Designing a replacement heifer rearing strategy: Effects of growth profile on performance of Norwegian Red heifers and cows

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ABSTRACT

The primary objective of this study was to design a growth profile from 3 mo through puberty to insemination that allows heifers to enter the milking herd at 22 mo of age without impairing milk production over 3 lactations compared with the current rearing practice leading to an age at first calving of 26 mo. Eighty heifers born into the Norwegian University of Life Sciences herd, 40 each from yr 2010 and 2011, were randomly assigned according to birth order either to a high or low intake energy treatment. Each energy group was further subdivided into 2 protein groups, 1 fed according to requirements and 1 fed 10% excess protein, to ensure that metabolizable protein supply would meet the requirements for rapidly growing bone and muscle of today's genetically improved Norwegian Red heifer. Utilizing growth rate and feed composition the energy and protein supply was regulated with roughage quality in a diet containing 1 kg/d of concentrate of 2 qualities. Average daily gain from 3 mo to confirmed pregnancy ranged from 900 to 1,000 g/d among high-energy animals, with high protein-fed animals growing the fastest. Growth rates for low energy animals were <700 g/d. From confirmed pregnancy to first calving, all animals were fed only grass silage to sustain an average daily gain <500 (high energy) or >600 g/d (low energy), excluding fetal and gravid uterus weight, and they reached a postcalving weight of 530 (high energy) to 570 kg (low energy) with body condition score ranging from 3.42 to 3.93 at calving. We have shown that heifers fed a high-energy treatment with the required amount of protein from 3 mo of age to successful insemination combined with an average daily gain of ~500 g/d throughout pregnancy will calve at 22 mo without becoming over-conditioned at calving and without impairing performance over 3 lactations. We recommend reducing rearing time by 4 mo, planning for an age at first calving of 22 mo of age. This rearing

practice would also improve energy efficiency during the heifer rearing period.

Key words: average daily gain, heifer feeding, dairy cow, lifetime yield

INTRODUCTION

Replacement heifer rearing is a high-cost enterprise involving capital, land, and labor, and it represents a major cost to the dairy farmer (Heinrichs, 1993; Gabler et al., 2000; Heinrichs et al., 2013). Rearing practices should thus be evidence-based and designed to maximize the lifetime performance of the animals (Brickell et al., 2009). Our recent field study indicated that current rearing practices do not meet the requirements of today's genetically improved Norwegian Red (NR) heifer (Storli et al., 2017). Consequently, replacement heifer growth is too slow from birth to successful insemination, which in turn means that heifers on the average Norwegian dairy farm enter the milking herd unnecessarily late. A means to reduce heifers' unproductive period would be a heifer growth profile that allows animals to reach puberty and sexual maturity at an early age and, subsequently, breed and calve without compromising future production. Designing such a model implies decisions on what age heifers should reach puberty and when they should be bred to attain a desired age at first calving (AFC). Puberty is a function of weight rather than the age of the animal (Wathes et al., 2014), and heifers of the dual-purpose NR breed reach puberty at around 280 kg (TINE Rådgiving, 2017). Thus, heifer calves must grow fast to reach puberty and sexual maturity in order for them to conceive at an early age (Drackley, 2008); however, what defines fast, or a high ADG, seems to vary among breeds (Hohenboken et al., 1995). In addition, animal growth rate and size will increase from the continuous genetic improvement of economically important traits attained through years of selection and breeding, in particular for increased milk yield (Ahlborn and Dempfle, 1992; Pryce and Harris, 2006).

We hypothesized that NR heifers can be fed for a rapid weight gain (>900 g/d) from 3 mo of age to confirmed

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pregnancy and a moderate weight gain (~500 g/d) during pregnancy without becoming over-conditioned at calving and without compromising subsequent milk production. Accordingly, the primary objective of this study was to design a growth profile through puberty to insemination that would allow heifers to enter the milking herd at 22 mo of age without impairing milk production over 3 lactations compared with the current rearing practice leading to an AFC of 26 mo (Norwegian Dairy Herd Recording System, 2017). A second objective was to achieve the targeted growth profile utilizing locally produced feed resources, and thus a minimum of (import-based) concentrate.

MATERIALS AND METHODS

All procedures were performed in compliance with the regulatory requirements that apply to the use of animals for scientific purposes in Norway and were approved by the National Animal Research Authority (FOTS id 2955, reference no. 2010/203231).

Calf Feeding

Eighty NR heifer calves born into the Norwegian University of Life Sciences (Ås, Norway) herd during late fall and winter, 40 each from 2010 and 2011, with BW of 37.1 kg (SD 4.3), were all treated in the same way from birth to 3 mo of age. They were given 2 L of good quality colostrum, preferably from the dam, within the first 2 h and another 4 L within 6 h. Calves were held in separate pens for 10 d where they were offered up to 6 L of whole milk/d for 5 d (given 4 times/d). On d 6, 50:50 of whole milk and acidified whole milk (with formic acid to a pH of 4.9) was provided, and then acidified whole milk from d 7. Calves had free access to a commercial starter compound feed (Formel Mysli Start, Felleskjøpet Agri, Lillestrøm, Norway) that contained 19.6% CP, 4.6% crude fat, 5.9% ash, 26.5% starch, 11.5% NDF, 0.80% Ca, and 0.45% P. Hay and water were available at all times. From d 10 calves were moved to group housing and offered 7 L acidified whole milk/d from an automated feeder (Lely, Maassluis, the Netherlands). Starter concentrate (from the automated feeder) was gradually increased to a maximum of 1.3 kg/d at 49 d of age. Hay and silage were provided ad libitum, and water was available at all times. Calves were weaned over a period of 2 wk from 35 to 49 d of age, after which the starter concentrate was changed to Formel Kalv (Felleskjøpet Agri, Lillestrøm, Norway), because it contains more NDF and less starch than Formel Mysli Start (19% CP, 5.1% crude fat, 8.0% ash, 20.2% starch, 21.3% NDF, 1.0% Ca, and 0.7% P).

