Rearing Norwegian Red heifers; growth and effects on subsequent milk production of primiparous cows

Oppdrett av NRF-kviger; tilvekst og effekter på avdrått i første laktasjon

Philosophiae Doctor (PhD) Thesis

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Ås, September 2015

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Papers I–III have individual page numbers.

Summary

The thesis is part of a larger research project aiming to determine the impact of calf and youngstock development on dairy cow production and profitability.

Paper I utilized field data to find a more marginal effect of parity of dam or age within parity of dam on daughters milk yield. This would suggest that age and parity of dam should be included in models when planning a future strategy. The milk yield of daughters decreased with increasing parity

Paper II found the average growth rate of Norwegian Red heifers to be moderate under field conditions in Norway with about 770 g/d. Normal biological variation might explain the spread shown for average herd BW gain between 5 and 15 months of age ranging from 615 to 1,053 g/day. Milk production in first lactation peaks at an AFC of 26 months of age, and suggests that Norwegian heifers with todays' feeding practices do not reach sexual maturity until 17 months of age, i.e. reach the level of maturity when they can sustain a pregnancy without adverse effects. Thus, the potential for growth of the genetically improved heifer is not met under field conditions in Norway.

Paper III Using a simple, roughage-based feeding strategy in which 66 Norwegian Red had been fed one kg of concentrate and energy supply was regulated with roughage quality we have confirmed that it is possible to rear heifers for a rapid weight gain (about 940 g/d) from 3 mo of age to conception and a moderate daily gain (about 550 g/d) through pregnancy without negative effects on lactation performance of the primiparous cow. This reduces age at first calving to 22 months, results in a flatter lactation curve, improved body condition score and body weight change profiles together with increased roughage uptake in the first part of the lactation. When challenged with reduced concentrate supply from 120 days in lactation the animals responded by keeping up milk production. Thus, results suggest we have succeeded to make a cow that have an increased uptake of DM from roughage.

Sammendrag

Hovedmålet med denne doktorgraden var å undersøke hvordan tilveksten til rekrutteringskviger i norske besetninger påvirker den senere melkeytelsen, og designe en fôringsstrategi som kan redusere innkalvingsalderen uten at det går utover senere egenskaper som melkeku.

Artikkel I viste at med en utbredt bruk av kviger som mødre eller at mødrene innen paritet er unge ved kalving vil det gi en systematiske effekt på døtrenes melkeytelse. Døtrenes melkeytelse reduseres i takt med økende paritet på mødrene. Effektene er imidlertid små og vil ikke gi utslag på små datasett som dem i artikkel II og III.

Artikkel II fant at gjennomsnittlig tilvekst hos NRF-kviger er moderat i norske besetninger, omtrent 770 g/d. Gjennomsnittlig besetningstilvekst for kviger mellom 5 og 15 måneder varierte fra 615 til 1.053 g/d og må nok tilskrives normal biologisk variasjon. Melkeproduksjonen var høyest for kviger med innkalvingsalder på 26 måneder, og antyder at dagens fôring av norske kviger ikke gir modne dyr, før ved 17 måneders alder. Noe som betyr at det økte vekstpotensialet på grunn av genetisk framgang ikke blir dekket i dagens rekrutteringsoppdrett.

Artikkel III ved å fôre kviger fra 3 måneders alder til konstatert drektighet ved bruk av 1 kg kraftfôr til alle og energitilførsel regulert ved hjelp av grovfôrkvaliteten (surfôr og surfôr tilblandet halm), vil kviger kunne vokse opptil 940 g om dagen (og 550 g om dagen etter konstatert drektighet) uten at det har påviselige negative effekter i første laktasjon. Da vil en kunne oppnå kalving så tidlig som ved 22 måneders alder, få en flatere melkekurve, bedre hold, ønskelig tilvekst og økt grovfôropptak. Slike dyr vil respondere bedre på redusert kraftfôrtilførsel seinere i laktasjonen. Dette tyder på at vi har lykkes med å lage ei ku som i større grad er i stand til å utnytte norske grovfôrressurser.

Abbreviations

AFC	Age at first calving
BCS	Body condition score
BW	Body weight
DIM	Days in milk
NDHRS	Norwegian Diary Herd Recording System
NRF	Norwegian Red

List of original papers

I) Storli, K. S., Heringstad, B., and Salte, R. 2014. Effect of dams' parity and age on daughters' milk yield in Norwegian Red cows. *Journal of Dairy Science*. 97(10): 6242–6249.
DOI: 10.3168/jds.2014-8072

II) Storli, K. S., Klemetsdal, G., Volden, H., and Salte, R. 2015. A longitudinal field study on the relationship between heifer growth and test-day milk yield of primiparous Norwegian Red. Manuscript.

III) Storli, K. S., Klemetsdal, G., Volden, H., Wærp, H. K. L., and Salte, R. 2015. Designing a feeding strategy for a replacement heifer management system: II. Effects of pre- and post-conception feeding on performance of primiparous Norwegian Red. Manuscript.

General introduction

The heifer calf is the future of the dairy farmer. A successful rearing strategy of heifers should produce healthy and productive cows with a maximized lifetime performance. Replacement heifers represents one of the major costs on a dairy farm, and because age at first calving (AFC) is an important contributor to the cost of rearing dairy heifers, there are clear management benefits provided by reducing the age at first calving (Heinrichs, 1993). However, a drawback with lower AFC is the widespread belief among farmers that older heifers produce more milk than their younger herd mates do, and there is support in the literature for this belief: several authors e.g. Berry and Cromie (2009) and Mohd Nor et al. (2013) have showed an almost linear increase in milk yield with increasing AFC. Conversely, a reduced AFC would be associated with decreased milk yields in the first lactation.

Higher BW at calving often explains the positive effect of high AFC on milk performance because heavier heifers seem to produce more milk due to a higher dry matter intake capacity and a potentially higher energy intake (Le Cozler et al., 2008). Therefore, introducing higher growth rates in the rearing period would be a logical solution to the question of how to obtain heavier heifers that also calve early. A problem with this is, however, that high growth rates in the pre-pubertal period is associated with a reduced capacity for future milk performance (Sejrsen and Purup, 1997).

The Norwegian dairy production has gone through a huge shift from smaller family farms towards larger units with a more intensive production. In only twenty years, the average herd size in Norway has increased from 12.8 to 24.8 cow equivalents per herd, while the number of dairy herds is approximately halfed. Within the same period of time the average milk yield per cow equivalent has increased with more than 16 %, resulting in an average milk yield of 7,600 kg in 2014 (NDHRS, 2015). With small herds, the farmers could focus on each individual, but focus would have to move towards the herd level as the herd size increases. This situation calls for a more systematic approach to choice of feeding strategy. The choice should be based on evidence. Thus, research on the topic is valuable. The Norwegian Red (NRF) is the dominant breed in Norway, representing almost 95 % of the cows registered in the Norwegian Dairy Herd Recording System (NDHRS). It is a dual-purpose breed, bred for both milk and meat production, and with additional emphasis on reproduction and health. Some 98% of the dairy herds register into the system, and this gives unique opportunities for studies of the population.

Current national recommendations on replacement heifer rearing are largely based on Danish studies from the late 1980-ies to the mid 1990-ies (Foldager and Sejrsen, 1991; Hohenboken et al., 1995; Sejrsen and Purup, 1997). The fact that these results were obtained on breeds different from the Norwegian Red (NRF) is probably of little consequence (see Hohenboken et al., 1995). Far more important is it that today's NRF is markedly different from the one that existed some 25 years ago due to a continuous genetic improvement of economically important traits (Geno, 2014). Rearing, and in particular feeding practices have not been updated accordingly.

Aim and outline of the thesis

The thesis is part of a larger research project aiming to determine the impact of calf and youngstock development on dairy cow production and profitability. A controlled feeding trial including about 100 heifers from birth through more than the first half of their first lactation is a major part of the project. In addition, a two-year field study was included where repeated on-site registrations of growth on all available females from newborn to calving in 30 commercial dairy herds were combined with registrations deriving from the Norwegian Dairy Herd Recording System (NDHRS) In addition the first paper utilized field data to examine the effect of parity of dam and age within parity of dam on daughters' milk yield in the NRF breed.

The main goals of the thesis was to

- Investigate whether parity of dam and age within parity of dam affect daughters' milk yield in NRF.

- Obtain information on how current rearing practices affects first lactation milk yield.

- Identify components from rearing practices that drive first lactation yield.

- Evaluate the effects of different growth profiles during both the pre- and post-pubertal periods until conception and similar profiles during pregnancy on performance of the same animals as primiparous cows.

Brief summary of papers I - III

Paper I

Effect of dams' parity and age on daughters' milk yield in Norwegian Red cows

To obtain enough heifers for the feeding trial in Paper 3, a major part of the test animals had to be daughters of heifers. This raised a question whether parity and/or age of dams would influence the subsequent milk production of the daughters, and if an extensive use of heifers as dams would have a systematic effect on daughters' milk yield in NRF. The aim of this study was to investigate whether parity of dam and age within parity of dam affect daughters' milk yield in the NRF breed. Lactation data from 276,000 cows were extracted from the NDHRS and analyzed using a linear animal model to estimate effects of parity and age within parity of dam.

Main results

- The 305-d milk yield of daughters decreased as parity of dam increased.
- The age of dam within parity had effect on 305-d milk yield of daughters in first lactation. Young first parity dams gave birth to daughters with a higher milk yield compared with older dams within the same parity.

Main conclusions

- Age and parity of dam should be included in the model when planning a future replacement heifer rearing strategy.

Paper II

A longitudinal field study on the relationship between heifer growth and test-day milk yield of primiparous Norwegian Red

Current national recommendations on replacement heifer rearing are largely based on Danish studies from the late 1980-ies to the mid 1990-ies. Today's NRF is markedly different from the one that existed some 25 years ago due to a continuous genetic improvement of economically important traits. The aim of this study was to obtain information on current rearing practices and identify major components of these rearing practices that drive first lactation yield. Information on replacement heifer growth and first lactation test-day milk yield from 30 larger Norwegian commercial dairy farms of which 15 herds had a history of producing on average more than 7,500 kg and the other half less than 6,500 kg energy corrected milk was used. Growth parameters were estimated based on information form 536 animals, whereas 350 of these animals had the required information needed to estimate the relationship between growth and test-day milk yield.

Main results

- The average growth rate of a NRF heifer under field conditions is moderate (770 g/d).
- First lactation milk yield increased with increasing growth rate, especially between 10 and 15 months of age.
- Heifers calving at 26 mo of age produce almost 900 kg more milk during the first 305 days lactation than heifers calving younger than 24 months of age.
- Heifers produced another 250 kg more milk if one standard deviation is added to the average BW at 21 months of age.

Main conclusions

- Due to a limited growth rate under field conditions, test-day milk yield of primiparous Norwegian Red peak at an age at first calving of 26 mo.
- In this environment, the majority of the heifers reach sexual maturity, i.e. the level of maturity when they can sustain a pregnancy without adverse effects, as late as 17 mo of age.
- Feeding practices have not been adjusted to meet the requirements of the genetically improved heifer of today.

Paper III

Designing a feeding strategy for a replacement heifer management system: II. Effects of pre-and post-conception feeding on performance of primiparous Norwegian Red

We hypothesized that rearing heifers for a rapid weight gain (800 – 950 g/day) in the pre- and post-pubertal period until conception would not have any negative effects on subsequent lactation performance. Eighty NRF heifers were assigned to a high (HE) or low (LE) energy group planned for a BW gain of 800 – 950 and 600 – 750 g/day from three months of age to confirmed pregnancy, respectively. Each energy group was split in two protein groups, low (LP) and high (HP). All groups were reared for a moderate daily gain through pregnancy. Lactation information from five to 175 days in milk (DIM) on 66 heifers were analyzed with a random regression model to reveal any differences between groups in test-day milk yield, body weight, body condition score (BCS) and dry matter intake.

Main results

- An improved energy supply made heifers to calve at 22 months of age.
- These heifers had a flatter lactation curve, improved BCS and BW change profiles together with increased roughage uptake in the first part of the lactation.
- When challenged with reduced concentrate supply from 120 days in lactation the animals fed the high-energy diet responded by keeping up milk production.
- Results suggest we have succeeded to make a cow that have an increased uptake of dry matter from roughage.
- There were only marginal effects of protein supply in the rearing period.

Main conclusions

- We have confirmed that it is possible to rear heifers for a rapid weight gain (about 940 g/d) from 3 mo of age to conception and a moderate daily gain (about 550 g/d) through pregnancy, using one kg of concentrate and by regulating energy supply with roughage quality, without negative effect on lactation performance of the primiparous cow .
- Thus, age at first calving could be reduced to 22 months of age without compromising milk yield.
- Results suggest we have succeeded to make a cow that have an increased uptake of DM from roughage.

General discussion

This thesis has studied the effect of age and parity of dam on daughters subsequent milk yield, the status of growth and effects on subsequent milk production of primiparous Norwegian Red, and finally, the effect of different growth rate in the rearing period on lactation performance.

In the field study (Paper II) we found that average BWgain of replacement heifers in Norway is moderate and that AFC is around 25 mo, and this suggests that in the field, NRF replacement heifers does not utilize their full potential for growth. The results in the controlled trial (Paper III) indicate that NRF heifers have a potential for faster growth both in the pre- and postpubertal period(> 770 g/d) without documented negative effects on subsequent milk production. However, the number of animals in the controlled trial was limited and it might be advisable to perform a larger field experiment to test effects of the different growth rates from the controlled trial primarily on traits like reproduction and longevity. This would determine whether the results are applicable to commercial Norwegian dairy production that will be dominated by automatic milking systems in the future. The recent years' increase in number of automatic milking systems in Norway gives a wealth of possibilities for data collection from participating herds in a field study to be able to answer many of the unanswered questions in the controlled trial, e.g. how will the shape of the lactation curves proceed after 175 days? Does a lower AFC affect the fertility either in replacement heifers or in subsequent lactations? How is the longevity and lifetime production of cows with high or low growth rate in the rearing period? Will any of the treatments reduce or enhance the mastitis risk and would the frequency of other health problems change?

Economy

A dairy farmer will choose the rearing strategy that is best suited to the available resources on the farm. Assuming that results from the controlled trial apply to the commercial situation the farmer would have a choice whether to calve his heifers at 22 mo of age or the present 25-26 without compromising future milk yield.

Space is often a limiting factor and intensifying the rearing with a higher growth rate to reduce the AFC could save several months of housing. In other situations the on farm resources, e.g. large available pasture, is well suited for an extensive rearing with a moderate growth rate towards a higher AFC. However, the economy is probably the most important driver in the dairy production and the shift towards a more efficient production is an obvious consequence of this. Therefore, if no particular drawbacks are associated with reducing the AFC, it might be difficult to justify a rearing of old heifers calving at 26 months over a heifer calving at 22 months of age based on profitability. The large potential for reducing replacement heifer costs lies in the possibility to reduced feed costs that might represent more than 60 % of the total cost of rearing replacement heifers (Gabler et al., 2000). Although an elevated growth rate require a higher energy concentration in the diet, a reduced AFC will lower the feed costs as showed under Pennsylvanian conditions (Tozer, 2000); total feed cost of a heifer growing 600 g/d was $90 higher compared to a growth rate of 800 g/d. The numerical estimates in Tozer (2000) are most likely incomparable to the Norwegian farming conditions. Anyhow, it is well known that the costs of producing roughage is quite high in Norway and with higher growth rates in the rearing period the farmer could save months of unproductive feeding of expensive roughage. In a 100-cow herd, this adds up to a considerable potential for cost reduction per year only considering the feed costs, followed by some additional reductions related to labor and housing.

Management of heifers in groups

Our findings in the field study reveals a relationship between weight at 21 months of age and milk yield. This has led us to speculate whether it is the losers within the herd that have the higher AFC and an inferior production. This should raise a question on group size and management of replacement heifers in groups. The literature on the area is sparse but may indicate some negative effects of keeping heifers in weight- and/or age-heterogeneous groups (Bøe and Færevik, 2003). Regrouping or dividing into smaller groups might be steps to avoid 'losers' but there is a need for more knowledge to be able to give the farmers good recommendations on grouping strategies for heifers.

