Norwegian University of Life Sciences
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Philosophiae Doctor (PhD)
Thesis 2018:62

Rearing of Norwegian Red replacement heifers; effect of growth rates on lifetime production and profitability

Oppdrett av NRF rekrutteringskviger; effekt av tilveksthastighet på livstidsproduksjon og lønnsomhet

Jon Kristian Sommerseth

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Ås, July 2018

Jon Kristian Sommerseth

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List of original papers

I) **Sommerseth, J. K.**, Klemetsdal, G., and Salte, R. 2018. A case study on herd lifetime profitability in dairy production. *Submitted to Animal.*

II) **Sommerseth, J. K.**, Storli, K. S., Klemetsdal, G., Hegrenes, A., and Salte, R. 2018. Assessing the profitability of different growth profiles in replacement heifers from three months of age to pregnancy over the same productive lifetime. *Manuscript.*

III) **Sommerseth, J. K.**, Shrestha, S., MacLeod, M., Hegrenes, A., and Salte, R. 2017. Simulating the financial and greenhouse gas impacts of different heifer growth strategies on dairy farms. *Manuscript.*

Summary

This thesis is part of a larger research project aimed at assessing the impact of calf and youngstock development on dairy cow production and profitability.

The rearing of Norwegian Red replacement heifers is largely based on Danish recommendations from the 1980 and 1990s. These recommendations suggest that growth should be restricted in the pre-pubertal period to avoid detrimental effects on the first lactation milk yield. This has led to an average age at first calving of approximately 26 months, which has been the national average for the last couple of decades. Most studies on the topic of heifer rearing have only investigated the effect on first lactation milk yield and not variables such as lifetime production or profitability. The main goals of this study were, thus, to identify variables that affect lifetime profitability and quantify the financial effects of different growth profiles in replacement heifers. We achieved this by utilizing data from a field study, a controlled experiment, and a data simulation model.

The findings in this thesis are of both practical and theoretical importance and identify management areas for farmers to address in order to improve their profitability. Roughage price is of great importance for profitability and a grassland management plan that secures a large grass yield of a high quality is a strategy recommended for most farmers. Early returns on investments, i.e., rearing heifers more rapidly so that they calve earlier than the present national average of 26 months, is another way to increase profit. This will save in rearing costs, especially those related to housing and labor, in addition to the advantage of receiving revenue earlier. Lowering the age at first calving by 4 months could potentially increase lifetime profitability in the range of 11-36%. Having heifers which are nearly full grown at calving also reduces the need to provide energy growth later, which could result in more energy being allocated towards milk production. Increasing sundry costs, such as bedding materials and post-milking teat dipping, etc. increased profitability, as did increasing the time cows were retained in the herd.

Based on the findings in this thesis, it can be concluded that heifer-rearing management is of great importance for dairy farm economics. There is large potential for dairy farmers to improve their profitability with careful surveillance of their rearing management; for example, by the use of methodical heart girth measures of their heifers. By doing this, the farmer could detect deviation from the pre-planned growth profile at an early point and implement necessary measures needed to regain the correct growth-profile.

Sammendrag

Denne avhandlingen inngår i et større forskningsprosjekt hvis hovedmål var å undersøke hvordan tilveksten til rekrutteringskviger påvirker senere melkeproduksjon og lønnsomhet.

Oppdrettet av NRF-kviger er i stor grad basert på danske anbefalinger fra 1980 og -90 tallet. Disse anbefalingene sier at tilveksten bør være begrenset i den pre-pubertale perioden for å unngå skadelige effekter på melkeytelse i første laktasjon. Dette har ført til en gjennomsnittlig alder ved første kalving på cirka 26 måneder, som har vært det nasjonale gjennomsnittet gjennom de siste tiårene. De fleste studier på kvigeoppdrett har bare undersøkt effekt på melkeytelse i første laktasjon, og ikke variabler som livstidsproduksjon eller lønnsomhet. Hovedmålene med dette studiet var derfor å identifisere variabler som påvirker lønnsomhet over dyrets levetid, og kvantifisere de økonomiske effektene av ulike tilvekstprofiler på rekrutteringskviger. Dette oppnådde vi ved å utnytte data fra en felt-studie, et kontrollert eksperiment, og en simuleringsmodell.

Resultatene i denne avhandlingen er av både praktisk og teoretisk betydning, og identifiserer områder ved driften bønder kan fokusere på for å bedre lønnsomheten. Grovforpris er meget viktig for lønnsomheten, og en plan for utnyttelse av grasarealet som sikrer en høy avling av god kvalitet er en anbefalt strategi for de fleste bønder. Tidlig avkastning på investeringer, dvs., hurtigere tilvekst på kvigene slik at de kalver tidligere enn det nasjonale gjennomsnittet på 26 måneder, er en annen måte å øke lønnsomheten på. Dette sparer oppdrettskostnader, særlig de som er relatert til fjøsplass og arbeid, og i tillegg kommer fordelen av tidligere inntekter. En senkning av alder ved første kalving med 4 måneder kan potensielt øke lønnsomheten over dyrets levetid i området 11-36%. Dersom kvigene er tilnærmet fullvoksne ved kalving reduseres også behovet for energi til senere vekst, som igjen resulterer i at mer av energien kanaliseres til melkeproduksjon. Økte kostnader til forbruksvarer som flis/strø og spenedypping etter melking etc., øker lønnsomheten, i likhet med å holde kyrne lengre i besetningen.

Basert på resultatene fra denne avahandlingen kan vi konkludere at godt management i kvigeoppdrettet har stor betydning for melkegårdens økonomi. Det er et stort potensiale hos melkebønder for å øke lønnsomheten med nøye overvåking av oppdrettet sitt, for eksempel gjennom metodisk å ta brystmål av kvigene. Ved å gjøre dette vil bonden kunne oppdage avvik fra den planlagte tilvekstprofilen på et tidlig tidspunkt, og iverksette nødvendige tiltak for å komme inn på den riktige tilvekstprofilen.

Abbreviations

ADG	average daily gain	HEHP	high-energy, high-protein
AFC	age at first calving	HELP	high-energy, low-protein
AG	accelerated growth	LE	low-energy
AGM	annual gross margin	LEHP	low-energy, high-protein
BL	baseline growth	LELP	low-energy, high-protein
BW	body weight	LMD	Ministry of Agriculture and Foods
BCS	body condition score	ME	monthly equivalent value
CR	culling rate	NDHRS	Norwegian Dairy Herd Recording System
DM	dry matter	NDFR	Norwegian Dairy Herd Financial Recordings
DMI	dry matter intake	NPV	net present value
ECM	energy corrected milk	NR	Norwegian Red
FAS	Farm Account Survey	ME	monthly annuity equivalent value
HE	high-energy		

1. Introduction

1.1 Trends in Norwegian dairy farming

Most dairy cows in Norway are of the Norwegian Red (**NR**) breed (NDHRS 2017), which is a dual-purpose breed bred both for milk and meat production with excellent health, fertility, and milk production traits (Geno 2017). Norwegian dairy production has undergone large structural changes in recent decades, as illustrated in Figures 1 and 2. Since the millennium, the average dairy cow herd size has increased by 81%, while the average farmland holding has increased by 41% since 2002 (Figure 1). Moreover, from 2003-2017 the numbers of dairy farms decreased by 51%, whereas the average milk quota per farm increased by 108% (Figure 2).

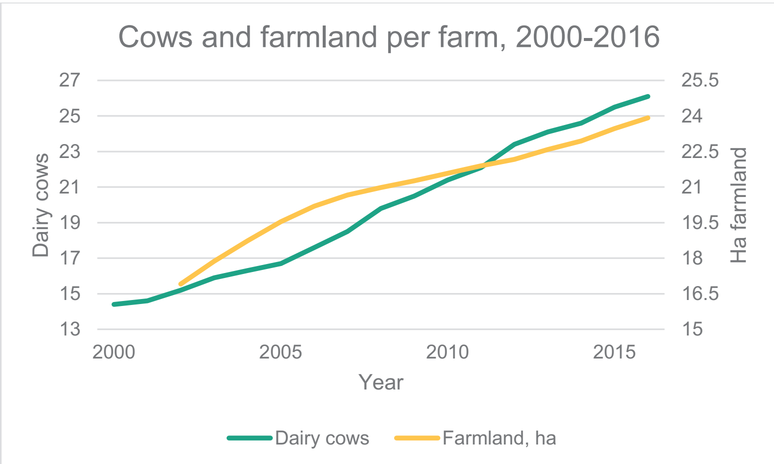

Figure 1. Structural changes from 2000-2016 in terms of number of dairy cows per herd and hectares of farmland per farming enterprise (all farms, not only dairy enterprises). Source: (StatisticsNorway 2017b).

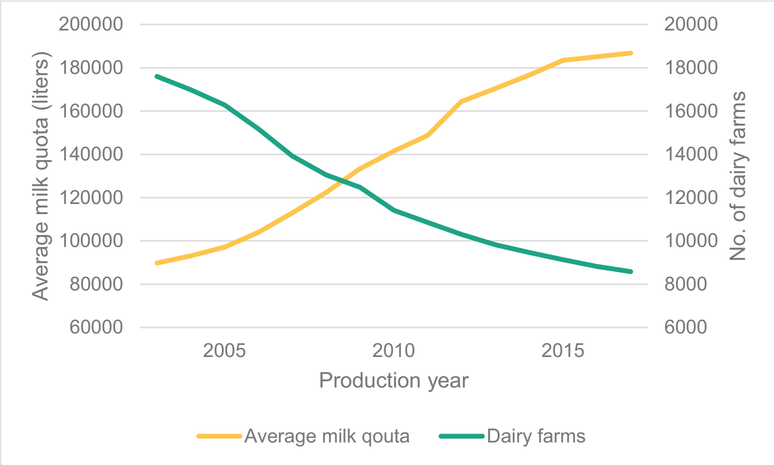

Figure 2. Development in average milk quota in liters and number of dairy farms from 2003-2017. Source: (NAA 2017)

At present, Norway has roughly 222,000 dairy cows, which is a ~35% decrease since 1990 (Figure 3) (StatisticsNorway 2017a). However, total milk production per year has not declined over the same period as milk yield per cow has had a significant increase. Figure 3 also shows how annual fresh and energy-corrected milk (**ECM**) yield has developed from 1993 until today (ECM from 2002). Annual yield per cow has increased every year since 2001 with the exception of 2011 (note the relatively larger fall in ECM yield this year), the year Norway suffered from a "butter crisis" (Andersen 2011), when the demand for butter could not be met resulting in a national butter shortage.

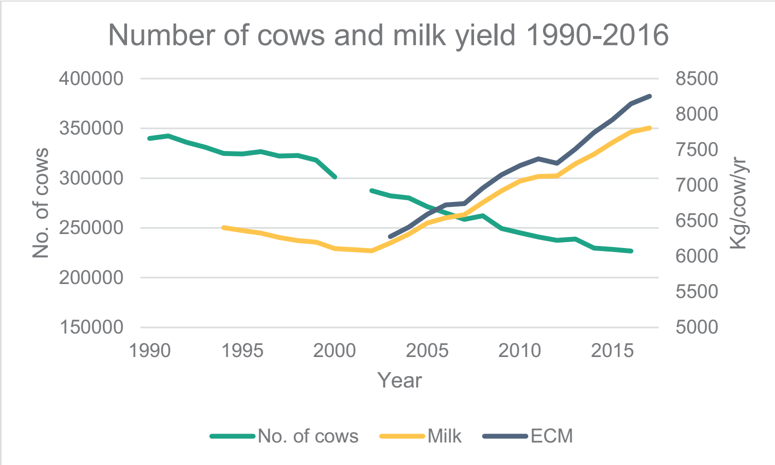

Figure 3. Dairy cow population in Norway [1990-2017, numbers for 2001 are missing, (StatisticsNorway 2017a)], milk yield per cow (Kg/cow/year) 1993-2013, and Energy-corrected milk (Kg/cow/year; 2003-2017) (NDHRS 2014; NDHRS 2017).

1.2 How Norwegian dairy production is politically regulated

Norwegian agricultural and food policies have a broad set of goals (Table 1), which are sought through extensive political and economic instrumentation such as border measures, budgetary payments and regulation of the domestic market (OECD 2017). This makes the agricultural policy in Norway markedly different from the one found in for example the European Union (EU). On behalf of all farmers in Norway, the farmers' organizations (Norges Bondelag and Norsk bonde- og småbrukarlag) negotiates yearly with the Ministry of Agriculture and Food (**LMD**), aiming to reach a commercial agreement (*Jordbruksavtalen*). For example, this agreement contains specified target prices for some product categories, the use of financial subsidies, and several other measures meant to secure the farmer's income. In return, the farmers commit themselves to working towards achieving the political goals for Norwegian agriculture set by the parliament (Table 1). At present, milk, pork meat, potatoes, fruit, vegetables, and grains have target prices set by these yearly negotiations. The large cooperation actors (owned by the farmers) attempt to achieve the agreed target prices by balancing the products available in the market to domestic demand. If the target price is not attained, for example due to overproduction of a product, every single farmer who produces this product carries the complete economic risk. There is no minimum price guaranteed. Cooperations owned by the farmers have had the role as market regulator since 1983. To avoid overproduction, the market regulators can reduce milk quotas and change stock balance. Because of the biological aspects of production, the process is demanding and requires both experience and expertise. If a product price exceeds the target price for more than two weeks in a row, the market balance is reestablished by easing import restrictions of the actual product (LMD 2017).

Table 1. Main goals for Norwegian agricultural and food policy. Source: (LMD 2011)

Food Security	Agriculture throughout the country	Creating more added-value	Sustainable agriculture
Increase sustainable food production	Secure the utilization of available farmland	Competitive value chains and robust units	Protect agricultural land resources
Food safety and nutritious food	Strengthen and contribute to employment and settlements in rural areas	Highly competent environment	Maintain the cultural landscape
Maintain consumer interests	Politics adapted to regional opportunities and challenges	Competitive income	Secure biodiversity
Norway as a constructive international actor			Climate changes – be a part of the solution
Develop Norway as a food nation			Reduce pollution from agricultural activity

According to *Jordbruksavtalen* (LMD 2017), governmental subsidies in 2018 are budgeted to make up around 14,957 million NOK, partitioned to price subsidies (around 3,332 million NOK) and directly paid subsidies to farmers holding animals or farmland (around 8,361 million NOK). The remaining 3,264 million NOK is used for different welfare and development purposes, where welfare purposes are subsidies such as holiday relief and relief during illness and maternity. The most important development purposes are subsidies for renewal of farm buildings and subsidies for farm counseling services and research.

To achieve increased profitability in dairy farming, one can either increase scale, optimize production at the existing scale, or combine the two options. Strict regulations regarding, for example, milk quota (Kumbhakar et al. 2008) and farm transfer and ownership (Forbord et al. 2014) imply that increasing scale is capitally demanding because the farmer will have to compensate, for example by buying milk quotas or enlarging production facilities before production can increase. One way to increase profitability, with or without an increase in scale, is to optimize heifer rearing.

1.3 Heifer rearing, management and profitability

Rearing of dairy replacements represents the second largest cost in dairy farming after feed for the dairy herd (Heinrichs 1993) and approximately 45% of the Norwegian dairy population is replaced each year (NDHRS 2017). Still, the rearing of replacement heifers is, unfortunately, an often under-prioritized factor in dairy farming as heifers reared to replace culled dairy cows seldom receive the attention needed to make use of their full potential (Mourits et al. 2000). Unless the farmer sells the animal as livestock or culls it for meat, the protracted time lag between birth and first calving is a period of accumulation of expenditures and invested capital during this period does not generate revenue until lactation commences. Applying an investment perspective in heifer rearing is therefore useful, since rearing dairy replacements is a long-term investment in future milk and meat revenues. To determine whether an investment is profitable or not, it is essential to have knowledge about the costs and revenues associated with the investment and at what times they occur.

According to Deloof (2003), the cash convention cycle, which is the time lag between the expenditure for buying raw materials and the collection of sales of the finished product, is a popular measure of working capital management. The way in which working capital is managed is highly likely to have an impact on profitability. A recent study examined the relationship between working capital and profitability over an 18-year period in Finnish companies and documented a negative relationship between the cash convention cycle and corporate profitability (Enqvist et al. 2014), meaning that a shorter cash convention cycle is more profitable. In dairy farming, the rearing of heifers is comparable to working capital in firms, as the heifer is comparable to the raw materials and the dairy cow to the finished product that generates income. Rapid rearing of heifers resulting in a sufficient size for breeding, thus calving at a younger age, should be beneficial with respect to profitability because this would reduce the cash convention cycle.

Giving birth is a natural consequence of a fulfilled gestation period. For this to be achieved, the animal will first not only have to reach onset of puberty but also be in a state of sexual maturity for it to conceive and maintain the pregnancy without any adverse side effects. As onset of puberty is a result of body weight (**BW**) rather than age (Gardner et al. 1977; Macdonald et al. 2005; Meyer et al. 2006b; Niezen et al. 1996), allowing heifers to grow at a higher rate of BW gain will lead to an earlier onset of puberty and sufficient sexual maturity for breeding. For decades, high growth rates in pre-pubertal life leading to heifers being bred at a younger age has been associated with unfavorable mammary parenchyma development (see, e.g., review by Sejrsen et al., 2000). These studies concluded that a high average daily gain (**ADG**) in early life and early breeding, thus lower age at first calving (**AFC**), had detrimental effects on subsequent milk yield. However, this was later refuted by the studies of Daniels et al. (2009) and (Meyer et al. 2006a; Meyer et al. 2006b) who reported that age, and not plane of nutrition, mainly determined parenchymal development. To secure a sufficient level of maturity prior to breeding, the heifer should reach a pre-determined target weight before first service. Recommendations are to achieve a body weight of around 60% of adult live-weight at breeding (Troccon 1993) and around 90% at first calving (Troccon 1993; Wathes 2012), which compares well with current recommendations (390-430 kg at breeding and 560-580 kg at calving) given by the Norwegian dairy cooperative (TINE Rådgiving 2017).

The costs of heifer rearing depend on factors like growth rate and days of feeding, i.e. time until first calving. In a Dutch survey carried out by Mourits et al. (2000), dairy farmers were asked to estimate their own rearing costs for a fully grown heifer. The majority of the farmers gave rather low estimates of costs and only 16% of the respondents came up with estimates the authors found to be in the most realistic range, which indicates that rearing costs is an area of low awareness amongst dairy farmers. Later, using a Monte Carlo simulation model that included uncertainties related to calf diseases, Mohd Nor et al. (2012) estimated the cost per successfully reared heifer in the Netherlands to be €1,567, varying between €1,423 and €1,715. In particular, costs related to feed and labor efficiency influence rearing costs (Mohd Nor et al. 2012). Increased growth rates require rations that contain more energy, thus more expensive ingredients, resulting in a higher daily feed cost. Conversely, reducing growth rates allow for cheaper feed rations and lower daily feed costs. However, the higher daily costs following an increased growth rate is offset by lower total feed costs (Tozer 2000) because less energy is lost to maintenance due to fewer days of feeding. In addition, lowering the AFC also reduces the costs associated with housing and labor; a reduction in the AFC by one month has been reported to decrease rearing costs by 2.6% - 5.7% (Mohd Nor et al. 2012; Tozer & Heinrichs 2001). Nevertheless, costs should not be considered one-sided only. For dairy cows, feed ration optimizing strategies have been reported to give higher milk revenues, measured as income over feed costs, than a minimizing feed cost strategy (Buza et al. 2014). An optimizing strategy should also be applicable to heifer rearing.

Sale of milk constitutes the major source of income in dairy production. Future milk yield is, therefore, one (of several) important determinants of lifetime profitability. Numerous studies have addressed the effects of heifer growth during different phases of rearing on future milk yield, in particular, on first lactation milk yield (Abeni et al. 2000; Abeni et al. 2012; Capuco et al. 1995; Dobos et al. 2000; Pirlo et al. 1997; Sejrsen & Purup 1997; Stelwagen & Grieve 1992). The results have been contradictory. The inconsistencies may be due to differences in post-calving BW and body condition score (**BCS**) as Van Amburgh et al. (1998) found these variables to influence the variation in first lactation milk yield more than pre-pubertal ADG. Moreover, the studies did not address profitability issues. Ettema and Santos (2004) tested the effect of AFC given the same growth rate from 4 months of age until breeding (0.7-0.8 kg/d) and from breeding to 252-258 days of pregnancy (0.8-0.9 kg/d). They reported the highest economic return from heifers calving between 23 and 24.5 months of age. Similarly, Pirlo et al. (2000) and Hultgren et al. (2011) reported reduced revenues with increasing AFC and suggested to target an AFC of 22-24 months. Davis Rincker et al. (2011) concluded that intensified feeding of calves could decrease AFC without affecting milk yield and economics negatively. Krpálková et al. (2014b) reported no negative effects on either production or reproduction parameters for heifers calving at < 699 days of age. They concluded that the presence of good management could justify the recommendation of shorter rearing periods. Recently, cows that achieved an AFC of less than 2 years, were reported to have the highest lifetime yield (Adamczyk et al. 2016). These results indicate that the present national average AFC of 26 months could be questioned from an economic point of view. It seems, however, to be a shortage of literature on the effect of heifer growth rate and management on lifetime production and profitability and no such studies has previously been done under Norwegian conditions.