Feeding from 3 Mo of Age to Confirmed Pregnancy

From 3 mo of age to confirmed pregnancy, heifers were housed in a tiestall barn and fed a high energy (**HE**) or low energy (**LE**) diet designed to sustain an ADG of either ~950 or ~700 g/d. Half of the animals on both planes of nutrition were fed protein according to requirement (**LP**) and the other half were fed ~10% excess CP (**HP**) to ensure that MP supply would meet the requirements for rapidly growing bone and muscle of today's genetically improved NR heifer (Nielsen and Volden, 2011). This gave 4 dietary treatments, **HELP**, **HEHP**, **LELP**, and **LEHP**, with 20 animals in each group, to which the animals had been randomly assigned according to birth order. Fresh feed was offered twice daily. Individual feed intake was recorded a maximum of 4 d/wk (Table 1). Heifers fed HE diets had ad libitum (>10% or at least 1 kg ort) access to silage of adequate quality for the predetermined ADG. Heifers fed LE diets were fed a restricted diet (consisting of the same silage mixed with an average 35% wheat straw on a DM basis) calculated with the growing cattle application of TINE OptiFôr (Tine SA, Ås, Norway) at each change of roughage. This application is scientifically based on Norfor, the Nordic feed evaluation system (Volden et al., 2011). For a comparison of NorFor with other feed evaluation systems, see Lapierre et al. (2018). To avoid substitution differences between diets, all heifers were fed a fixed amount of 1 kg of concentrate mixture per d, with 1 of 2 custom-made qualities. Roughage quality varied because of the length of the trial and field of origin, with grass silage ensiled in round bales originating from grass of first, second, and third cuts comprising a total of 11 different field cuts. To avoid hunger stress, LE animals were offered 0.5 kg extra wheat straw if the daily ration had been consumed before the evening routine. Intake of extra wheat straw was recorded. An additional supply of vitamins and minerals was given throughout the experiment.

Before the experimental feeding started, 1 silage sample from each field cut was analyzed for chemical composition by near-infrared spectroscopy according to the NorFor package (Eurofins Agro, Moss, Norway), as were the 2 concentrates.

The BW was recorded at birth, bi-weekly to successful insemination, and then monthly until calving (Table 1). To aid the choice of roughage and to calculate the restricted LE diets, we used BW gain and the required energy density and protein level for the 4 groups together with composition of the 2 custom-made concentrates. Wheat straw was analyzed in-house for DM concentration, and the values were included when composing the LE diets. Moreover, BCS was recorded monthly, starting from 6 mo of age and until calving

Table 1. Description of data recorded during heifer rearing and during the 3 lactations, with number of records

Variable ¹	Frequency	n
3 mo to successful insemination		
BW, kg	Every other week	2,041
BCS, 1–5 scale	Monthly ²	722
Roughage intake, kg/d	Weekly mean ³	3,479
Concentrate intake, kg/d	Weekly mean ³	3,479
Silage sample	Weekly, pooled	11 ⁴
Straw sample	Weekly, pooled	5 ⁵
Concentrate sample	Weekly, pooled	2 ⁶
Progesterone, ng/mL	Weekly ⁷	1,198
Pregnancy		
BW, kg	Monthly	1,354
BCS, 1–5 scale	Monthly	819
First lactation		
BW, kg	Twice daily, automatic	9,304
BCS, 1–5 scale	Weekly	2,239
Silage intake, kg/d	Daily, automatic	12,900
Concentrate intake, kg/d	Daily, automatic	12,697
Silage sample	Weekly, pooled	34 ⁴
Concentrate sample	Weekly, pooled	4 ⁵
Test-day milk yield, kg	Daily, automatic	12,312
Fat content, %	Monthly	787
Protein content, %	Monthly	792
Lactose content, %	Monthly	792
Second and third lactation		
Test-day milk yield, kg of ECM, 2nd lactation	Monthly	365
Test-day milk yield, kg of ECM, 3rd lactation	Monthly	246

¹BCS 1–5 scale with increments of 0.25 (Gillund et al., 1999).

²From 6 mo of age.

³Based on 1–4 registrations/wk.

⁴Equals number of field cuts (heifers) or combinations of field cuts (cows).

⁵Consignments.

⁶High protein and low protein concentrates.

⁷Measured weekly from 220 kg to established cyclicity.

(Table 1). The Norwegian 1 to 5 scale BCS system is based on Edmonson et al. (1989) but calibrated for NR (Gillund et al., 1999) with steps of 0.25; one BCS score unit is equivalent to ~60 kg.

During the period when feed intake was recorded (3 mo to confirmed pregnancy), weekly silage samples were stored at –20°C. All samples were pooled per field cut (Table 1), and 1 subsample per field cut was analyzed each following summer by near-infrared spectroscopy (NorFor, Eurofins Agro). A second subsample was analyzed chemically in-house for DM, CP (expressed as Kjeldahl-nitrogen $\times$ 6.25), crude fat, and NDF. Pooled concentrate and pooled wheat straw samples, a total of 2 and 5, respectively (Table 1), were analyzed chemically in-house for DM, ash, CP, crude fat, total starch (only concentrates), and NDF. Dry matter in silage was determined by drying at 60°C for 24 h. Loss of volatiles during drying was corrected as described in Åkerlind et al. (2011). The analyses were conducted as follows: DM by heating at 103°C overnight, ash using ISO 5984 method (550°C for a minimum of 4 h), Kjeldahl-N using AOAC International Method 2001.11 according to

Thiex et al. (2002) with Kjeltex 2400/2460 Auto Sampler System (Foss Analytical, Hilleroed, Denmark) and CP estimated as $N \times 6.25$, total starch using AACCI Method 76–13.01 (Megazyme amyloglucosidase/ α -amylase method), NDF with an ANKOM220 fiber analyzer (ANKOM Technology, Fairport, NY) according to Mertens (2002) using sodium sulfite and α -amylase but not corrected for residual ash, and finally, crude fat using an Accelerated Solvent Extractor (ASE200; Dionex, Sunnyvale, CA). The average (SD) chemical composition of the forages and concentrates are described in Table 2.

To determine time of first estrus, progesterone was measured by ELISA (Monobind Inc., Lake Forest, CA) in weekly serum samples taken from all animals from 220 kg BW until established cyclicity (Table 1). First estrus was defined as the wk before the first sample with a progesterone level >2 ng/mL or the first wk of an established 3-wk cyclicity pattern. Breeding was initiated at 380 and 370 kg BW for the LE and HE groups, respectively, aiming for an average BW at successful insemination of 400 kg, or around 60% of

Table 2. Average (SD) chemical composition from the pre- and posttrial analyses and estimated feeding value of roughages and concentrates fed to heifers (weighted by number of feed days, g/kg of DM if not stated otherwise)¹

Variable ²	From 3 mo of age to successful insemination				Pregnancy ³
	Roughage ⁴		Concentrate ⁵		Roughage
	HE (SD)	LE (SD)	LP	HP	All (SD)
DM, g/kg	323 (40.8)	403 (48.9)	856	855	390 (35.5)
Ash	68 (8.0)	62 (6.5)	88	98	53 (11.9)
CP	140 (13.7)	107 (8.9)	155	233	113 (2.4)
Soluble CP, g/kg of CP	567 (37.8)	518 (36.8)	—	—	519 (79.8)
Crude fat	34 (2.9)	28 (1.6)	44	53	35 (2.7)
Starch	—	—	372	263	—
NDF	542 (18.5)	631 (25.8)	176	178	569 (34.3)
iNDF, g/kg of NDF	162 (40.2)	197 (23.4)	—	—	207 (50.1)
Sugar	38 (30.5)	29 (23.7)	—	—	27 (53.5)
MP	64	62	83	98	62
NE _L , MJ/kg of DM	7.0	6.5	7.6	7.7	6.6

¹Note that MP and NE_L are default NorFor values for growing cattle. To calculate the table values, a weighted (by feed day) average for the 3 roughages (high energy, low energy, and during pregnancy) and 2 concentrates (low protein and high protein) were used.