Parity and age of dams

In Paper I we showed that daughters of heifers produced more milk than daughters of older dams. In addition, young dams within parity gave higher-producing daughters than did older dams. The effects of age and parity of dam were tested on the data in Paper 2 and 3, but there were only small effects of dams' parity or age on daughters milk yield, thus the variables were not included in the final models of either paper.

Conclusions

The main findings of this thesis were:

Under Norwegian field conditions the NRF replacement heifers do not utilize their full potential for growth.

- The majority of the heifers reach sexual maturity as late as 17 mo of age in the field due to moderate average growth rate.
- Preferentially, heifers could be reared for an average daily gain of 940 g/day from three months of age to conception.
- The AFC could be reduced to 22 months of age without compromising milk yield.
- Reducing AFC by 4 months may considerably reduce the rearing costs of the replacement heifer rearing system.
- Results suggest we have succeeded to make a cow that have an increased uptake of DM from roughage.

Recommendations

- The results from the controlled feeding trial could be followed up with designed field experiments in automatic milking systems to investigate effects on e.g. health, fertility and longevity.
- Investigation of the economic aspects regarding heifer replacement under Norwegian farming conditions are needed to give final recommendations.
- A strategy to avoid ‘losers’ within a group should be developed.

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Paper 1

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Effect of dams' parity and age on daughters' milk yield in Norwegian Red cows

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ABSTRACT

The effect of age and parity of dams on their daughters' milk yield is not well known. Lactation data from 276,000 cows were extracted from the Norwegian Dairy Herd Recording System and analyzed using a linear animal model to estimate effects of parity and age within parity of dam. The 305-d milk yield of daughters decreased as parity of dam increased. Daughters of first-parity dams produced 149 kg more milk than did daughters of seventh-parity dams. We also observed an effect of age of dam within parity on 305-d milk yield of daughters in first lactation. Dams that were young at first calving gave birth to daughters with a higher milk yield compared with older dams within the same parity. The effect of age within parity of dam was highest for second-parity dams. Extensive use of heifers would have a systematic effect, and age and parity of dam should be included in the model when planning a future strategy.
Key words: heifer, dam age, dam parity, milk yield

INTRODUCTION

To obtain enough heifers for a project aimed to develop the best feeding strategy for a replacement heifer management system for Norwegian Red cows, a major part of the test animals had to be daughters of heifers. This raised the question of whether extensive use of heifers as dams could have a systematic effect on daughters' milk yield. To date, only a few studies have addressed effects of age and parity of dam on milk production of their daughters. Banos et al. (2007) reported that younger first-parity dams gave daughters with higher milk yield than did older first-parity dams. The same was observed for daughters of second-parity dams. Similarly, Fuerst-Waltl et al. (2004) found that ECM yield of daughters decreased with increasing age of dam in Austrian dual-purpose Simmental, whereas Berry et al. (2008) found a negative effect of high milk yield in dams on daughters' milk yield in their first and second lactations. On the other hand, Banos et al. (2007) could not detect any significant effects of maternal milk yield on daughters' milk yield in first lactation.

Available information on the effects of age and parity of dams on the performance of their daughters was unclear. The aim of this study was, therefore, to investigate whether parity of dam and age within parity of dam affect daughters' milk yield in the Norwegian Red breed.

MATERIALS AND METHODS

Data

Data were extracted from the Norwegian Dairy Herd Recording System (Ås, Norway) and the final data set included information on 275,707 first-lactation Norwegian Red cows born from 2001 to 2011. Only records for which both sire of daughter and sire of dam were Norwegian Red AI sires were included. Daughters had to be between 18 and 36 mo old at first calving. Twin births were excluded. Only daughters that had completed 305 d of the first lactation were used. Information from the second lactation for the same daughters (n = 145,356), using the same editing criteria, was also included. The daughter had to be older than 32 mo at second calving, and age at calving of dam had to be within defined intervals (Table 1). Descriptive statistics of the analyzed data are given in Table 2.

In total, 38.8% of first-lactation daughters had first-parity dams, and 27.1% had second-parity dams. Likewise, 38.3% of dams of second-lactation daughters were first-parity dams, and 26.9% were second-parity dams. The distribution of parity of dams is given in Figure 1. About 20% of the dams were fourth- to seventh-parity dams; parities >7 were excluded. The phenotypic trend for average 305-d milk yield of daughters calving from 2003 to 2012 by parity of dam is shown in Figure 2. Average 305-d milk yield increased with time for

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Table 1. Estimated effects (BLUE = best linear unbiased estimator) with standard error of age × parity of dam, expressed as deviation from dams older than 95 mo in parity 7, on 305-d milk yield (kg) of daughters in first and second lactation

		First lactation			Second lactation		
Parity	Age mo	n	BLUE	SE	n	BLUE	SE
1							
	18–23	22,047	191	26.6	11,512	145	40.1
	24–29	75,686	155	25.9	39,449	141	39.1
	30–36	9,230	133	27.5	4,720	113	41.8
2							
	27–35	15,873	164	26.6	8,408	102	40.3
	36–41	49,078	110	25.8	25,625	78	39.0
	42–46	7,584	112	27.7	3,895	75	42.2
	>46	2,305	47	32.7	1,206	5	50.1
3							
	36–46	4,787	160	28.9	2,514	98	44.2
	47–51	30,249	111	25.8	16,070	84	39.2
	52–57	9,499	127	27.0	5,009	89	41.2
	>57	2,623	73	31.6	1,353	17	48.7
4							
	45–58	3,081	129	30.6	1,701	130	46.6
	59–63	15,990	94	26.1	8,721	96	39.8
	>63	7,064	104	27.5	3,769	77	42.0
5							
	53–69	794	78	42.5	426	88	65.5
	70–74	7,737	65	27.2	4,309	85	41.4
	75–80	3,023	93	30.4	1,638	69	46.6
	>80	1,207	100	37.7	621	24	58.6
6							
	63–82	839	56	41.7	469	31	63.6
	83–87	3,244	40	29.9	1,819	72	45.7
	>87	1,510	86	35.2	842	76	53.7
7							
	72–95	672	22	45.0	400	15	67.3
	>95	1,585	0	0.0	880	0	0.0

daughters in first and second lactation, and were higher overall for daughters of younger dams.

The pedigree file had a total of 726,826 animals, consisting of the 275,707 daughters with data and their pedigree (sire and dam) traced back as far as possible

Statistical Analyses

General linear model (GLM) analyses in SAS version 9.3 (SAS Institute Inc., Cary, NC) were conducted to test which explanatory variables had a significant effect on 305-d milk yield in first and second lactations, respectively. Age at calving, year-month of calving, parity of dam, age of dam, and herd-year of calving had significant effects on both traits.

Two different definitions of age of dam were used: parity of dam (parity 1 to 7) and age of dam within parity (23 classes). Age of dam was divided into 3 or 4 classes per parity, except for parity 7, which was divided into 2 classes because of the small number of records (Table 1). Bivariate linear animal models with 305-d milk yield in first and second lactations as ge-

Table 2. Summary statistics of data used for analyses of effect of parity of dams on 305-d milk yield in Norwegian Red cows

Item	First lactation	Second lactation
Cows, no.	275,707	145,356
Herd-year, no.	78,592	57,506
Dams, no.	213,855	122,592
Sires, no.	1,432	1,258
Daughters of first-parity dams, %	38.8	38.3
Mean 305-d milk yield, kg	6,129	7,059
SD 305-d milk yield, kg	1,202	1,396
Mean age at calving, mo	25.4	37.7
SD age at calving, mo	2.6	3.2

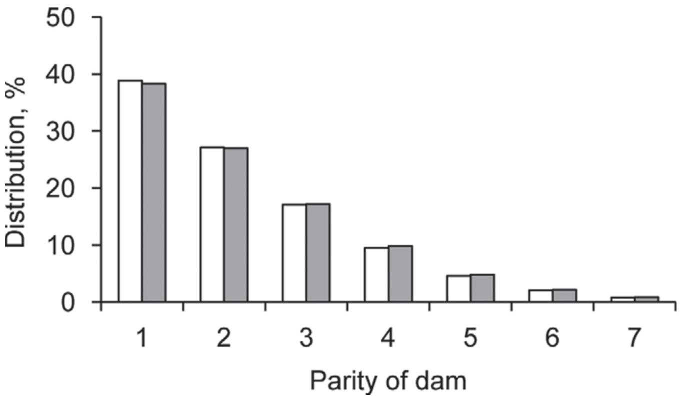

Figure 1. Distribution of parity of dam for 275,707 Norwegian Red daughters born from 2001 to 2011; white bar = first-lactation cows, gray bar = second-lactation cows.

netically correlated traits were fitted. By using a model with genetic effect of animal, the genetic trend in the population is taken into account. In matrix notation, the model was

$$\mathbf{y} = \mathbf{X}\boldsymbol{\beta} + \mathbf{Z}_h\mathbf{h} + \mathbf{Z}_a\mathbf{a} + \mathbf{e},$$

where $\mathbf{y}$ is the observed records of 305-d milk yield in first and second lactation, respectively; $\boldsymbol{\beta}$ is the vector of systematic effects, including age at calving (19 classes in first and 34 in second), parity of dam (7 classes) or age × parity of dam (23 classes), and the effects of year × month of calving (119 classes in first lactation and 106 in second); $\mathbf{h}$ is the vector of herd-year at calving effects; $\mathbf{a}$ is the vector of genetic effect of animal (daughter); $\mathbf{e}$ is the vector of residuals; and $\mathbf{X}$, $\mathbf{Z}_h$, and $\mathbf{Z}_a$, are the corresponding incidence matrices.

The following (co)variance structures were assumed for random effects:

$$\mathbf{h} \sim \mathrm{N}(\mathbf{0},\ \mathbf{H} \otimes \mathbf{I}),\ \mathbf{a} \sim \mathrm{N}(\mathbf{0},\ \mathbf{G} \otimes \mathbf{A}),$$
$$\text{and } \mathbf{e} \sim \mathrm{N}(\mathbf{0},\ \mathbf{R} \otimes \mathbf{I}),$$

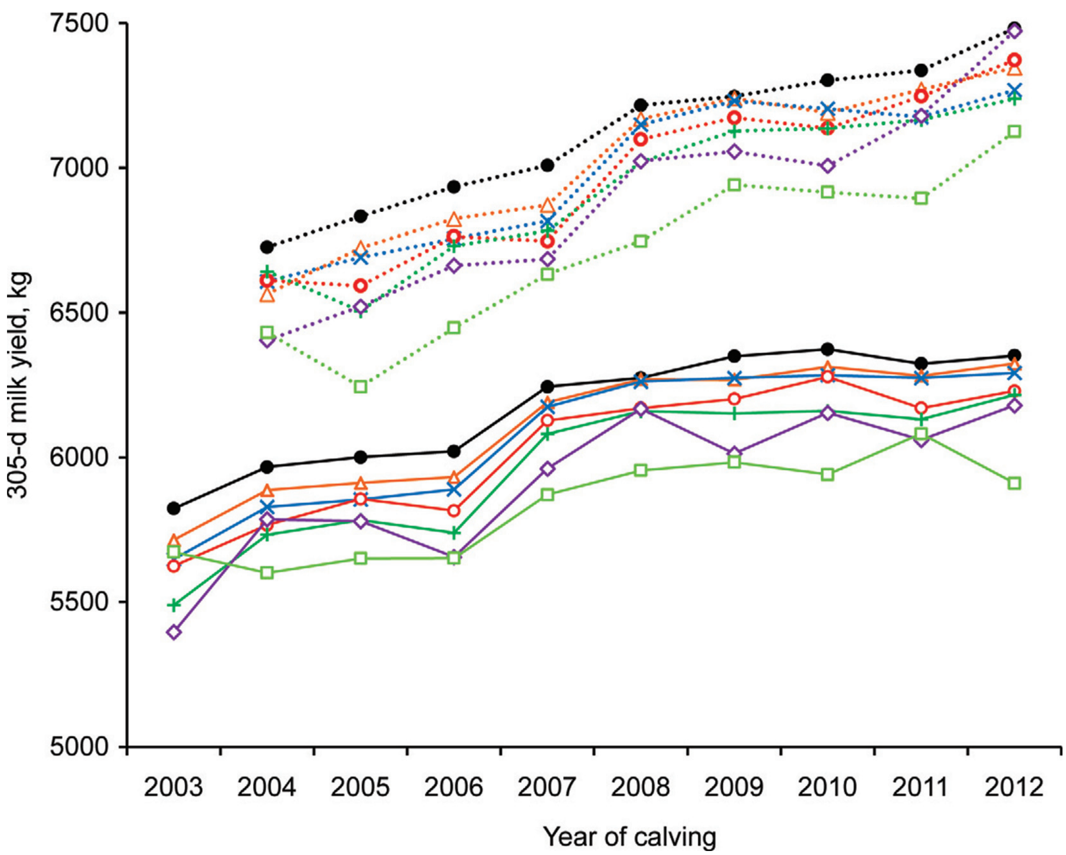

Figure 2. Phenotypic trend, average 305-d milk yield (kg) in first- (solid lines) and second- (dotted lines) lactation daughters calving from 2003 to 2012 by parity of dams: first = ● (black), second = △ (orange), third = × (blue), fourth = ○ (red), fifth = + (dark green), sixth = ◊ (purple), and seventh = □ (light green). Color version available in online PDF.

Table 3. Estimated effects (BLUE = best linear unbiased estimator) with standard error of parity of dam, expressed as deviation from dams in parity 7, on 305-d milk yield (kg) of daughters in first and second lactation

	First lactation			Second lactation		
Parity	no.	BLUE	SE	no.	BLUE	SE
1	106,963	149	22.0	55,681	130	32.7
2	74,840	109	21.7	39,134	72	32.5
3	47,158	107	21.6	24,946	75	32.5
4	26,135	92	21.8	14,191	88	32.9
5	12,761	67	22.5	6,994	71	34.0
6	5,593	47	24.3	3,130	61	36.8
7	2,257	0	0	1,280	0	0

where

$$\mathbf{H} = \begin{bmatrix} \sigma^2_{hy1} & \sigma_{hy12} \\ \sigma_{hy12} & \sigma^2_{hy2} \end{bmatrix},$$

$$\mathbf{G} = \begin{bmatrix} \sigma^2_{g1} & \sigma_{g12} \\ \sigma_{g12} & \sigma^2_{g2} \end{bmatrix},$$

$$\text{and } \mathbf{R} = \begin{bmatrix} \sigma^2_{e1} & \sigma_{e12} \\ \sigma_{e12} & \sigma^2_{e2} \end{bmatrix}.$$

Here, **H**, **G**, and **R** were herd-year, genetic, and residual (co)variance matrices, respectively, between the 2 traits (first- and second-lactation 305-d milk yield); **A** was the additive genetic relationship matrix; **I** was an identity matrix; σ^2_{hy1} and σ^2_{hy2} are the herd-year variances of 305-d milk yield in first and second lactation, respectively, and σ_{hy12} is the herd-year covariance between the 2 traits; σ^2_{g1} and σ^2_{g2} are the genetic variances and σ_{g12} is the genetic covariance of 305-d yield in first and second lactation; σ^2_{e1}, σ^2_{e2}, and σ_{e12} are the residual (co)variances of 305-d yield in first and second lactation.

The DMUAI routine in the DMU software (Madsen and Jensen, 2008) was used to estimate (co)variance components and predict breeding values and solutions for fixed effects.

RESULTS AND DISCUSSION

Parity of Dam

Estimated effects of parity of dam on daughters 305-d milk yield in first and second lactations, expressed as deviation from parity 7, are shown in Table 3. Increasing parity number of dam had a negative effect on daughters' 305-d milk yield in first and in second lactation. Daughters of first-parity dams had 149-kg higher 305-d milk yield in their first lactation than did daughters of seventh-parity dams. In the second lactation, the difference was 130 kg of milk. Differences between parities 2 to 5 were not significant (because their estimates ± standard errors overlap) for either first- or second-lactation milk yield. Second-parity daughters produced, on average, 40 and 58 kg less milk in first and second lactations, respectively, than did first-parity daughters, but the difference was not significant. For second-lactation daughters, we detected no significant difference in 305-d milk yield if dams were in parities 2 to 6.

