 2003. Altering soluble and potentially rumen degradable protein for prepubertal Holstein heifers. *J. Dairy Sci.* 86:2122–2130.
- Goering, H. K., and P. J. Van Soest. 1970. Pages 8–11 in *Forage Fiber Analyses (Apparatus, Reagents, Procedures, and Some Applications)*. Agric. Handbook No. 379. ARS-USDA, Washington, DC.
- Hicks, R. B., F. N. Owens, D. R. Gill, J. J. Martin, and C. A. Strasias. 1990. Effects of a controlled feed intake on performance and carcass characteristics of feedlot steers and heifers. *J. Anim. Sci.* 68:233–244.
- Hironaka, R. C., C. B. Bailey, and G. C. Kozub. 1970. Metabolic fecal nitrogen in ruminants estimated from dry matter excretion. *Can. J. Anim. Sci.* 50:55–59.
- Hoffman, P. C., N. M. Brehm, S. G. Price, and A. Prill-Adams. 1996. Effect of accelerated postpubertal growth and early calving on lactation performance of primiparous Holstein heifers. *J. Dairy Sci.* 79:2024–2031.
- Hoffman, P. C., N. M. Esser, L. M. Bauman, S. L. Denzine, M. Engstrom, and H. Chester-Jones. 2001. Effect of dietary protein on growth and nitrogen balance of Holstein heifers. *J. Dairy Sci.* 84:843–847.
- Horst, R. L. 1986. Regulation of calcium and phosphorus homeostasis in the dairy cow. *J. Dairy Sci.* 69:604–616.
- Lammers, B. P., A. J. Heinrichs, and R. S. Kensinger. 1999. The effects of accelerated growth rates and estrogen implants in prepubertal Holstein heifers on estimates of mammary development and subsequent reproduction and milk production. *J. Dairy Sci.* 82:1753–1764.
- Littell, R. C., R. J. Freund, and P. C. Spector. 1991. *SAS System for Linear Models*, 3rd ed. SAS Inst., Inc., Cary, NC.
- Loerch, S. C. 1990. Effects of feeding growing cattle high-concentrate diets at a restricted intake on feedlot performance. *J. Anim. Sci.* 68:3086–3095.
- Loerch, S. C. 1996. Limit-feeding corn as an alternative to hay for gestating beef cows. *J. Anim. Sci.* 74:1211–1216.
- Marini, J. C., and M. E. Van Amburgh. 2003. Nitrogen metabolism and recycling in Holstein heifers. *J. Anim. Sci.* 81:545–552.
- Mertens, D. R. 1992. Critical conditions in determining detergent fibers. Page C-1 in *Proc. Natl. Forage Testing Assoc. Forage Anal. Workshop*, Denver, CO. Natl. Forage Testing Assoc., Omaha, NE.
- MidWest Plan Service. 2003. *Raising Dairy Replacements*. MidWest Plan Service, Ames, IA.
- NRC. 1981. *Nutritional Energetics of Domestic Animals*. Natl. Acad. Press, Washington, DC.
- NRC. 2001. *Nutrient Requirements for Dairy Cattle*. 7th rev. ed. Natl. Acad. Sci., Washington, DC.

- SAS Institute. 1999. SAS User's Guide: Statistics, Version 8 Edition. SAS Inst., Inc., Cary, NC.
- Susin, I., S. C. Loerch, K. E. McClure, and M. L. Day. 1995. Effects of limit-feeding a high grain diet on puberty and reproductive performance of ewes. *J. Anim. Sci.* 73:3206–3215.
- Wertz, A. E., L. L. Berger, D. B. Faulkner, and T. G. Nash. 2001. Intake restriction strategies and sources of energy and protein during the growing period affect nutrient disappearance, feedlot performance, and carcass characteristics of crossbred heifers. *J. Anim. Sci.* 79:1598–1610.
- Wildman, E. E., G. M. Jones, P. E. Wagner, R. L. Boman, H. F. Troutt, and T. N. Lesch. 1982. A dairy cow body condition scoring system and its relationship to selected production characteristics. *J. Dairy Sci.* 65:495–501.
- Wilkerson, V. A., D. R. Mertens, and D. P. Casper. 1997. Prediction of excretion of manure and nitrogen by Holstein dairy cattle. *J. Dairy Sci.* 80:3193–3204.