2 Aims of the thesis

This thesis is part of a larger research project entitled “The impact of calf and youngstock development on dairy cow health, production, and profitability”. The primary objective of the project was to obtain new knowledge on feeding strategies in dairy heifers designed to achieve high production efficiency. The sub-objective for the work presented here was to compare the profitability of various strategies for rearing Norwegian Red heifers while accounting for the cash flow from both rearing the heifers and the productive life of the cows.

The main goals of Papers I-III were:

I. To identify which variables affect lifetime profitability in commercial dairy farms.

II. To assess lifetime profitability in four groups of heifers fed to achieve different growth profiles from 3 months of age until confirmed pregnancy.

III. To simulate the financial effects of an accelerated heifer growth rate compared to the current practice, under different culling rates, on farm annual gross margin.

3. Brief summary of papers I-III

3.1 Paper I

A case study on herd lifetime profitability in dairy production

In order to identify variables that affect lifetime profitability of NR dairy cows, we performed a screening of 13 Norwegian commercial dairy herds from three different regions in Norway. These herds were previously studied by Storli et al. (2017) who carried out repeated BW measurements to determine the effect of heifer growth on first-lactation milk yield. We calculated the average lifetime cash flow, on a monthly basis, at the herd-level for the average animal in each herd by combining the data collected by Storli et al. (2017) with additional herd-level production data from NDHRS and herd-level financial data from NDFR. Fixed costs and labor costs were not included in the analysis. We discounted and summarized the lifetime cash flow to a net present value (NPV) and further converted the NPV to a monthly annuity equivalent (ME), or profitability, to adjust for differences in the average lifetime per herd. Fifty-three recorded and estimated variables were analyzed in a general linear model with forward selection and a significance level for entry of 2%. Furthermore, we standardized the variables and applied factor analysis, as a multivariate method, to identify underlying, but unobservable, random quantities that describe the covariance relationships among the explanatory variables. Factors with eigenvalues greater than 2 were kept and analyzed with the above mentioned model.

MAIN RESULTS

- Of the original 53 variables, the forward selection method showed herd average rearing costs per month of productive life, herd average income in lactation 1, and herd average rearing costs per month from birth to calving to have an influence on ME at a 2% level.
- The factor analysis disclosed eight factors with eigenvalues above 2. Two of which could be associated with the output from the forward selection model: roughage costs and early return on investment.
- Running the eight factors in the forward selection model with a 2% significance level of entry disclosed five factors that influenced ME. These factors were

interpreted to account for roughage costs, early return on investment, sundry costs for dairy cows, delayed culling in third lactation and a reduced need for own growth in second lactation.

CONCLUSIONS

- Regression on factor scores gives a deeper insight into which factors affect profitability than regression on original variables.
- Herd profitability as defined by the ME is positively affected by low roughage costs, early return on investment, enlarged sundry costs, delayed culling in third lactation, and the reduced need for own growth in second lactation due to an increased post-pubertal ADG, in decreasing order of importance.
- Herd management costs in early life, pre-pubertal ADG, and cow size had no significant effect on profitability.

3.2 Paper II

Assessing the profitability of different growth profiles in replacement heifers from three months of age to pregnancy over the same productive lifetime

The objective of this study was to assess the lifetime profitability for four treatment groups of heifers fed a high-energy, low-protein (HELP); a high-energy, high-protein (HEHP); a low-energy, low-protein (LELP); or a low-energy, high-protein (LEHP) ration designed to give different growth profiles from 3 months of age until confirmed pregnancy. Planned body weight at breeding and calving were the same for all animals irrespective of treatment. All groups were fed the same ration after confirmed pregnancy. Age at first calving was 22 and 26 months for the high-energy (HE) and low-energy (LE) groups, respectively. We utilized experimental data, as well as external data, and assumed the same productive lifetime of 2.7 lactations per group. We calculated the net present value (NPV) for the average animal in each treatment by discounting monthly cash flow summed over the expected lifetime of the animal. The NPVs were converted to their monthly annuity equivalent value (ME) before comparing the alternatives.

MAIN RESULTS

- The total rearing cost per animal was €180 lower on average for heifers fed a high-energy diet compared to heifers fed a low-energy diet.
- Lactation costs and income were similar between treatments.
- The ME was most sensitive to changes in milk price, followed by roughage price, housing costs, concentrate price, labor costs, roughage subsidies, interest rate, and, finally, animal subsidies.

CONCLUSIONS

- Feeding heifers for rapid growth from 3 months of age until confirmed pregnancy is financially beneficial since it reduces the age at first calving by four months.
- The gained profit originates from reduced rearing costs, mainly those related to housing and labor.

3.3 Paper III

Simulating the financial and greenhouse gas impacts of different heifer growth strategies on dairy farms

The aim of this paper was threefold. Firstly, we aimed to simulate the effect of an accelerated growth (AG) scenario resulting in an age at first calving (AFC) of 22 months compared to a baseline growth (BL) scenario with an AFC of 26 months, on farm annual gross margin (AGM). The BL scenario reflects the average rearing practice of today. Secondly, we aimed to examine how reducing the culling rate (CR) from the present average of 0.45 to 0.35 or 0.25 affected farm AGM. Lastly, we aimed to simulate the effects of growth rate scenario and CR on farm level greenhouse gas (GHG) emissions. Three model farms (small, medium, and large) were created by applying cluster analysis on a Farm Accounting Survey (FAS) dataset containing physical and financial information on 311 Norwegian dairy farms. Data from the NDHRS was used where herd data was not available in the FAS dataset. We assumed the growth rate scenario did not influence later production. The impact of heifer-rearing time on AGM was modelled under different culling rates using a modified version of ScotFarm for the three farms. ScotFarm is a farm-level optimizing model that maximizes the annual gross margin. Output data from ScotFarm, in addition to data from NDHRS and official statistics provided by Statistics Norway, was used as input in the Global Livestock Environmental Assessment Model (GLEAM) to estimate emission intensities in a partial life cycle assessment perspective for each model farm.

MAIN RESULTS

- Given optimal utilization of available resources, the AG scenario significantly increased farm AGM in the range of 14-16%, 18-22, and 16-29% for the small, medium, and large model farm, respectively, depending on CR.
- CR did not significantly affect farm AGM, except when reducing CR from 0.45 to 0.25 in the large model farm.
- Changing heifer growth rate from a BL to an AG scenario reduced farm level GHG emissions by up to 1%.
- Reducing CR from 0.45 to 0.35 and 0.25 reduced farm level GHG emissions by 4% and 8%, respectively.

CONCLUSIONS

- Accelerating heifer growth rate in a way that heifers reach a sufficient level of maturity to be bred at 13 months and calve at 22 months of age increases AGM compared to an AFC of 26 months.
- For most dairy farms, reducing CR does not increase AGM significantly, mainly because of the high culling value of NR cows.
- Reducing CR is a more efficient way to reduce GHG emissions from Norwegian farms than accelerating heifer growth rate, provided it does not lead to increased specialized beef production.

4. General discussion

Managing a dairy farm involves activities such as grassland exploitation, milking herd management, and replacement rearing and management. As components of a dairy farm production system, these activities are mutually dependent (Figure 4). The dairy herd provides the replacement herd with calves, which again provides the dairy herd with replacements for culled cows. Manure produced by the animals contains organic matter and nutrients, which is utilized to fertilize grasslands for pasture or roughage harvested for indoor feeding. Together with other inputs, this system produces outputs like milk and meat. Due to a continuous genetic progress of the NR breed, the cows of today are markedly different from the ones existing 30-35 years ago (Geno 2016). Consequently, it is reasonable to ask whether heifer-rearing procedures based on the NR from 30 years ago are still applicable and if the rearing of today's heifers could be managed in a way that is more profitable. In this chapter, I discuss how changing heifer-rearing time and management affects the animal's lifetime economic performance.

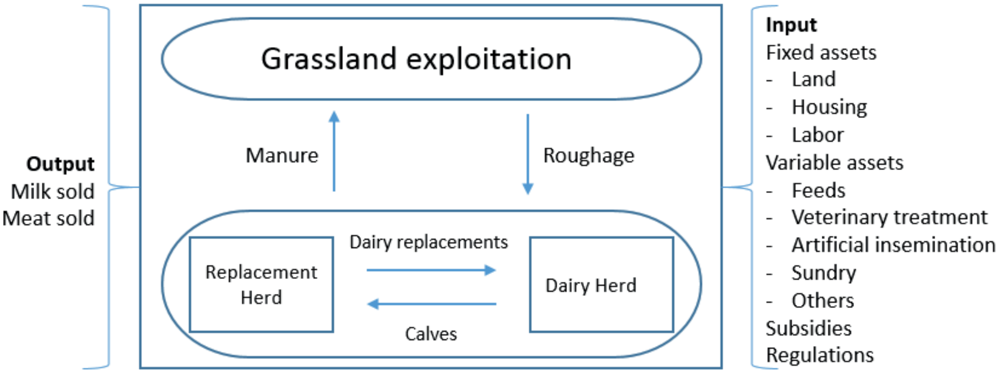

Figure 4. Components of a dairy farm production system. After Mourits (2000).

4.1 The effect of calf nutrition and management on subsequent performance

Because Papers II and III were based on treatments of post-weaning heifers, the effect of calf nutrition was not included in this thesis. However, nutrition in early life has proved to influence subsequent production. Therefore, this section provides a short summary of calf treatments in our studies and important findings from literature regarding the importance of calf nutrition. In Paper II, all calves were treated equally until 3 months of age and the simulations in Paper III assumed heifers were of equal size at 3 months of age. The field study (Paper I) included information on calf feeding management originating from an annual questionnaire filled in by the participating farmers over the 2 year duration of the data collection (Storli et al. 2017). However, this information was only used to assess costs of milk feed and calf concentrate. Only one of the 13 farms reported the use of milk replacer after the colostrum period for both years, whereas three of the farms used milk replacer one of the years. Milk feeding lasted 6-12 weeks. In Norway, there is a rule of thumb that feeding calves whole milk is profitable when filling the milk quota. Conversely, if not enough milk is produced to fill the quota, milk replacer is profitable. The long-term effects of ad libitum feeding (2 x 30 min/day) of whole milk or milk replacer was studied by Moallem et al. (2010). They reported that calves fed whole milk gained more BW until weaning and the difference was evident throughout the complete rearing period. In addition, the calves were younger at first insemination and yielded more milk in first lactation than their milk replacer-fed counterparts did. The observed improvements in milk yield in cows fed whole milk early in life could be related to the higher BW at calving (Dobos et al. 2004) or to physiological effects of whole milk on mammary development (Meyer et al. 2006a). In another study, Soberon et al. (2012) tested the long-term effects of milk replacer intake in both a research farm and a commercial farm. For every additional 1 kilogram of pre-weaning ADG, the first lactation milk yield increased by 850-1,113 kg. Furthermore, a meta-study evaluating the results of 11 studies on the long-term effects of pre-weaning ADG indicated an even higher milk return of 1,550 kg of milk for every additional kilogram of ADG in the milk feeding period (Soberon & Van Amburgh 2013). In line with this, a study on 795 Holstein calves from 21 Pennsylvanian herds showed that dry matter intake (**DMI**) at weaning and BW at calving increased first lactation milk yield; whereas, delivery score, days of illness from scours and cough before 4 months, and increased AFC had negative effects (Heinrichs & Heinrichs 2011). Results from a Swedish experiment also associated calfhood diarrhea with reduced first lactation milk yield (Svensson & Hultgren 2008). Although calf nutrition is not a direct part of this study, these results emphasizes the importance of high quality calf feeding and management routines.

4.2 Growth rate and rearing costs

In a recent paper, feed cost was reported to make up around 73% of total heifer rearing costs (Heinrichs et al. 2013). The rearing of heifers, again, makes up one of the largest inputs on a dairy farm, accounting for up to 20% of milk production costs (Heinrichs 1993). In the work presented in this thesis, we could not find any distinct relationship between AFC and rearing costs in the field study (Paper I) (R^2 = 0.04), whereas the opposite was found in the controlled experiment (Paper II) (R^2 = 0.98). Because the herds studied in Paper I were located in three different regions (Figure 5) with different subsidies schemes, state subsidies, fixed costs, and labor costs were omitted in this study, while included in the controlled experiment (Paper II). However, reduced AFC was associated with increased profitability in Paper I through the significance of the early return factor. In Paper II, the results show that total rearing costs with reduced heifer-rearing time is lower than the costs of today's practice, mainly because of lower housing and labor costs (Paper II; Table 3), which is likely to explain the above mentioned difference in R^2. Although our rearing costs in Paper II were on a higher level, the difference between our HE and LE fed groups was comparable with the rearing costs from birth to 21 months of age for heifers growing either > 0.8 or < 0.7 kg/day in a Czech study reported by Krpálková et al. (2014a). Similarly, the optimizing results in Paper III show an increased farm annual gross margin with accelerated heifer growth rate. The accelerated growth rate scenario had a €220 lower feed cost per heifer compared to the baseline scenario, mainly due to a higher feed intake from pasture, which is less expensive than grass silage. An increased ADG reduces the percentage of energy provided used for maintenance, which increases energy efficiency. Furthermore, a higher growth rate resulting in calving at an earlier age saves fixed costs. The average total rearing costs for the HE groups in Paper II were 6.3% lower than for the LE groups. As opposed to the results in Paper III, the HE groups in this study had an average feed cost €62.25 higher than the LE groups as a result of a higher roughage intake per day and the more expensive roughage. However, with a 4 month earlier AFC for the HE groups, the reduction in rearing costs was 1.6% per month. This is considerably lower than the 2.6% to 5.7% cost reduction of lowering AFC by one month reported by Mohd Nor et al. (2012) and the 4.3% reported by Tozer and Heinrichs (2001). A plausible reason for this discrepancy could be that neither of these studies included the cost of time in their models. We calculated rearing costs as a present value, which means that all costs were discounted to the time of birth, i.e. that the costs occurring late in the rearing period were relatively lower than the costs occurring at an earlier stage.

Figure 5: Map of Europe with Norway in gray. Inset shows the (1) mid, (2) south-west, and (3) south-east regions with 5, 2, and 6 farms present in Paper I, respectively. From Storli et al. (2017).

4.3 The effect of pre- and post-pubertal growth on milk yield

Sale of milk is the most important source of income on dairy farms and the effects of heifer growth on subsequent milk yield has been subject to many studies, often with contradictory conclusions. Already in 1960, Swanson (1960) studied the effect of growth rate on identical twins and found that fattened, fast growing heifers yielded less milk than their lean, non-fattened sisters when they were bred to calve at 23-31 months of age. Later studies further examined the effects of ADG in different periods of growth and culminated with the theory of “the critical period” (Sejrsen et al. 1982). The theory stated that high pre-pubertal growth rates, thus younger AFC, could be harmful with respect to mammary development and, therefore, reduce subsequent milk yield. Later reviews (see, e.g., Sejrsen and Purup, 1997) supported this view, although the reported results were not unambiguous. A likely solution to this was presented a decade later when it was shown that not only the plane of nutrition and accelerated growth in pre-pubertal heifers, but also age had to be considered because the latter influenced mammary parenchyma development (Daniels et al. 2009; Meyer et al. 2006a; Meyer et al. 2006b). These findings were in accordance with what was reported already in the late 1930s, namely that estrogens stimulated ductular growth, whereas the estrogen/progesterone interaction was needed for lobule-alveolar development (Turner 1939, cited in Tucker, 1969). This could imply that the observed negative effect on mammary gland development from high pre-pubertal ADG (leading to a younger AFC) did not originate from high ADG, but rather from a management decision to breed the heifers too early. The estrogen/progesterone interaction is only present a few days before the estrus phase in each estrous cycle (Figure 6) (Sjaastad et al. 2010) and because conception leads to the formation of a corpus luteum that maintains a high concentration of progesterone thus blocking this interaction, conception too early is likely to inhibit further lobule-alveolar development. This is a possible explanation for the lacking effect of pre-pubertal growth rate on subsequent milk yield in studies where heifers that were allowed to complete several estrous cycles before pregnancy (see, e.g., (Archbold et al. 2012; Krpálková et al. 2014b; Macdonald et al. 2005)) yielded no less than slower growing heifers did. These results are likely to be caused by the lobule-alveolar development driven by hormonal factors that requires cyclic activity, as described by Turner (1939, cited in Tucker, 1969) and not by ADG or age per se. In addition, this provides an explanation for the lack of effect of post-pubertal growth on mammary development (Lacasse et al. 1993; Sejrsen et al. 1982) and 305-day first lactation milk yield (Hoffman et al. 1996) because cyclic activity is present in this period until pregnancy occurs. In a recent review, Roche et al. (2014) suggested that the positive effects of first calving live weight originating from an accelerated post-pubertal growth could be an effect of heifers being closer to mature live weight at calving, thus ensuring more of the consumed nutrients are partitioned to milk production rather than growth. The significance of a reduced need for own growth during the second lactation on profitability, resulting from an increased post-pubertal growth, as found in Paper I, is in accordance with this.

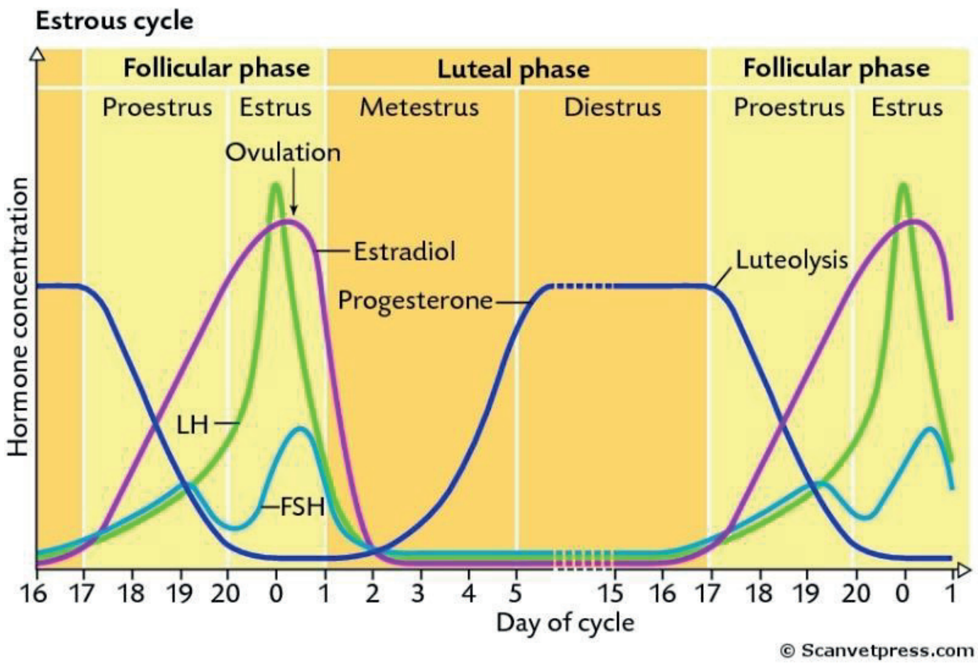

Figure 6 Endocrine changes during the estrous cycle in cows (Sjaastad et al. 2010).

Our experimental heifers (Paper II) were bred at a BW around 390 kg (Table 2) and were allowed to complete several estrous cycles before conception. This is also true for the heifers in the simulation paper (Paper III), where the feed plans assumed pregnancy to occur at 360-400 kg of BW. Body weight at either breeding or calving was not recorded in the field study (Paper I), but estimated live weight at calving (data not shown) indicated BW at breeding to be high enough to complete several estrous cycles prior to breeding.