To our knowledge, this effect of parity of dams has not been shown previously. Fuerst-Waltl et al. (2004) analyzed effect of age classes of dams at calving, regardless of parity, in Austrian dual-purpose Simmental, and found that the older the dam, the lower the milk yield of their daughters. The oldest dams in the present study (seventh parity) were 6 to 8 yr old, and would correspond to age classes 3 and 4 of Fuerst-Waltl et al. (2004). The difference between first and seventh parities in the present study were 149 and 130 kg of milk in first and second lactations of daughters, respectively, whereas the differences between age classes 1 and 4 reported by Fuerst-Waltl et al. (2004) were 83 and 89 kg of ECM in first and second lactations of daughters, respectively.

It is not entirely clear what distinguishes a first-parity heifer from the same animal as a second- or higher-parity cow that could explain the difference between daughters' production. One major difference, however, is the high energetic demand of lactation that has to be met by a second- or later-parity dam compared with a first-parity one. A pregnant heifer needs energy and nutrients for maintenance, for her own growth and development, and for growth and development of the fetus. Heifers are generally managed to calve at greater BCS than multiparous herdmates, which, in turn, will lead to reduced postpartum DMI (Roche et al., 2009). Moreover, Holstein-Friesian first-parity cows fail to regain their BCS as effectively as older cows after peak lactation, probably because they are still growing (Berry et al., 2008). During early lactation, the energy demand for milk production is normally higher than the energy supply, particularly in high-yielding individuals, hence the cow has to mobilize from body tissues (Bauman and Currie, 1980).While experiencing this period of negative energy balance, the animal should then resume estrous cyclicity and become pregnant for the second time. The unfavorable relationship between negative energy balance and fertility is well documented (Butler, 2003; Wathes et al., 2007; Lucy, 2008). During the second pregnancy, the cow again needs energy and nutrients for maintenance, her own growth, and growth and development of the fetus. Demands for growth of the fetus will be the same but, compared with the first pregnancy, maintenance demands will be higher, and demands for the cow's own growth will be lower. The single factor contributing most to the difference between a first- and second-parity cow is that the second-parity cow needs energy and nutrients for milk production during the pregnancy. Looking at the third pregnancy compared with the second pregnancy, maintenance costs will be somewhat higher, demands for the cow's own growth will still be lower, and demands for growth and development of the fetus will again be the same. But during her third lactation and pregnancy, the cow will need energy and nutrients for even higher production than during her previous lactations (Schutz et al., 1990; Banos et al., 2007). From the third parity on, the cow will be fully grown and, as long as the cow stays healthy, the differences between demands for nutrients and energy from one pregnancy to the next will vary less. This line of events may explain a major part of the effects of parity of dam in Table 3.

Over the last decade, several authors have discussed whether epigenetic effects of an adverse uterine environment in the dam might affect the fetus and subsequent performance of the offspring (Butler, 2003; Roche et al., 2009; Schoonmaker and Eastridge, 2013). A well-functioning placenta is important for an adequate supply of nutrients to and removal of heat and waste from the fetus. However, the uterine environment would probably have to be extremely adverse to seriously affect fetal growth. This is clearly illustrated in the study of effects of extreme malnutrition on the offspring of women who were pregnant during the Dutch famine in the winter of 1944 to 1945 (see, for example, Roseboom et al., 2001). In that study, effects on health in later life were dependent on the timing of malnutrition during gestation but no effects on, for example, birth size of the baby were noted. In today's conventional dairy production, offspring will never have experienced remotely comparable adverse uterine environments. On the other hand, it is not clear whether the results from human underfeeding are applicable to dairy cows. Thus, the potential effects of negative energy balance or underfeeding during key periods of embryo and fetal development cannot be excluded. In any case, both occasional overfeeding and underfeeding due to different management practices were taken into account by including the herd-year effect in the model.

Age Within Parity of Dam

Table 1 shows the estimated effects of age × parity of dam, expressed as deviation from dams older than 95 mo in parity 7 on 305-d milk yield of daughters in first and second lactation. The effect of age × parity of dam was highest for the youngest dams in all parities except for first-lactation daughters of fifth-parity dams and daughters of sixth-parity dams. The difference in 305-d milk yield of daughters from young and old dams (it should be noted that the terms "young" and "old" refer to a normal range of age at calving) within parity were significantly different for first-lactation daughters of first-, second-, and third-parity dams. Daughters of young dams produced, on average, 58, 117, and 87 kg more milk in first lactation than did daughters of old first-, second-, and third-parity dams, respectively. This is consistent with the findings of Banos et al. (2007), showing that daughters of young first-parity Holstein dams produced 1.18 kg more milk on the third test-day than did daughters of older first-parity dams. Daughters of young second-parity dams also produced significantly more milk in their second lactation than did daughters of old second-parity dams. The milk yield of daughters from young and old dams in parities 4, 5, 6, and 7 were not significantly different.

The differences in milk yield between daughters of young and old first-parity dams could, to some extent, be a function of age and size of the animal. Herd management will affect age at first calving (**AFC**). Some farmers may prefer to have heifers with a high AFC, because older heifers are expected to produce more milk than young heifers. The effect of AFC on subsequent milk yield has been studied by several authors (e.g., Van Amburgh et al., 1998; Ettema and Santos, 2004) and is confirmed in our data (Figure 3). However, the association between AFC and milk yield could also be ascribed to BW at calving, because older heifers usually have a higher BW at calving than young heifers (Van Amburgh et al., 1998). Ettema and Santos (2004) showed that milk yield did not differ between younger and older Holstein heifers until 50 d in milk; thereafter, the older heifers increased their yield. Those authors further discussed whether a low BW at first calving could be an indirect disadvantage for the subsequent

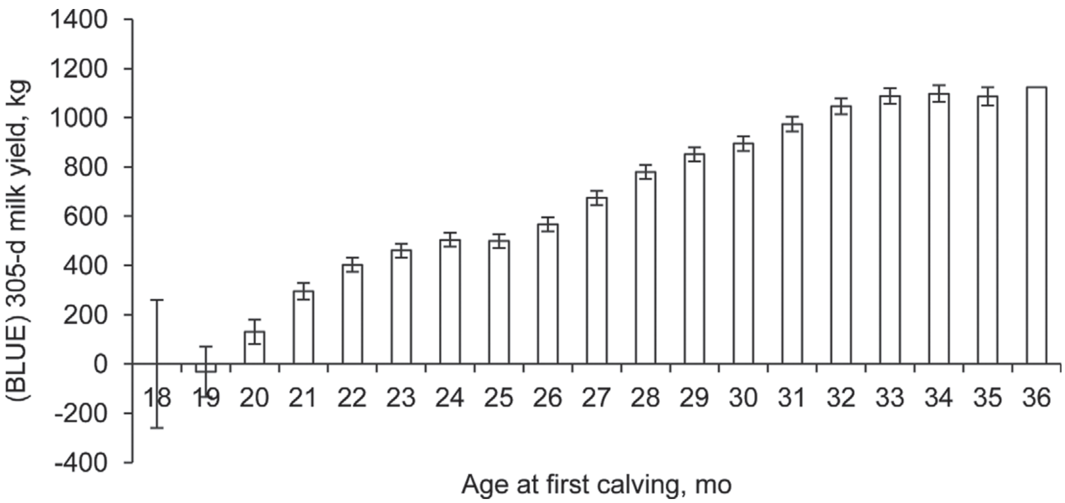

Figure 3. Effect of age of daughters at first calving on their 305-d milk yield expressed as deviation from 18 mo. (BLUE = best linear unbiased estimator). Error bars indicate standard error.

milk yield of the cow. First, heifers with low BW at calving are known to have a higher risk of dystocia, and dystocia is often associated with decreased milk yield in the first lactation (Berry et al., 2007; Eaglen et al., 2011). Second, small heifers may have a lower DMI than their potential because of the high competition for feed with larger herdmates (Ettema and Santos, 2004).

Milk yield of different age classes of first- and second-parity dams should be distributed similarly to the milk yield of the daughters in first and second lactation, as presented in Figures 3 and 4, respectively. This is also supported by the findings of Ettema and Santos (2004). Thus, young first-parity dams will produce less milk than older first-parity dams. This effect of age × parity of dam would also be expected to continue into the subsequent parities of the dam. As parity number increases, the number of animals in each group will inevitably decrease because an increasing number of animals are culled. Thus, the effect of age × parity of dam will be less evident toward parity 7.

The reasons for the effect of age × parity of dam are not known. But if age and BW at first calving are major factors, a heifer management system should favor heifers to calve large, lean, and young; no conflict necessarily exists between being large and lean on one side and young on the other. Being large would also mean that the heifers are closer to their mature BW at first calving. Consequently, they would allocate less

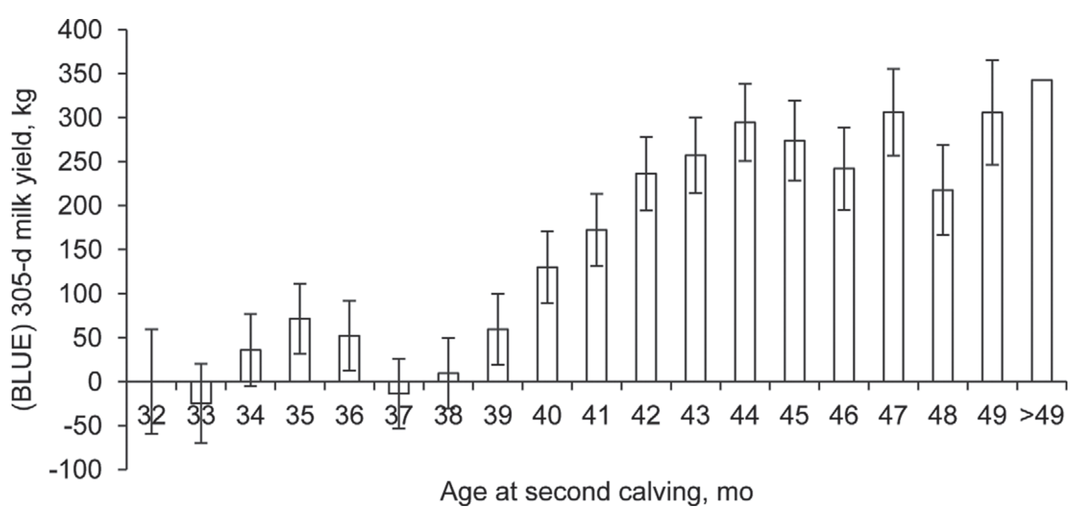

Figure 4. Effect of age of daughters at second calving on their 305-d milk yield expressed as deviation from 32 mo. (BLUE = best linear unbiased estimator). Error bars indicate standard error.

energy to their own growth and more to milk production in their first lactation.

Other Effects

Age at first calving affects 305-d milk yield in first lactation, as shown in Figure 3. Young first-lactation cows produce less milk than older first-lactation cows, but the effect of age levels off at around 33 mo of age. This is consistent with results shown by others (Lin et al., 1986; Van Amburgh et al., 1998; Ettema and Santos, 2004). A similar trend for second-lactation cows is shown in Figure 4, with increasing milk yield from 38 mo of age at calving. The effect of AFC on 305-d milk yield is much greater than the effect of parity and age of dam. As mentioned, low AFC is often associated with lower BW at calving, which could be the reason for the lower milk yield.

Estimated effects of year × month of calving showed that 305-d milk yield has increased over time and that seasonal variations exist (results not shown); cows calving in autumn tend to produce more milk than cows calving in early spring and summer. During the summer, most Norwegian cows stay on pasture. Because of variable weather conditions and roughage quality during summer, feeding is more stable during winter.

Heritability and Correlations

In both models, estimated heritabilities of 305-d milk yield of daughters were 0.46 and 0.44 in the first and second lactations, respectively. Estimated heritabilities for 305-d milk yield in the present study were higher than the heritability of 0.277 used in routine genetic evaluations for Norwegian Red (Geno Breeding and AI Association, 2014). This is probably because only cows that had completed 305 d of lactation were used in the present study.

Estimated (co)variance components were similar for both models. The estimated genetic correlation between 305-d yield in first and second lactation was 0.92 (SE 0.005). This estimate is consistent with the genetic correlation of 0.90 reported by Carlén et al. (2004) for Swedish Holstein. The estimated herd-year and residual correlations were 0.78 (SE 0.006) and 0.19 (SE 0.009), respectively. Estimated correlations for the model with age × parity of dam were identical, except for estimated residual correlation of 0.18 (SE 0.009).

Age at Calving

Results from the present study illustrate a conflict of interest in whether the dam or the daughter should be young or old at first calving. If the dam is young at first calving, her daughter is expected to produce more milk than a daughter of an older first-parity dam. On the other hand, our results, as well as those of other studies (Van Amburgh et al., 1998; Ettema and Santos, 2004), show that young heifers produce less milk than older heifers. Thus, both age and parity of dam should be included in future models aiming to detect differences in milk yield.

CONCLUSIONS

Extensive use of heifers as dams would have a systematic effect because daughters of heifers produced more milk than did daughters of older dams. Within parity, young dams gave higher-producing daughters than did older dams.

ACKNOWLEDGMENTS

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Paper 2

INTERPRETIVE SUMMARY

Heifer growth and milk yield of primiparous Norwegian Red *By Storli et al., page X.*

Due to a limited growth rate under field conditions, test-day milk yield of primiparous Norwegian Red peak at an age at first calving of 26 mo. This leads us to conclude that in this environment the majority of the heifers becomes sexually mature, i.e. reach the level of maturity when they can sustain a pregnancy without adverse effects, rather late This is likely due to rearing, and in particular feeding, practices that have not been adjusted to meet the requirements of the genetically improved heifer of today.

A longitudinal field study on the relationship between heifer growth and test-day milk yield of primiparous Norwegian Red

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ABSTRACT

The present study utilized information on replacement NRF-heifer growth and first lactation test-day milk yield from 30 larger Norwegian commercial dairy farms of which 15 of the herds had a history of producing on average more than 7,500 kg (305 days) and the other half less than 6,500 kg ECM. The herds were visited six to eight times over a period of two years. At each visit, heart girth circumference was measured on all available young females, from newborn to calving. Registrations were made on a total of 3,111 heifers. After imposing restrictions on the data growth parameters were estimated based on information from 536 animals, whereas 350 of these animals had the required information needed to estimate the relationship between growth and test-day milk yield. The observed spread in average herd

body weight gain between 5 and 15 mo of age (from 615 to 1,053 g/d) is presumably normal biological variation. Much of this variation was established already at the onset of puberty. Under field conditions in Norway, milk production of primiparous cows peaked at an AFC of 26 months of age, possibly because in this environment the majority of the heifers reach sexual maturity, i.e. the stage where they can sustain a pregnancy without adverse effects, as late as 17 mo of age due to a low individual average growth rate. This is likely due to rearing, and in particular feeding practices that have not been adjusted to meet the requirements of the genetically improved heifer of today.

Key words: dairy cow, repeated registration, lactation test-day data, heifer growth, longitudinal model

INTRODUCTION

In Norway, around 35-40% of the milking herd is replaced annually, and replacement heifer rearing constitutes some 25-30% of the running costs on a dairy farm. If dairy farming is to remain sustainable, it is imperative to rear replacement heifers in a manner that maximizes their lifetime production in terms of yield and profitability (Brickell et al., 2009). Current national recommendations on replacement heifer rearing are largely based on Danish studies from the late 1980-ies to the mid 1990-ies (Foldager and Sejrsen, 1991; Hohenboken et al., 1995; Sejrsen and Purup, 1997). The fact that these results were obtained on breeds different from the Norwegian Red (NRF), the dual purpose large breed that is the dominant one in Norwegian cattle production, is probably of little consequence (see Hohenboken et al., 1995). Far more important is it that today's NRF is markedly different from the one that existed some 25 years ago due to a continuous genetic improvement of economically important traits (Geno, 2014). Whether rearing, and in particular feeding practices have been updated accordingly is less clear. To resolve this question we aimed to obtain information on how current rearing practices affects first lactation milk yield, and to identify major components of these rearing practices that drive first lactation yield. To this end, we conducted a longitudinal field study on 15 high-producing and 15 low-producing dairy farms from the three geographical regions in Norway where we combined repeated on-site registrations of growth on all available females from newborn to calving with registrations deriving from the Norwegian Dairy Herd Recording System (NDHRS) (2015).