²iNDF = indigestible NDF; MP (expressed as AA absorbed in the small intestine) and NE_L are standard feed values at 8 kg of DMI calculated with TINE OptiFôr (Tine SA, Ås, Norway).

³Animals were not fed any concentrate during pregnancy.

⁴HE = high energy; LE = low energy; an average 35% straw included for LE animals.

⁵LP = low protein; HP = high protein.

mature BW, which is the current recommendation for the NR breed (TINE Rådgiving, 2017).

Feeding from Confirmed Pregnancy to First Calving

From confirmed pregnancy, heifers were managed together with the rest of the university herd and fed a roughage diet optimized to sustain an ADG of ~500 g/d, excluding fetal and gravid uterus weight, using the growing cattle application of TINE OptiFôr. All animals were fed the same diet ad libitum. To avoid competition for feed, all animals had feed bunk access at any time. No concentrate was offered, and feed intake was not monitored. Heifers were housed in a deep-straw barn except for the compulsory 8 wk on pasture during the grazing season. The only information recorded during pregnancy was BW and BCS (Table 1). Postcalving target weight was 560 kg, with a BCS of 3.5 to 3.75 at calving, and the diets were formulated for a mature BW of 600 kg.

Feeding of Primiparous Cows

About 3 wk before expected calving, animals were moved to a freestall barn. Cows were offered grass silages from different field cuts as described earlier. Silages were blended in a Cormall multimix 30 M3 (Cormall, Sønderborg, Denmark) to give a total of 34 combina-

tions aiming at a uniform nutrient content for both year-classes during lactation (Table 1). Grass silage from the different field cuts had been analyzed as described for heifers to aid choice of field cuts and to calculate concentrate supply. Animals were fed ad libitum (>10%orts), and silage intake was recorded automatically on a daily basis (Table 1) in bins with vertically moving gates, where automatic cow identification ensured each cow access (BioControl AS, Rakkestad, Norway). All animals were fed 0.5 kg/d commercial concentrate from 2 wk before expected calving and 1.0 kg/d in the last wk. Nutrient intakes during the second last and last wk before calving, entering feeding values from Table 3 into the growing cattle application of TINE OptiFôr were, respectively: DM 10.1 and 9.9 kg/d, NE_G 76.0 and 75.4 MJ/d, CP 1,486 and 1,483 g/d, NDF 4.8 and 4.6 kg/d, and MP 817 and 820 g/d. After calving, cows were given concentrates that met NorFor nutrient requirements (Nielsen and Volden, 2011) optimized for a milk yield of 7,500 kg ECM following a step-up scheme of 0.3 kg/d until a maximum of 7 to 9 kg/d depending on roughage quality and type of commercial concentrate. This level was kept until 120 DIM, after which it was linearly reduced by about 33 g/d. Concentrate intake was recorded automatically on a daily basis (Table 1).

Weekly samples were taken from the fed silage combinations, and the 4 commercial concentrates (Table 1), and stored at -20°C. Silage and concentrate samples

were pooled and subsamples analyzed chemically as described for heifers. In addition, fermentation products and ammonia-N in fresh silage samples were analyzed by Eurofins Agro. Nutrient composition, fermentation quality, and estimated feeding values of silage and concentrates are given as averages, weighted by number of DIM, in Table 3.

After calving, BW was recorded twice daily and BCS weekly (Table 1). All cows were inseminated on the second observed estrus after calving. Low fertility was the major reason for culling in first lactation, involving 5 and 6 cows from the LELP and LEHP groups, respectively, but only 1 from each of the HE groups. Milk-yield data in first lactation was recorded daily, whereas fat, protein, and lactose data were available on a monthly basis (Table 1).

Feeding in Second and Third Lactation

From second lactation, the animals were returned to the university herd without any restrictions or claims other than the monitoring of monthly milk yield and quality (Table 1). Monthly test-day ECM data from second and third lactation had been reported from the university herd to the Norwegian Dairy Herd Recording

System database, from where we extracted the cows' monthly ECM yield (Table 1).

Statistical Analyses

For a detailed description of models and calculations, see Supplemental File S1 (<https://doi.org/10.3168/jds.2020-18385>).

Heifers. Initially, we analyzed heifers' age and BW at 3 mo ($n = 80$ heifers), and in addition to age and BW, BCS at onset of puberty ($n = 79$), at successful insemination ($n = 79$), and at first calving ($n = 66$, animals that completed first lactation). Due to the recording pattern, BW and BCS curves had to be fitted per individual animal by random regressions, and individual values were predicted at the mentioned stages (Model 1; Supplemental File S1). These predicted values, together with heifers age at the same stages, were then exposed to a model containing fixed treatment group effects, with adjustments for the individual breeding value for milk production (milk index) included as a fixed covariate, and year-season as a fixed effect (Model 2; Supplemental File S1). From the treatment group effects we calculated least squares means (LSM) and main effects of energy, protein, and their interaction. Because preplanned ADG was different between treatments, fair comparisons of feed efficiency between 3 mo and onset of puberty, and from puberty to successful insemination could only be done on cumulative values, in this case on DMI, intake of NE_G , and CP. To obtain the cumulative values we first corrected individual values for a fixed effect of year-season and a random effect of field cut in a model also containing individual random regressions (in addition to fixed orthogonal polynomials; Model 3; Supplemental File S1). The resulting values were cumulated per animal in the 2 periods. These cumulated values were then averaged by day of feeding per period to obtain estimated nutrient intakes. Treatment group effects and derived statistics (LSM, main effects, and interaction) were obtained with Model 2 without the year-season effect. Moreover, we depicted BW and BCS development as LSM from 3 mo to confirmed pregnancy, and through first pregnancy. To this end we fitted a linear model with fixed orthogonal polynomials nested within treatment, adjusting for the milk index, fixed year-season of birth effects, and random effects of animal and field cut (the latter only from 3 mo to confirmed pregnancy; Models 4 and 5; Supplemental File S1). We used the same approach and model (Model 4; Supplemental File S1) to depict the trajectory of daily intake of DM, NE_G , NDF, CP, and MP from 3 mo to confirmed pregnancy.