In Paper II, the HEHP treatment experienced the highest growth rate and the youngest age at first calving. However, the first lactation milk yield was the lowest for the animals in this group (Paper II, Table 2). In a comparable study, Radcliff et al. (2000) concluded the same, but their HEHP treatment gained on average 160 g/d more in the experimental period lasting from 135 kg to confirmed pregnancy than our HEHP treatment did. In a meta-analysis summarizing the results from eight studies, Zanton and Heinrichs (2005) reported a curvilinear relationship between pre-pubertal ADG and first lactation milk yield. They found the optimal pre-pubertal ADG, with respect to first lactation yield, to be 799 g/day. However, at least five of these studies (Abeni et al. 2000; Lammers & Heinrichs 2000; Peri et al. 1993; Stelwagen & Grieve 1992; Waldo et al. 1998) used animals weighing from 150-200 kg at the start of their experiments. As discussed in section 4.1, pre-weaning nutrition and ADG can influence on later performance. Therefore, one has to be cautious when interpreting results from studies assessing pre-pubertal ADG due to possibly large effects of early life nutrition on subsequent milk yield. This is especially important if heifers as large as 150-200 kg enter experimental treatments with little or no knowledge about previous management and nutrition practices.

As seen in Table 2, our heifers, which formed the basis of Paper II, achieved pre-pubertal ADG's either higher or lower than the optimum reported by Zanton and Heinrichs (2005). Although the relationship between ADG and milk yield is dynamic and varies with the genetic capacity for growth and milk (Sejrsen et al. 2000), our experimental heifers' pre-pubertal ADG's were most likely outside the optimum. Similarly, there is an optimum growth rate in the post-pubertal period (10 to 15 months of age) of 830 g/day with respect to first lactation milk yield (Storli et al. 2017), which our HE and LE heifers' ADG's were also on either side of. Consequently, the growth profile for our experimental heifers was not optimal with respect to first lactation milk yield. Even though the HE groups had lower milk yield than LE groups in first and second lactation (the only significant difference was between LELP and HEHP groups in first lactation), the HE animals yielded much higher in third lactation so that lifetime yield was equal between energy levels within protein levels (Paper II; Table 2).

Table 2. Estimated least-squares means (SE) of age and BW at start of experimental feeding, successful artificial insemination (AI), and calving for the four dietary treatments groups, as well as average daily BW gain (ADG) during the pre-pubertal, post-pubertal, and pregnancy periods. Data from (Storli et al. 2018)

	Treatment			
	HELP[1]	HEHP	LELP	LEHP
Age in months at				
Start	3.0 (0.03)	3.0 (0.03)	3.1 (0.03)	3.0 (0.03)
Successful AI	13.5 (0.28)	12.9 (0.27)	17.1 (0.27)	16.7 (0.29)
Calving	22.5 (0.28)	21.9 (0.27)	26.1 (0.27)	25.8 (0.29)
Body weight in kg at				
3 months (start of experiment)	112.8 (1.63)	111.9 (1.56)	112.6 (1.59)	112.4 (1.68)
13 months (successful AI)	386.8 (4.03)	395.6 (3.90)	-	-
17 months (successful AI)	-	-	396.5 (3.76)	394.1 (4.00)
22 months (calving)	531.6 (8.57)	554.3 (8.11)	-	-
26 months (calving)	-	-	567.6 (12.70)	579.0 (13.76)
ADG (g/d) during				
3 months – onset of puberty	917	936	667	719
Puberty – successful AI	948	1 000	648	672
Pregnancy	476	498	659	596

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

4.4 The effect of growth rate on fertility and longevity

The onset of puberty is a function of BW, rather than age (Capuco et al. 1995; Meyer et al. 2006b; Niezen et al. 1996; Radcliff et al. 1997), and puberty is a premise for cyclic activity and later conception. Our experimental heifers (Paper II) were documented to have reached puberty at around 280 kg BW with an age ranging from 8.8-11.8 months depending on treatment (Storli et al. 2018) and this was in line with the literature. A pre-pubertal ADG which is too low can result in heifers not reaching puberty before the planned start of breeding, which leads to delayed breeding and first calving, and possibly poorer first lactation fertility. The latter was expressed as lower survivability to the beginning of second lactation for heifers with a BW below 317 kg at mating start date, which was defined as the date of first breeding (Archbold et al. 2012). A study by Brickell et al. (2009) involving 13 UK dairy herds showed increased BW gain reduced age at first breeding and concluded that increased AFC, as a result of suboptimal heifer growth, could be abated by improved monitoring of heifer growth during rearing. The majority of farmers reported age to be the determinant of when to breed in a survey carried out among 959 Dutch dairy farmers about their routines regarding heifer management, while 26% and 17% claimed to use wither height and BW, respectively, to determine first breeding in addition to age (Mourits et al. 2000). However, when asked to provide information on record for those factors, only 12% and 28% of the farmers, respectively, were able to give information on wither height and BW, and only half of the 60% of farmers with a spoken target AFC < 24 months managed to realize that goal. This is likely no different in Norway today. Accordingly, there is potential for improvement in heifer growth monitoring, which is crucial if the goal is to optimize heifer rearing management. A feasible approach to this issue is regular heart girth measurement of heifers to gain control over ADG and BW at key periods of rearing. By doing this, the farmer takes control over his/her heifer-rearing process and will be able to identify possible problems, such as an ADG which is too low on pasture or a BW which is too low at breeding.

An ADG which is too low will result in older heifers at calving. Alvåsen et al. (2014) demonstrated increased AFC for primiparous cows to increase the risk for on-farm mortality. Similarly, Holstein-Friesian heifers calving at an age younger than 2 years old have a decreased age at culling compared with an AFC > 2 years (Adamczyk et al. 2016) which is negative for longevity. Nevertheless, cows with the youngest AFC had the numerically highest lifetime ECM yield. On the contrary, a study on Iranian Holstein cows conducted by Nilforooshan and Edriss (2004) reported heifers that calved at 21 months of age to have both the longest lifetime and productive lifetime compared to heifers calving at an older age. They concluded, however, that an AFC of 23-24 months was most profitable as cows with such an AFC experienced the highest milk and milk fat yields without harming reproductive efficiency. These results indicate that it is difficult to draw exact conclusions on how heifer growth rate affects fertility and longevity in dairy cows. We did not study the effect of growth rate on longevity in this thesis. However, given the high cost of rearing heifers it is sound thinking that keeping cows longer in the herd would be profitable, as long as they are healthy and fertile. One of the factors found to affect profitability positively in the field study (Paper I) was delayed culling in third lactation. Because the average cow in all of the 13 herds studied was culled during third lactation we cannot conclude from our results that keeping cows for later lactations is profitable. This is a topic that is interesting from both an animal welfare and an economic point of view and should be examined further.

4.5 The effect of growth rate on profitability

From time of birth until first calving, the animal produces meat and one calf without generating any income. This period should be seen as an investment in future revenues. At the end of the cow's life, the investment in meat is realized when the cow is slaughtered. In the larger picture, the slaughter value of the cow at the end of first lactation is equal to the slaughter value later in life because the cow is close to adult BW at that time. Thus, the lifetime milk production will determine the overall profitability of the cow. The dairy farmer has little influence on the milk price and the sensitivity analysis in Paper II (Paper II; Figure 1) shows that changes in milk price affects the ME the most. At present, the farmer receives an additional 0.07 NOK per liter milk for every 0.1% of milk fat above 4.0% and 0.05 NOK for every 0.1% milk protein above 3.2%. There is also a corresponding draw in milk price for fat- and protein levels below these values. Increased DM content in milk increases the energy requirement of the cow but providing the cow more energy does not necessarily realize higher levels of milk solids. It could just as well result in an increased milk yield with less DM (with similar ECM yield) or a higher BCS, or these effects combined. Whether feeding for increased content of milk solids is profitable or not needs to be examined separately.

The goal should be to maximize lifetime milk yield in order to increase profit. This can be achieved either by increasing milk yield or by increasing the productive life of the cow. Because the average NR cow only lives, on average, for 2.7 lactations (NDHRS 2017), an efficient means to increase the productive life is to reduce AFC. Although the four groups studied in Paper II had the same productive lifetime of 31 months, the HE groups were productive 59% of their total lifetime, whereas the corresponding number for LE groups were productive 54% of their productive lifetime (Paper II; Table 2). This, in addition to the advantage of collecting revenues 4 months earlier, made the HE animals, on average, 22% more profitable than the LE animals. This equals €68.40 per animal per year. In a 40 cow herd, for example, this means €2,736, or almost 25,500 NOK, per year using the average exchange rate for 2015 (NorgesBank 2017). If subsidies for roughage production and animals were removed, the picture changes dramatically as illustrated in Figure 7. The simulated increases in AGM with accelerated growth rate found in Paper III were 16%, 22%, and 29% for the small, medium, and large farms, respectively, at a CR of 0.45. The percentage increase in AGM decreased with decreasing CR (Paper III; Table 5).

Given the large costs associated to heifer rearing, it is logic to think that keeping the cow in the herd for a longer time by reducing CR would be profitable. This option was not found to have a significant impact on farm AGM in the simulation (Paper III), most likely because of the high cull value of NR cows (Paper III; Table 2). There was, however, an exception for large farms when reducing CR from 0.45 to 0.25 (Paper III; Table 5). Keeping the cows longer reduces the need for replacements, which gives an opportunity to use sexed semen to produce more meat. Although cows of dual-purpose breeds like the NR have a higher slaughter value than Holstein cows (Bazzoli et al. 2014), crossbreeding with beef bulls could also potentially increase the slaughter value. However, older cows have an increased possibility for health issues such as increased somatic cell count (Hand et al. 2012), mastitis (Valde et al. 2004), milk fever and claw diseases (Fleischer et al. 2001). Keeping cows too long could, therefore, result in increased costs for veterinary services, medical treatment, and lost milk and slaughter income due to sickness and/or death. Currently, around 33% of NR cows are culled before their second lactation (NDHRS 2017). The financial consequences of this are illustrated in

Figure 8. The figure also demonstrates the importance of the third lactation as approximately 2/3 of the calculated lifetime profitability originates from this lactation. Furthermore, it visualizes why delayed culling in third lactation was one of the variables found to increase profitability in Paper I. Using a stochastic dynamic optimization model that included the risk of disease, Heikkila et al. (2008) determined the optimal replacement policy for Ayrshire and Holstein-Friesian Finnish herds. Their results showed that the optimal mean parity were 3.8 and 3.7 lactations for the two breeds, respectively. To the best of my knowledge, no studies on the optimal culling policy for NR cows, with respect to profitability, exists. Figures 7 and 8 suggest that finding an optimal culling policy for NR cows is likely to be an important variable determining lifetime profitability in NR cows, and should be investigated.

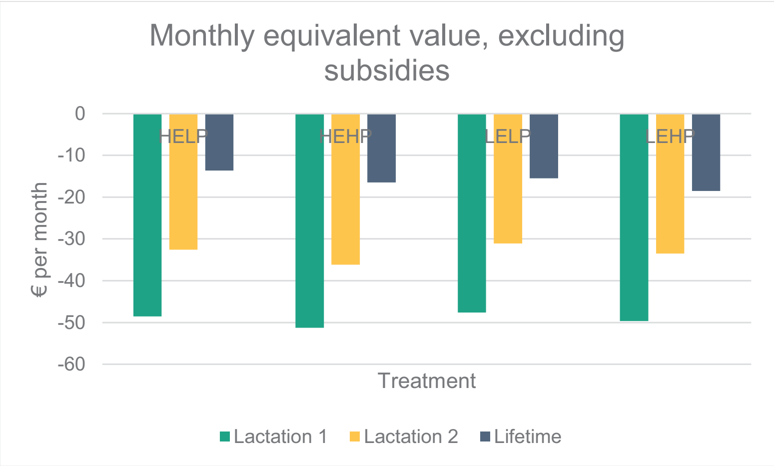

Figure 7. Profitability expressed as monthly equivalent value exclusive subsidies in Norwegian Kroner (NOK) for the four treatments when culled after first or second lactation, or average lifetime (2.7 lactations). Exchange rate €1 = 8.953 NOK.

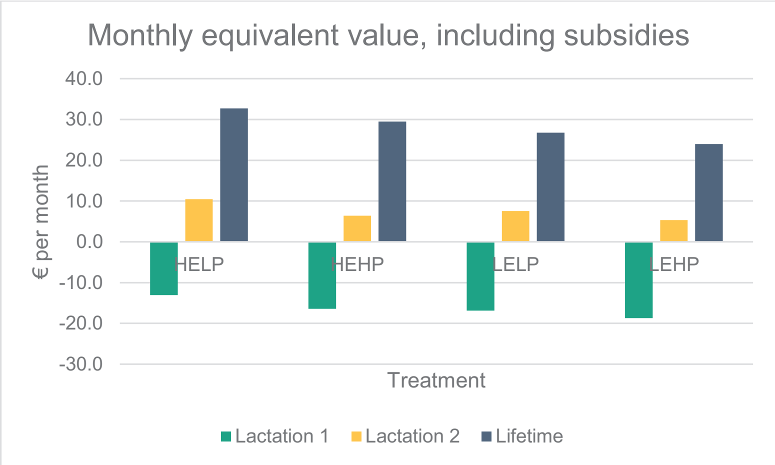

Figure 8. Profitability expressed as monthly equivalent value in Norwegian Kroner (NOK) for the four treatments when culled after first or second lactation, or average lifetime (2.7 lactations). Exchange rate €1 = 8.953 NOK.

5. Conclusions and future perspective

This thesis has examined the effect of heifer growth on lifetime production and profitability. The papers examined dairy profitability in the field, in a controlled experiment, and by a simulation model. The main conclusions from the present work are:

- Omitting state subsidies and only considering variable costs minus labor, herd profitability in commercial Norwegian dairy farms is positively affected by, in decreasing order of importance: low roughage costs, early return on investment, enlarged sundry costs, delayed culling in third lactation, and the reduced need for own growth in second lactation due to a higher post-pubertal ADG.
- As long as sufficient BW both at breeding and at calving are ensured, the rapid rearing of heifers from 3 months of age until confirmed pregnancy can lower the AFC down to 22 months. This could potentially increase the lifetime profitability of the average animal in the range of 10-36% compared to the present day practice when state subsidies, housing costs, and labor costs are included.
- The simulated effect of an accelerated growth scenario to achieve an age at first calving of 22 months, compared to a baseline scenario with an age at first calving of 26 months, increased farm annual gross margin (AGM) significantly. The increase was in the range of 14-29%, depending on farm size.
- The simulated effect of reducing culling rate from the present average of 0.45 to 0.35 and 0.25 did not significantly affect farm annual gross margin, except for large farms in a baseline growth scenario where reducing culling rate from 0.45 to 0.25. The latter gave a significant increase in farm AGM by 12% in the simulation model.

As stated at the end of the discussion, culling apperas to be an important determinant of profitability. According to theory, the culling of a cow should occur at the time when a new cow is more profitable. Several models for optimal culling policy exists, but these models were developed for other breeds and price structures than those in Norway. Thus, finding the optimal culling policy for NR cows would be of interest.

With production and health records available in the NDHRS, this topic should be possible to investigate further. In addition, the introduction of “big data” in agriculture, for example, real-time collection of animal data from voluntary milking systems and feed robots, will give better possibilities for carrying out further field studies on both lifetime profitability and culling policies.

6. Recommendations to farmers

General recommendations for farmers to ensure the best economic result from their production is:

- To improve their heifer rearing management in order to reduce the AFC to 22 months. This will save rearing costs, especially costs related to housing and labor. The savings can be up to 6.2%, or €180 per heifer, compared to an AFC of 26 months. This is in addition to the effect of collecting revenue from milk sales at an earlier time. In total, lifetime profitability can be increased by 22% on average (ranging from 10% to 36%).
- To produce a high-quality roughage with high content of energy as it lowers roughage cost per unit of energy. High-quality roughage increases roughage DMI and could save on concentrate costs.
- To keep cows longer in the herd. Unless cows experience health problems or an unexpected decline in production, culling them too early can mean a loss in revenue.

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A case study on herd lifetime profitability in dairy production

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Short title: LIFETIME PROFITABILITY VARIABLES

Abstract

This study aimed to analyze dairy cow lifetime profitability at the farm level, and to identify important production-economic variables affecting profitability. Starting out with 30 herds with detailed information on heifer growth and feeding, and utilizing that 13 of these both had detailed financial data from being members of the Norwegian Dairy Herd Financial Recording System and additional data from the Norwegian Dairy Herd Recording System, we could calculate cash flow for an average individual per month and herd, omitting state subsidies and only considering variable costs. Individual cash flow was discounted and summarized to a net present value at time of birth and further converted to a monthly annuity equivalent value, or profitability. Regressing profitability either on 53 original variables or on factor scores derived from the original variables, a stepwise forward selection algorithm gave preference to the latter because it was not

affected by co-linearity, gave a higher resolution, and thus deeper insight. In decreasing order of importance, the parameters that affected lifetime profitability the most were low roughage costs, early return on investment, enlarged sundry costs, delayed culling in third lactation, and reduced need for own growth in second lactation.

Keywords: cattle, cash flow, net present value, production parameters, profit analysis

Implications

When not considering income from state subsidies and fixed costs, e.g. housing and labor costs, what dairy farmers should do to ensure the best economic result from their production is, in decreasing order of importance: to produce high-quality roughage at a low cost per megajoule, rear their heifers to calve and enter the milking herd at an early age, i.e. down to 22 months of age, use rubber mats and plenty of bedding material in the cowshed, and delay culling until late in third lactation.

Introduction

In a recent field trial we concluded that Norwegian Red replacement heifers grow too slowly during the rearing period, reach the size at which they are deemed large enough to be bred accordingly and consequently enter the dairy herd unnecessarily late (Storli *et al.*, 2017). This would likely affect the dairy farmers' economy. Previously, several studies have aimed to identify key variables or indicators to assist farmers in making good decisions to increase their economic efficiency (see e.g. Hansen *et al.* (2005); Heinrichs *et al.* (2013)). Hansen *et al.* (2005) utilized data from the Norwegian Dairy

Herd Recording System (**NDHRS**) and the Norwegian Dairy Herd Financial Recording (**NDFR**) databases to identify key performance indicators on Norwegian farms. Many of these production-economic parameters will likely be co-linear, and principal component analysis could advantageously be used to identify underlying economic patterns as was recently done by Atzori *et al.* (2013).

To the best of our knowledge, an analysis of dairy cow lifetime profitability has not been conducted in Norwegian dairy production. Starting out with the 30 herds from Storli *et al.* (2017) with detailed information on heifer growth and feeding, and utilizing that 13 of these both had detailed financial data from being members of the NDFR and additional lifetime production data from the NDHRS, we aimed to analyze dairy cow lifetime profitability at the farm level. To this end, we calculated the net present value (**NPV**) at time of birth for an average individual and herd from lifetime cash flow, and converted these NPV to a monthly annuity equivalent (**ME**), or profitability; we omitted state subsidies since they cannot be assumed to be sustained in the long term, together with fixed and labor costs, and considered only variable costs. Finally, we regressed potential production-economic parameters on this annuity in order to rank their mutual importance.

Materials and methods

The present analysis is based on the calculation of monthly individual, average cash flow per herd over each herd's average dairy cow's lifetime derived from the NDHRS (Table 1). These monthly cash flows were discounted and summarized to a NPV corresponding with the starting point of the investment period, i.e. birth of a heifer calf. NPVs were then recalculated to ME values to adjust for differences in average lifetime of cows between herds. Fixed costs and labor costs were not included in the analysis.

Of the 30 herds contained in the study of Storli *et al.* (2017), 13 were members of the NDFR for the years 2012 and 2013. These farms were included in the study. Among the 13 herds, the mean herd size was 66 cow equivalents (range 34 to 129), which is well over the national current average of 26 cow equivalents (NDHRS, 2017). Except for the compulsory 8 weeks on pasture during summer, the animals had been fed a diet of roughage and concentrate, and they were housed in either tiestalls or freestalls.

Cash flow of income and variable costs

Using a Microsoft Excel 2013 spreadsheet for each herd, we calculated average cash flows at the herd level. Utilizing a timeline of four periods, the calculations were as follows.

Calf period. We defined the calf period as the first three months of life. A newborn heifer calf was assigned a value of NOK 2 500 in month one for all herds, because it is the standard value used in NDFR (Table 2). Information on the amount of milk, concentrate and roughage fed to the calves was obtained from a questionnaire that had been answered twice by the participating farmers during the study conducted by Storli *et al.* (2017) (Table 1). Costs per liter of milk fed to calves were set equal to the milk price obtained by each herd (Table 2). Roughage prices, veterinary costs, as well as sundry costs per herd were as obtained from the NDFR (Table 2). Concentrate price was obtained from the TINE OptiFôr client in the NorFôr feed evaluation system (Volden, 2011) (Table 2).