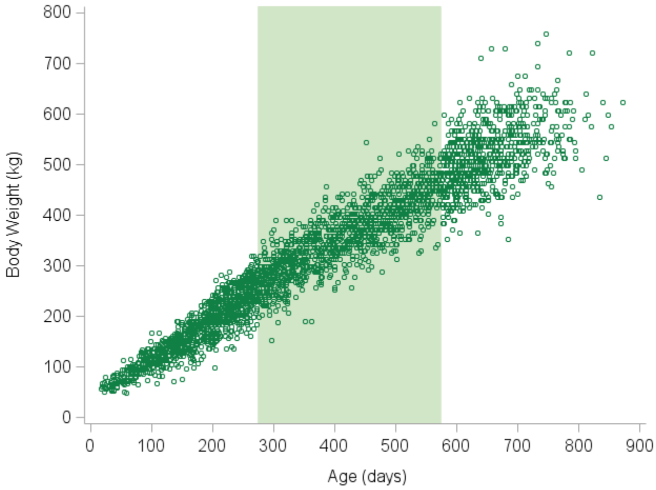
MATERIALS AND METHODS

A total of 30 herds from 3 geographical regions in Norway (Mid, South-West and South-East), 10 from each region, were selected in a study based on the following: More than 30 cow equivalents, free stall barns, unchanged heifer management from 2010 to 2012, Norwegian Red as the main breed, membership of the NDHRS, and farmers' willingness to commit to the trial. To assure variation in milk yield, five herds from each region should historically have an average 305-day milk yield above 7,500 kg energy corrected milk (**ECM**) on first lactation cows and the other five herds below 6,500 kg ECM.

The herds were visited six to eight times from May 2012 to May 2014. 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. At each visit, heart girth circumference was measured on all available young females, from newborn to calving. Only heifers born into the herd with Norwegian Red AI sires were included in the data. Twins were excluded. Measurements were conducted by eight different persons from TINE SA, the dairy advisory team. All measurements within herd where performed by the same person, except in one region where there was a change halfway through the study. The total data set included 11,071 heart girth measurements from 3,111 heifers. Heart girth measurements (cm) were converted to body weights (kg) using an equation developed by TINE SA (unpublished), and validated by Wærp et al. (2015)

$BW = 0.000468816 \times \text{Heart girth}^{2.67}$.

Figure 1. Body weights (kg) of heifers, converted from heart girth measurements (cm). All heifers were required to have measurements on both sides of the shaded age interval of 300 days.



When editing data the following specifications were set: The heifers had to have measurements over an interval of at least 300 days to cover a central part of the growth period of a heifer, with the first measurement taken before 275 days of age and the last after 575 days. Measurements after calving were excluded. Edited data included 3,144 measurements from 536 heifers (Figure 1). Numbers of measurements varied from two to eight per heifer, and 95 % of the animals had four or more.

Herd body weight model

The following model was used to calculate body weights of herd$_j$ at given ages (**hBW**);

$$Y_{ijl} = \mu + P_i + \beta_1 \cdot LEG_1 + \beta_2 \cdot LEG_2 + \beta_{0j} \cdot LEG_0 + \cdots + \beta_{4j} \cdot LEG_4 + e_{ijl} \qquad \textbf{\textit{Model 1}}$$

where, Y_{ijl} is one observation of body weight (kg); μ is the overall mean; P_i is the effect of the *i*-th person who measured heart girth (i = 1, …, 8); β_1, and β_2 are regression coefficients of first and second order Legendre Polynomials (***LEG***) for the average growth curve; β_{0j}, …, β_{4j} are random regression coefficients of order 0, …, 4 for growth of individual herds deviating from the average growth curve, respectively, and assuming

$\sim \boldsymbol{N}\left(\begin{pmatrix} \mathbf{0} \\ \vdots \\ \mathbf{0} \end{pmatrix}, \begin{pmatrix} \boldsymbol{\sigma^2_{\beta_0}} & \cdots & \boldsymbol{\sigma_{\beta_0\beta_4}} \\ \vdots & \ddots & \vdots \\ \boldsymbol{\sigma_{\beta_0\beta_4}} & \cdots & \boldsymbol{\sigma^2_{\beta_4}} \end{pmatrix}\right)$, and e is a random error term for the *l*-th measurement within herd$_j$ modelled with heterogeneous and independent variances for six age periods to have a similar number of observations (mo; < 5, 5 – 8, 9 – 12, 13 – 16, 17 – 20 and > 20).

The BW gains of herds (**hBWG**, g/day) were calculated from the weight differences between two given hBWs divided by number of days between the two.

Body size model

The following model was used to calculate constants for herds (hSIZE) and for body weight of heifers (iSIZE);

$$Y_{ijkl} = \mu + P_i + \beta_1 \cdot LEG_1 + \beta_2 \cdot LEG_2 + \beta_{0j} \cdot LEG_0 + \beta_{0k} \cdot LEG_0 + e_{ijkl} \qquad \textbf{\textit{Model 2}}$$

where, Y_{ijkl} is one observation of body weight (kg); μ, P_i, β_1, β_2, *LEG1* and *LEG2* are as in Model 1; β_{0j} and β_{0k} are random regression coefficients of order 0 for growth of herds and individual heifers, both assuing $\sim \boldsymbol{N}(\mathbf{0}, \boldsymbol{\sigma^2_{\beta_0}})$, and e is a random error term for the *l*-th measurement of heifer$_k$ modelled as with Model 1.

Individual body weight model

The model was used to calculate individual body weights (**iBW**) of the heifers at four given ages. Five mo of age was selected as an early age level (**iBW5**), because the average age at first heart girth measurement was 4.7 mo. Norwegian Red females reach puberty on average between 9 and 11 months of age, thus the choice of **iBW10**. Fifteen mo of age (**iBW15**) was selected because it has historically been the recommended age for breeding Norwegian heifers. Finally, 21 mo of age (**iBW21**) was selected because the youngest heifers in the data calved at 22 mo of age.

The following model was used to calculate body weights of heifer$_k$ at the selected ages;

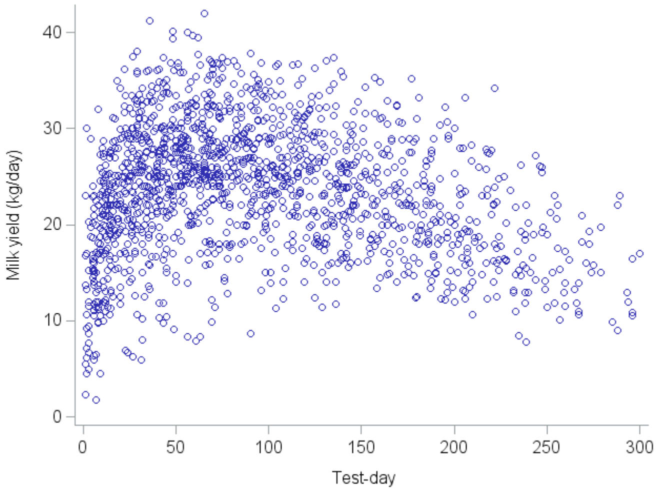
$$Y_{ikl} = \mu + P_i + \beta_1 \cdot LEG_1 + \beta_2 \cdot LEG_2 + \beta_{0k} \cdot LEG_0 + \cdots + \beta_{2k} \cdot LEG_2 + e_{ikl} \qquad \textbf{\textit{Model 3}}$$

where, Y_{ikl} is one observation of body weight (kg); μ, P_i, β_1, β_2, *LEG1* and *LEG2* are as in Model 1; β_{0k}, …, β_{2k} are random regression coefficients of order 0, …, 2 for growth of individual heifers assuming $\sim \boldsymbol{N}\left(\begin{pmatrix}\mathbf{0}\\ \vdots\\ \mathbf{0}\end{pmatrix}, \begin{pmatrix}\boldsymbol{\sigma^2_{\beta_0}} & \cdots & \boldsymbol{\sigma_{\beta_0\beta_2}}\\ \vdots & \ddots & \vdots\\ \boldsymbol{\sigma_{\beta_0\beta_2}} & \cdots & \boldsymbol{\sigma^2_{\beta_2}}\end{pmatrix}\right)$, and *e* is a random error term for the *l*-th measurement of heifer$_k$, modelled as with Model 1.

At a predefined age iBW (iBW5, …, iBW21) will in essence be a weighted mean of the intercept solution for an animal (β_{0k}), and the first and second order solutions for the animal (β_{1k} and β_{2k}, respectively). Thus, at low ages iBW will mainly be determined by the intercept solution for an animal (β_{0k}), while at high ages iBW will be more influenced by the higher order solutions for the animal (β_{1k} and β_{2k}).

Individual body weight gains, **iBWG**, g/day, were calculated from the weight difference between two given iBW ages divided by number of days between the two.

Figure 2. Plot of first lactation test-day observations of heifers.



First lactation test-day yield models

Age at first calving and first lactation test-day milk yields (kg/day) were extracted from the NDHRS for the 30 herds. Heifers calving from October 2013 to October 2014, who had been mated with Norwegian Red AI sires, were included. Heifers giving birth to twins were excluded. Test-day observations after day 305 of lactation were deleted. It was further required that animals had to have both BW and test-day observations, implying that additional animals were excluded; the restriction led to the exclusion of one herd from the South-East region. A total of 1,510 test-day observations from 350 heifers were included in the study (Figure 2). The shape of their lactation curves, peaking at around 50 days, can easily be seen from Figure 2. The number of test-day observations varied from one to 12 per cow, and 41 % of the animals had five or more observations. The following model was used to analyze the test-day data, ***Model 4a***:

$$Y_{ijklm} = \mu + \beta_1 \cdot LEG_1 + \cdots + \beta_3 \cdot LEG_3 + S_i + AFC_j + \beta_4 \cdot X + cow_k + herd_l + e_{ijklm}$$

where Y_{ijklm} = one observation of test day yield (kg/day) in the first lactation; μ is the overall mean; β_1, …, β_3 are regression coefficients of 1st, …, 3rd order Legendre Polynomials (*LEG*) for the lactation curve; S_i is the effect of the *i*-th calving season ($i = 1, \ldots, 4$; Mar. – May (n= 97), June – Aug. (n= 135), Sept – Nov. (n= 59), Dec. – Feb. (n= 59)); AFC_j is the effect of the j-th age at first calving class (($j = 1, \ldots, 5$; ≤ 23, 24, 25, 26 and ≥ 27 mo of age, representing 19, 28, 21, 14 and 18% of the animals, respectively); $\beta 4$ is the linear regression on the calculated variables of growth (hBW, hBWG, iSIZE, hSIZE, iBW, iBWG); cow is a random effect of *k*-th *cow* (1, …, 350, $\sim N\ (0, I\sigma^2_{cow})$); herd is a random effect of *l*-th *herd*

(1, …, 29, $\sim N\ (0, I\sigma^2_{herd})$), and e_{ijklm} is a random error term modeled with heterogeneous and independent variances at eight periods of lactation (weeks; 0 - 1, 2 - 3, 4 - 7, 8 - 11, 12 - 15, 16 - 19, 20 – 23 and > 23).

A second model was used to analyse the test-day milk yield data, ***Model 4b***:

$Y_{ijklm} = \mu + \beta_1 \cdot LEG_1 + \cdots + \beta_3 \cdot LEG_3 + S_i + \beta_4(AFC \cdot X)_j + cow_k + herd_l + e_{ijklm}$

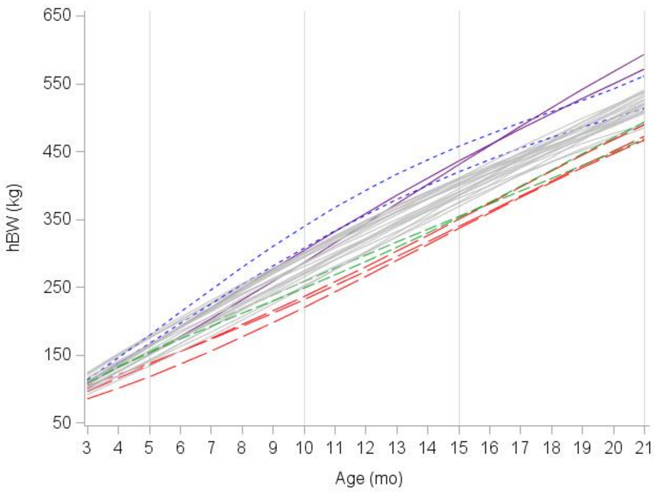
The remainder of the model is as defined in model 4a. The SAS MIXED Procedure (SAS, version 9.4, SAS Institute Inc., Cary, NC) was used to carry out all analyses. Satterthwaite approximation was used for approximation of denominator degrees of freedom of F-tests.

RESULTS

Herd body weight

The Legendre polynomials of order one and two were significant (P < 0.005) with estimates of regression coefficients being 253.6 and -8.4, respectively. There was no significant effect (P = 0.21) of the person who made heart girth measurements. Figure 3 shows predicted BWs for each herd; it illustrates the large variation of average BWG between herds and shows that much of this variation was already established at around 10 mo of age. Calculated hBWG from 5 – 10, 10 – 15 and 15 – 21 mo of age varied from 615 – 1,053, 630 – 946 and 511 – 889 g/day, respectively. Herd means were calculated based on 6 to 44 animals. Mean and standard deviation of herd growth variables for the 350 lactating cows from the 29 herds are given in Table 1.

Figure 3. Predicted average weight of heifers per herd (kg) between 3 and 21 mo of age (Model 1, for details see text).



Body size

The Legendre polynomials of order one and two were significant (P < 0.0001) with estimates of regression coefficients being 248.6 and -14.3, respectively. In this case there was a significant effect (P < 0.004) of the person who made heart girth measurements, and the largest contrast between persons was 29.8 kg. Variation in the individual size of heifers (iSIZE) is depicted in Fig. 4. Mean and standard deviation of iSIZE and hSIZE are given in Table 1.

Table 1. Predicted (with Model 1) average weight gain per herd of heifers[1] (hBWG) between 5 – 10, 10 – 15 and 15 – 21 mo of age; predicted (with Model 2) individual size (iSIZE) and predicted herd means (hSIZE); predicted (with Model 3) individual body weights (iBW) at 5, 10, 15 and 21 mo of age, as well as individual BW gain (iBWG).

	n	Mean	SD
Model 1			
hBWG5-10, g/day	29	802	100.9
hBWG10-15, g/day	29	747	71.0
hBWG15-21, g/day	29	681	99.8
Model 2			
iSIZE, kg	350	0	23.2
hSIZE, kg	29	-2	35.1
Model 3			
iBW5, kg	350	153	20.8
iBW10, kg	350	274	31.2
iBW15, kg	350	387	36.9
iBW21, kg	350	512	43.6
iBWG5-10, g/day	350	792	80.5
iBWG10-15, g/day	350	743	68.5
iBWG15-21, g/day	350	682	112.0

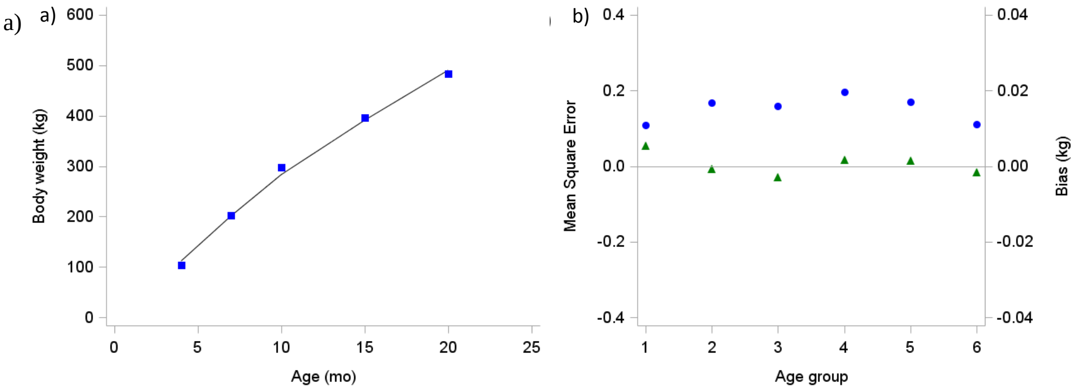
[1]Based on the 350 animals from 29 herds that had test-day milk yield data

Individual body weight

Again, the Legendre polynomials of order one and two were significant (P < 0.0001) with estimates of regression coefficients being 251.28 and -12.5391, respectively. Moreover, the effect of the person who made heart girth measurements was significant (P < 0.0001), the largest contrast between recorders being 25.7 kg. Figure 5a illustrates how the model fits to the data, while Fig. 5b shows the bias and mean-squared error. The model prediction was close to unbiased and the mean-squared error varied between 108 and 197 grams per day. Mean and standard deviation of individual growth variables are given in Table 1.