Table 3. Average (SD) of chemical composition of nutrients, fermentation quality, and estimated feeding value of silage and concentrates fed to cows (weighted by number of DIM, g/kg of DM if not stated otherwise)¹

Variable ²	Silage (SD)	Concentrate (SD)
DM g/kg	343 (53.6)	854 (9.4)
Ash	73 (12.4)	78 (3.2)
OMD, %	76 (2.4)	—
CP	145 (13.0)	204 (22.8)
Soluble CP, g/kg of CP	619 (48.7)	—
Crude fat	—	55 (4.7)
Starch	—	312 (40.6)
NDF	483 (32.0)	172 (11.0)
iNDF, g/kg NDF	155 (29.0)	—
Sugar	91 (19.9)	—
Ammonia nitrogen, g of N/kg of N	70 (17.1)	—
Lactic acid	45 (9.3)	—
Acetic acid	8.1 (2.8)	—
Propionic acid	2.3 (1.9)	—
Butyric acid	0.0 (0.1)	—
Formic acid	6.3 (2.2)	—
Alcohol	7.7 (1.9)	—
pH	4.5 (0.2)	—
MP	85	139
NE_L , MJ/kg of DM	6.4	7.3

¹Results are from pre- and posttrial analyses.

²OMD = organic matter digestibility; iNDF = indigestible NDF; MP (expressed as AA absorbed in the small intestine) and NE_L are standard feed values at 20 kg of DMI calculated with TINE OptiFör (Tine SA, Ås, Norway); to calculate the table values, weighted (by DIM) averages for both silage and concentrate were used.

Primiparous Cows. Test-day milk yield, BW, BCS, DM, NE_L/DM (MJ/kg), and MP/NE_L (g/MJ) were calculated as LSM. Data from the 66 animals were analyzed with the linear model with fixed orthogonal polynomials nested within treatment described for heifers (Model 4; Supplemental File S1). Main effects of energy, protein, and their interaction were calculated at 25, 85, and 205 DIM.

Second- and Third-Lactation Cows. Data for the cows in second ($n = 45$) and third ($n = 30$) lactation were extracted from the Norwegian Dairy Herd Recording System database and analyzed with the linear model, with fixed orthogonal polynomials nested within treatment. However, random effect of field cut could not be included because feed intake had not been recorded in the second and third lactations (variant of Model 5; Supplemental File S1). The predicted values were cumulated over 305 d of lactation. The cumulated values were analyzed with an ANOVA model (containing only the treatment group effects).

RESULTS

At 3 mo of age all heifers were the same BW, whereas BCS was not applicable (Figure 1a; Tables 4 and 5). At onset of puberty, the heifers had reached the physiologically determined BW between 280 and 300 kg, with no differences among groups ($P > 0.05$; Table 4). The HE heifers were now younger than LE heifers ($P < 0.0002$; Tables 4 and 5), because they had experienced a higher ADG [918 (HELP) and 936 (HEHP) g/d] than their LE peers [667 (LELP) and 719 (LEHP) g/d] from 3 mo until puberty (Figure 1a). Animals in the LEHP group were also younger than LELP heifers ($P = 0.004$; Table 4), reflected in a main effect of increased protein supply on age ($P = 0.02$; Table 5). At the onset of puberty BCS of the HE heifers were higher than that of their LE counterparts ($P < 0.0001$; Tables 4 and 5), but BCS was unaffected by protein level (Table 5). The age differences between HE and LE heifers had increased as planned at successful insemination (Figure 1a; $P < 0.0001$; Tables 4 and 5). This was, again, due to the higher ADG of the HE animals (948 g/d for HELP and 1,000 g/d for HEHP compared with 648 g/d for LELP and 672 g/d for LEHP; Figure 1a). In addition, HELP heifers were older than HEHP heifers ($P = 0.04$; Table 4). At successful insemination, average BW was near the target weight of 400 kg for all 4 groups (Table 4). Now, HELP heifers tended to be heavier than their HEHP contemporaries ($P = 0.059$) and were heavier than LELP heifers ($P = 0.02$) resulting in an interaction between energy and protein ($P = 0.01$; Table 5).

At the same time, the BCS of HE heifers was higher than that of LE heifers ($P < 0.0001$; Tables 4 and 5), illustrated in Figure 1c.

During pregnancy HE animals experienced ADG of 476 g/d for HELP and 498 g/d for HEHP, and LE animals experienced ADG of 659 g/d for LELP and 596 g/d for LEHP (Figure 1b). The differences in BCS established between HE and LE animals at successful insemination disappeared through the gestation period. HE groups reduced their score, whereas LE groups remained unchanged as all groups converged toward a BCS of around 3.75 at calving (range: 3.42–3.93, $n = 66$; Figure 1d). The HE animals calved some 4 mo younger than LE heifers, around the targeted 22 and 26 mo of age, respectively ($P < 0.0001$; Tables 4 and 5). Whereas LE groups were near the postcalving target BW of 560 kg, HE groups were ~30 kg lighter ($P < 0.006$; Table 5).

From 3 mo until successful insemination daily intake of DM, NE_G , CP, and MP (Figures 2a, b, d, and e) all followed a consistent pattern with steeper curves for the HE groups. Intake of NDF was virtually the same in both HE and LE groups until around 8 mo of age (Figure 2c). The dietary protein levels could only be identified as marginal differences within the HE and LE treatments (CP and MP; Figures 2d and e). The mean intake per day of DM, NE_G , NDF, CP, and MP for the 4 experimental groups from 3 mo of age to onset of puberty, and from puberty to successful insemination, are shown in Table 6.

From 3 mo of age to onset of puberty, LE heifers had a higher cumulative DMI than HE heifers ($P < 0.0001$; Table 5). The LELP group also had a higher cumulative DMI than LEHP ($P = 0.03$; Table 7) with the consequence that increased protein supply also reduced DMI ($P < 0.05$; Table 5). Between puberty and successful insemination, the difference between energy groups diminished ($P = 0.01$; Table 5), especially with larger intake for LEHP than for HEHP ($P = 0.003$; Table 7). With cumulated NE_G intake, the picture was largely similar to that of cumulative DMI (Tables 5 and 7). Cumulative intake of CP did not differ between groups in either of the 2 periods (Tables 5 and 7).