Heifer and pregnant heifer periods. The length of the heifer-rearing period varied from 12 to 15 months between herds and was derived from each herd's average age at first calving (**AFC**) as given in the NDHRS (Table 1). Expenses in the entire heifer period were limited to feed, veterinary, and sundry costs. Roughage costs and the two latter were obtained from the NDFR (Table 2). Information on concentrate use during the two periods was obtained from the questionnaire from Storli *et al.* (2017) (Table 1) and the cost of concentrate were obtained from the TINE OptiFôr client in NorFôr (Table 2). Using the TINE OptiFôr client we calculated the energy required by a heifer to reach its first calving BW (defined as the average slaughter weight for first parity cows in the actual herd as given in the NDHRS (Table 1) divided by an assumed slaughter percentage of 0.45) at the herd's average AFC. Monthly roughage intake in megajoule (**MJ**) was obtained by subtracting the energy provided by the fed concentrate, and is presented as intake per day (Table 1). Feed intake and associated costs during pregnancy were calculated in the same manner as in the heifer-rearing period (Table 1).

Lactation period. We defined the lactation period as the entire period between AFC and herd average age at culling (Table 1). This period varied from 26 to 37 months between herds. Further, we assumed a 12-month calving interval made up of a 305-day lactation period and a 60-day dry period. Revenues included sale of milk, sale of three calves to the replacement herd assuming a fixed price of NOK 2 500 per newborn calf, and the slaughter value assigned at culling (Table 2), being the product of the adult slaughter weight in the herd as given in the NDHRS (Table 1), times price per kg and herd obtained from the NDFR (Table 2). Monthly roughage intake was calculated as the difference between the energy required for maintenance and production given the herd's monthly average energy corrected milk yield (**ECM**), and the energy provided by the herd's average concentrate use extracted from the NDHRS (Table 1). Energy requirement calculations were carried out using the TINE OptiFôr client in NorFôr. In these calculations we used a fixed BW set as the herd's average adult slaughter weight (Table 1) divided by 0.45. Concentrate price per MJ was obtained from the TINE OptiFôr client in NorFôr, and veterinary and sundry costs from the NDFR (Table 2). Average daily yield in kg ECM and kg milk were calculated utilizing monthly test-day records from the NDHRS database on animals born from Norwegian Red sires through artificial insemination into the 13 herds after 1 Jan 2011. We used the SAS® MIXED procedure (SAS/STAT software; SAS inc., Cary, NC) to estimate daily milk production in first and second lactation per herd utilizing a test-day model (**TDM**) with fixed regression coefficients of 1st to 3rd order Legendre polynomials; and random regression coefficients of 0 to 2nd order. Legendre polynomials is frequently used to model nonlinear relationships (Schaeffer, 2016). Heterogeneous and independent variances were assumed for three periods of lactation (1-50, 51-150 and > 150 days in milk). In third lactation, with few records for most animals because they were culled, only a first-order polynomial was modelled for the random effect. By only accepting cows that had test-day records in all three periods of lactation, we were able to run the TDM just for 5 herds, and 36 cows. For these cows, we regressed daily milk production in third lactation on the production of the same animals in the second lactation, whereafter the obtained regression equations was used to predict third-lactation daily milk production for all individuals in all herds. Table 3 lists the obtained herd mean production variables in first, second, and third lactation, calculated as the cumulated sum of the individual daily production within lactation over 10 months assuming a monthly length of 30.5 days. Monthly herd production averages were calculated correspondingly.

Net present value

Monthly cash flow was discounted and summarized for the average animal in the 13 herds using the following expression:

$$NPV = \sum_{t=0}^{T} \left[\frac{(I_t - E_t)}{(1+r)^t}\right] + \frac{S}{(1+r)^T} \tag{1}$$

where I is monthly revenue, E is monthly expense, t is a monthly index, r is the discount rate, set to 3.5% p.a., corresponding to the current short term credit rate for agriculture in Norway. S is the slaughter value of the cow when culled, and T is the herd average lifetime in months. Variables contained in I, E and S, are specified in Table 4.

Monthly annuity equivalent value

Using expression (2) we converted the NPV of the estimated lifetime cash flow of the average dairy cow in a given herd into a monthly annuity equivalent value, ME, as described by e.g. Konstantin and Konstantin (2018). This standardizes the NPV, which is necessary because of the unequal lengths of investments in the different herds, which again is due to differences in the average lifetime of cows per herd. The ME is the monthly amount of cash demanded by the farmer to render him/her indifferent whether to choose the ME or the uneven cash flow from the heifer investment over the same period. Assuming that rearing of a new heifer calf immediately takes place when a cow is culled and that this is a perpetual swirl of events, the ME is the value generated each month as the opportunity cost of capital, calculated as:

$$ME = NPV\left(\frac{r*(r+1)^T}{(1+r)^T-1}\right) \qquad (2)$$

where *r*, *T*, and NPV are defined as in (1).

Variables affecting the monthly annuity equivalent value

The relationship between ME and 53 recorded and estimated variables given in Table 5 were explored utilizing various statistical methods. First, we used the SAS® PROC GLMSELECT with the forward selection option and a significance level of 0.02 to decide which variables regressed on the ME value. Then, we standardized the variables and did a factor analysis using the PROC FACTOR in SAS®. Factor analysis is a multivariate method used to identify underlying, but unobservable, random quantities called factors, which describe the covariance relationships among the explanatory variables (see e.g. Johnson and Wichern (2002)). We used the principal component method where each variable's largest absolute correlation with any other variable was used as the prior communality estimate. The number of factors was determined by keeping eigenvalues greater than 2, and a varimax rotation was chosen to facilitate the interpretation of the factor loadings. Finally, we tested the identified factors for their effect on ME using the PROC GLMSELECT, described above. Obviously, the R^2 will be high with the regression approach from some of the independent variables being contained in the cash flow calculations, but the approach should be adequate in order to determine the variables' mutual importance.

Results

Table 6 gives rearing and milk production costs in addition to milk and slaughter income for the average animal in each herd, discounted to a present value at time of birth. The estimated NPV and ME values for the 13 herds are also shown in Table 6. The mean ME value summarized to NOK 772.9, with large variation between herds (min = 339; max = 1 305) as was the case for most variables in Table 6.

Using forward selection, only three of the 53 variables in Table 5 regressed significantly on ME with the following model fit statistics: F = 157.7 and R^2 = 0.975 (Table 7). The three variables were herd average rearing costs per month of productive lifetime, herd average milk income per cow in lactation 1, and herd average rearing costs per month from birth to first calving (Table 7).

The factor analysis identified eight factors with eigenvalues > 2 (Table 8), with respectively 15, 14, 8, 9, 9, 6, 6 and 3 variables having loadings above |0.4|. Table 7 shows the results when regressing the factor scores on ME. The model was highly significant (F = 128.8) and explained 98.2% of the variance (R^2). Five factors (1, 2, 5, 7 and 8) were significant at a 2% level.

Discussion

Stepwise regression identified 3 variables that affected ME. However, since many variables were strongly co-linear, we decided to subject the explanatory variables to a factor analysis with the final aim of regressing also these factors on ME. The factor analysis revealed eight factors with eigenvalues above 2 (Table 8). Ten of the variables included in the first factor had a direct or indirect relation to roughage costs (Table 8), all with loadings equal to or above 0.86. Thus, we interpreted factor 1 as a roughage cost factor. With rearing costs per month from birth to calving, and rearing costs per month of productive life being contained in the factor, the significance of these variables ($P < 0.001$; Table 7) and that of factor 1 ($P = 0.003$; Table 7) combined with the negative regression coefficients would mean that increased roughage costs would significantly reduce ME. This is consistent with the findings of Heinrichs *et al.* (2013) who reported feed costs to account for around 75% of heifer-rearing costs, which again made up 15-20% of total milk production costs (Heinrichs, 1993). In the present study, total feed costs made up as much as 88% of variable costs of rearing, of which 66% were roughage costs (Table 6). Had fixed costs, e.g. for housing, been included in the analysis these percentages would obviously have decreased and results approached those of Heinrichs (1993) and Heinrichs *et al.* (2013). Our study showed that the roughage costs explained more of the profitability than was reported by Hansen *et al.* (2005), probably because of the more detailed calculations of roughage costs than those Hansen and coworkers obtained from the NDFR. An additional explanation could be that roughage costs was contained in a number of the variables they used, as was also discussed by the authors.

Factor 7 loaded decreasingly positive on variables related to income in lactations 1, 2 and 3, especially income per month, and negatively on AFC (Table 8). This would mean that factor 7 is an early return factor. Not only did the scores for this factor regress positively on ME (P = 0.013; Table 7), but so did milk income in lactation 1 (Table 7), meaning that early returns definitely improve profitability. In accordance with this, Enqvist *et al.* (2014) documented that an increased cash convention cycle affected profitability negatively. The cash convention cycle is a measure referring to the time between a firm's disbursement when buying raw materials for production and the collection of cash when selling the finished product, which is comparable to investing in a heifer to collect future revenues from milk and meat production. Previous studies report reduced revenues with increasing AFC (Pirlo *et al.*, 2000, Hultgren *et al.*, 2011), and suggest first calving age should be some 22-24 months. In our study, only two herds achieved such an AFC (Table 1).

Sundry costs in lactations 1, 2 and 3 were the only variables with loadings above |0.40| in factor 8 (Table 8). The factor scores regressed positively on ME (P = 0.002; Table 7), meaning that increased sundry costs affect ME positively. Sundry costs include costs for e.g. bedding material and post-milking teat dipping, which are associated with lower herd somatic cell count (Dufour *et al.*, 2011). Increased somatic cell count increase lactation milk loss (Hand *et al.*, 2012) and can further lead to mastitis with additional costs from milk production losses (Hogeveen *et al.*, 2011).

Largely, factor 2 loaded positively on variables related to costs as well as milk income in lactation 3, age at culling, and an increased post-pubertal growth rate that produces a larger animal, but it loaded negatively on variables related to the slaughter value of the cow and culling rate (Table 8). Therefore, we considered factor 2 an income minus cost factor in third lactation, bearing in mind that culling occurred during this lactation in all herds. The factor scorings regressed positively on ME (P =0.003; Table 7), meaning that profitability increased with increasing age at culling in third lactation. This corresponds well with the results of Heikkila *et al.* (2008) who obtained an economic optimum of 3.7-3.8 lactations per cow.

The fifth factor had the highest positive loadings for post-pubertal ADG and total ADG (the two were also strongly correlated (0.84)), and a negative loading for concentrate costs in lactation 2 (Table 8). We interpreted this factor as a reduced need for own growth in second lactation, resulting mainly from a high post-pubertal ADG. Loadings for factor 5 regressed negatively on ME (P = 0.019; Table 7), meaning that an increased need for growth in second lactation would decrease ME. This is in accordance with the findings of Storli *et al.* (2017) that post-pubertal heifers should grow faster, which is also biologically sound (Capuco and Ellis, 2013).

None of the following three factors had any significant effect on ME. In particular concentrate and veterinary costs, but also milk feed costs from birth to calving had high loadings in factor 3 (Table 8), which we interpreted as a herd management cost factor in early life. The farmers participating in this study reported to feed their calves on average from 2.8 to 8.0 l of milk per day during calfhood and concentrate feeding for heifers and pregnant heifers varied much, from 0-12.5 and 0.3-6.4 MJ/day, on average during the respective periods (Table 1). Factor 4 had the highest loadings for average daily BW gain (**ADG**) in the pre-pubertal period (Table 8), and would thus be a factor determined by early growth. Pre-pubertal ADG has been reported to impact first lactation milk yield in a number of studies (see e.g. Zanton and Heinrichs, (2005)). The corresponding negative loading for growth during gestation is logic, since a high growth rate early in life that leads to a higher BW at e.g. time of mating reduces the need for the heifers' own growth to achieve the preferred calving BW. In addition, and in agreement with the latter argument, the correlation between these variables was negative (-0.62). The variables with the highest loading in factor 6 were number of cows, estimated live weight at calving and carcass weight (Table 8). Further, the carcass weight correlated strongly (0.66) with the number of cows meaning that larger herds on average have larger cows. Consequently, factor 6 can be interpreted as cow size. A high body weight at first calving is desirable with respect to first lactation milk yield (Hoffman, 1997).

The present study demonstrates the capacity of a factor analysis to give insight into the underlying pattern made up of 53 explanatory variables by reducing them down to 8 interpretable factors. Five of these factors, i.e. roughage costs, delayed culling in third lactation, post-pubertal growth rate, early return and sundry costs were shown to explain a large part of the variance in ME values, or profitability, among herds. Analyzing the same data on basis of the original variables picked only three variables, two of which loaded heavily on factor 1 and one loading on factor 7, supporting the findings from regressing on the factor scores, but also pointing to co-linearity problems when regressing on original variables. However, the same consistency could not be found between the two approaches on which culling strategy to advice. Factor analysis suggested that culling should be delayed to late in third lactation, whereas an analysis based on the original data could not disclose such an association. The higher resolution of the underlying quantities and the deeper insight obtained from regressing on the factor scores were further illustrated by the additional findings that sundry costs as well as post-pubertal growth rate affected profitability.

We conclude that herd regression on factor scores gives a deeper insight into which factors affect profitability than regression on the original variables. A further conclusion is that herd profitability as defined by the monthly annuity equivalent value is positively affected by low roughage costs, early return on investment, enlarged sundry costs, delayed culling in third lactation, and the reduced need for own growth in second lactation, in decreasing order of importance. Herd management costs in early life, pre-pubertal ADG, and cow size had no significant effect on profitability.

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Declaration of interest

None.

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Table 1 *Production variables taken from the Norwegian Dairy Herd Recording System for cows or from the questionnaire of Storli et al. (2017), except for roughage intake for heifers, pregnant heifers and cows, which were calculated values from the TINE OptiFôr client in NorFôr (Volden, (2011)*

	Herd												
	1	2	3	4	5[1]	6	7	8	9	10	11	12	13
Production variables													
Age at culling, months	55	62	54	61	55	60	54	57	51	55	52	58	64
Age at first calving, months	26	26	24	25	24	26	27	26	25	27	25	26	27
1st parity slaughter weight, kg	252	284	254	252	271	252	256	276	246	247	262	242	247
Adult slaughter weight, kg	277	302	261	296	286	273	268	280	255	253	269	255	258
Liters of milk per calf/day	3.4	6.0	3.8	2.8	5.4	4.4	4.2	3.3	4.5	8.0	4.0	3.8	3.6
Concentrate per calf, MJ[2]/day	5.6	12.2	8.9	6.1	6.1	7.0	7.0	7.4	12.2	8.6	7.7	8.6	9.9
Roughage per calf, MJ/day	12.6	10.1	10.2	12.1	14.1	11.2	11.1	10.9	8.0	10.0	11.0	10.0	9.6
Concentrate per heifer, MJ/day	7.6	11.8	10.6	0.0	3.7	4.4	3.0	10.8	12.5	11.2	12.2	10.7	6.5
Roughage per heifer, MJ/day	30.5	31.1	27.6	38.0	37.1	33.2	36.1	30.9	24.7	26.4	27.3	26.1	31.9
Concentrate, pregnant heifer, MJ/day	1.5	4.2	1.6	0.5	0.3	4.4	0.7	3.1	2.3	6.4	3.5	0.5	3.2
Roughage, pregnant heifer, MJ/day	54.9	57.9	56.3	56.4	60.8	52.2	56.1	57.6	53.7	46.5	53.0	54.3	52.0
Concentrate per cow, MJ/day	46.1	50.1	56.2	47.5	36.4	41.5	38.5	49.9	55.1	56.9	57.9	56.2	45.9
Roughage per cow, MJ/day	69.7	76.8	73.6	79.4	76.0	80.1	70.3	74.9	65.3	70.6	71.1	69.7	67.9

[1] Organic herd.
[2] MJ = megajoule.

Table 2 *Costs and unit prices in Norwegian Kroner (NOK) as given in the Norwegian Dairy Herd Financial Recording System, except for concentrate prices that were obtained by combining information on type of concentrate from Storli et al. (2017) and prices from the TINE OptiFôr client in NorFôr (Volden, 2011)*

	Herd												
	1	2	3	4	5[1]	6	7	8	9	10	11	12	13
Costs													
Recruitment calf, in 1 000 NOK	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Veterinary costs, calves and heifers, per month	49.3	78.3	78.8	40.0	45.9	63.1	56.5	60.0	77.0	79.8	41.3	75.6	68.3
Veterinary costs, cows, per month	103.2	155.9	124.3	75.3	95.0	120.5	105.3	94.5	135.5	73.7	107.4	87.3	109.9
Sundry costs, calves and heifers, per month	13.1	15.0	8.0	22.8	12.6	10.8	6.0	16.9	10.9	10.9	31.9	22.1	12.9
Sundry costs, cows, per month	124.3	122.8	93.1	80.2	44.1	50.9	32.8	88.3	50.7	68.4	71.8	44.5	52.5
Roughage costs, per MJ[2]	0.228	0.197	0.279	0.446	0.391	0.247	0.480	0.487	0.264	0.404	0.618	0.493	0.446
Concentrate costs, calves, per MJ	0.592	0.592	0.592	0.592	0.592	0.592	0.592	0.592	0.592	0.592	0.592	0.592	0.592
Concentrate costs, heifers, per MJ	0.575	0.575	0.575	0.575	0.575	0.575	0.575	0.575	0.575	0.575	0.575	0.575	0.575
Concentrate costs, cows, per MJ	0.587	0.608	0.608	0.608	0.861	0.608	0.608	0.608	0.608	0.608	0.608	0.608	0.587
Unit prices													
Per newborn calf, in 1 000 NOK	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Milk price, per liter[3]	4.83	4.56	5.05	4.97	5.34	4.88	4.85	4.96	4.80	4.77	4.83	4.87	4.57
Slaughter value, per kg	44.15	40.20	44.34	35.19	43.68	39.90	42.57	43.22	43.20	42.86	43.19	40.90	41.77

[1] Organic herd.

[2] MJ = megajoule.

[3] Also equal to cost per liter of milk fed to calves.

Table 3 *Calculated 305 d milk production both as kg milk and as kg energy corrected milk (ECM) (mean ± SD) in first, second and third lactation per herd. Number of cows and number of test-day observations in first and second lactation are included*

	Herd												
	1	2	3	4	5[1]	6	7	8	9	10	11	12	13
Lactation 1													
Cows (n)	30	51	26	19	81	25	21	40	39	38	42	33	19
Obs (n)	314	495	234	185	774	218	164	339	334	316	385	297	182
Kg milk	6 441	7 930	8 021	7 900	5 932	7 020	6 066	7 471	7 202	7 248	7 249	7 192	6 305
SD	1 152	1 197	1 262	1 424	884	1 127	940	1 125	1 036	1 082	1 252	823	1 198
Obs (n)	305	428	220	181	686	187	163	99	290	196	208	215	174
Kg ECM	6 708	8 291	8 311	8 248	6 458	7 365	6 502	7 603	7 525	7 640	7 869	7 453	6 403
SD	1 175	987	1 108	1 267	888	1 057	970	816	1 027	907	913	727	1 093
Lactation 2													
Cows (n)	7	27	12	11	30	14	8	25	17	16	21	19	7
Obs (n)	81	267	102	101	267	111	62	195	139	126	183	164	73
Kg milk	8 047	9 453	9 909	9 643	6 901	8 254	7 107	8 327	8 835	9 147	8 820	9 009	8 061
SD	1 055	1 861	1 202	1 442	1 393	789	701	1 315	1 009	1 293	1 343	1 195	1 603
Obs (n)	81	228	95	98	234	96	59	43	117	80	90	132	69
Kg ECM	8 227	10 177	10 053	10 354	7 759	8 992	7 428	8 932	9 054	9 570	8 447	9 304	8 205
SD	881	1 771	1 246	1 256	1 438	402	447	1 403	1 156	1 098	947	1 216	1 681
Lactation 3													
Kg milk	8 549	9 715	10 092	9 872	7 598	8 720	7 769	8 780	9 202	9 461	9 190	9 346	8 560
SD	875	1 543	997	1 196	1 155	654	581	1 091	837	1 073	1 114	991	1 329
Kg ECM	8 341	10 209	10 091	10 379	7 893	9 075	7 576	9 017	9 134	9 628	9 510	9 373	8 320
SD	844	1 697	1 194	1 203	1 378	385	428	1 344	1 108	1 052	907	1 165	1 610

[1] Organic herd.