Estimated (co)variance parameters of $\sigma^2_{\beta0}$, $\sigma_{\beta0\beta1}$, $\sigma^2_{\beta1}$, $\sigma_{\beta0\beta2}$, $\sigma_{\beta1\beta2}$ and $\sigma^2_{\beta2}$ were 2,120.97, 1,086.25, 1,082.61, 2.1916, 431.1 and 439.02, respectively. The standard deviation of the error term for the six age periods increased with age from eight to 27 kg (see Figure 1).

Figure 4. a) Observed (■) and predicted body weights (solid line, obtained with Model 3) for one randomly sampled cow. **b)** Bias (△) and mean-squared error of prediction (○) from Model 3; six age periods (< 5 , 5 – 8, 9 – 12, 13 – 16, 17 – 20 and > 20 mo).



First–lactation test-day yield

Table 2 shows the analysis of variance results for how growth affects test-day milk yield. When considered as main effects both iBW21 and iBWG10-15 regressed significantly on milk yield (P < 0.05), while the main effect of AFC in general was significant irrespective of which growth variable was included in the calculations. Furthermore, there was a significant (P < 0.05) interaction between AFC and variables of growth, and mostly so for iBW21 and iBWG10-15.

The estimated least-squares means of AFC on daily milk yield from the interaction model (*Model 4b*) at peak lactation (50 DIM) are given in Table 3. Estimates were almost similar when regressing on iBW15 or iBW21. But regardless of iBW variable, the estimates were most pronounced for an AFC of 26 mo of age. The contrasts between the estimated least-squares means from Table 3 are given in Table 4, and show that heifers calving at ≤ 23 mo of age produced less (*P* < 0.005) milk per day than those calving at 26 mo (2.8 and 2.9 kg for iBW15 and iBW21, respectively) . Similar results were found for the contrast between ≤ 23 and 25 mo of age (*P* < 0.05).

Table 2. F-values and P-values of fixed effects[1] included in Model 4, which is a first lactation test-day model. Fixed effects are either main effects or interactions. Main effects are either regressions on variables of growth (see Table 1) or age at first calving (AFC with 5 classes).

	F-values (P-values)		
Variables[3] (X)	BW/BWG/SIZE	AFC	BW/BWG/SIZE × AFC
Model 1			
hBWG5-10	0.0 (0.86)	2.4 (0.05)	-
hBWG10-15	0.2 (0.64)	2.4 (0.05)	-
hBWG15-21	0.4 (0.53)	2.4 (0.05)	-
hBWG5-10 × AFC	-	-	2.0 (0.09)
hBWG10-15 × AFC	-	-	2.1 (0.07)
hBWG15-21 × AFC	-	-	2.0 (0.08)
Model 2			
iSIZE	3.0 (0.08)	2.6 (0.03)	-
iSIZE × AFC	-	-	0.6 (0.67)
hSIZE	0.2 (0.65)	2.4 (0.05)	-
hSIZE × AFC	-	-	0.8 (0.53)
Model 3			
iBW5	1.0 (0.32)	2.5 (0.04)	-
iBW10	1.6 (0.21)	2.6 (0.04)	-
iBW15	2.6 (0.11)	2.7 (0.03)	-
iBW21	3.9 (0.05)	2.8 (0.03)	-
iBW5 × AFC	-	-	2.0 (0.08)
iBW10 × AFC	-	-	2.2 (0.06)
iBW15 × AFC	-	-	2.4 (0.04)
iBW21 × AFC	-	-	2.7 (0.02)
iBWG5-10	2.2 (0.14)	2.7 (0.03)	-
iBWG10-15	3.8 (0.05)	2.7 (0.03)	-
iBWG15-21	2.0 (0.16)	2.5 (0.05)	-
iBWG5-10 × AFC	-	-	2.3 (0.04)
iBWG10-15 × AFC	-	-	2.8 (0.02)
iBWG15-21 × AFC	-	-	2.4 (0.04)

[1] Legendre polynomials (LEG0, LEG1 and LEG3): P < 0.0001 and calving season: P < 0.06 – 0.31.
[2] σ_{ID}: 4.2 – 4.3, σ_{HERD}:3.5 – 3.7, σ_{eMIN}: 2.0 – 2.1 and σ_{eMAX}: 8.4 kg.

Estimated regression coefficients for the interaction between AFC and body weight variables at 15 and 21 mo of age are given in Table 5. An illustration of the effect of regressing on growth within AFC classes is given for iBW21 in Table 6. For an AFC of e.g. 26 mo increasing or decreasing mean iBW21 by one standard deviation (43.6 kg), milk yield would increase or decrease by 0.7 kg.

Heifers calving from December to February produced more ($P < 0.05$) milk per day than heifers calving from June to August (data not shown). The Legendre polynomials of order 1, 2 and 3 were different ($P < 0.0001$) from zero with estimates of regression coefficient being -4.96, -1.94 and 2.24, respectively (data not shown).

The standard deviation of cow and herd was 4.2 and 3.5 kg milk per day, respectively, and the standard deviation for the error term of the 8 lactation-week periods were 8.4, 3.7, 3.2, 2.6, 2.0, 2.2, 2.2, and 3.0 kg milk per day, respectively.

Table 3. First lactation test-day milk yield in kg at 50 days in milk; estimated least-squares means for age at first calving (AFC, mo) at average individual body weights[1] and ages 15(iBW15) and 21 (iBW21) mo. Results are from the iBW × AFC interaction model listed in Table 2.

	LSmeans	
AFC	iBW15	iBW21
≤ 23	24.9	24.8
24	26.0	26.0
25	26.8	26.8
26	27.7	27.7
≥ 27	26.4	26.5

[1] Predicted average body weights were 387 and 512 kg, respectively.

Table 4. First lactation test-day milk yield in kg at 50 days in milk; estimated least-squares mean contrasts (P-value) between age at first calving (AFC) classes obtained when predicted individual body weights at 15(iBW15) and 21(iBW21) mo of age were included in the analyses. Least-squares means are from Table 3.

	iBW15				iBW21			
AFC	24	25	26	≥ 27	24	25	26	≥ 27
≤ 23	-1.1 (0.13)	-1.9 (0.02)	-2.8 (0.00)	-1.6 (0.10)	-1.2 (0.11)	-2.0 (0.01)	-2.9 (0.00)	-1.7 (0.08)
24	.	-0.8 (0.29)	-1.7 (0.05)	-0.4 (0.62)	.	-0.9 (0.26)	-1.7 (0.05)	-0.5 (0.56)
25	.	.	-0.9 (0.32)	0.4 (0.69)	.	.	-0.8 (0.33)	0.3 (0.71)
26	.	.	.	1.2 (0.19)	.	.	.	1.2 (0.23)

Table 5. First lactation test-day milk yield in kg; estimated regression coefficients for the interaction between age at first calving (AFC) and body weight (iBW) obtained when predicted individual body weights at 15 (iBW15) and 21(iBW21) mo of age were included in the analyses. Results are from the iBW x AFC interaction model listed in Table 2.

iBW ×	iBW15	iBW21
AFC ≤ 23	0.011 (0.21)	0.012 (0.10)
AFC 24	0.014 (0.12)	0.015 (0.06)
AFC 25	0.016 (0.08)	0.016 (0.03)
AFC 26	0.019 (0.05)	0.018 (0.02)
AFC ≥ 27	0.016 (0.11)	0.016 (0.05)

Table 6. First lactation test-day milk yield in kg at 50 days in milk; estimated least-squares means when body weight at 21 mo of age are either increased or decreased by one standard deviation (43.6 kg) from the iBW21 average[1].

	iBW21		
AFC	Mean iBW	Mean iBW - 1 SD	Mean iBW + 1 SD
≤ 23	24.8	24.3	25.3
24	26.0	25.4	26.6
25	26.8	26.1	27.6
26	27.7	26.9	28.4
≥ 27	26.5	25.8	27.2

[1] Average iBW21 = 512 kg.

DISCUSSION

The present study utilized information on replacement heifer growth and first lactation test-day milk yield from 30 larger Norwegian commercial dairy farms. Fifteen of the herds had a history of producing on average more than 7,500 kg (305 d) and the other half less than 6,500 kg ECM, to ensure representative variation in production on a herd mean basis.

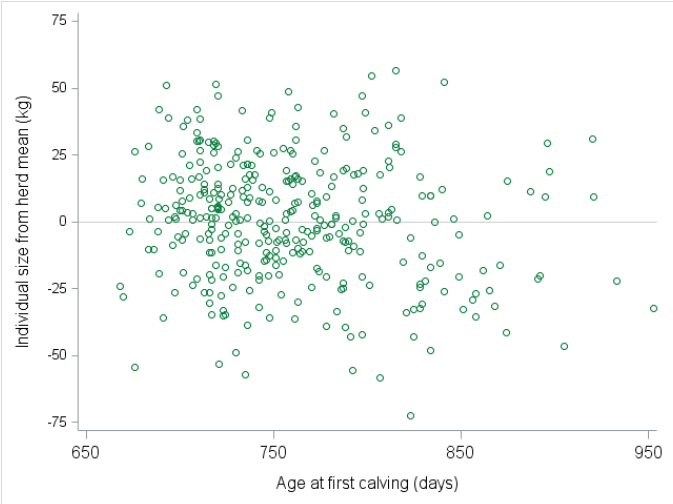
Heifer growth rates varied considerably between herds (see Figs 1 and 3), but not surprisingly, the rate by which the average animal in a given herd grows has little bearing on subsequent milk yield (Table 2, first column under Model 1). The spread depicted in the figures is presumably normal biological variation. Whereas genetics probably is a notable source of this variation in growth of heifers on an individual level, the contribution would be minor on a herd level because the genetic material is the same in all NRF herds. Heifer feeding practices follow a uniform, mainly roughage-based regime with only restricted use of concentrate. Still, feeding will probably be the major source of the variation in growth. Firstly, pre-weaning and calf management practices vary substantially between farms.

Secondly, farmers prefer to use available natural pasture for their youngstock from as early and for as long as possible, often moving them from one small area to another. The quality of the pastures vary considerably with geography and season and will thus affect growth of animals that start grazing early in the summer differently from those that start grazing later. In addition comes the hierarchy of status among the members of the group of animals. During indoor group-feeding the same considerations will apply.

Interestingly, much of the average variation in herd BWG is established already at the onset of puberty; calculated hBWG from 5 to 10 mo of age varied from 615 to 1,053 g/d. When the effect of herd growth rate was separated from that of individual heifers within the same herd (thus expressing the effect of the size of a given individual animal within the herd), there was a near significant ($P = 0.08$) effect of individual size within the herd on subsequent milk yield (Table 2, column 1 under Model 2). This implies that it is beneficial to be large, and size has long since been identified as one driver of increased milk production (see e.g. Sejrsen, 2005). Moreover, although obtained as a regression the result compares favourably with the positive genetic correlation that has previously been shown to exist between body size and milk yield in dairy breeding (Ahlborn and Dempfle, 1992; Pryce and Harris, 2006).

With the iBW model (Model 3) one can calculate weight at given ages (BW5, BW10, BW15 and BW21). The model predicts well, which is amply illustrated for one random cow in Figure 4a, whereas Fig. 4b shows the model to have close to no bias and only a minor mean-squared error The individual random regression of weight on age is actually regressed for uncertainty and this explains why even minor weight differences become significant in the interaction between BW-variables and AFC. The largest F-values were obtained when milk yield was regressed on individual weight and individual growth rate (Table 2, column 1 under Model 3), more specifically from iBW21 and iBWG10-15 ($P = 0.05$ for both). On the other hand there was no effect of prepubertal growth (iBWG5-10, $P = 0.14$). This could well be because the feeding level and thus the growth rate of the majority of heifers during this time period (herd average about 800 g/d) were not of a magnitude that would lead to reduced milk yield (Sejrsen et al., 2000). Additionally, for both parameters and with the same model, there was a general, significant main effect of AFC (Table 2, column 2) and significant interactions ($P < 0.05$) (Table 2, column 3); again, most information could be obtained from the interactions with iBW21 and iBWG10-15 ($P = 0.02$ for both). We decided to base further inferences on iBW21.

Figure 5. Predicted individual size adjusted for the random effect of herd (Model 2), plotted against age at first calving. For details, see text.



Figur 6. Predicted **i**ndividual body weight at 21 mo of age (obtained with Model 3) plotted against age at first calving.

Heifers with an AFC of 26 mo produced about 3 kg more milk per day than heifers with an AFC of ≤ 23 months of age, whereas AFC ≥ 27 mo again lead to reduced milk production (Table 3). The former suggests that heifers are punished yield wise if they calve in too early. This is most likely because they have not yet reached sexual maturity at the time of conception, i.e. they are not physiologically ready to go through a pregnancy without adverse effects. Under field conditions in Norway, milk production of primiparous cows peaked at an AFC of 26 mo. This could mean that in this environment the largest fraction of heifers reach a level of maturity that allows them to sustain a pregnancy without adverse effects as late as at 17 months of age, due to a rather moderate average growth rate of, in this material, some 770 g/d from 5 to 15 mo of age. Furthermore, the decision on when to start insemination is more often than not based on age, and the animals are considered to be sufficiently old and therefore, estimated by eye, large enough for the majority to become pregnant at around 17 mo of age. That milk yield declines at AFC ≥ 27 mo suggests, on the other hand, that heifers are also punished if they calve in too late. Interestingly, Figure 5 reveals that it is not the smallest animals in the herd that calve in the latest, it is, according to Fig 6, rather the ones that weigh the least at 21 months of age, likely the losers in the herd. Here, inferences were made from BW21, because BW at calving, that would have allowed separating age effect from that of weight on milk yield, was unavailable. Consequently, the effect of AFC also includes the effect of BW gain from BW21 to calving, which is expected to be more pronounced with increasing AFC. The interaction between predicted body weights at 21 months of age (BW21) and AFC was significant, meaning that a cow calving in aged 26 months will produce an extra 0.8 kg milk per day (Table 6). Furthermore, because body weight at BW21 to a greater extent will be determined by growth rate from BW5 to BW21 than by BW5 alone (which here ideally should have been replaced by birth weight), the effect of BW is actually an effect of ADG. Thus, it follows that a high ADG in the rearing period is favorable for first lactation milk yield. But how to define high will likely vary with breed (Hohenboken et al., 1995). In addition comes the continuous genetic improvement from years of selection and breeding (Geno, 2014). Generally, a high ADG in the post-pubertal period is considered to be positive for subsequent milk production (Lacasse et al., 1993; Macdonald et al., 2005), whereas the literature on growth rate in the pre-pubertal period generally associate a high ADG with reduced future milk yield (Hohenboken et al., 1995; Sejrsen and Purup, 1997; Lammers et al., 1999). It should, however, be borne in mind that ADG in the present field material was rather restricted, only about 770 g/day from 5 to 15 mo of age, which is considerably lower than for the most intensively fed groups in feeding trials (Van Amburgh et al., 1998; Lammers et al., 1999). This is probably due to rearing, and in particular feeding practices that have not been adjusted to meet the requirements of the genetically improved heifer of today.

Economy

The present study showed that a rather moderate ADG of around 770 g/d during the rearing period and an AFC of 26 mo of age would maximize milk production in the first lactation. But if we take into account the additional feed, labor and housing costs related to rearing heifers for extra kg and mo, rearing replacement heifers to calve at 26 mo of age might not be the economical optimum. This is of course dependent on milk price and rearing costs, which might vary considerably between countries. Pirlo et al. (2000) concluded that reducing AFC below 25 mo of age had a positive effect on the difference between milk yield returns and rearing costs for Italian Holstein-Friesian heifers. When modelling performance of Holstein heifers in the US and in the Netherlands, Mourits et al. (1999, 2000) concluded that an AFC of 20.5 or 22.6 mo would maximize heifer lifetime economic performance, respectively. Reducing AFC below the maximum for milk yield could be favorable from an economic point of view and Ettema and Santos (2004) found that an AFC between 23 and 24.5 mo would be the most beneficial using data from commercial US dairy herds. Economical calculations are outside the scope of this paper, but data generated should be included in efforts to determine in which manner heifers should be reared to maximize their lifetime production in terms of yield and profitability.