The trajectory of the first-lactation milk yield curve for the HEHP group lay below those of the other groups ($P < 0.0001$ at 25, 85, and 205 DIM; Figure 3a; note that group contrasts are not shown). Near peak lactation (85 DIM) the LELP group produced better than the other 3 groups ($P < 0.003$), and there were main effects of both energy and protein in that HE and HP animals produced the least ($P < 0.02$ and $P < 0.004$, respectively; Table 8). Primiparous cows were still growing, and the HELP group was lighter than

the other 3 groups at 205 DIM ($P < 0.03$, Figure 3b). Throughout the lactation there were differences in BCS among energy groups, with higher scores in the HE groups ($P < 0.04$; Figure 3c and Table 8). Between energy groups there were no differences in BCS at 25 DIM, but at 205 DIM the HE groups differed from one another in that HELP cows reduced their BCS ($P < 0.0001$; Figure 3c). The first lactation DMI pattern showed a consistently lower intake for the HEHP animals over the entire lactation ($P < 0.004$; Figure 3d). Moreover, the DMI of the HELP animals was lower than that of both LE groups, and increasingly so toward the end of the lactation ($P < 0.0001$ at 205 DIM; Figure 3d). At 205 DIM there was also a main effect of energy on DMI ($P < 0.002$; Table 8).

For completeness, Table 9 lists 305-d ECM yield in the second and third lactations of the 4 groups. Differences in yield were small and reduced only for the LEHP group in the third lactation, reflected in a main effect of energy in third lactation ($P = 0.011$; Table 8).

DISCUSSION

Using a simple, roughage-based feeding strategy, we made 4 groups of heifers that entered puberty at ~9, 9, 11, and 12 mo of age with BCS of 3.8, 3.8, 3.6, and 3.6, respectively, but near identical weight because they followed different targeted growth curves. All animals were fed just 1 kg/d of concentrate, and both energy and protein supply were regulated with known roughage quality employing the growing cattle application of TINE OptiFör, using NorFor as feed evaluation system (Volden et al., 2011). As a result, we could time the insemination of the heifers so that the fast-growing HE groups calved at 22 mo with a somewhat lower BW (~30 kg), but similar BCS within the targeted maximum of 3.75. Thus, HE groups entered the milking herd 4 mo younger than their slower growing LE contemporaries. The HEHP group produced less milk than the other 3 groups during first lactation, whereas ECM yield was not impaired for the HELP group over 3 lactations.

Figure 1. Least squares means of BW (panels a and b) and BCS (1–5 scale, panels c and d) in the high energy, low protein (long-dashed line), high energy, high protein (dotted line), low energy, low protein (short-dashed line) and low energy, high protein (solid line) groups from 3 mo to confirmed pregnancy ($n = 79$), and during first pregnancy ($n = 73$).

Table 4. Means (LSM, on the diagonal in bold) and differences between means (on the off-diagonals, with *P*-values in parentheses) of age (mo), BW (kg) and BCS (1–5 scale) for experimental treatment groups¹ at start of experimental feeding (n = 80 heifers), onset of puberty (n = 79), successful insemination (n = 79), and at calving (n = 66, animals with full first lactation)

Variable	HELP	HEHP	LELP	LEHP
Start experimental feeding				
Age				
HELP	3.0	−0.03 (0.353)	0.00 (0.818)	0.00 (0.999)
HEHP		3.1	0.02 (0.483)	0.03 (0.354)
LELP			3.0	−0.00 (0.818)
LEHP				3.0
BW				
HELP	114	1.38 (0.677)	−0.28 (0.933)	−0.21 (0.950)
HEHP		113	−1.66 (0.616)	−1.58 (0.640)
LELP			115	−0.07 (0.983)
LEHP				115
BCS				
HELP	—	—	—	—
HEHP		—	—	—
LELP			—	—
LEHP				—
Onset of puberty				
Age				
HELP	9.0	0.19 (0.642)	−2.81 (<0.0001)	−1.60 (0.0002)
HEHP		8.8	−3.00 (<0.0001)	−1.79 (<0.0001)
LELP			11.8	1.21 (0.004)
LEHP				10.6
BW				
HELP	280	4.18 (0.689)	−8.48 (0.425)	2.13 (0.838)
HEHP		276	−12.66 (0.233)	−2.05 (0.845)
LELP			289	10.62 (0.318)
LEHP				278
BCS				
HELP	3.82	0.04 (0.221)	0.24 (<0.0001)	0.26 (<0.0001)
HEHP		3.78	0.19 (<0.0001)	0.21 (<0.0001)
LELP			3.59	0.03 (0.480)
LEHP				3.56
Successful insemination				
Age				
HELP	13.6	0.83 (0.042)	−3.48 (<0.0001)	−3.27 (<0.0001)
HEHP		12.8	−4.31 (<0.0001)	−4.10 (<0.0001)
LELP			17.1	0.21 (0.600)
LEHP				16.9
BW				
HELP	410	14.33 (0.059)	17.46 (0.021)	4.91 (0.507)
HEHP		395	3.13 (0.676)	−9.42 (0.211)
LELP			392	−12.55 (0.094)
LEHP				405
BCS				
HELP	3.99	0.057 (0.031)	0.26 (<0.0001)	0.25 (<0.0001)
HEHP		3.93	0.20 (<0.0001)	0.20 (<0.0001)
LELP			3.72	−0.01 (0.751)
LEHP				3.73
Calving				
Age				
HELP	22.5	0.58 (0.152)	−3.64 (<0.0001)	−3.22 (<0.0001)
HEHP		21.9	−4.23 (<0.0001)	−3.80 (<0.0001)
LELP			26.1	0.43 (0.300)
LEHP				25.7
BW				
HELP	538	5.25 (0.737)	−33.56 (0.038)	−25.45 (0.123)
HEHP		533	−38.80 (0.013)	−30.70 (0.057)
LELP			572	8.11 (0.614)
LEHP				564
BCS				
HELP	3.70	0.05 (0.110)	−0.01 (0.734)	−0.04 (0.265)
HEHP		3.64	−0.06 (0.049)	−0.08 (0.008)
LELP			3.70	−0.02 (0.422)
LEHP				3.73

¹HELP = high energy, low protein; HEHP = high energy, high protein; LELP = low energy, low protein; LEHP = low energy, high protein.

That is, over the average lifetime of a NR cow who goes through 2.7 lactations until culling (Norwegian Dairy Herd Recording System, 2017).