Table 4 *Variables included in the expressions for revenues (I and S) and the expenses (E) in the net present value (NPV) equation (1)*

NPV expression	Variables included
I	Newborn calves sold from the dairy herd
	Income from sale of milk
E	Replacement calf bought from the dairy herd
	Feed costs
	Veterinary costs
	Sundry costs
S	Slaughter value of the cow when culled

Table 5 *Description of the 53 variables used to explain the monthly annuity equivalent value (ME). Explanation of variables 2-34 can be found in Material and methods. Variable 2-53 are herd averages*

No.	Variable	Description
1	Cows	Number of herd cow-years, equal to sum of cow-days divided by 365, from NDHRS
2	AFC	Age at first calving in months
3	EstLWC	Estimated live weight at calving
4	AAC	Age at culling in months
5	Slwt	Carcass weight at slaughter
6	C_mfeed	Milk feed costs per calf, 0-3 months
7	C_conc	Concentrate costs per calf, 0-3 months
8	C_RG	Roughage costs per calf 0-3, months
9	C_VM	Veterinary costs per calf, 0-3 months
10	C_sun	Sundry costs per calf, 0-3 months
11	H_conc	Concentrate costs per heifer, 3 months until pregnancy
12	H_RG	Roughage costs per heifer, 3 months until pregnancy
13	H_VM	Veterinary costs per heifer, 3 months until pregnancy
14	H_sun	Sundry costs per heifer, 3 months until pregnancy
15	PH_conc	Concentrate costs per pregnant heifer
16	PH_RG	Roughage costs per pregnant heifer
17	PH_VM	Veterinary costs per pregnant heifer
18	PH_sun	Sundry costs per pregnant heifer
19	L1_conc	Concentrate costs per cow, lactation 1
20	L1_RG	Roughage costs per cow, lactation 1
21	L1_VM	Veterinary costs per cow, lactation 1
22	L1_sun	Sundry costs per cow, lactation 1
23	L1_income	Milk income per cow, lactation 1
24	L2_conc	Concentrate costs per cow, lactation 2
25	L2_RG	Roughage costs per cow, lactation 2
26	L2_VM	Veterinary costs per cow, lactation 2
27	L2_sun	Sundry costs per cow, lactation 2
28	L2_income	Milk income per cow, lactation 2
29	L3_conc	Concentrate costs per cow, lactation 3
30	L3_RG	Roughage costs per cow, lactation 3
31	L3_VM	Veterinary costs per cow, lactation 3
32	L3_sun	Sundry costs per cow, lactation 3
33	L3_income	Milk income per cow, lactation 3
34	Sl_income	Carcass value per cow
35	ADG1	ADG[1], g/d, 5-10 months (Storli *et al.*, 2017)
36	ADG2	ADG, g/d, 10-15 months (Storli *et al.*, 2017)
37	ADG3	ADG, g/d, 15-21 months (Storli *et al.*, 2017)
38	CR	Culling rate, from NDHRS
39	SqADG1	(Variable 35)^2
40	SqADG2	(Variable 36)^2
41	SqADG3	(Variable 37)^2
42	ADG_tot	Weighted ADG, g/d, 5-21 months, (5/16 variable 35) + (5/16 variable 36) + (6/16 variable 37)
43	RC_mo_BC	Rearing costs per month, birth to calving, Σ variables 6-18/AFC
44	RC_mo_LT	Rearing costs per month of lifetime, Σ variables 6-18/AAC
45	RC_mo_PLT	Rearing costs per month productive life, Σ variables 6-18/(AAC-AFC)
46	Sl_I_mo_PLT	Carcass income per month productive life, variable 34/(AAC-AFC)
47	Sl_I_mo_LT	Carcass income per month of lifetime, variable 34/AAC
48	L1_C_mo	Lactation 1 costs per month, Σ variables 19-22/12
49	L1_I_mo	Lactation 1 milk income per month, variable 23/12
50	L2_C_mo	Lactation 2 costs per month, Σ variables. 24-27/12
51	L2_I_mo	Lactation 2 milk income per month, variable 28/12
52	L3_C_mo	Lactation 3 costs per month, Σ variables. 29-32/(AAC - AFC - 24)
53	L3_I_mo	Lactation 3 income per month, variable 33/(AAC - AFC - 24)

[1] ADG = Average daily BW gain.

Table 6 *Cost and income given as present value, as well as net present value (NPV) and monthly annuity equivalent (ME); all in Norwegian Kroner (NOK) per herd*

	Herd												
	1	2	3	4	5[1]	6	7	8	9	10	11	12	13
Raising costs													
New calf	2 500	2 500	2 500	2 500	2 500	2 500	2 500	2 500	2 500	2 500	2 500	2 500	2 500
Milk feed	1 486	2 499	1 770	1 286	2 649	1 975	1 846	1 511	1 970	3 484	1 765	1 706	1 505
Concentrate	2 348	4 120	2 887	405	1 136	2 102	478	3 446	3 789	4 282	3 637	3 089	2 684
Roughage	6 371	5 669	7 078	13 533	11 846	6 981	13 153	13 964	6 384	9 924	15 604	12 704	12 686
Veterinary	1 237	1 964	1 829	967	1 066	1 583	1 137	1 505	1 860	2 076	997	1 898	1 778
Sundry	329	376	187	551	293	270	120	424	263	284	770	556	335
Lactation costs													
Concentrate	21 352	29 658	27 937	28 165	26 381	23 244	20 589	25 461	23 901	26 285	24 109	29 616	26 190
Roughage	12 484	14 630	16 807	34 348	25 163	18 135	27 211	30 653	12 299	21 673	32 444	29 773	29 231
Veterinary	2 670	4 957	3 340	2 400	2 636	3 629	2 808	2 606	3 164	1 838	2 602	2 482	3 575
Sundry	3 215	3 903	2 503	2 558	1 223	1 533	874	2 435	1 184	1 705	1 740	1 266	1 708
Income													
Calves born	6 729	6 729	6 767	6 748	6 767	6 729	6 709	6 729	6 748	6 709	6 748	6 729	6 709
Milk	84 604	111 939	115 342	123 750	91 312	105 759	83 609	102 779	81 231	91 610	85 740	106 171	95 705
Slaughter	10 476	10 193	9 941	7 970	10 701	9 198	9 801	10 307	9 545	9 288	10 038	8 857	8 996
Profitability													
NPV	47 817	58 585	65 213	51 756	33 889	59 157	20 051	35 309	40 209	33 558	16 359	36 207	29 217
ME	941	1 033	1 305	926	667	1 075	401	672	849	660	339	679	500

[1] Organic herd.

Table 7 *Variables and factors with significant effect on monthly annuity equivalent (ME), and adjusted R^2 obtained from stepwise regression with forward selection and a significance level for entry set to P = 0.02. Regression coefficient estimates (SE) and F-values are included*

Step	Source	Estimate	SE	*F*	*P*	R^2
1	RC_mo_PLT[1]	-0.23	0.15	28.4	< 0.001	0.633
2	L1_Income[2]	0.05	0.00	21.7	< 0.001	0.907
3	RC_mo_BC[3]	-0.78	0.15	33.4	< 0.001	0.975
1	Factor 1	-222.36	11.14	14.2	0.003	0.524
2	Factor 7	163.67	11.16	9.1	0.013	0.723
3	Factor 8	91.26	10.44	17.5	0.002	0.896
4	Factor 2	62.91	11.00	17.0	0.003	0.963
5	Factor 5	-34.07	11.22	9.2	0.019	0.982

[1] RC_mo_PLT = rearing costs per month productive lifetime.

[2] L1_Income = milk income per cow, lactation 1.

[3] RC_mo_BC = rearing costs per month, birth to calving.

Table 8 *Factor loadings of the 53 variables on seven varimax-rotated principal component with eigenvalues > 2. Factor loadings > |0.4| are underlined*

No.	Variable[1]	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6	Factor 7	Factor 8
1	Cows	-0.05	0.01	0.18	0.20	0.04	0.82	-0.08	0.03
2	AFC	0.19	0.10	0.32	-0.41	0.09	-0.29	-0.57	0.13
3	EstLWC	0.13	0.07	-0.07	-0.07	0.12	0.86	0.10	0.27
4	AAC	-0.08	0.92	0.07	-0.12	0.19	0.00	-0.22	0.12
5	Slwt	-0.13	0.17	-0.25	-0.01	0.23	0.75	-0.03	0.37
6	C_mfeed	-0.10	-0.23	0.48	-0.29	-0.04	0.36	-0.06	-0.15
7	C_conc	-0.21	0.10	0.71	0.19	-0.29	0.03	-0.01	-0.04
8	C_RG	0.86	0.01	-0.38	0.06	-0.04	0.09	-0.05	-0.16
9	C_VM	-0.38	0.03	0.81	-0.17	-0.28	-0.08	0.09	-0-14
10	C_sun	0.64	0.20	-0.02	0.63	0.12	-0.01	0.16	0.27
11	H_conc	0.01	-0.23	0.80	0.32	-0.05	0.14	0.10	0.25
12	H_RG	0.86	0.28	-0.26	-0.06	-0.01	-0.06	-0.17	-0.14
13	H_VM	-0.32	0.18	0.90	-0.08	-0.09	-0.07	-0.01	-0.01
14	H_sun	0.60	0.26	0.07	0.62	0.15	-0.03	0.11	0.30
15	PH_conc	0.04	-0.05	0.70	-0.20	0.41	0.03	-0.06	0.18
16	PH_RG	0.91	0.03	-0.26	0.11	-0.14	0.02	-0.03	-0.20
17	PH_VM	-0.38	0.03	0.81	-0.17	-0.28	-0.07	0.09	-0.15
18	PH_sun	0.63	0.20	-0.03	0.64	0.12	-0.01	0.15	0.27
19	L1_conc	0.12	0.02	0.64	0.50	-0.29	-0.22	0.19	0.28
20	L1_RG	0.93	0.00	-0.22	-0.02	-0.06	0.02	0.03	-0.20
21	L1_VM	-0.49	-0.08	0.24	0.28	0.06	0.22	0.04	0.06
22	L1_sun	-0.29	0.05	0.06	0.07	0.03	0.22	0.21	0.90
23	L1_income	0.02	0.24	0.16	0.05	-0.07	0.00	0.93	0.21
24	L2_conc	0.08	-0.02	0.26	0.02	-0.79	-0.07	0.15	-0.28
25	L2_RG	0.94	-0.05	-0.26	-0.02	-0.10	-0.07	0.00	-0.15
26	L2_VM	-0.41	-0.16	0.12	0.14	-0.03	0.17	-0.04	0.01
27	L2_sun	-0.28	0.03	0.03	0.04	0.01	0.21	0.19	0.91
28	L2_income	0.12	-0.07	-0.10	-0.25	-0.48	-0.34	0.66	0.10
29	L3_conc	-0.09	0.78	-0.05	0.08	0.07	0.47	0.28	-0.05
30	L3_RG	0.24	0.93	-0.17	0.05	0.04	-0.09	-0.03	-0.06
31	L3_VM	-0.31	0.77	0.15	0.05	0.19	0.25	-0.08	0.15
32	L3_sun	-0.24	0.68	0.05	-0.01	0.04	0.26	0.11	0.56
33	L3_income	-0.16	0.90	-0.05	-0.05	0.16	0.13	0.26	0.08
34	SI_income	-0.16	-0.58	-0.07	0.06	0.06	0.70	-0.11	0.16
35	ADG1	-0.09	-0.14	-0.10	0.94	0.07	0.12	-0.05	-0.09
36	ADG2	-0.31	0.23	-0.09	0.08	0.87	0.06	-0.21	0.01
37	ADG3	-0.02	0.56	-0.07	-0.61	0.46	0.06	0.17	-0.15
38	CR	0.30	-0.58	-0.19	-0.26	-0.03	0.07	-0.09	-0.37
39	SqADG1	-0.04	-0.17	-0.07	0.95	0.08	0.12	-0.04	-0.08
40	SqADG2	-0.32	0.22	-0.09	0.06	0.87	0.03	-0.19	-0.02
41	SqADG3	0.00	0.55	-0.08	-0.58	0.50	0.04	0.18	-0.15
42	ADG_tot	-0.19	0.51	-0.15	0.00	0.75	0.15	0.03	-0.17
43	RC_mo_BC	0.99	0.04	0.03	0.05	-0.07	0.01	0.03	-0.04
44	RC_mo_LT	0.97	-0.19	0.08	0.01	-0.11	-0.02	-0.02	-0.06
45	RC_mo_PLT	0.92	-0.34	0.11	-0.04	-0.13	-0.05	-0.06	-0.03
46	SI_I_mo_PLT	0.00	-0.95	-0.04	0.05	-0.10	0.28	-0.04	0.02
47	SI_I_mo_LT	-0.06	-0.85	-0.11	0.13	-0.05	0.47	0.05	0.03
48	L1_C_mo	0.98	-0.04	0.04	0.04	-0.14	-0.11	0.09	0.05
49	L1_I_mo	0.02	0.24	0.16	0.05	-0.07	0.00	0.93	0.21
50	L2_C_mo	0.92	-0.09	-0.16	-0.11	-0.24	-0.13	0.03	-0.06
51	L2_I_mo	0.12	-0.07	-0.10	-0.25	-0.48	-0.34	0.66	0.10
52	L3_C_mo	0.13	0.97	-0.09	-0.02	0.06	0.09	0.08	0.03
53	L3_I_mo	-0.12	0.40	0.10	-0.09	-0.17	0.09	0.52	-0.01
Variance explained, %		11.56	9.32	5.48	4.87	4.57	3.97	3.89	3.32

[1] Variables descried in Table 5.

Assessing the profitability of different growth profiles in replacement heifers from three months of age to pregnancy assuming the same productive lifetime per group

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Manuscript

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Short title: Dairy cow lifetime profitability

ABSTRACT

The objective of this study was to assess the lifetime profitability for four treatment groups of heifers, each with intentionally 20 animals, fed either a high-energy, low-protein (**HELP**), a high-energy, high-protein (**HEHP**), a low-energy, low-protein (**LELP**) or a low-energy, high-protein (**LEHP**) ration designed to give different growth profiles from three months of age until confirmed pregnancy. Planned body weights at breeding and calving were to be the same for all animals irrespective of treatment. Breeding was initiated at first estrous after achieving a BW of 360 kg, and all groups were fed the same ration after confirmed pregnancy. Age at first calving was 22 and 26 months for the high-energy (**HE**) and low-energy (**LE**) groups, respectively. Utilizing experimental as well as external data, assuming the same productive life of 2.7 lactations per group, lifetime cash flow for an average animal per group was used to calculate a corresponding net present value at time of birth that was converted to a monthly annuity equivalent value, or lifetime profitability per treatment group. Profitability was assessed the highest for HELP, that can be ascribed to the four months shorter rearing period with reduced veterinary, sundry, labor and housing costs. Through a sensitivity analysis, it was shown that profitability was affected mostly by milk price, followed in decreasing order by roughage price, housing costs, concentrate price, labor costs, roughage subsidies, interest rate, and animal subsidies. Except for the interest rate, sensitivity was proportional to size of income or cost factors.

Keywords: cattle, cash flow, net present value, lifetime production, profit analysis

Implications

Previous findings show that it is possible to rear Norwegian Red heifers for a rapid growth from three months of age until confirmed pregnancy, followed by a moderate average daily gain during pregnancy without negative effects on subsequent performance. Here it is shown that such a strategy also is economically beneficial since it reduces age at first calving by four months, thus reducing rearing costs, primarily those related to housing and labor.

Introduction

Heifer rearing constitutes as much as 15-20% of total costs in dairy production (Heinrichs, 1993). Replacement heifer management implies that the farmer must invest capital in e.g. feed, labor and housing for the complete rearing period without receiving any realized financial gains before heifers start milking. Economically, an early return on investment is advantageous (see, e.g., Enqvist *et al.,* 2014; Sommerseth *et al.*, 2018), and previous studies have shown that reduced heifer-rearing time is an efficient means to lower rearing costs (Mourits *et al.*, 1997; Tozer, 2000; Tozer and Heinrichs, 2001). Biologically the goal should then be to rear heifers in a way that ensures they become productive early, but without adverse effects on later production. Numerous studies have examined the effects of different calf- and heifer growth strategies and age at first calving (**AFC**) on subsequent milk production, but the results have been contradictory, see e.g., Roche *et al.* (2014). This notwithstanding, the demonstration of a curvilinear response in milk yield to increased pre-pubertal average daily BW gain (**ADG**) (Sejrsen *et al.*, 2000; Zanton and Heinrichs, 2005), and the recent findings of a corresponding response to increased post-pubertal ADG (Storli et al., 2017), suggest there exists an optimum growth rate during the heifer-rearing period and that this optimum would increase from selection over time. Moreover, a recent field study (Storli *et al.*, 2017) concluded that Norwegian dairy farmers have not updated rearing, and in particular feeding practices, to meet the requirements of today's genetically improved Norwegian Red (**NR**) heifer. Consequently, heifers grow too slowly and enter the milking herd unnecessarily late (Storli *et al.*, 2017). Based on these findings we aimed to optimize NR replacement heifer growth rate in a controlled study where we contrasted groups of heifers with different pre-planned growth profiles until confirmed pregnancy followed by an evaluation of the effects of these profiles on milk yield over three lactations (Storli *et al.*, 2018). Results show that it is possible to rear NR heifers for a rapid weight gain from 3 months of age to successful insemination combined with a moderate ADG during pregnancy without negative effect on subsequent performance over three lactations. The objective of the present study was to assess the financial implications of these rearing strategies in order to obtain a sound basis for drawing conclusions and giving recommendations to the dairy farmers. To this end, we calculated the net present value (**NPV**) at time of birth for an average animal per group from lifetime cash flow and converted these to a monthly equivalent value (**ME**), or lifetime profitability, per group of animals.

Materials and methods

The basis for the present analysis was the experiment reported by (Storli *et al.*, 2018). In this experiment, four groups of animals, each with intentionally 20 animals, were kept under experimental conditions until the end of first lactation whereafter they were moved to the university herd without any restrictions or claims other than the monitoring of milk yield and quality. Thus, we had to assume the same productive lifetime for all groups, equal to 2.7 lactations, in accordance with the national average as obtained from the Norwegian Dairy Herd Recording System (**NDHRS**, 2017). With the lack of realistic culling information on the individual animal level, and consequently the need to base these on the same group means, the remaining assessment also had to be done on a group basis. This assessment was based on monthly average cash flow per treatment group, discounted and summarized to a net present value corresponding with the start of investment, i.e., time of birth. Due to the unequal length of heifer-rearing time per treatment, the NPV values had to be transformed to a ME value to become comparable.

In the experiment, eighty heifers from the dairy herd of the Norwegian University of Life Sciences (year classes 2010 and 2011) were assigned either to high (**HE**) or low (**LE**) energy groups, and fed for an ADG of 800–1 000 or 600–750 g/day from three months of age till confirmed pregnancy, respectively. Each energy group was further subdivided into two protein groups, i.e., low (**LP**) or high protein (**HP**) to give four dietary treatments with 20 animals in each group: high-energy low-protein (**HELP**), high-energy high-protein (**HEHP**), low-energy low-protein (**LELP**), and low-energy high-protein (**LEHP**). HE groups were fed grass silage *ad libitum*, whereas LE groups were fed restricted rations of the same silage mixed with 10 to 40% wheat straw on a DM basis. All heifers were fed a fixed amount of 1 kg custom-made concentrate per day. The energy density and protein content of the diets were adjusted with the roughage quality. This resulted in a large difference between energy levels, but smaller differences within protein levels. For detailed information on feeding levels, growth rates and production data until the end of first lactation, see (Storli *et al.*, 2018).