CONCLUSION

Under field conditions in Norway, milk production of primiparous cows peaked at an AFC of 26 months of age, possibly because in this environment the majority of the heifers reach sexual maturity as late as 17 months of age due to a rather moderate average growth rate. For all ages at first calving, production increased additionally with increasing growth rate, and especially that between 10 and 15 months of age. Heifers calving at 26 months of age produce almost 900 kg more milk during the first 305 days lactation than heifers calving younger than 24 months of age. Moreover, by adding one standard deviation (43.6 kg) to the average BW at 21 months of age they produce close to another 250 kg more milk in the first lactation.

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Paper 3

INTERPRETIVE SUMMARY

Norwegian Red heifers can be made to calve at 22 months of age without compromising subsequent milk yield using one kg of concentrate and by regulating energy supply with roughage quality. This would result in a flatter lactation curve, improved body condition score and body weight change profiles together with increased roughage intake.

Designing a feeding strategy for a replacement heifer management system: II. Effects of pre- and post-conception feeding on performance of primiparous Norwegian Red

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ABSTRACT

Using a simple, roughage-based feeding strategy in which 66 Norwegian Red had been fed one kg of concentrate and energy supply was regulated with roughage quality, we have confirmed that it is possible to rear heifers for a rapid weight gain (about 940 g/d) from 3 mo of age to conception and a moderate daily gain (about 550 g/d) through pregnancy without negative effects on lactation performance of the primiparous cow. This reduces age at first calving to 22 months, results in a flatter lactation curve, improved body condition score and body weight change profiles together with increased roughage uptake in the first part of the lactation. When challenged with reduced concentrate supply from 120 days in lactation the animals responded by keeping up milk production. Thus, results suggest we have succeeded to make a cow that have an increased uptake of DM from roughage.

Key words: heifer growth, first lactation, milk yield, body condition score, body weight change, roughage intake, dry matter intake

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). Rearing should thus be evidence-based, and designed to maximize life-time performance of the animals (Brickell et al., 2009). A means to this end would be a heifer growth model that allows animals to reach puberty and sexual maturity at an early age and then to be bred to reduce age at first calving (**AFC**) without compromising future milk production. Developing such a model implies a decision on at what age heifers should reach puberty, and when to breed them to attain a desired AFC. But decision making will soon be in conflict with the biology of the animals. Puberty is a function of weight rather than age of the animal, and Norwegian Red heifers reach puberty at around 280 kg regardless of age. Thus, to reach puberty and sexual maturity at an early age heifer calves must grow fast. Generally, a high average daily gain (**ADG**) in the pre-pubertal period is associated with a reduced capacity for future milk production (Hohenboken et al., 1995; Sejrsen and Purup, 1997; Lammers et al., 1999). A high ADG in the post-pubertal period is on the other hand positive for subsequent milk production (Lacasse et al., 1993; Macdonald et al., 2005; Storli et al., 2015). What defines a high ADG seems, however, to vary between breeds (Hohenboken et al., 1995). And, in addition comes the continuous genetic improvement of economically important traits attained through years of selection and breeding (Geno, 2014). Based on this we hypothesized that rearing heifers for a rapid weight gain (>850 g/day) from 3 mo of age to confirmed pregnancy and a moderat daily gain through pregnancy would not have any negative effects on subsequent lactation performance.

We approached this task by first contrasting groups of Norwegian Red with different growth profiles during both the pre- and postpubertal periods until conception and similar feeding but dissimilar profiles during pregnancy, which is described in a companion paper (Wærp et al., 2015). Here we report on our second objective, which was to evaluate the effects of the different growth profiles on performance of the same animals as primiparous cows.

MATERIALS AND METHODS

The experimental procedures involving animals complied 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.

Eighty Norwegian Red heifers from the university herd (year classes 2010 and 2011) were randomly assigned either to a high (**HE**) or low (**LE**) energy group, planned for a BW gain of 800 – 950 or 600 – 750 g/day from three mo of age to confirmed pregnancy, respectively. Each of the energy groups were split at random into two protein groups, low (**LP**) or high (**HP**), to give four dietary treatment groups with 20 animals in each group: Low-protein high-energy (**LPHE**), high-protein high-energy (**HPHE**), low-protein low-energy (**LPLE**) and high-protein low-energy (**HPLE**). A full description of the experimental design and the growth of the replacement heifers was discussed by Wærp et al., (2015).

Of the 80 animals, 14 were excluded during the experimental period: infertility (LPHE = 1, HPHE = 1, LPLE = 1 and HPLE = 2), lameness (LPLE = 1 and HPLE = 1), neurological condition (LPHE = 1), mastitis (LPHE = 1, LPLE = 1 and HPLE = 1), poor milk yield (LPHE = 1), twin birth (HPLE = 1), and finally one HPHE-cow due to bad temper.

Heifer feeding and management

All heifers were fed the same diet prior to the experimental feeding. From three mo of age and until confirmed pregnancy, they were housed in a tie-stall barn and fed one of the four experimental diets; individual feed intake was recorded on week days. The energy concentration of the diet was adjusted with the roughage quality. In HE groups grass silage was fed ad libitum (> 10 % or at least one kg orts) and in LE groups the energy level of the grass silage was diluted by mixing with wheat straw. The protein level was adjusted by giving the LP- and HP-groups one of two concentrates of differing crude protein (**CP**) content; 150.6 and 229 g CP/ kg DM, respectively. All heifers were fed 1 kg concentrate per day throughout the experimental feeding period. In the LE groups the mix was fed in restricted amounts, but to avoid hunger stress, they were offered 0.5 kg extra wheat straw if the daily ration had been eaten before the evening routine. The amount of roughage mix fed to LE-groups at different ages was optimized using the TINE Optifôr Ungdyr client for the NorFor rationing system (Volden, 2011). A description of the average content of consumed nutrients in the total ration is given in Table 1.

Table 1. The average (SD) content of consumed nutrients (crude protein (CP), neutral detergent fiber (NDF), net energy growth to body weight (NEG_BW)) in the total ration between three mo of age and conception. Data from Wærp et al. (2015).

Variables	LPHE[1]	HPHE	LPLE	HPLE
CP, g/kg DM	141 (12.7)	153 (15.2)	111 (8.6)	123 (10.8)
NDF, g/kg DM	490 (29.8)	489 (29.9)	565 (28.7)	566 (28.2)
NEG_BW, MJ/kg BW	0.15 (0.033)	0.14 (0.035)	0.12 (0.043)	0.12 (0.041)

[1] Low-protein high-energy (LPHE), high-protein high-energy (HPHE), low-protein low-energy (LPLE) and high-protein low-energy (HPLE).

Breeding was initiated at 380 and 370 kg of BW for the LE and HE groups, respectively, aiming for an average BW at breeding of 400 kg. From confirmed pregnancy, the heifers were managed as the rest of the university herd and were fed a diet of roughage optimized to sustain an ADG of 500-550 g/day: They were housed in a deep-straw barn, except for the compulsory eight weeks on pasture during summer.

Feeding and management during lactation

Calving started at the end of June 2012 and ended in March 2014. About three weeks prior to expected calving, animals were housed in a free-stall barn. All animals were fed 0.5 kg concentrates per day from two weeks prior to calving and 1.0 kg per day in the last week. After calving, they followed a concentrate escalation scheme of 0.3 kg/d until maximum, i.e. from seven to nine kg/d depending on roughage quality and type of concentrate. This level was kept until 120 days in milk (**DIM**) followed by a gradual reduction by about 33 g/day, linearily.

Grass silage was fed *ad libitum* (> 10 % orts) consisting of Timothy (*Phleum pratense*), Meadow fescue (*Festuca pratensis*), Red clover (*Trifolium pratense*) and Meadow grass (*Poa pratensis*) as the main species. Representative silage samples were analyzed by near-infrared spectrometry (NIR-NorFor) (Eurofins, Norway) to aide silage mixing and choice of concentrate. Chosen silages were mixed with a Cormall multimix 30 M3 (Cormall, Denmark) and fed in bins with vertically moving gates where automatic cow identification ensured each cow access.

The concentrates were commercial concentrates (Felleskjøpet Agri, Norway) that met NorFôr nutrient requirements optimized for a milk yield of 7,500 kg energy corrected milk (**ECM**) using the TINE OptiFôr Ku client for the NorFor rationing system (Volden, 2011).

Separate representative samples of the fed silage mix and concentrates were taken biweekly and once a week, respectively, and frozen at -20°C. The samples from each mix used were pooled and analyzed by near-infrared spectroscopy (NIR-NorFor) (Eurofins, Norway). Samples from each concentrate used were pooled and analyzed chemically for ash, Kjeldahl nitrogen, crude fat (**CFat**), starch and neutral detergent fiber (**NDF**) at the Department of Animal and Aquacultural Sciences (LabTek, Norway). In total, four different concentrates were used, and the average quality of concentrate and roughage weighted by number of feed days in milk is given in Table 2.

A mineral mixture (VitaMineral Mg-rik, Vilomix Norway AS, Norway) containing 10.0 % Ca, 5.0 % P, 13 % Mg, and 8.5 % Na was available *ad libitum* throughout the experimental period.

All cows were inseminated on the second observed estrus after calving and the data was considered too limited for further analyses.

Original data and NorFor calculations

For practical reasons (huge variation in AFC, overlap between year-classes, limited available space, compulsory weeks on pasture) data were only recorded until day 175 of lactation and included twice daily records of milk yield, monthly fat and protein content in milk, averaged BW per day (after milking), weekly BCS (1-5 scale, Gillund et al., 1999), and daily intake of roughage and concentrate. Extreme outliers and records on days with claw trimming, technical problems, etc. were excluded from the data. The total number of original data that were accepted for analyses are given in Table 3.

With considerable differences in frequency of recording of original variables it was decided to base NorFor calculations on the original data, but with fill-ins calculated by individual smoothing using the following model (for BW and BCS only smoothed values were used):

$$Y_{ij} = \mu + \beta_1 \cdot LEG_1 + \ldots + \beta_4 \cdot LEG_4 + \beta_{0i} \cdot LEG_0 + \ldots + \beta_{xi} \cdot LEG_x + e_{ij} \quad \textbf{Model 1}$$

were Y_{ij} = records of variables given in Table 3 in the first 175 days of the first lactation; μ is the overall mean; $\beta_1, \ldots, \beta_4$ are regression coefficients of order 1 to 4 for Legendre Polynomials (***LEG***) for the average curve (however, 1st, …, 3rd order for fat and protein content in milk); $\beta_{0i}, \ldots, \beta_{xi}$ are random regression coefficients of orders 0 to x for individual cows deviating from the average curve, respectively, and

assuming $\sim \boldsymbol{N}\left(\begin{pmatrix}\mathbf{0}\\ \vdots \\ \mathbf{0}\end{pmatrix}, \begin{pmatrix}\boldsymbol{\sigma}^2_{\boldsymbol{\beta}_0} & \cdots & \boldsymbol{\sigma}_{\boldsymbol{\beta}_0\boldsymbol{\beta}_x}\\ \vdots & \ddots & \vdots \\ \boldsymbol{\sigma}_{\boldsymbol{\beta}_0\boldsymbol{\beta}_x} & \cdots & \boldsymbol{\sigma}^2_{\boldsymbol{\beta}_x}\end{pmatrix}\right)$, and e is a random error term for the j-th measurement of cow_i.

Table 2. Average and SD of variables contained in silage and concentrates weighted by number of feed days in milk.

	Silage		Concentrate[2]	
Variables[1]	Mean	SD	Mean	SD
DM, g/kg	336	51.0	845	8.6
Ash, g/kg DM	72	12.1	75	4.0
OMD, %	76	2.3	.	.
CP, g/kg DM	144	13.0	210[3]	9.8
sCP, g/kg CP	622	46.5	.	.
CFat, g/kg DM	.	.	56	3.1
ST, g/kg DM	.	.	311	27.0
NDF, g/kg DM	485	31.2	163	10.6
iNDF, g/kg NDF	153	29.2	.	.
SU, g/kg DM	90	20.2	.	.
PBV_{N20}, g/kg DM	19	11.6	5	23.4
AAT_{N20}, g/kg DM	82	2.8	131	7.7
NEL_{20}, g/kg DM	6.4	0.21	7.3	0.21
NH3N, g N/kg N	71	18.1	.	.
LAF, g/kg DM	46.4	8.84	.	.
ACF, g/kg DM	8.0	2.42	.	.
PRF, g/kg DM	2.4	1.99	.	.
BUF, g/kg DM	0.0	0.10	.	.
ALF, g/kg DM	7.8	1.91	.	.
FOF, g/kg DM	6.3	2.11	.	.
pH	4.5	0.15	.	.

[1] Dry matter (DM), apparent total digestibility of organic matter (OMD), crude protein (CP), soluble crude protein (sCP), crude fat (CFat), starch (ST), neutral detergent fiber (NDF), indigestible NDF in feedstuff (iNDF), sugar (SU), protein balance in rumen (PBV_{N20}), standard feed value for amino acids absorbed in the small intestine (AAT_{N20}), and net energy lactation (NEL_{20}) at 20 kg dry matter intake. Ammonia nitrogen (NH_3N), lactic (LAF), acetic (ACF), propionic (PRF), butyric (BUF), formic (FOF) acids and alcohol (ALF) in feedstuff.
[2] PBV_{N20}, AAT_{N20} and NEL_{20} are values from the NorFor fôrmiddeltabell.
[3] Kjeldahl nitrogen × 6.25

In the NorFor calculations NorFor assumptions for Norwegian Red mature BW (600 kg) and a unit of BCS change corresponding to 60 kg BW were included, meaning that it is the daily BCS change (BCS_change) that was used (Volden 2011). Further, gain_P1 was set to zero, and detailed information on silage mix and concentrate was included. Day of second conception was included. In case of missing variables NorFor default values were employed.

Table 3. Descriptive statistics of the original data.

Variables	N	Mean	SD
Milk yield, kg/d	8,876	24.3	4.09
BW , kg	6,640	546.7	52.97
BCS, 1-5 scale	1,364	3.6	0.33
Fat content in milk, g/kg	481	43.7	5.43
Protein content in milk, g/kg	491	33.0	2.55
DMI[1] roughage, kg DM/d	9,405	11.5	2.64
DMI concentrate, kg DM/d	8,710	6.0	1.15

[1] DMI= dry matter intake.

Rearing period

The university herd consists of two breeding lineages, a high-milk yield and a low-clinical mastitis line (Heringstad et al., 2007), Thus, the average milk index of dam and sire for each animal was included in all the following models.

Ages at start of feeding experimental diets, conception and calving were analyzed with a univariate model:

$Y_{ij} = \mu + T_i + \beta_1 \cdot M + e_{ij}$ ***Model 2***

were Y_{ij} = either age at start, conception or calving (mo); μ is the overall mean; T_i is the fixed effect of i-th treatment group (i = 1, 2, 3, 4; LPHE, HPHE, LPLE and HPLE); β_1 is the regression coefficient on the milk index of cows (M) and e is the random error term.

Utilizing BW from birth to start of the experiment for the 66 animals with lactation data (a subset of the data from Wærp et al. (2015), estimated least-squares means of BW at start of experiment for treatment groups were calculated with the following univariate model:

$Y_{ijk} = \mu + \beta_1 \cdot LEG_1 + \ldots + \beta_3 \cdot LEG_3 + T_i + \beta_4 \cdot M + \beta_{0j} \cdot LEG_0 + \ldots + \beta_{4j} \cdot LEG_4 + e_{ijk}$

Model 3a

were Y_{ijk} = records of BW from birth to start of experiment (3 mo of age, n = 465); μ is the overall mean; $\beta_1, \ldots, \beta_3$ are regression coefficients of order 1 to 3 on *LEG* for the average growth curve; T_i is the fixed effect of *i*-th treatment group (i = 1, 2, 3, 4; LPHE, HPHE, LPLE and HPLE); β_4 is the regression coefficient on milk index (M); $\beta_{0j}, \ldots, \beta_{4j}$ are random regression coefficients of orders 0 to 4 for growth of individual heifers deviating from the average curve, respectively, and assuming $\sim \boldsymbol{N}\left(\begin{pmatrix}\mathbf{0}\\ \vdots \\ \mathbf{0}\end{pmatrix}, \begin{pmatrix}\boldsymbol{\sigma^2_{\beta_0}} & \cdots & \boldsymbol{\sigma_{\beta_0\beta_4}} \\ \vdots & \ddots & \vdots \\ \boldsymbol{\sigma_{\beta_0\beta_4}} & \cdots & \boldsymbol{\sigma^2_{\beta_4}}\end{pmatrix}\right)$, and e is a random error term for the k-th measurement of $heifer_j$.