Age at puberty is an important determinant in dairy production systems (Archbold et al., 2012; Wathes et al., 2014). High energy intake has previously been shown to reduce the age at which heifers reach puberty (Radcliff et al., 1997; Meyer et al., 2006a). Accordingly, our HE heifers were younger at puberty than the LE heifers ($P < 0.0002$; Tables 4 and 5). BW at puberty was, however, unaffected by nutrient intake (Tables 4 and 5), again in line with the results of Radcliff et al. (1997) and Meyer et al. (2006a). All groups followed their targeted growth curves (Figure 1a) from 3 mo of age to onset of puberty. That is, at the physiologically determined weight (Joubert, 1963) of 280 to 300 kg (Table 4), or at 40 to 45% of their expected average mature BW, currently 658 kg in the university herd. This is somewhat below the National Research Council (2001) expectations of about 55% of the mature BW for dual-purpose and dairy heifers. Similarly, they had achieved their target BW of 400 kg, or around 60% of mature weight, at successful insemination (Figure 1a; Table 4). This would have allowed sufficient time for the animals to go through 6 to 7 estrous cycles, and thus for the mammary gland to develop properly before they were inseminated. Current recommendations for the NR breed given by the Norwegian dairy cooperative (TINE Rådgiving, 2017) are to achieve around 60% of mature BW (390–415 kg) at breeding. It is also comparable to current recommendations that Holstein heifers should be bred between 55 and 60% of their mature

BW (Van Amburgh et al., 2019). Body condition scores of the LE groups stayed within the targeted maximum score of 3.75, whereas the HE animals were somewhat over-conditioned already at 6 mo of age, and thus before the onset of puberty (Figure 1c), with a higher BCS than their LE counterparts ($P < 0.0001$; Tables 4 and 5). This is most likely due to the HE heifers having free access to roughage. It is well known that accelerated heifer rearing can lead to excessive fat deposition (Swanson 1960; Stelwagen and Grieve, 1992).

The similar daily intake of NDF in the 4 groups until 8 mo of age (Figure 2c) indicates that all animals ate to satiation until 8 mo, whereafter an effect of the restricted straw-diluted roughage supply to LE heifers became evident. Moreover, the calculated daily MP values (Figure 2e) were somewhat lower for the LE groups and the pattern similar to that of CP (Figure 2d). This might, to some extent, explain why the LELP heifers that had the lowest daily protein intake experienced the lowest growth rate of the 4 groups (Figure 1a). This was also reflected in a minor effect of protein on early growth rate (i.e., age; Table 5). The somewhat enlarged ADG in the HP groups further translated into a reduced cumulative DMI and NE_G from 3 mo to onset of puberty (Table 5).

When portraying nutrient intake as cumulative values (Tables 5 and 7), and not as intake per d (Figures 2a–e), we account for the fact that the number of d needed for the animals to reach a given stage of physiological development at approximately the same BW differed among the groups. It would be difficult to make fair comparisons between HE- and LE groups

Table 5. Effects (P -value) of energy [(HELP + HEHP) – (LELP + LEHP)] and protein [(HEHP + LEHP) – (HELP + LELP)], and their interaction [(HEHP + LELP) – (HELP + LEHP)] in heifers on age (mo), BW (kg), BCS (1–5 scale), and on cumulated intakes of DM (kg), NE_G (MJ), and CP (kg) at start of experimental feeding ($n = 80$), onset of puberty ($n = 79$), successful insemination ($n = 79$), and at calving ($n = 66$, animals with full first lactation)¹

Variable	Stage or interval	Energy (P -value)	Protein (P -value)	Energy × Protein (P -value)
Age	Start experimental feeding	0.0 (0.620)	0.0 (0.618)	0.0 (0.414)
	Onset of puberty	–2.3 (<0.0001)	–0.7 (0.018)	0.5 (0.082)
	Successful insemination	–3.8 (<0.0001)	–0.5 (0.068)	–0.3 (0.275)
	Calving	–3.7 (<0.0001)	–0.5 (0.082)	–0.1 (0.795)
BW	Start experimental feeding	–1 (0.691)	–1 (0.756)	–1 (0.781)
	Onset of puberty	–5 (0.480)	–7 (0.320)	3 (0.666)
	Successful insemination	4 (0.446)	–1 (0.866)	–13 (0.013)
	Calving	–32 (0.006)	–6 (0.550)	1 (0.899)
BCS	Onset of puberty	0.22 (<0.0001)	–0.03 (0.173)	–0.01 (0.720)
	Successful insemination	0.22 (<0.0001)	–0.02 (0.183)	–0.03 (0.078)
	Calving	–0.05 (0.032)	–0.01 (0.583)	–0.03 (0.094)
	Calving	–32 (0.011)	–1 (0.967)	–22 (0.082)
DM	3 mo to onset of puberty	–47 (<0.0001)	–18 (0.049)	11 (0.233)
	Puberty to successful insemination	–32 (0.011)	–1 (0.967)	–22 (0.082)
NE_G	3 mo to onset of puberty	–193 (0.0002)	–101 (0.045)	61 (0.223)
	Puberty to successful insemination	–116 (0.110)	–1 (0.992)	–134 (0.065)
CP	3 mo to onset of puberty	–1.0 (0.400)	–0.1 (0.963)	0.8 (0.495)
	Puberty to successful insemination	0.5 (0.777)	1.2 (0.434)	–3.0 (0.060)

¹HELP = high energy, low protein; HEHP = high energy, high protein; LELP = low energy, low protein; LEHP = low energy, high protein.

Table 6. Mean year-season and field cut corrected intake of DM (kg/d), NE_G (which includes NE_M; MJ/d), NDF (kg/d), CP (g/d), and MP (g/d; expressed as AA absorbed in the small intestine), for experimental treatment groups¹ from 3 mo to onset of puberty (n = 79) and from puberty to successful insemination (n = 79)

Stage	Treatment	DM	NE _G	NDF	CP	MP
3 mo to onset of puberty	HELP	5.3	31.3	2.5	771	485
	HEHP	5.2	30.7	2.5	825	510
	LELP	5.1	28.0	2.8	580	432
	LEHP	5.0	27.3	2.8	637	456
Puberty to successful insemination	HELP	7.9	46.4	4.0	1,067	665
	HEHP	7.8	45.6	3.9	1,118	693
	LELP	7.4	39.5	4.3	785	558
	LEHP	7.2	39.4	4.2	840	578

¹HELP = high energy, low protein; HEHP = high energy, high protein; LELP = low energy, low protein; LEHP = low energy, high protein; extra wheat straw included for LE animals.