Calculation of housing and labor costs

Housing costs were calculated based on an annuity of an estimated construction cost of € 1 005 250 for a new, fully mechanized 950 m^2 cowshed for 40 cows including space for rearing all calves to adult size, assuming 30 years of expected life and a real interest rate of 3.5% p.a. The latter corresponds with the current short-term credit rate for agriculture in Norway. This gave an annual housing cost of € 54 657, which was distributed to each of 5 different animal cohorts, i.e., calves, heifers, pregnant heifers, lactating cows, and bulls, based on how much of the area of the shed they occupied. The required area per animal relative to that required by a cow, corresponding to 12.54 m^2, was the following: heifer > 18 months, 0.7; heifer 12-18 months, 0.5; bulls > 12 months, 0.65; youngstock 6-12 months, 0.4; and a calf < 6 months, 0.3. The costs were distributed accordingly. Bulls were assigned their part of the housing costs, but otherwise were meat production on bulls not considered in the economic calculations. Labor costs per animal per day from the tariff salary for agricultural workers in Norway (€ 20.1/h) was based on the expected time used per working operation in the different cohorts divided by the number of animals in the actual cohort. The estimates used were in accordance with those listed in Garnsworthy (2005).

Cash flow calculations

We used a MS Excel spreadsheet to calculate cash flow per treatment and month for the following four periods:

Calf period. The calf period equaled the first three months of life. A recruitment calf was assigned a cost value of € 279.2 in month one for all treatments, identical to the standard value used in the Norwegian Dairy Herd Financial Recordings (**NDFR**) (Table 1). Other costs were those for feed, i.e., milk, concentrate and roughage, and veterinary, sundry, labor, and housing (Table 1). Information on the amount of milk, concentrate and roughage fed to the calves were obtained from (Storli *et al.*, 2018) (Table 2). When calculating milk feed costs, the average milk price per kg ECM for the years 2012-2013 in Norway was used (Table 1). The costs of roughage per megajoule (**MJ**), veterinary and sundry costs were obtained as averages from the NDFR (Table 1), since the University farm is not a member of the NDFR. Concentrate costs were set equal to € 0.066 per MJ, which equals a typical calf concentrate obtained from the TINE OptiFôr client in the NorFôr feed evaluation system (Volden, 2011) (Table 1). Housing and labor costs were calculated to €25.6 and €18.0 per month, respectively. Income during this period was limited to subsidies for youngstock and grassland production, which normally are paid twice a year, but payments were accrued to a monthly income to avoid large effects of the animal's cohort at the given date of payment (Table 1).

Heifer and pregnant heifer periods. The heifer period was 10 months for the HE treatments and 14 months for the LE treatments. Roughage cost per unit as well as veterinary and sundry costs in Table 1 were obtained from the NDFR. Concentrate, which was custom made for the HP and LP groups in this experiment, was assigned a cost similar to a high- and a low-protein commercial concentrate obtained from the TINE OptiFôr client, equal to € 0.064 and €0.056 per MJ for the HP and LP treatments, respectively (Table 1). During pregnancy, heifers were not fed concentrate, except for the last period before calving. Information on feed intake for each of the four groups was obtained from (Storli *et al.*, 2018) (Table 2). Housing costs varied from €18.0 to €42.1 per animal and month depending on age of the animal in a given cohort (Table 1). Correspondingly, labor costs depended on age, being €12.8 per month and animal for heifers and €10.3 per month and animal for pregnant heifers (Table 1). Income from subsidies were treated as in the calf period (Table 1).

Lactation period. We defined the lactation period as the period between first calving, which occurred at different ages for the four groups, and culling after 2.7 lactations, i.e., after a productive period of 31 months (Table 2), the same for all treatments. We assumed a 12-month calving interval, made up of a 305-day lactation period and a 60-day dry period (Table 2). For each treatment group, first lactation feed intake was obtained from (Storli *et al.*, 2018). Roughage unit cost and veterinary and sundry costs were obtained from the NDFR (Table 1). Concentrate cost was obtained from the TINE OpifFôr client and set equal to €0.063 per MJ (Table 1). In lactations 2 and 3, monthly roughage intake for each treatment group was calculated as the difference between the energy required for maintenance and for production according to each treatment group's average monthly ECM production (data not shown), minus the energy provided by the corresponding concentrate information as reported to the NDHRS (data not shown). Roughage and concentrate averages per day and lactation are shown in Table 2. Roughage intake during the dry periods was calculated correspondingly. Energy requirement calculations were carried out using the TINE OpifFôr client. We calculated labor costs to be €53.6 per month in the milking period and €5.11 per month in the dry period (Table 1). Housing costs were €60.1 per month (Table 1). Income during lactations included the value of calves (3 calves at € 279.2 each, which is the standard value of a newborn calf in the NDFR; Table 1) and milk revenues, in addition to subsidies for animals and grassland production (Table 1). In lactation 1, daily milk yield was recorded and converted to ECM using test-day fat, protein and lactose records. Income was calculated from average ECM yield per month and treatment group multiplied with the obtained milk price per kg ECM

(Table 1). For lactations 2 and 3, we utilized test-day milk yield from the NDHRS database to calculate average monthly milk production in kg ECM per treatment. Milk price was the same as in lactation 1. In all three lactations, daily ECM yield was estimated with a test-day model with fixed regression coefficients of 1st to 3rd order Legendre polynomials nested within treatment, and random regression coefficients of 0, …, 3rd order, in addition to fixed cross-classified effect of year-season of test-day (lactation 1: 6 periods; lactation 2: 6 periods; lactation 3: 4 periods) and a fixed regression on the milk index of the animals. Analyses was carried out using the SAS® MIXED procedure (SAS/STAT software; SAS inc., Cary, NC). Heterogeneous and independent variances were assumed for five periods of lactation (days in milk; 1-14, 15-56, 57-98, 99-140, and > 140). Average monthly ECM yield in each of the three lactations was calculated from the cumulated sum of daily ECM within a lactation over 10 months, assuming a monthly length of 30.5 days. The cumulated 305-day ECM yield is given in Table 2. Total lifetime ECM yield was the largest for LELP, 22 330 kg, and the least for LEHP, 21 648 kg (Table 2). After 31 months the cows were assumed slaughtered and the slaughter value was calculated to €1 275, which equals the product of the average slaughter weight for dairy cows in the NDHRS (Table 2) times the average slaughter value per kg for dairy cows in the NDFR (Table 1).

Net present value calculations

The monthly cash flows for each of the four treatments were first discounted to a present value and then summarized as NPV using the following expression:

$$NPV = \sum_{t=0}^{T} \left[\frac{(I_t - E_t)}{(1+r)^t} \right] + \frac{S}{(1+r)^T}$$

where I is monthly revenue, E is monthly expense, t is monthly index, r is the discount rate set to 3.5% p.a., corresponding to the short term credit-rate for agriculture in Norway, S is the slaughter value of the cow when culled, and T is the assumed lifetime in months.

Monthly annuity equivalent calculation

Since AFC varied between treatments, groups were compared expressed as an expected monthly return, by converting the NPV of the lifetime cash flow into a monthly annuity equivalent (ME) value for the animal's expected lifespan, as described by (Konstantin and Konstantin, 2018). The ME is the constant cash flow that the farmer would require not to prefer the uneven flow of cash from the heifer investment during the same period. The ME was calculated as:

$$ME = NPV * \left(\frac{r*(r+1)^T}{(1+r)^T-1}\right)$$

where NPV, r and T are defined as above.

Sensitivity analysis

In order to assess the importance of key variable assumptions, we performed a sensitivity analysis by altering by ± 20% the values of the interest rate, the price of milk per liter, the price per MJ of concentrate as well as that of roughage, the costs of housing and labor, and animal and roughage subsidies. Only one variable was altered at a time, and we did not consider any interaction between the variables.

Results

Present value, net present value and profitability

Table 3 gives the calculated costs of rearing and of milk production for the four heifer treatment groups as well as income from calves, milk, slaughter and subsidies, discounted to a present value at time of birth. The derived lifetime NPV and ME values are also listed. The average HELP animal had the highest ME value of €32.7 per month of lifetime while the average LEHP animal was calculated with the lowest value of only €24.0. If subsidies were to be excluded from the calculations, all treatments came out with negative ME estimates, values ranging from €-13.6 to €-18.5, with the highest and the lowest value for the same groups as above. (Table 3).

Sensitivity analysis

Figure 1 depicts the results of the sensitivity analysis for each of the four treatment groups. The figure shows that the relative change of ME was largest for milk price since a change of ± 20% changed the ME value by ± 113-142%, most for the LEHP and least for the HELP group. Correspondingly, roughage price was the second most important variable, changing ME values by ± 56-70%, followed by housing costs and concentrate price, which were almost similar, at ± 28-38%. Then in decreasing order of magnitude came labor costs (± 20-26%), roughage subsidies (± 19-22%), interest rate (± 16-22%), and animal subsidies (± 10-13%). In general, the HE groups were less sensitive than the LE groups, and within energy level, the LP groups were less sensitive than the HP groups.

Discussion

The assessment of lifetime profitability, expressed as ME in this study, shows that feeding replacement dairy heifers a high-energy diet from 3 months of age until confirmed pregnancy to reduce their unproductive period is financially beneficial in a lifetime perspective of a dairy cow. This assumes that the effect of increased energy level in the diet on heifers' growth rate ensures not only early onset of puberty but also a sufficient level of maturity before breeding at an earlier age (Storli *et al*., 2018). Furthermore, the results of Storli *et al* (2018) show that offering protein above the normative level in the diet is a waste of both nutritive and financial resources; this is corroborated by the present profitability results. The average AFC in Norway is close to 26 months (NDHRS, 2017) and thus equal to the average AFC of the present LE-fed heifers. However, the mean ME was some 22% higher for the HE groups that achieved an AFC of 22 months (Table 3), which means that accelerating replacement-heifer growth rate definitely has a financial potential for the average dairy farmer. This corresponds well with the results of Mourits *et al.* (1999b) who found the economic optimal AFC to be 22.6 months under Dutch conditions, and with the recent study of Krpálková *et al.* (2014) in which heifers with an ADG > 0.8 kg/day were found to be more profitable than heifers with ADG's < 0.7 kg/day.

Although veterinary, sundry, labor and housing costs were equal for all groups per month of rearing, the LE groups accumulated higher costs because their rearing period was four months longer than for the HE groups (Table 3). However, the LE groups experienced some €100 less in roughage costs (Table 3) due to a cheaper roughage (Table 1), while concentrate costs were higher for the LE animals (Table 3) because of the four extra months until confirmed pregnancy, with 1 kg of concentrate per day. For the HP animals, concentrate costs were also enlarged due to a higher price per MJ (Table 1). The total rearing costs from birth to first calving in the four treatment groups ranged from €2 668 to €2 874 and accounted for 22.6 – 24.2% of the total costs (Table 3), which is higher than the 15 – 20% previously reported by Heinrichs (1993). The difference between HE and LE groups of approximately €180 compared well with the rearing cost differences reported by Krpálková *et al.* (2014) until 21 months of age for heifers with ADG's either > 0.8 or < 0.7 kg/day. In percentage, total feed costs to total rearing costs (Table 3) were 50.3%, 50.7%, 44.9%, and 45.4%, for the HELP, HEHP, LELP, and the LEHP group, respectively. This is considerably less than the 73% that Heinrichs *et al.* (2013) reported under US conditions, likely due to the higher costs of housing and labor in Norway.

For dairy cows, feed was the major cost accounting for around 61% of lactation costs in all four treatment groups (Table 3). Roughage costs were rather similar between treatments, differing by only €88, whereas concentrate costs differed by €114 because cows in second and third lactation were allocated concentrate according to yield. Thus treatment groups ranked the same for concentrate costs and total feed costs as they did for lifetime ECM yield (Table 2). There were only found a €8 higher feed cost for LELP than for HELP. The largest contrast was that to HEHP, being €113.7. The sum of veterinary, sundry, labor and housing costs were €40.5 higher for the HE groups, which is an effect of discounting.

Income from milk made up around 69% of total income for all treatment groups (Table 3). Next to milk came grassland subsidies with 11%, slaughter with 8%, animal subsidies, 6%, and sale of three calves, 6%. Income from milk was largest for the LELP group, €20.2, €213.7 and €235.3 higher than that for HELP, LEHP and HEHP, respectively. Discounting actually evened out the income difference for milk between the HE and LE groups and also had some effect on other income and cost variables.

Rearing feed costs differed on average €62.2 between the HE and the LE animals in favor of the LE groups (Table 3), but the four extra months of rearing, which accounted for €241.4 in additional costs in present value, outweighed this by far. However, the LELP group had only €20.2 higher income from milk over the three lactations than HELP, followed by LEHP and HEHP. With the cost of feed for the treatment groups ranking as for milk income but only with a €8 increased cost for LELP relative to HELP, and other income subtracted cost being €37 in favor of the HELP, this in sum explains why the HELP group had the highest NPV and ME values in the study.

The sensitivity analysis showed that the ME was the most sensitive to a change in milk price in that a change in milk price of ± 20% altered the ME by more than 100%. This can be explained by milk making up as much as 69% of the total income. Further, HE treatments were found to be less sensitive than LE treatments, likely an effect of early retur on investment, that also Sommerseth *et al.* (2018) found to affect profitability. Similarly, Heikkila *et al.* (2008) found milk price to have a significant impact on profitability in Finnish dairy, although the effect was not as large as in this study. In Norway, however, farmers can only to a small degree affect the milk price by changing the content of milk solids (±0.782 and ±0.558 € cents per 0.1% above or below 4.0% and 3.2% of fat and protein, respectively). Whether this is profitable needs to be examined separately.

With energy intake from roughage being predominant and roughage costs making up 30-40% of costs on dairy farms, it is not surprising that ME is highly sensitive to a change in roughage price. A change of price by ± 20% altered ME by ± 55-70%. This corresponds well with the finding of Sommerseth *et al.* (2018), that roughage costs affected profitability the most, or Mourits *et al.* (1999a) who found that roughage price influenced net returns per heifer the most, next to market price. Thus, producing lots of high quality roughage should therefore take priority, as it lowers the fixed costs for roughage production. Relative to roughage price, concentrate price influenced ME less, likely because concentrate supplied less of the total energy intake than roughage, and that concentrate costs being less than that of roughage. In size, the fixed housing costs were comparable to that for concentrate and affected ME correspondingly. The same logic applied to the relative importance of labor, and roughage as well as animal subsidies. For the discount rate, the effect on ME was considerable through both cost and income variables.

The treatment groups analyzes had intentionally 20 heifer calves, but due to various externalities only 72 of them reached first calving; 18, 19, 18, and 17 cows were in the HELP, HEHP, LELP, and LEHP group, respectively. Corresponding numbers were 12, 15, 8, and 10 in second lactation, and 8, 11, 5, and 6 in third lactation. For 305-day ECM yields in first lactation (Table 2), we found a significant difference ($P < 0.05$) only between the LELP and the HEHP treatments, while in second and third lactation no significant differences in ECM yield between groups were found. Because cows were moved to the university herd after first lactation, we lack reliable data on reasons why the LE groups were diminished throughout the experiment. Fewer animals in the LE groups might be due to a shorter productive lifetime, known to affect profitability (Heikkila *et al.*, 2008). However, exploring this would require a field study with far more animals under research than in the study of Storli *et al.* (2018).

This evaluation of lifetime profitability concludes that there are financial benefits of feeding heifers for rapid growth from three months of age until confirmed pregnancy as long as they reach a sufficient size before breeding and there is no excess of protein in the ration.

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Declaration of interest

None.

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Table 1 *Costs, unit prices, and subsidies in € as used in the cash flow calculation for the four treatment groups*

	Treatment			
	HELP	HEHP	LELP	LEHP
Costs				
Recruitment calf	279.2	279.2	279.2	279.2
Milk, per liter	0.483	0.483	0.483	0.483
Concentrate, calf, per MJ[1]	0.066	0.066	0.066	0.066
Concentrate, heifer, per MJ	0.056	0.064	0.056	0.064
Concentrate, cow, per MJ	0.063	0.063	0.063	0.063
Roughage, calf and heifer, per MJ	0.052	0.052	0.045	0.045
Roughage, pregnant heifer/dry cow, per MJ	0.045	0.045	0.045	0.045
Roughage, lactating cow, per MJ	0.052	0.052	0.052	0.052
Veterinary, pre calving, per month	6.42	6.42	6.42	6.42
Veterinary, post calving, per month	12.09	12.09	12.09	12.09
Sundry, pre calving, per month	1.91	1.91	1.91	1.91
Sundry, post calving, per month	7.58	7.58	7.58	7.58
Labor, calf period, per month	25.55	25.55	25.55	25.55
Labor, heifer period, per month	12.78	12.78	12.78	12.78
Labor, pregnant heifer period, per month	10.22	10.22	10.22	10.22
Labor, lactating cow, per month	53.66	53.66	53.66	53.66
Labor, dry cow, per month	5.11	5.11	5.11	5.11
Housing, 0-6 months, per month	18.04	18.04	18.04	18.04
Housing, 6-12 months, per month	24.05	24.05	24.05	24.05
Housing, 12-18 months, per month	30.06	30.06	30.06	30.06
Housing, > 18 months, per month	42.09	42.09	42.09	42.09
Housing, cows, per month	60.13	60.13	60.13	60.13
Unit prices				
Per newborn calf	279.2	279.2	279.2	279.2
Milk, per liter	0.483	0.483	0.483	0.483
Slaughter value, cow, per kg	4.64	4.64	4.64	4.64
Subsidies				
Animal subsidies, pre calving, per month	7.45	7.45	7.45	7.45
Animal subsidies, post calving, per month	22.34	22.34	22.34	22.34
Roughage subsidies[2], per month per				
Calf	5.23	5.18	3.83	4.17
Heifer	13.78	14.01	8.80	8.86
Pregnant heifer	18.43	17.38	11.50	11.50
1st 305-day lactation	43.16	40.88	44.88	45.54
1st 60-day dry period	17.46	17.46	17.46	17.46
2nd 305-day lactation	48.41	48.72	47.96	48.20
2nd 60-day dry period	17.99	17.99	17.99	17.99
3rd 214-day lactation	47.26	47.34	47.99	48.47

HELP = high-energy, low-protein; HEHP = high-energy, high-protein; LELP = low-energy, low-protein; LEHP = low-energy, high-protein

[1] MJ = megajoule

[2] Roughage subsidies (incl. subsidies for pasture): Calculated assuming average roughage intake for each cohort and treatment group as given in Table 2

Table 2 *Production variable averages used in the cash flow calculations for the four treatment groups*

	Treatment group			
Production variables	HELP	HEHP	LELP	LEHP
Age at first calving, months	22	22	26	26
Productive lifetime, months	31	31	31	31
Calving interval, months	12	12	12	12
Adult slaughter weight, kg	275	275	275	275
Milk fed to calves, l/day[1]	6.09	6.09	6.09	6.09
Concentrate per calf, MJ[2]/day	7.0	7.1	7.1	7.1
Roughage per calf, MJ/day	9.2	9.1	6.7	6.3
Concentrate per heifer, MJ/day	6.1	6.2	6.1	6.2
Roughage per heifer, MJ/day	35.6	36.3	26.8	27.0
Concentrate per pregnant heifer, MJ/day	0.4	0.4	0.4	0.4
Roughage per pregnant heifer, MJ/day	54.7	54.7	53.5	53.5
Concentrate per cow, MJ/day, lactation 1	36.1	35.5	37.5	35.8
Roughage per cow, MJ/day, lactation 1	75.9	71.9	78.9	80.0
305-d milk production, kg ECM, lactation 1	6 975	6 632	7 117	7 049
Concentrate per cow, MJ/day, lactation 2	44.3	41.0	49.9	47.5
Roughage per cow, MJ/day, lactation 2	85.1	85.6	84.3	84.7
305-d milk production, kg ECM, lactation 2	8 176	7 886	8 593	8 422
Concentrate per cow, MJ/day, lactation 3[3]	64.6	65.6	56.5	52.5
Roughage per cow, MJ/day, lactation 3	83.1	83.2	84.4	85.2
Daily milk production, kg ECM, lactation 3	7 022	7 138	6 620	6 177
Total lifetime milk yield, kg ECM	22 173	21 656	22 330	21 648

HELP = high-energy, low-protein; HEHP = high-energy, high-protein; LELP = low-energy, low-protein; LEHP = low-energy, high-protein

[1] Weaning at 49 days of age.

[2] MJ = megajoule.

[3] Only 7 months of milk production, i.e., 213 days.