Similarly, utilizing only BW data from start of experiment to conception estimated least-squares means for the average BW at conception ages of 13 and 17 mo for HE and LE groups, respectively, were obtained with the following univariate model:

$Y_{ijk} = \mu + \beta_1 \cdot LEG_1(T_i) + \ldots + \beta_8 \cdot LEG_8(T_i) + \beta_9 \cdot M + \beta_{0j} \cdot LEG_0 + \ldots + \beta_{10j} \cdot LEG_{10} + e_{ijk}$

Model 3b

were Y_{ijk} = records of BW from start of experiment to conception (n = 1663); μ is the overall mean; $\beta_1, \ldots, \beta_8$ are coefficients of order 1 to 8 on *LEG* within T_i, the fixed effect of the *i*-th treatment group (i = 1, 2, 3, 4; LPHE, HPHE, LPLE and HPLE); β_9 is the regression coefficient on milk index (M); $\beta_{0j}, \ldots, \beta_{10j}$ are random regression coefficients of orders 0 to 10 for growth of individual heifers deviating from the average growth curve, respectively and assuming $\sim \boldsymbol{N}\left(\begin{pmatrix}\mathbf{0}\\ \vdots \\ \mathbf{0}\end{pmatrix}, \begin{pmatrix}\boldsymbol{\sigma^2_{\beta_0}} & \cdots & \boldsymbol{\sigma_{\beta_0\beta_{10}}} \\ \vdots & \ddots & \vdots \\ \boldsymbol{\sigma_{\beta_0\beta_{10}}} & \cdots & \boldsymbol{\sigma^2_{\beta_{10}}}\end{pmatrix}\right)$, and e is a random error term for the k-th measurement of $heifer_j$. Heterogeneous variances were estimated by five age groups (< 5; 5-8; 9-12; 13-16; 17-20 mo).

Finally, by use of data from conception to calving estimated least-squares means for the average BW at a calving age of 22 and 26 mo for HE and LE groups, respectively, were calculated as follows:

$Y_{ijk} = \mu + \beta_1 \cdot LEG_1(T_i) + \ldots + \beta_7 \cdot LEG_7(T_i) + \beta_8 \cdot M + \beta_{0j} \cdot LEG_0 + \ldots + \beta_{10j} \cdot LEG_{10} + e_{ijk}$

Model 3c

were Y_{ijk} = records of BW from conception to calving (n = 1242); μ is the overall mean; $\beta_1, \ldots, \beta_7$ are coefficients of order 1 to 7 of *LEG* within T_i; β_8 is the regression coefficient on milk index (M); $\beta_{0j}, \ldots, \beta_{10j}$ are random regression coefficients of orders 0 to 10 for growth of individual heifers deviating from the average growth curve, respectively, and assuming $\sim \boldsymbol{N}\left(\begin{pmatrix}\mathbf{0}\\ \vdots \\ \mathbf{0}\end{pmatrix}, \begin{pmatrix}\boldsymbol{\sigma^2_{\beta_0}} & \cdots & \boldsymbol{\sigma_{\beta_0\beta_{10}}}\\ \vdots & \ddots & \vdots \\ \boldsymbol{\sigma_{\beta_0\beta_{10}}} & \cdots & \boldsymbol{\sigma^2_{\beta_{10}}}\end{pmatrix}\right)$, and e is a random error term for the k-th measurement of $heifer_l$. Heterogeneous variances were estimated by five age groups (9-12; 13-16; 17-20, 21-24, > 24 mo).

Lactation period

All traits, either those from the original data or those from NorFor, were analysed (except fat and protein content in milk) with the following model:

$$Y_{ijkl} = \mu + \beta_1 \cdot LEG_1(T_i) + \ldots + \beta_x \cdot LEG_x(T_i) + YS_j + \beta_5 \cdot M + \beta_{0k} \cdot LEG_0 + \ldots + \beta_{zk} \cdot LEG_z + e_{ijkl} \qquad \textbf{Model 4}$$

where Y_{ijkl} = traits (see Table 3) as well as the following NorFor variables and one derived variable: Net energy for lactation in ration (NEL_DM, MJ/kg DM), energy balance for cows (NEL_bal, %), neutral detergent fiber in feedstuff per kg body weight (NDF_BW, g/kg BW), AAT supplied from the feed ration to net energy in the ration (AAT/NEL, g/MJ), and protein balance in rumen (PBV_DM, g/kg DM) until 175 DIM ; μ is the overall mean; $\beta_1, \ldots, \beta_x$ are regression coefficients of order 1 to X on *LEG* within T_i, the fixed effect of i-th treatment group (i = 1, 2, 3, 4; LPHE, HPHE, LPLE and HPLE); YS_j is the j-th fixed year-season effect of test day (j = 1, …, 10; June – Sept. 2012, Oct. – Dec. 2012, …, Oct. – Dec. 2014); β_5 is the regression coefficient on milk index (M); $\beta_{0k}, \ldots, \beta_{zk}$ are random regression coefficients of order 0, …, z for daily records of individual cows deviating from the average curve, respectively, and assuming, $\sim N\left(\begin{pmatrix}\mathbf{0}\\ \vdots \\ \mathbf{0}\end{pmatrix}, \begin{pmatrix}\boldsymbol{\sigma^2_{\beta_0}} & \cdots & \boldsymbol{\sigma_{\beta_0\beta_z}}\\ \vdots & \ddots & \vdots \\ \boldsymbol{\sigma_{\beta_0\beta_z}} & \cdots & \boldsymbol{\sigma^2_{\beta_z}}\end{pmatrix}\right)$, and e is a random error term for the l-th measurement of cow_k modeled with heterogeneous and independent variances for five periods of lactation (weeks; 0-2, 3-8, 9-14, 15-20 and > 20).

The SAS MIXED Procedure (SAS, version 9.4, SAS Institute Inc., Cary, NC) was used in all analyses. Satterthwaite approximation was used for approximation of denominator degrees of freedom of F-tests. The Bayesian information criterion was used to determine the number of Legendre polynomials to include in the random parts of the model.

RESULTS

Rearing period

Table 4. Estimated least-squares means of ages and BW at start of experimental feeding (3 mo), conception and calving for the four[1] dietary treatment groups (SE).

	LPHE	HPHE	LPLE	HPLE
Age at				
Start, mo	3.0 (0.03)	3.0 (0.03)	3.1 (0.03)	3.0 (0.03)
Conception, mo	13.5 (0.28)	12.9 (0.27)	17.1 (0.27)	16.7 (0.29)
Calving, mo	22.5 (0.28)	21.9 (0.27)	26.1 (0.27)	25.8 (0.29)
Body weight at				
3 mo, kg	112.8 (1.63)	111.9 (1.56)	112.6 (1.59)	112.4 (1.68)
13 mo, kg	386.8 (4.03)	395.6 (3.90)	.	.
17 mo, kg	.	.	396.5 (3.76)	394.1 (4.00)
22 mo, kg	531.6 (8.57)	554.3 (8.11)	.	.
26 mo, kg	.	.	567.6 (12.70)	579.0 (13.76)

[1] Low-protein high-energy (LPHE), high-protein high-energy (HPHE), low-protein low-energy (LPLE) and high-protein low-energy (HPLE) with 16, 18, 17 and 15 animals, respectively.

Table 4 shows the estimated least-squares means of age and BW at the start of the experiment, at conception and at calving. All treatment groups started out with approximately the same BW at three mo of age and had similar BW at conception, but the energy levels fed during the experimental period affected both age at conception and calving ($P < 0.001$) (Table 5), with about four mo lower age for heifers in the HE-groups. For AFC contrasts between treatment groups are given in Table 6. The LE-groups were apparently heavier at calving.

Table 5. Analyses of variance results (F-values (p-values)) for age at the start of the experimental feeding period, at conception and at calving.

	Variables	
	Treatment	Milk index
Age at		
Start	0.75 (0.528)	0.41 (0.526)
Conception	59.98 (<0.001)	0.00 (0.966)
Calving	61.54 (<0.001)	0.00 (0.981)

Table 6. Estimated least-squares mean contrasts (P-value) between treatment groups[1] for age at first calving (AFC) in months.

	AFC		
Treatment	HPHE	LPLE	HPLE
LPHE	0.6 (0.12)	-3.6 (<0.01)	-3.2 (<0.01)
HPHE	.	-4.2 (<0.01)	-3.8 (<0.01)
LPLE	.	.	0.4 (0.35)

[1] Low-protein high-energy (LPHE), high-protein high-energy (HPHE), low-protein low-energy (LPLE) and high-protein low-energy (HPLE).

Lactation period

Figure 1 shows estimated least-squares means of the four treatment groups (at every second week from 7 to 175 DIM) for test-day milk yield (kg), body weight (kg) and body condition score (5 point scale), wheras Table 7 contains contrasts (t-tests) of a sample of these least-square means (at 7, 91 and 175 DIM).

Peak lactation occurred at around 50 DIM for HPHE and both LE groups, whereas the LPHE peaked at 70 DIM. From calving to peak lactation, the HPLE cows produced most milk, followed by LPLE, whereas the HE groups produced the least. Note that there seems to be a minor effect of protein supply, but significant only at seven DIM between LPHE and HPHE ($P = 0.02$). When supply of concentrate was reduced from 120 DIM, a drop in milk yield occurred in all groups, but less pronounced for the HE-cows. As a consequence the HPHE-cows produced 2.1 and 2.4 kg more ($P < 0.05$) than the two LE-groups at 175 DIM, respectively (Table 7). Furthermore, the LPHE group tended ($P = 0.07$) to produce more than HPLE-cows.

For BW the HPHE group deviated most from the other groups at seven DIM (Table 7), weighing 31.6 and 20.0 kg less ($P < 0.02$) than LPLE and HPLE, respectively. Moreover, the HPHE group weighed 19.3 kg less than the LPHE group ($P = 0.03$). However, at 175 DIM HPHE was 21.6 kg heavier than HPLE ($P = 0.04$) and 19.1 kg heavier than LPLE ($P = 0.07$).

At start of lactation BCS was especially high for the HPLE animals, and significantly higher than for the other three groups ($P < 0.05$; Table 7). However, in mid-lactation average BCS score was less, but non-significant, for the HPLE group than for the other three, meaning that the HPLE animals experienced the most pronounced drop in BCS after calving.

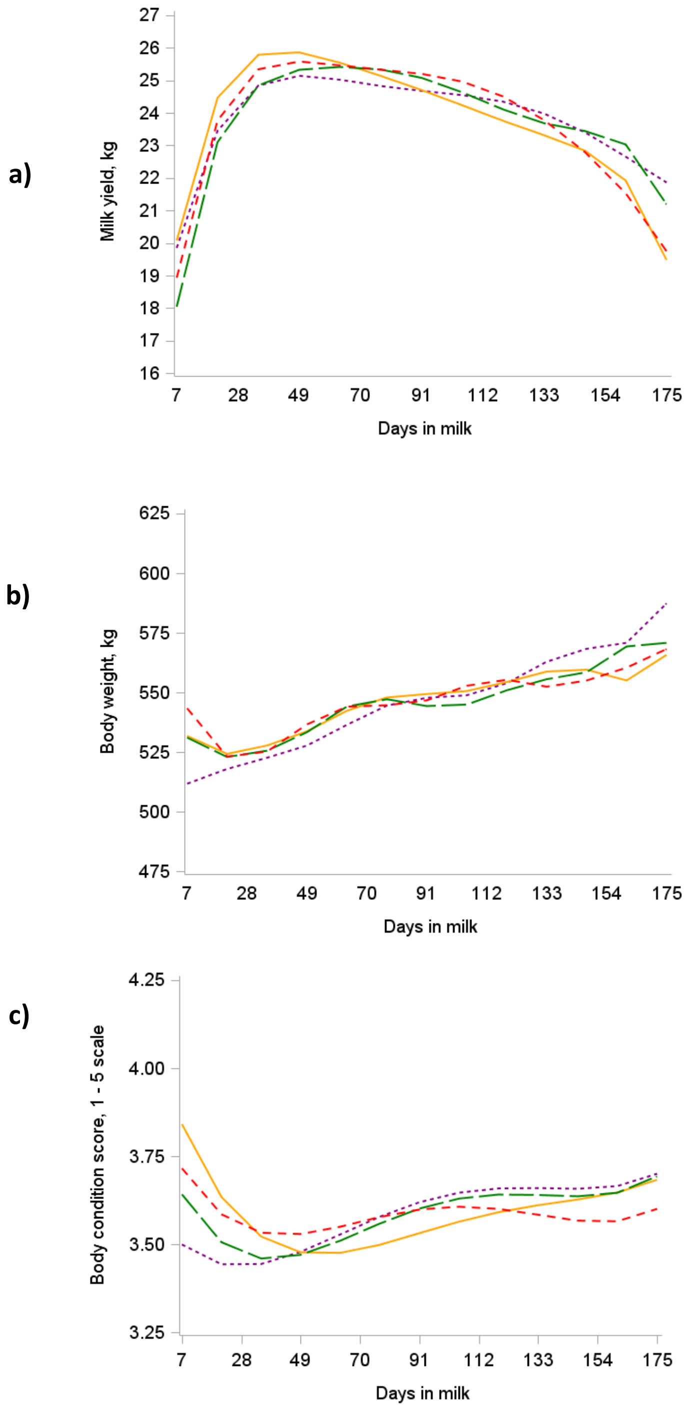

Figure 1. Estimated least-squares means of low-protein high-energy (long-dashed line), high-protein high-energy (dotted line), low-protein low-energy (short-dashed line) and high-protein low-energy (solid line) groups from 7 to 175 DIM for a) test-day milk yield, b) body weight, and c) body condition score.

Table 7. Estimated least-squares mean contrasts (P-values) between low-protein high-energy (LPHE), high-protein high-energy (HPHE), low-protein low-energy (LPLE), and high-protein low-energy (HPLE) groups at 7, 91 and 175 DIM; first-lactation test-day milk yield (kg), body weight (BW, kg) and body condition score (BCS, 1-5). Least-squares means are from Figure 1.

	Milk yield			BW			BCS		
Treatment	HPHE	LPLE	HPLE	HPHE	LPLE	HPLE	HPHE	LPLE	HPLE
DIM = 7									
LPHE	-1.8 (0.02)	-0.9 (0.26)	-2.0 (0.01)	19 (0.03)	-12 (0.15)	-1 (0.94)	0.14 (0.10)	-0.07 (0.39)	-0.20 (0.03)
HPHE	.	0.9 (0.24)	-0.2 (0.78)	.	-32 (<.01)	-20 (0.02)	.	-0.22 (0.02)	-0.34 (<.01)
LPLE	.	.	-1.1 (0.16)	.	.	12 (0.17)	.	.	-0.13 (0.15)
DIM = 91									
LPHE	0.4 (0.17)	-0.1 (0.68)	0.4 (0.22)	-3 (0.05)	-2 (0.15)	-5 (<.01)	-0.02 (0.59)	0.00 (0.94)	0.07 (0.05)
HPHE	.	-0.5 (0.07)	0.0 (0.94)	.	1 (0.55)	-2 (0.37)	.	0.02 (0.53)	0.09 (0.01)
LPLE	.	.	0.5 (0.10)	.	.	-3 (0.11)	.	.	0.07 (0.05)
DIM = 175									
LPHE	-0.7 (0.45)	1.4 (0.12)	1.7 (0.07)	-17 (0.11)	3 (0.81)	5 (0.64)	-0.01 (0.94)	0.09 (0.38)	0.01 (0.93)
HPHE	.	2.1 (0.02)	2.4 (0.01)	.	19 (0.07)	22 (0.04)	.	0.10 (0.33)	0.02 (0.87)
LPLE	.	.	0.3 (0.78)	.	.	2 (0.82)	.	.	-0.08 (0.44)

Table 8. Descriptive statistics of the Norfôr output and AAT/NEL.