Figure 2. Daily intake (LSM) of (a) DM; (b) NE_G (which includes NE_M); (c) NDF; (d) CP, and (e) MP (expressed as AA absorbed in the small intestine) in the high energy, low protein (long-dashed line), high energy, high protein (dotted line), low energy, low protein (short-dashed line), and low energy, high protein (solid line) groups from 3 mo of age to successful insemination (n = 79). Extra wheat straw included for low energy animals.

Table 7. Means (LSM, on the diagonal in bold) and differences between means (on the off-diagonal, with *P*-values in parentheses) of cumulated intake of DM (kg), NE_G (which includes NE_M; MJ), and CP (kg) from 3 mo of age to onset of puberty (n = 79) and from puberty to successful insemination (n = 79) for experimental treatment groups¹

Variable	3 mo to onset of puberty				Puberty to successful insemination			
	HELP	HEHP	LHELP	LEHP	HELP	HEHP	LHELP	LEHP
DM	144	7.3 (0.574)	-57.7 (<0.0001)	-28.3 (0.031)	163	22.6 (0.205)	-10.4 (0.561)	-31.9 (0.071)
	HEHP	136	-65.0 (<0.0001)	-35.6 (0.007)		140	-32.9 (0.070)	-54.5 (0.003)
	LHELP		201	29.5 (0.027)			173	-21.5 (0.227)
	LEHP			172				195
NE _G	849	40.0 (0.567)	-253.4 (0.0006)	-91.6 (0.191)	953	134.6 (0.186)	18.4 (0.856)	-114.8 (0.252)
	HEHP	809	-293.3 (<0.0001)	-131.6 (0.062)		818	-116.2 (0.259)	-249.3 (0.016)
	LHELP		1,103	161.8 (0.025)			934	-133.1 (0.191)
	LEHP			941				1,068
CP	20.9	-0.8 (0.650)	-1.9 (0.286)	-1.0 (0.571)	21.9	1.7 (0.427)	3.4 (0.125)	-0.8 (0.720)
	HEHP	21.7	-1.1 (0.532)	-0.2 (0.911)		20.1	1.6 (0.457)	-2.5 (0.252)
	LHELP		22.8	0.9 (0.607)			18.5	-4.2 (0.060)
	LEHP			21.9				22.7

¹HELP = high energy, low protein; HEHP = high energy, high protein; LHELP = low energy, low protein; LEHP = low energy, high protein; extra wheat straw included for LE animals.

otherwise. We found the lowest cumulative DMI and NE_G values in the HE groups. This means that HE animals consistently consumed less feed and energy than LE animals to reach a given stage of physiological development at approximately the same BW. This is likely because LE animals would require more nutrients for maintenance over their longer rearing period. On the other hand, when we consider cumulative intake of CP there were no differences between groups (*P* > 0.05; Tables 5 and 7). This is because HE animals consumed a considerably higher amount of CP per d for a shorter period than the LE groups.

From confirmed pregnancy to calving the 4 groups were managed together with the rest of the university herd and were offered the same roughage ad libitum but no concentrate. During this time, BW and BCS were recorded, but feed intake was not. During pregnancy, HE animals displayed growth rates somewhat lower than the targeted ~500 g/d, whereas the LE animals revealed growth rates of 600 g/d or more. For the HE groups, this meant transfer from a diet, which until confirmed pregnancy had resulted in an ADG of between 900 and 1,000 g/d to one that halved this growth rate. The HE heifers responded by reducing their BCS to end with a score near equal to that of the LE groups at the end of the gestation period (Figure 1d). The BCS trajectory of the LE heifers remained flat. The LE animals were transferred from restricted feeding of silage mixed with 35% wheat straw, to a situation with ad libitum access to the same silage as the HE animals. The LE animals responded by increasing their ADG relative to the HE animals (Figure 1b). We interpret this response as classical compensatory growth.

What distinguished primiparous HE animals from LE animals, other than that they calved 4 mo earlier, was that they gave birth at a somewhat lower BW than the targeted 560 kg achieved by the LE animals (Figures 1b and 3b; Tables 4 and 5). Although HE animals had achieved a mean postcalving BW of 82% of the mean mature BW of the herd, the corresponding postcalving BW for the 4 mo older LE animals were just above 85%. Both are comparable to the after first calving BW bench mark of 82 to 85% of mature weight for Holstein heifer rearing (Van Amburgh et al., 1998; Fox et al., 1999; National Research Council, 2001). The HE animals further calved with a BCS of roughly 3.7, similar to that of the LE animals (Figure 1d; Tables 4 and 5) and near the recommended maximum score of 3.75 for NR heifers (TINE Rådgiving, 2017). In line with the findings of Radcliff et al. (2000), a higher BCS among the HE heifers was evident at breeding (370 kg, Figure 1c), although the differences at the end of the gestation were small (Figure 1d). The seeming inconsistency relative to the somewhat lower BCS displayed by

Table 8. Effects (*P*-value) of energy [(HELP + HEHP) – (LELP + LEHP)] and protein [(HEHP + LEHP) – (HELP + LELP)], and their interaction [(HEHP + LELP) – (HELP + LEHP)] in heifers on test-day milk yield (kg), on daily BW (kg), BCS (1–5 scale), and DMI (kg) in primiparous cows (*n* = 66, animals with full first lactation) at 25, 85, and 205 DIM¹

Variable	DIM	Energy (<i>P</i> -value)	Protein (<i>P</i> -value)	Energy × Protein (<i>P</i> -value)
Test-day milk yield	25	–1.94 (0.003)	–1.10 (0.083)	–1.36 (0.033)
	85	–1.56 (0.016)	–1.87 (0.004)	–0.82 (0.193)
	205	–0.54 (0.395)	–1.14 (0.071)	–0.68 (0.277)
BW	25	–5 (0.738)	6 (0.376)	1 (0.854)
	85	–3 (0.820)	9 (0.199)	3 (0.712)
	205	–7 (0.656)	14 (0.063)	14 (0.048)
BCS	25	0.23 (0.001)	–0.03 (0.716)	0.02 (0.810)
	85	0.28 (<0.0001)	–0.03 (0.710)	0.11 (0.080)
	205	0.14 (0.037)	0.05 (0.357)	0.08 (0.219)
DMI	25	–0.6 (0.146)	–0.2 (0.754)	–0.3 (0.397)
	85	–0.8 (0.059)	–0.3 (0.486)	–0.6 (0.130)
	205	–1.5 (0.002)	–0.7 (0.144)	–0.2 (0.762)
ECM	2nd	–293 (0.417)	–397 (0.273)	116 (0.747)
	3rd	1,249 (0.011)	–521 (0.263)	469 (0.313)

¹HELP = high energy, low protein; HEHP = high energy, high protein; LELP = low energy, low protein; LEHP = low energy, high protein; included are also effects on 305-d ECM yield (kg) in second and third lactation.

the HE animals after calving seen in Figure 3c is most likely due to the statistical correction for the effect of year-season affecting the LSM in the gestation period (Figure 1d).