Table 3 *Specified costs and income as present value at time of birth; summarized as a net present value (NPV) and converted to a monthly annuity equivalent (ME), with and without subsidies, for an average animal per treatment. All values are given in €*

	Treatment group			
	HELP	HEHP	LELP	LEHP
Rearing costs				
Replacement calf	279.2	279.2	279.2	279.2
Milk feed	144.0	144.0	144.0	144.0
Concentrate	150.7	166.7	189.9	211.4
Roughage	1 046.9	1 054.6	942.9	950.2
Veterinary	137.1	137.1	161.1	161.1
Sundry	40.8	40.8	47.9	47.9
Labor	289.1	289.1	342.0	342.0
Housing	580.5	580.5	737.9	737.9
Σ rearing costs	2 668.3	2 692.0	2 844.9	2 873.8
Lactation costs				
Concentrate	2 161.5	2 106.5	2 163.3	2 049.1
Roughage	3 415.2	3 364.5	3 421.4	3 452.3
Veterinary	337.1	337.1	333.2	333.2
Sundry	211.5	211.5	209.1	209.1
Labor	1 322.5	1 322.5	1 307.4	1 307.4
Housing	1 676.9	1 676.9	1 657.8	1 657.8
Σ lactation costs	9 124.8	9 019.0	9 092.3	9 008.9
Income				
Calves born	760.2	760.2	751.5	751.5
Milk sale	9 265.5	9 050.4	9 285.7	9 072.0
Slaughter	1 098.7	1 098.7	1 086.2	1 086.2
Animal subsidies	782.0	782.0	802.7	802.7
Roughage subsidies[1]	1 492.9	1 468.0	1 415.9	1 428.8
Σ income	13 399.3	13 159.3	13 342.0	13 141.3
Profitability incl. subsidies				
NPV	1 606.2	1 448.3	1 415.8	1 258.5
ME	**32.7**	**29.5**	**26.8**	**24.0**
Profitability excl. subsidies				
NPV	-668.6	-809.1	-813.9	-973.0
ME	-13.6	-16.5	-15.5	-18.5

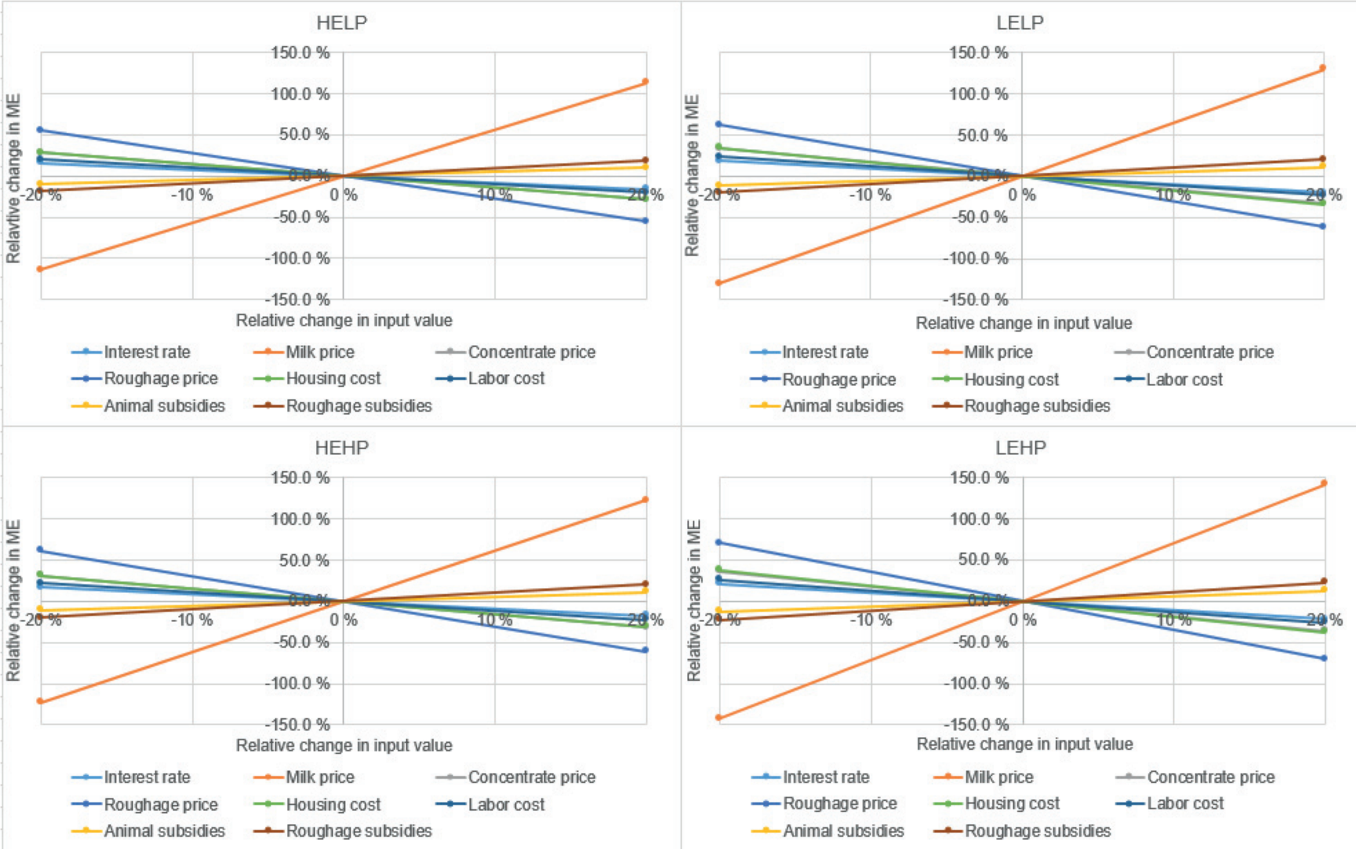
HELP = high-energy, low-protein; HEHP = high-energy, high-protein; LELP = low-energy, low-protein; LEHP = low-energy, high-protein

[1] Roughage subsidies (incl. subsidies for pasture): Calculated assuming average roughage intake for each cohort and treatment group as given in Table 2.

Figure captions

Figure 1 *Graphical presentation of the sensitivity analysis for the four treatments: High-energy, low-protein (HELP), high-energy, high-protein (HEHP), low-energy, low-protein (LELP), and low-energy, high-protein (LEHP).*

Figure 1


HELP
LELP
HEHP
LEHP
150.0 %
100.0 %
50.0 %
0.0 %
-50.0 %
-100.0 %
-150.0 %
-20 %
-10 %
0 %
10 %
20 %
Relavtive change in ME
Relative change in ME
Relative change in input value
Interest rate
Milk price
Concentrate price
Roughage price
Housing cost
Labor cost
Animal subsidies
Roughage subsidies

Simulating the financial and greenhouse gas impacts of different heifer growth strategies on dairy farms

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Manuscript

Simulating the financial and greenhouse gas impacts of different heifer growth strategies on dairy farms

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Short title: Financial and GHG impact of heifer growth rates

Abstract

The rearing of replacement heifer represent a large part of the total costs in dairy farming. By increasing heifer growth rate, thus reducing rearing time, these costs can be lowered. Hence, this study aimed to simulate the financial and greenhouse gas impacts of different heifer rearing strategies on Norwegian dairy farms. The rearing strategies compared were a baseline growth scenario and an accelerated growth scenario, resulting in an age at first calving of 26 and 22 months, respectively. Heifers in both scenarios achieved the same body weight prior to calving, and growth scenario was assumed not to influence later production. Furthermore, three different culling rates, 0.45 (corresponding to the present national average), 0.35, and 0.25, were compared within each growth scenario. A Farm Account Survey dataset containing physical and financial information on 311 Norwegian farms was clustered based on information on farmland area, number of animals, milk quota, revenues, costs and labour input to define three model farms of different size. We used a farm-level optimising model, ScotFarm, to model the financial consequences of the two management practices. Accelerating heifer growth had a significant positive effect on farm annual gross margin (14-29% depending on farm size and culling rate) compared to the baseline scenario, while no additional significant effect was observed with reduced culling rate. A second model, the Global Livestock Environmental Assessment Model, was used to conduct a life cycle analysis of greenhouse gas emissions. Accelerated heifer growth gave only minor reductions in emissions at the farm level, up to 1%, compared to the baseline scenario, whereas reduced culling rate lowered total farm level emissions by up to 8%.

Keywords: heifer rearing, replacement rearing, gross margin, farm level modelling, greenhouse gas emission

Implications

This study demonstrates that farm annual gross margin increases significantly with rapid rearing of heifers. With improved heifer management and implementation of growth rate monitoring, for example, by regular hearth girth measurements, farmers could increase their profitability. With increasing consumer awareness in environmental issues, dairy farmers can increase their competitiveness by reducing culling rate, as it can reduce their greenhouse gas emissions by up to 8%. This, however, assumes that the reduction in meat produced from dairy is not replaced by specialized beef production.

Introduction

Rearing of replacement heifers has been estimated to represent between 15 and 20% of the total costs in dairy farming (Heinrichs, 1993), costs which many farmers tend to underrate (Mourits *et al.*, 2000). Reducing rearing time to first calving has previously been reported to lower rearing costs (Mourits *et al.*, 1997, Tozer and Heinrichs, 2001). Heifer-rearing strategies could therefore be an attractive means for farmers to increase profitability.

A recent study based on field trials concluded that the Norwegian dairy farmers had not updated their rearing practices, in particular their feeding practices, to meet the requirements of today's Norwegian Red (**NR**) heifer (Storli *et al.*, 2017). Therefore, heifers grow too slowly, calve at a too high age, and enter the milking herd after an unnecessarily long financially unproductive period. A controlled station experiment documented that heifers, which were reared to calve at 22 months of age produce at least as much milk over 3 lactations as their contemporaries that calved at 26 months of age (Storli *et al.*, 2018); 26 months has been the average age at first calving (**AFC**) in Norway for the last couple of decades (Larsgard, A. G., personal communication).

Norwegian dairy production is undergoing fundamental change. The average dairy herd is still small in an international context at some 25 cows, but the average herd size is steadily increasing, while at the same time both the number of herds and total number of dairy cows are decreasing (NDHRS, 2017). One major goal of the present simulation experiment was thus to decide to which extent a reduction in AFC from todays 26 months of age to 22 months would affect the annual gross margin (**AGM**) of groups of farms consisting of either small, medium, and large sized farms. At 45%, the average herd culling rate (**CR**) in Norway is very high (NDHRS, 2017), consisting of a CR of 33% in primiparous cows, some 50% in multiparous cows, and an average productive life-time of barely 3 years (NDHRS, 2017). With replacement rearing representing such a high percentage of total costs as mentioned above, a second goal was to examine to which extent a reduction of the CR from today's 45% to levels found in the EU and in the US would affect the AGM of the same farm groups.

The Norwegian government expects all sectors, including the agricultural sector, to contribute to cuts in national greenhouse gas (**GHG**) emissions (LMD, 2009). A significant part of the reduction is to be achieved through reducing GHG emissions per unit of milk and beef (Bonesmo *et al.*, 2013). One means that is expected to give cuts is to accelerate rearing of replacement heifers. An accelerated heifer growth rate has the potential to reduce GHG emissions mainly due to a decreased demand for replacement animals per time unit, e.g. a smaller average replacement herd per year (Knapp *et al.*, 2014), but also due to a reduced need for maintenance feed. A third objective was thus to simulate effects of accelerating the growth rate of replacement heifers on GHG emissions from the same three groups of farms.

Materials and methods

Norwegian agricultural policy

Norway has one of the highest levels of support to the farming sector, and principal policy instruments supporting agriculture include e.g. border measures, budgetary payments, and regulations of the domestic market (Kumbhakar *et al.*, 2008, OECD, 2017). In addition, agricultural support is connected to regional and rural policies (OECD, 2017). Moreover, there are numerous legal regulations regarding e.g. farm transfer, ownership, and production (Forbord *et al.*, 2014). Prices received by Norwegian farmers are generally high because of border measures like import tariffs. The outcome of annual negotiations between the government and the two farmers' unions determines target prices, direct support measures, and various other measures. At present, there are target prices for milk, pork, cereals, potatoes, and some vegetables. There is also tradable milk quotas on farm level. All these regulations limits the possibilities to increase profitability by increasing scale. Therefore, optimizing production at the existing scale through farm management measures could be a suitable way of improving profitability.

Farm data inputs

Farm level data used for this study was taken from the Norwegian Farm Account Survey (**FAS**), which is rather similar to EU's Farm Accountancy Data Network. The dataset contained both financial and physical information including e.g. available land, animals, milk quota, revenues, expenses and labour input on 311 Norwegian dairy farms. Farms with similar characteristics were grouped together using the CLUSTER Procedure in SAS® version 9.4 (SAS Institute Inc., Cary, NC). Ward's minimum-variance method with squared Euclidian distance was used. The farm variables used in the clustering procedure was available grassland area, number of animals, milk quota, variable cost per animal, and labour input, including both family and hired labour. These five variables were chosen because they were considered to be the most important parameters differentiating the farm groups with respect to scale of production and efficiency. Farm level parameters which were not available in the FAS dataset were taken from other sources: CR, calving rate and survival rate of calves were from the NDHRS (2017) and fertiliser use and manure management were from StatisticsNorway (2015). Grass yield data was calculated based on an average yield for the years 2012-2013, modelled with a Norwegian grass growth simulator (VIPS, 2017). The model predicted kg DM grass yield per 1/10 ha and the simulations were run using Ås, Norway as base for soil and weather conditions. The content of energy and protein of the grass silage was set to 6.32 megajoule (**MJ**) net energy for lactation and 16% CP per kg DM. Grass silage of this quality is possible to produce all over the country. Grass silage production costs were obtained from the Norwegian Dairy Herd Financial Recordings for the years 2012 and 2013, and calculated as the average production costs for the participating farms, equal to €0.2139 per kg DM incl. subsidies. This gave a silage production cost per hectare of €941. Similarly, grass for grazing contained 16% CP and 6.5 MJ per kg DM while corresponding figures for concentrate were 19.5% and 7.07 MJ. Their costs were €0.1452 and €0.4585 per kg DM, respectively. Figure 1 shows a schematic illustration of the data flow in the simulations.

Farm level optimisation Model

The first part of the study aimed to model farm AGM for two different heifer rearing scenarios: a baseline growth (**BL**) scenario with no change in heifer management from today's practice resulting in an AFC of 26 months and with a CR of 0.45 (estimated average daily BW gain (**ADG**) of 651 g/day), and one accelerated growth (**AG**) scenario where farms were allowed to accelerate heifer growth for them to calve at an AFC of 22 months but keeping the same CR (estimated ADG of 776 g/day). The second part of the study models the effects on farm AGM of three different culling rates within the same two growth scenarios, where we compared the current national average CR of 0.45 (NDHRS, 2017) with two alternative CR of 0.35 and 0.25, which is similar to CR found in the US (Smith *et al.*, 2000) and the EU (Mohd Nor *et al.*, 2014), respectively. The model uses the Norwegian farm level data as input in a modified version of ScotFarm (Figure 2). ScotFarm is a profit optimising financial model developed at Scotland's Rural College and is based on farming system analysis. A schematic diagram of the model is provided in Figure 2. The model has been used in several studies of farm level profitability under varying management and policy conditions around Europe, (Shrestha *et al.*, 2015, Glenk *et al.*, 2017). The modified model configured for this paper simulates over a nine-year time-frame, and aims to maximise annual farm gross margin under a set of limited farm resources, using the following objective functions:

$$Max\ AGM = \sum_{f=1,y=1}^{m,n} \rho + GSP - l - fp - fb$$

Where, *AGM* is annual gross margin, ρ is dairy margin, *GSP* is governmental subsidies, l is costs for hired labour, *fp* is feed production costs, *fb* is costs of buying feed, *f* is number of *m* farm types and *y* is number of *n* years.

Dairy margin (ρ) is defined as:

$$\rho = \sum_{f=1,y=1}^{m,n} rm + rc + rd - cr - vc$$

where *rm* is total milk revenue, *rc* is calf revenue, *rd* is culled dairy revenue, *cr* is costs of replacement, and *vc* is livestock variable costs.

The model assumes that all farmers are profit oriented and aim to maximise farm income over the time-frame the model runs. The production system in this modified model is a combined milk and meat system where heifer calves are bred for replacement and male calves for meat. Although not included in the above equations, it is important to note that revenues from bulls culled for meat were included in the AGM as additional income. Their numbers were fixed within model farm size and all bulls were fed the same ration, thus, revenues from bulls made no impact on decision making. The system is constrained by available land, labour, feed, and stock replacement as well as the milk quota for each farm. Milk quotas cannot be purchased or hired. Total available land is fixed, but farms are allowed to buy feeds, animal replacements, and hire labour if profitable. Land use is only for grass production either as grass silage or as pasture, and comprises a mixture of timothy (*Phleum pratense*), meadow fescue (*Festuca pratensis*) and clover (*Trifolium pratense)*.

The tails of the modelled period, i.e. years 1-2 and 7-9 were deleted to avoid starting and terminal effects of optimisation modelling. Culled dairy cows were either replaced by the farms' own replacement stock, or, if necessary, by externally bought replacements. Energy- and protein requirements for growing heifers, bulls and dairy cows were obtained from NorFor – the Nordic Feed Evaluation System (Volden, 2011). Available feeds were grass pasture, grass silage, and concentrate.

Greenhouse Gas Model

In the third part of the study we aimed to calculate the GHG emission intensity of meat and milk produced by the same set of model farms (the small, medium and large) under the BL and the AG scenarios, both with all three CR. The emission intensity was calculated using an excel model based on the Global Livestock Environmental Assessment Model (**GLEAM**) (MacLeod *et al.*, 2017, FAO, 2018). GLEAM is a life-cycle assessment model, which simulates processes within livestock production systems in order to estimate their environmental impact (**EI**). The model primarily focuses on the quantification of GHG emissions and, in this study, includes pre-farm emissions originating from the manufacture of inputs (e.g., feed, fertiliser and energy), and on-farm emissions during grass and animal production.

The data used in GLEAM is classified into basic input data and intermediate data. Basic input data is data such as herd parameters, e.g. fertility and mortality rates, and crop parameters like yields and nutrient application rates, which are derived from the literature, surveys and databases. Data generated with GLEAM that were used for subsequent calculations are defined as intermediate data and include parameter values for e.g. herd structures and manure application rates. GLEAM consists of five modules: 1) the herd module, which calculates herd structure i.e. the number of animals in each cohort and the rates at which animals move between cohorts, and animal characteristics like average BW and growth rates; 2) the manure module that calculates the rates by which excreted nitrogen is supplied to land; 3) the feed module, which calculates the composition of the feed ration for each cohort, the nutritional value per kg of feed in the ration, the land use, and the GHG emissions per kg of feed; 4) the system module, which calculates the average energy requirement in MJ and feed intake in kg DM for each cohort, the total emissions and land use originating from production, processing and transport of feed, methane (CH_4) and nitrous oxide (N_2O) emissions from manure management, and enteric CH_4 emissions, and finally 5) the allocation module that summarizes total emissions from each cohort, calculates the amount of meat and milk produced, allocates emissions to edible, non-edible and services outputs, and calculates total emissions and EI of each commodity. For a more detailed description, see MacLeod *et al.* (2017). The link between the ScotFarm and the GLEAM is that some of the output from the former, e.g. the herd size, milk yield, culling rates, and the composition of each cohorts feed ration listed in Table 4, was used as input into GLEAM. A more detailed description of the linkage between GLEAM and ScotFarm is provided in Eory *et al.* (2014). Manure management data were derived from StatisticsNorway (2015) and herd management input from NDHRS (2017). The GLEAM was only applied to the model farms. Thus, it was not possible to test the EI statistically.

Statistical Analysis

The GLM procedure in SAS® version 9.4 (SAS Institute Inc., Cary, NC) was used to test the variables for significance. Both main effects, i.e. model farm size, ADG and CR, and possible interaction effects were tested. A total of 7 464 observations were analysed with the following model:

$$y_{ijkl} = \mu + \alpha_i + \beta_j + \gamma_k + \alpha\beta_{ij} + \alpha\gamma_{ik} + \beta\gamma_{jk} + \alpha\beta\gamma_{ijk} + \varepsilon_{ijkl}$$

where y_{ijk} is the estimated average AGM for years 3-6 for model farm size *i* with ADG *j* and CR *k*, μ is the overall mean, α_i is the random effect of model farm size *i* , β_j is the effect of ADG *j*, γ_k is the effect of CR *k*, $\alpha\beta_{ij}$ is the interaction effect of model farm size *i* and AFC *j*, $\alpha\gamma_{ik}$ is the interaction effect of model farm size *i* and CR *k*, $\beta\gamma_{jk}$ is the interaction between ADG *j* and CR *k*, $\alpha\beta\gamma_{ijk}$ is the interaction effect of model farm size, ADG and CR, and ε_{ijkl} is a random error term for the *l*-th year.