Variables[1]	n	Mean	SD
NEL_DM, MJ/kg DM	11,286	6.6	0.17
NEL_bal, %	11,191[2]	100.3	16.23
PBV_DM, g/ kg DM	11,286	25.4	10.82
AAT/NEL, g/MJ	11,286	14.7	0.86

[1] Net energy for lactation in ration (NEL_DM), energy balance for cows (NEL_bal), protein balance in rumen (PBV_DM) and AAT supplied from the feed ration to net energy in the ration (AAT/NEL).
[2] Illogical values were excluded (n = 95).

Chosen average values from the NorFor output as well as AAT/NEL is given in Table 8. Further, Figure 2 shows the estimated least-squares means of the chosen NorFor variables and the estimated least-squares means of DMI of roughage and concentrates for the treatment groups every two weeks from seven to 175 DIM. The general pattern of the variables was one of differences between high and low energy supply. With respect to roughage intake the HE-groups had the lowest intake at 7 DIM (only significantly lower for LPHE versus the LPLE group (P = 0.01, Table 9)), but in mid-lactation this relationship had been reversed (Figure 2a). For concentrates DMI were similar over groups (Figure 2b). Figure 2c illustrates the net energy per kg DM in the total ration being higher in the HE-groups at DIM 7, due to relatively more concentrate in the ration. This was most pronounced for the LPHE group versus the two LE groups (P < 0.01 for both, Table 9). As expected, the shape of the curves for energy balance was inverse to the lactation curves except for the two HE-groups at 175 DIM, when they were significantly lower than the two LE groups (P < 0.01; Figure 2d, Table 9). The protein balance in rumen (PBV_DM, g/kg DM) was within the NorFor recommendations of above 10 g/kg DM as was the AAT/NEL-ratio (g/MJ) that was in line with the recommended 15 g/MJ of AAT_N_NEL (Volden, 2011).

Table 9. Estimated least-squares mean contrasts (P-values) between low-protein high-energy (LPHE), high-protein high-energy (HPHE), low-protein low-energy (LPLE) and high-protein low-energy (HPLE) groups at 7, 91 and 175 DIM; first-lactation roughage dry matter intake (DMI roughage, kg DM/d), net energy for lactation in ration (NEL_DM, MJ/kg DM), and energy balance for cows (NEL_bal, %). Least-squares means are from Figure 2.

	DMI Roughage			NEL_DM			NEL_bal		
Treatment	HPHE	LPLE	HPLE	HPHE	LPLE	HPLE	HPHE	LPLE	HPLE
DIM = 7									
LPHE	-0.4 (0.42)	-1.4 (0.01)	-1.1 (0.06)	0.06 (0.15)	0.12 (<.01)	0.16 (<.01)	1.0 (0.71)	5.7 (0.05)	1.4 (0.63)
HPHE	.	-1.0 (0.07)	-0.7 (0.24)	.	0.06 (0.12)	0.10 (0.02)	.	4.7 (0.09)	0.4 (0.90)
LPLE	.	.	0.3 (0.57)	.	.	0.03 (0.42)	.	.	-4.3 (0.13)
DIM = 91									
LPHE	0.3 (0.09)	0.6 (0.01)	0.2 (0.32)	-0.01 (0.04)	-0.02 (<.01)	-0.01 (0.01)	2.2 (<.01)	2.8 (<.01)	1.7 (<.01)
HPHE	.	0.2 (0.25)	-0.1 (0.53)	.	-0.01 (0.22)	<-0.01 (0.46)	.	0.6 (0.25)	-0.5 (0.38)
LPLE	.	.	-0.4 (0.08)	.	.	<0.01 (0.65)	.	.	-1.1 (0.05)
DIM = 175									
LPHE	-0.4 (0.51)	-1.1 (0.10)	-0.5 (0.46)	-0.02 (0.59)	0.02 (0.68)	-0.01 (0.78)	-4.1 (0.07)	-17.2 (<.01)	-16.7 (<.01)
HPHE	.	-0.7 (0.28)	-0.1 (0.90)	.	0.04 (0.33)	0.01 (0.81)	.	-13.0 (<.01)	-12.6 (<.01)
LPLE	.	.	0.6 (0.37)	.	.	-0.03 (0.49)	.	.	0.4 (0.85)

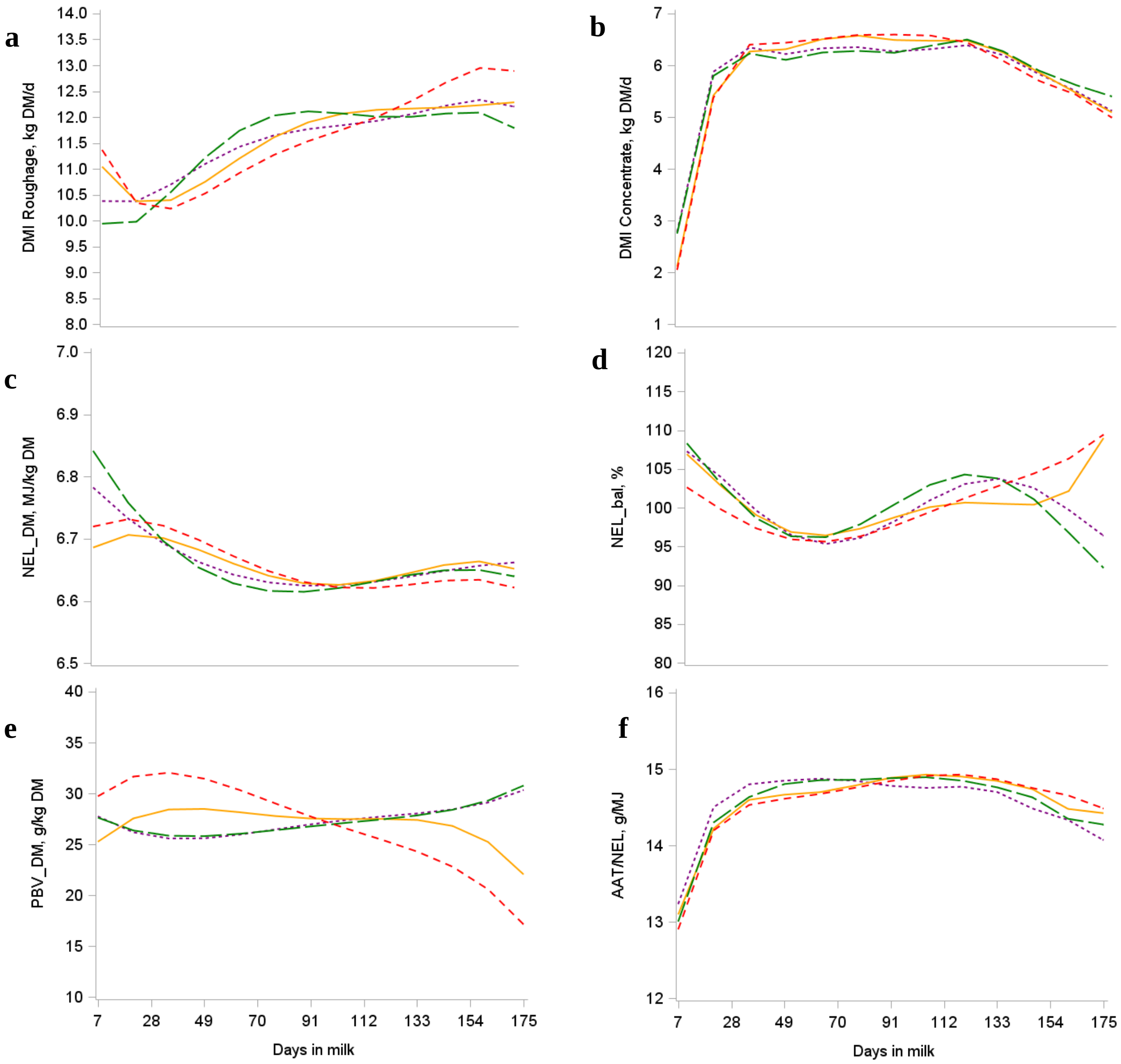

Figure 2. Estimated least-squares means of low-protein high-energy (long-dashed line), high-protein high-energy (dotted line), low-protein low-energy (short-dashed line) and high-protein low-energy (solid line) groups from 7 to 175 DIM for dry matter intake (DMI) from roughage and concentrate, net energy for lactation in ration (NEL_DM), energy balance for cows (NEL_bal), protein balance in rumen (PBV_DM) and AAT supplied from the feed ration to net energy in the ration (AAT/NEL).

Table 10 shows the regression coefficients on milk index for all variables analyzed with Model 2 and 4. Animals selected for high milk yield produced significantly more ($P < 0.001$), but had lower BW ($P = 0.001$) and BCS ($P < 0.0001$) than the low-mastitis animals. Interestingly, there were no significant differences in DMI from roughage or concentrates.

Table 10. Regression coefficients on milk index.

Variables	β	SE	P-value
Original records			
Age at first calving, mo	-0.000	0.0109	0.981
Milk yield, kg/d	0.114	0.0280	<0.001
Body weight, kg	-1.101	0.3106	0.001
Body condition score, 1-5 scale	-0.012	0.0023	<.0001
DMI[1] Roughage, kg DM/d	0.011	0.0165	0.497
DMI Concentrate, kg DM/d	0.006	0.0050	0.242
NorFor output[2]			
NEL_DM, MJ/ kg DM	-0.001	0.0012	0.567
NEL_bal, %	-0.173	0.0798	0.035
PBV_DM, g/ kg DM	-0.023	0.0499	0.647
AAT/NEL, g/MJ	-0.045	0.0207	0.035

[1] DMI = dry matter intake.

[2] NEL_DM = net energy for lactation in ration, NEL_bal = energy balance for cows, PBV_DM = protein balance in rumen, and AAT/NEL = AAT supplied from the feed ration to net energy in the ration.

DISCUSSION

Using a simple, roughage-based feeding strategy where all animals were fed one kg of concentrate and energy supply was regulated with roughage quality we have confirmed that it is possible to rear heifers for a rapid weight gain, in this case about 940 g/d, from 3 mo of age to conception and a moderate daily gain through pregnancy, here about 550 g/d, without negative effects on lactation performance of the primiparous cow. The energy supply was regulated during the period from 3 mo of age to conception (Wærp et al., 2015), whereas protein levels planned to be either at or above required protein levels evidently had marginal effects. Heifer groups fed a high-energy (HE) diet were made to calve on average at 22 mo of age and 4 mo earlier than groups fed a low-energy (LE) diet. The LE-groups, in turn, had an AFC equal to the 26 mo which was previously found to be the most favorable for first lactation milk yield based on field data (Storli et al., 2015). Management and feeding regime throughout pregnancy was similar for all the animals. Thus, the basis for the differences obtained in the first lactation would mainly be due to differences between high and low energy groups established pre conception.

What distinguished primiparous HE animals from LE animals other than that they calved 4 months earlier, was that they tended to give birth at a lower body weight than the LE animals. They further calved with a lower BCS than the LE animals, close to the nationally recommended 3.5 points for heifers. They produced less milk from start to peak lactation than did their LE congeners, and they reached peak lactation later. There was a striking difference between HE and LE groups in roughage dry matter intake pattern. Among HE animals roughage DMI progressed according to what would be expected; they increased their intake of roughage from the start, first quickly and then steadily until about 120 DIM. The pronounced hump in the LPHE curve is mainly due to one single animal whose roughage intake approached 30 kg DM per day from 50 DIM. Differences in DMI from concentrate between energy groups were minimal. LE-animals clearly chose a totally different strategy to meet the energy demand from a steeply increasing yield from the start of their first lactation: They compensated for the imbalance by mobilizing from their larger body reserves. And instead of increasing their intake of roughage DMI as would be expected they decreased intake to around 30 DIM, before it started to rise and then progressed in a steady manner, however not reaching the HE groups until 150 DIM. The LE groups reduced their BCS considerably more than the HE animals. But they also lost body weight, whereas the HE groups at the same time increased theirs. Tissue mobilization normally increases with increased feed intake in early lactation (Ingvartsen and Andersen, 2000; Berry et al., 2006). But the LE animals did not increase their feed intake. They probably allowed themselves to mobilize body reserves instead of increasing feed intake because being fatter and larger gave them the choice.

The HE-groups had a flatter lactation curve than the LE groups but typically for primiparous cows (Miller et al., 2006; Bossen et al., 2009). At 120 DIM they were challenged by a reduction in supply of concentrate. All groups experienced a subsequent drop in milk yield but the drop was less pronounced for the HE-groups. The HE animals evidently had developed an ability to respond when challenged by a reduction in supply of concentrate. Because they had a persistent lactation curve, increased their feed intake, increased their body weight and increased their BCS, they obviously had the resources to respond in this way. Conversely, the LE groups had a peaked lactation curve, while feed intake decreased, they reduced their body weight and their BCS. Thus, they did not have the resources to respond when challenged at about 120 DIM. Consequently the lactation dropped steeply. Reproduction is not likely to be part of the observed differences. Firstly, although there were considerable variation in at which time the animals conceived during their first lactation, the group differences were minor and at about 70 DIM for the LE animals and 85 DIM for the HE groups. This would mean that up to 175 DIM all animals were in the first trimester of the pregnancy, where energy demand from the growing fetal membranes and placenta and the growing fetus is still negligible.

When challenged at 120 DIM the HE group respond by keeping up production, which results in an atypical energy balance curve,- atypical towards a negative energy balance. At this lactation stage the LE groups have a positive energy balance, but still, they increase their feed intake possibly striving to reestablish their body condition score at calving. It should be borne in mind that the present curve is a hybrid curve and an approximation to the energy balance for cows (NEL_bal, %) curve that results from the NorFor equation. When calculating the energy balance we had to set body weight gain to zero, which means that our calculated values will somewhat overestimated.

The finding that the HE groups kept up production from 120 DIM led us to calculate the feed conversion ratio, i.e. net energy lactation per kg energy corrected milk (NEL/ECM, MJ/kg ECM, Figure 3) which showed that the HE groups needed less feed to produce one kg of ECM than did the LE groups. However, looking at the early lactation the results were in favor of the LE groups, meaning that the ratio is mostly driven by milk yield and not necessarily due to improved feed efficiency. Thus, this variable is not an adequate measure of feed efficiency alone. One might be just as informed by looking at longitudinal results of feed intake, milk production, BCS and BW.

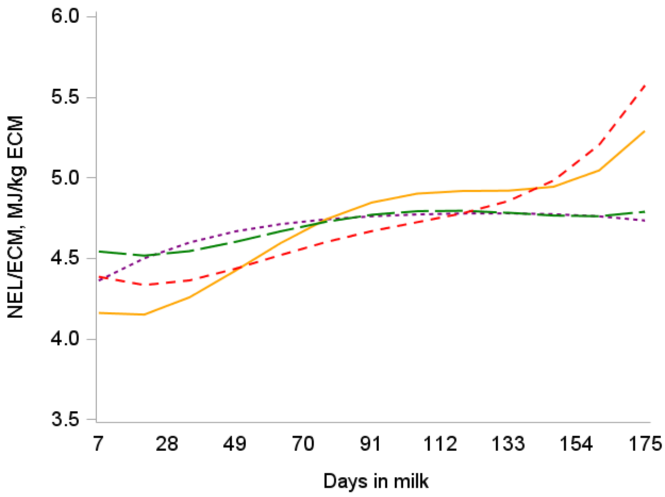

Figure 3. Estimated least-squares means of low-protein high-energy (long-dashed line), high-protein high-energy (dotted line), low-protein low-energy (short-dashed line) and high-protein low-energy (solid line) groups from 7 to 175 DIM for feed conversion ratio (net energy lactation per kg energy corrected milk (NEL/ECM).

CONCLUSION

We have confirmed that it is possible to rear Norwegian Red heifers for a rapid weight gain, in this case about 940 g/d, from 3 mo of age to conception and a moderate daily gain through pregnancy, here about 550 g/d, without negative effect on lactation performance of the primiparous cow. This would mean that age at first calving could be reduced to 22 months of age without compromising milk yield. Just as important, results suggest we have succeeded to make a cow that have an increased uptake of DM from roughage.

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