First-lactation curves of HELP animals closely followed that of their LE contemporaries, whereas that of HEHP animals followed a lower trajectory ($P < 0.0001$; Figure 3a). All groups increased their BW during the

Figure 3. Least squares means of first lactation (a) test-day milk yield; (b) BW, (c) BCS (1–5 scale), and (d) daily intake of DM in the high energy, low protein (long-dashed line), high energy, high protein (dotted line), low energy, low protein (short-dashed line), and low energy, high protein (solid line) groups from 5 to 305 DIM (*n* = 66, animals with full first lactation).

Table 9. Least squares means 305-d ECM yield (kg) in second and third lactation of experimental treatment groups¹ with number of animals within each group (n)

Lactation	Treatment							
	n	HELP	n	HEHP	n	LELP	n	LEHP
Second	12	8,300 ^a	15	8,018 ^a	8	8,709 ^a	10	8,196 ^a
Third	8	9,135 ^a	11	9,083 ^a	5	8,355 ^{ab}	6	7,365 ^b

^{a,b}Significant ($P < 0.05$) differences within lactation when letters are different.

¹HELP = high energy, low protein; HEHP = high energy, high protein; LELP = low energy, low protein; LEHP = low energy, high protein.

first lactation to approximately 600 kg, or just above 90% of mature weight (Figure 3b), according to expectations (the waving tails of the LE groups' curves are due to few observations toward the end). This is, again, comparable with target weights for Holstein (Fox et al., 1999). The increase was the least for the HELP animals, which at 205 DIM were lighter than the other groups ($P < 0.03$; Figure 3b). At the same time, HE animals had a higher BCS than the LE animals ($P < 0.04$; Table 8). Moreover, at 205 DIM the BCS of the HELP group was reduced relative to the HEHP group ($P < 0.0001$; Figure 3c), consistent with an upregulation of lipolytic pathways in adipose tissue (Roche et al., 2009). The BCS trajectory of the HEHP group, however, seemed to follow the lactation curve rather than presenting a mirror of it (Roche et al., 2009).

Dry matter intake increased toward peak lactation and followed the lactation curve, as would be expected (Figure 3d). The net energy value for lactation of the diet (NE_L/DM) was similar for all groups, but higher for the HEHP group due to their lower DMI with the same amount of concentrate ($P < 0.004$ at 25, 85 and 205 DIM; Figure 3d). Although the HELP animals reduced their BCS during the lactation their DMI was lower than that of both LE groups at 205 DIM ($P < 0.0001$; Figure 3d). This is most likely because the HELP animals were smaller. The calculated MP/NE_L was in line with the recommended value, 15 g/MJ for all 4 groups (Nielsen and Volden, 2011).

Accelerated growth during the rearing period leading to an AFC of 22 mo did not impair milk production over 3 lactations for the group fed protein according to recommendations. This is consistent with the results of Wathes et al. (2008), who showed that heifers calving at 22 to 23 mo of age had the highest lifetime yield over 5 yr. In our previous paper (Storli et al., 2017), we reported a curvilinear relationship between postpubertal ADG and first-lactation yield. The curvilinear relationship supports the suggestion that a heifer's physiological age is a major player in mammary development (Meyer et al., 2006b) and suggests that an optimum ADG for first-lactation yield would be one at which physiological age, BW, and stage of mammary development are har-

monized. The curvilinear relationship further emphasizes the importance of the postpubertal period. It also provides an explanation of why Macdonald et al. (2005) reported a positive association between postpubertal ADG and first-lactation yield, whereas Hoffman et al. (1996) found the opposite. The fastest-growing HEHP animals experienced a postpubertal ADG of 1,000 g/d and had the lowest first-lactation yield of the 4 groups until 205 DIM ($P < 0.0001$; Figure 3a). We hypothesize that this is because their growth rate exceeded the optimum for first-lactation yield in the postpubertal period (Storli et al., 2017). The mechanism behind might be found in the lower DMI of these animals relative to the other groups ($P < 0.004$; Figure 3d), which again would be due to their higher whole-body adiposity, as indicated in Figure 3c and Table 8. In this situation, one should expect to find higher circulating nonesterified fatty acids (**NEFA**) signaling energy availability (Drackley, 1999). However, NEFA and BHB measured at roughly 14 DIM did not differ between groups ($P > 0.05$; results not shown). This suggests that the HEHP animals, rather than mobilizing omental fat, down-regulated their milk production. Another possibility is that the HEHP animals prioritized growth and body condition over milk production during their first lactation (Figures 3a, b, and c). The HELP group, which grew slower at 948 g/d postpubertally may have been closer to their ADG optimum for subsequent yield. In contrast to the HEHP animals, they kept up milk production and lost BCS throughout first lactation. Moreover, at 205 DIM they were lighter than the other groups and consequently had a lower DMI than both LE groups. Our results indicate that feeding MP higher than recommended in the rearing period from 3 mo to confirmed pregnancy have no beneficial effect on later milk production.

Postnatal growth until puberty and thereafter in pregnancy will not only affect heifers' growth rate, but also nutrient partitioning and the allometric development of organs. This in turn would result in changes in embryonic and fetal growth capacity and pattern and postnatal performance even though BW at insemination is the same (Meyer et al., 2010). The only relevant

phenotype available was BW at birth for the offspring of the heifers that on average was 35.9 kg ($n = 61$). However, there were no differences between treatments obtained with Model 2 ($P = 0.17$). It should be noted that the present results are strictly valid only for the setup tested. Any differences (e.g., in the preweaning period or during gestation) could have resulted in different outcomes.

CONCLUSIONS

We have shown that heifers fed high energy treatment with the required amount of protein from 3 mo of age to successful insemination combined with an ADG of ~500 g/d throughout pregnancy will calve at 22 mo without becoming over-conditioned at calving and without impairing milk performance over 3 lactations. Based on this and results from our previous field trial we thus recommend reducing rearing time by 4 mo, planning for an AFC of 22 mo of age. This was obtained by regulating energy and protein supply with roughage quality in a diet containing only 1 kg/d of concentrate. This rearing practice would also improve energy efficiency during the heifer rearing period, and reduce rearing costs.

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