It should be noted that the main focus in the current study was to examine the financial and environmental effects of altering heifer-rearing time, i.e. growth rate. Possible technological advances and herd production parameters, other than CR, were kept unchanged between scenarios.

Results

Farm Characteristics

The cluster analysis grouped the 311 farms from the FAS dataset into three model farms: a small (based on n=107 farms), a medium (based on n=148) and a large size (based on n=56 farms) model farm (Table 1). Table 2 shows input characteristics of these three model farms used in the optimization model. Larger farms produced more milk per cow, and the obtained milk price differed between model farms. Stocking rate increased with increasing size. The ScotFarm optimizing output showed that the optimum number of replacements for all six growth x CR scenarios, with three exceptions, were lower than the input number of replacements (Table 3). Although small, the surplus relative to the input was the largest in the medium sized model farm, whereas the least was in the small one (Table 3). The optimal number of dairy cows were between one and two cows lower than the input numbers in all scenarios (Table 3). The number of bulls on each of the model farms was fixed not to influence heifer management results. All three model farms fully utilized their milk quota. Because all of the model farms were self-sufficient with roughage there was no change in land use.

Accelerated growth rate decreased heifer DM intake during rearing (Table 4). DM intake was some 7.3 kg/day from weaning (>2 months) to calving for the AG scenario, compared to 7.5 kg/day for the BL (Table 4). Total feed intake was about 1 000 kg DM higher for replacement heifers in the BL than in the AG scenario. The AG scenario had a more energy dense daily feed ration because of larger part of concentrate and fresh grass in the ration. Daily feed costs during rearing for the AG and BL scenarios were similar, although the cumulative feed costs for the AG scenario was lower because of less days of feeding (Table 4).

Financial impacts

Replacement heifer-rearing time had a strong impact on AGM ($P < 0.0001$). The AG scenario increased model farm AGM by 16%, 22% and 28% for the small, medium and large model farms with a CR of 0.45 compared with BL results (Table 5). With CR of

0.35 and 0.25 the increase in AGM with the AG scenario were in the range 15-26% and 14-18%. However, CR had no significant influence on AGM (P = 0.761). Reducing CR from 0.45 to 0.35 and 0.25 increased AGM in the AG scenario by only 0.2 to 0.3%, whereas AGM for the BL scenario actually decreased by 0.6 to 2.4% (Table 5).

GHG Impacts

Calculations of GHG emissions revealed only minor effects of altering replacement heifer-rearing time. Table 6 compiles the estimated GHG emissions expressed as kg CO_2-equivalents (**CO_2-e**) per kg meat protein, per kg milk, per kg edible protein, and as total farm GHG emissions in tons for the BL scenario compared with the alternative scenario (AG) for the small, medium and large model farms at the 3 CR (0.45, 0.35 and 0.25). Calculated as CO_2-e per kg meat, the AG scenario increased EI by 0.2% compared with BL. Calculated as EI per kg of milk the picture changed, and the AG scenario decreased EI by 0.3 to 1.7% relative to BL. Summed up to EI as kg CO_2-e per kg edible protein (milk and meat) the AG scenario had the lowest calculated emissions. Given as total farm GHG emissions, the AG scenario produced up to 0.9% less GHG than BL. Accelerated heifer ADG thus slightly decreased emissions of GHG given the assumptions in the model.

Discussion

Reducing replacement heifer-rearing time to first calving from the present average of 26 months (BL) down to 22 months (AG), could potentially increase AGM by 14-29% depending on farm size and CR (Table 5). Thus, the impact of reducing heifer-rearing time on dairy farm revenues could indeed be substantial. Post-weaning feed costs came out €220 (17%) less for the AG scenario compared with BL (Table 4). This is in line with previous findings by Tozer and Heinrichs (2001) who reported that reducing AFC by one month within the range of 21-29 months of age lowered the cost of a replacement program by 4.3%. Similarly, Mourits *et al.* (1999) demonstrated that the economically optimal AFC would be between 22 and 23 months of age.

The effect of AG on AGM was the highest for the large farm, which is likely to be a result of increased stocking rate (Table 3). Intensively run farms, i.e. higher stocking rates, has been reported to be more cost efficient (Alvarez *et al.*, 2008). Farms with more than 50 dairy cows, close to our large model farm, is also the dairy herd size that has increased the most in Norway over the last decade (NDHRS, 2006 and 2017); at the same time the number of dairy farms has decreased from 14 033 to 8 331 (StatisticsNorway, 2017). In order to obtain day to day flexibility and more leisure time, a large number of dairy farmers (21% of farms with 38% of the dairy cows) have invested in milking robots (NDHRS, 2017). In addition comes the fact that 60-70 cows can be served by one milking robot. Automatic milking systems are therefore an attractive option for many Norwegian farmers.

Optimisation results indicated that the financially optimal herd structure, with a CR of 0.45, did not differ much from the initial herd structure as obtained from the cluster analysis and used as input in the model (Table 3). Because rearing of replacements represents a large cost and CR determines the required number of replacements, we ran the financial optimising model not only with the current national average CR of 0.45, but also with a CR of 0.35 and 0.25 to see which impact varying the CR would have on AGM. These alternative CR are comparable with figures found in the US (Smith *et al.*, 2000) and the EU (Mohd Nor *et al.*, 2014), respectively. Neither of the two alternative CR significantly affected AGM, even though the number of heifers needed decreased with decreasing CR as was also shown by Knapp *et al.* (2014). This is likely to be an effect of the high cull value of cows (Table 2).

Our assessment of the financial impacts of the two replacement heifer-rearing scenarios assumes that milk yield, reproductive performance and longevity are the same for the two growth scenarios. There is a host of literature from the last 4 decades on the effects of ADG on heifers' mammary gland development and subsequent milk production, however with conflicting results (see e.g., reviews by Sejrsen *et al.*, 2000, Roche *et al.*, 2014). (Meyer *et al.*, 2006a and 2006b) presented a likely solution to this conundrum showing that whereas the mammary fat pad responded to accelerated pre-pubertal growth the parenchyma did not; instead there was an effect of age of the animal. This notwithstanding, the response in milk yield to heifer growth rate seems to be curvilinear both in the pre-pubertal and the post-pubertal phase, and the relationship is most likely a dynamic one, increasing from selection over time (Zanton and Heinrichs, 2005, Storli *et al.*, 2017). Thus, there exists an optimal growth rate for heifers. Today's NR are markedly different from the ones that existed 30 to 40 years ago due to a continuous genetic progress (Geno, 2016), and they will thus endure a much higher growth rate. This is supported by the recent findings of both Krpálková *et al.* (2014) and (Storli *et al.*,

2018) who demonstrated that lifetime production is not negatively affected by high heifer growth rates. Actually, a higher lifetime milk yield was observed when the AFC was below 23 months (Krpálková *et al.*, 2014). Recent work further showed that the levels of ADG used in the present simulations are well within the range of what the Norwegian Red breed can handle (Storli *et al.*, 2017). These findings imply that our assumptions on growth scenarios, milk yield and longevity in the model can be justified.

A limitation of the ScotFarm model, as for many optimisation models, is the assumption of profit maximising even though farmers might have several goals in their farming practises, and not always follow economic incentives. Furthermore, the model presumes all farm resources to be used optimally, which obviously is not the case all the time in reality. Because feed costs were not available in the FAS dataset, we had to assume a static cost similar for all farms. However, variables like e.g. milk yield and milk price, available land, labour, and variable costs, varied between the 311 farms (Table 1) and thus gave variability within model farm, which strengthened the model.

Estimated total Norwegian GHG emissions in 2015 were 53.9 million tonnes CO_2-e, and agriculture's share was 8.3% of these emissions (StatisticsNorway, 2016). A benchmark study of GHG emissions from bovine milk production systems in 38 countries conducted by Hagemann *et al.* (2011) quantified emission levels per kg energy corrected milk yield (**ECM**) to be from 0.80 to 3.07 kg CO_2-e. Most typical farms had emissions ranging from 1.00-1.50 kg CO_2-e/kg ECM. Our estimates of emissions are in the middle of this range (Table 6). Replacement heifer-rearing time had some effect on GHG emission. A change from a BL to an AG scenario gave an estimated change in total GHG emissions from our model farms of +100 to -5 000 kg (between 0 and 0.9%) CO_2-e subject to farm size and CR (Table 6). One management measure that would contribute more to reduced emissions is to reduce culling rate. According to Knapp *et al.* (2014), a reduction in culling rate from 40% to 30% would reduce the replacements contribution to whole-herd enteric CH_4 from 31.6% to 25.7% at an AFC of 26 months; simultaneously accelerating growth rate for heifers to calve at 22 months would bring this contribution further down to 22.7%. We were not able to isolate the replacements contribution in our calculations, but accelerating growth reduced herd enteric CH_4 by 1-2% (data not shown), whereas a decrease in CR from 0.45 to 0.35 and 0.25 reduced CH_4 by approximately 3% and 6% (data not shown). Furthermore, our calculations revealed a decrease in total farm GHG emissions of around 4% and 8% if CR were to be reduced from today's 0.45 to 0.35 and 0.25, respectively. Reducing CR is thus more efficient with respect to lowering GHG emissions from dairy production. However, reducing the culling rate would decrease the amount of beef coming from the dairy industry, which again would require an increase in either domestic specialized beef production or import to meet national demands for beef. Specialized beef production give higher GHG emissions per kg of meat than meat from dual-purpose dairy systems (Zehetmeier *et al.*, 2012). The GHG reducing effect of reduced CR is thus questionable.

To conclude, the present simulation illustrates the financial potential of accelerated heifer growth. Given the current national average AFC of 26 months, there is a potential for a large number of Norwegian dairy farmers to increase heifer growth rate.

Accelerating growth rate in a way that heifers reach a sufficient level of maturity for them to be bred at 13 months and calve at 22 months could potentially increase AGM by some 14 to 29%, depending on farm size and CR, compared with a calving age of 26 months. As for GHG emissions, accelerating ADG from a BL to an AG scenario would reduce emissions by up to 1% of CO_2-e on farm level subject to farm size. However, reducing the CR would be a more efficient way to reduce GHG emissions provided it does not lead to increased specialized beef production.

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Declaration of interest

None.

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Table 1 *Means, minimum, and maximum values for the three model farm sizes from the cluster analysis used as input in ScotFarm*

	Model farm size								
	Small (n=107)			Medium (n=148)			Large (n=56)		
Variable	Mean	min	max	Mean	min	max	Mean	min	max
Grassland, ha	25.6	9.6	84.1	37.4	14.7	75.7	55.5	21.4	130.0
Rough grazing, ha	5.0	0.0	29.1	5.3	0.0	24.0	9.5	0.0	42.0
Milk quota, l	100 014	48 000	131 450	197 173	134 785	302 917	379 078	309 007	558 165
Milk sold/cow, l	6 717	3 431	8 792	7 491	4 596	10 142	8 054	5 672	10 495
Milk price, €/l	0.599	0.505	0.718	0.594	0.535	0.802	0.595	0.496	0.674
Livestock units	29.0	9.3	77.0	53.2	15.8	151.3	91.6	52.8	154.0
VC/LU[1], €	1 439	520	2 505	1 505	745	3 788	1 578	706	3 359
Stocking rate	1.2	0.5	2.6	1.5	0.5	4.2	1.8	0.8	3.5
Labor, man-years	1.7	0.8	3.0	1.9	1.1	3.7	2.3	1.2	4.1

VC/LU = variable costs per livestock unit

Table 2 Model input characteristics similar for the small, medium and large model farms[1]

Variable	Unit	Value
Cow weight	Kg head^{-1}	600
Fertility rate		0.95
Calving interval	Months	12
Age at first calving	Months	22/26
Replacement rate	percent	0.45/0.35/0.25
Cull value cow	€ head^{-1}	1 382.2
Cull value bulls	€ head^{-1}	1 669.3

[1] The system is year round calving, pasture available during May - September, winter housing with grass silage feed supplemented with concentrate. Pasture for bulls not allowed. Male calves were bred for meat and slaughtered at 18 months of age, at a slaughter weight of 305 kg.

Table 3 *Herd structure input and optimized herd structure output for the three model farms for the baseline and the accelerated growth scenario at different culling rates*

		Scenario					
		BL			AG		
	CR	S	M	L	S	M	L
Input	0.45						
Heifers		15.2	29.5	53.0			
Dairy cows		15.0	26.9	47.6			
Bulls		13.1	23.6	35.6			
Stocking rate		1.23	1.51	1.80			
Output							
Heifers	0.45	15.6	28.2	52.3	16.1	28.9	52.7
	0.35	15.0	27.2	50.3	15.4	27.7	50.7
	0.25	14.3	26.1	48.4	14.6	26.4	48.6
Dairy cows	0.45	13.8	25.2	46.7	14.1	25.6	47.0
	0.35	13.8	25.2	46.6	14.0	25.5	46.9
	0.25	13.6	25.0	46.5	13.8	25.3	46.7
Bulls	All	13.1	23.6	35.6	13.1	23.6	35.6
Stocking rate	0.45	1.12	1.39	1.66	1.13	1.39	1.65
	0.35	1.10	1.37	1.64	1.11	1.37	1.63
	0.25	1.08	1.35	1.61	1.08	1.35	1.60

CR = culling rate; AG = accelerated growth; BL = baseline; S = small size model farm; M = medium size model farm; L = large size model farm

Table 4 *Average ration composition and total and per day feed intake and feed cost per animal for the 4 cohorts in the two heifer-growth scenarios at a culling rate of 0.45. The difference between culling rates were negligible*

		Scenario													
		Baseline[1]							Accelerated growth[2]						
Farm size	Cohort	Fg,% of DM	Gsil, % of DM	Conc, % of DM	Total feed, kg DM	Feed per day, kg DM	Total feed cost, €	Feed cost per day, €	Fg,% of DM	Gsil, % of DM	Conc, % of DM	Total feed, kg DM	Feed per day, kg DM	Total feed cost, €	Feed cost per day, €
Small	Replace-ments[3]	22.1	61.7	16.2	5 462	7.5	1 302	1.78	32.0	47.2	20.9	4 448	7.3	1 081	1.77
	Dairy[4]	42.4	37.6	20.0	5 965	16.3	1 394	3.82	34.2	44.6	21.2	5 757	15.8	1 395	3.82
Medium	Replace-ments	22.1	61.7	16.3	5 462	7.5	1 303	1.78	32.0	47.1	20.8	4 451	7.3	1 081	1.77
	Dairy	40.2	35.6	24.3	6 325	17.3	1 554	4.26	32.4	42.5	25.1	6 145	16.8	1 556	4.26
Large	Replace-ments	22.1	61.6	16.2	5 459	7.5	1 301	1.78	32.0	47.1	20.8	4 451	7.3	1 081	1.77
	Dairy	38.7	34.3	27.1	6 588	18.0	1 671	4.58	31.2	41.0	27.8	6 389	17.5	1 664	4.56
All	Bulls[5]	0.00	0.50	0.50	3 619	7.4	1 216	2.49	0.00	0.50	0.50	3 619	7.4	1 216	2.49

Fg = fresh grass; Gsil = grass silage; Conc = concentrate

[1] From post-weaning until calving at 26 months of age.

[2] From post-weaning until calving at 22 months of age.

[3] Per heifer from post-weaning until calving.

[4] Per cow and year.

[5] From post-weaning until slaughter at 18 months of age.

Table 5 *Average annual gross margin in € for the baseline and the accelerated heifer growth scenarios with three different culling rates for the three model farms*

			Scenario	
Model farm size	n	CR	BL[a]	AG[b]
Small	107	0.45	66 207	77 105
		0.35	67 156	77 225
		0.25	67 917	77 177
Medium	148	0.45	98 771	120 483
		0.35	100 561	120 641
		0.25	102 152	120 652
Large	56	0.45	151 797[A]	195 371
		0.35	155 962	196 166
		0.25	169 404[B]	196 629

CR = culling rate; AG = accelerated growth; BL = baseline

[a,b] = $P < 0.001$

[A,B] = $P < 0.05$

Table 6 *Estimation of greenhouse gas (GHG) emissions expressed as kg CO_2-equivalents per kg meat protein, per kg milk, per kg edible animal protein (meat and milk) as well as total GHG emissions per farm for the baseline growth (BL) and the accelerated growth (AG) scenarios for the small, medium and large sized model farm at three different culling rates (CR).*

Model farm size	Small		Medium		Large	
Heifer-rearing management	BL	AG	BL	AG	BL	AG
EI per kg of meat protein						
- CR 0.45	79.3	79.4	78.6	78.8	78.3	78.4
- CR 0.35	84.6	84.7	84.1	84.2	83.8	84.0
- CR 0.25	91.4	91.5	91.1	91.3	91.0	91.1
EI of milk per kg						
- CR 0.45	1.3	1.3	1.3	1.3	1.2	1.2
- CR 0.35	1.3	1.3	1.2	1.2	1.2	1.2
- CR 0.25	1.2	1.2	1.2	1.2	1.1	1.1
Emission per kg of all edible protein (meat and milk)						
- CR 0.45	45.7	45.2	43.2	42.8	41.8	41.3
- CR 0.35	44.5	44.2	42.1	41.9	40.7	40.5
- CR 0.25	43.3	43.2	41.0	40.9	39.6	39.5
Total GHG emissions, tons per farm per year						
- CR 0.45	158.8	157.4	306.4	304.0	569.3	564.3
- CR 0.35	152.3	151.6	294.4	293.3	547.6	544.9
- CR 0.25	145.9	145.8	282.4	282.5	525.9	525.5

Figure captions

Figure 1 Flowchart of data. ADG = average daily BW gain (growth scenarios); CR = culling rate scenarios; GHG = greenhouse gas

Figure 2 Schematic diagram of the ScotFarm model (Modified after Shrestha, 2017; https://www.sruc.ac.uk/downloads/file/3513/scotfarm_%E2%80%93_a_farm_level_optimising_model)

Figure 1

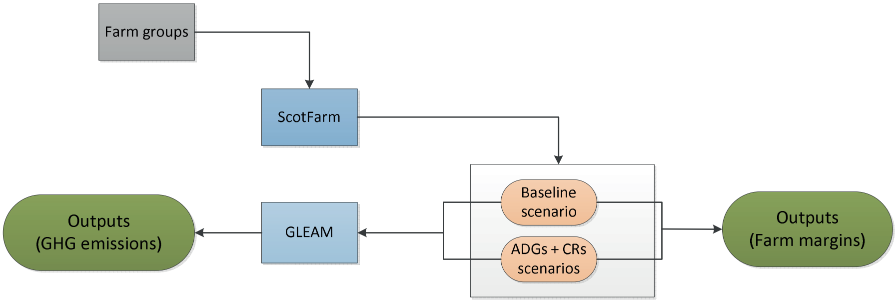
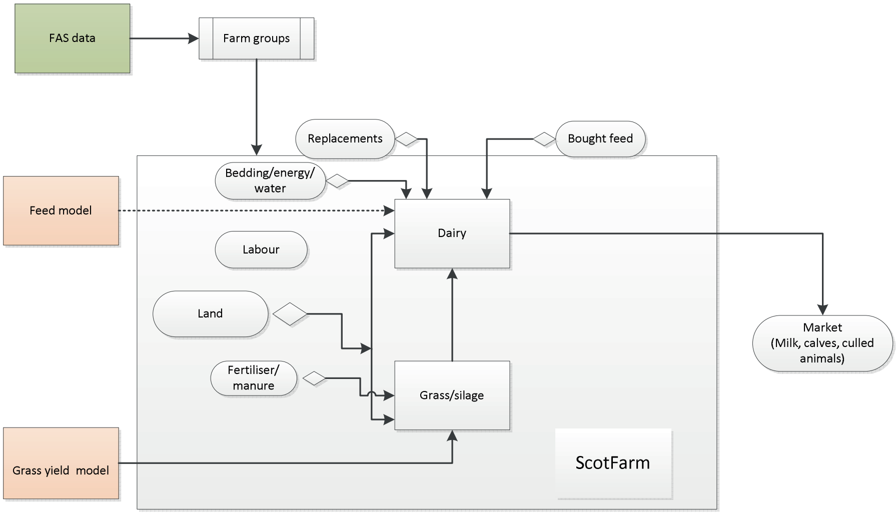

Farm groups
ScotFarm
Baseline scenario
ADGs + CRs scenarios
GLEAM
Outputs (GHG emissions)
Outputs (Farm margins)

Figure 2



FAS data
Farm groups
Replacements
Bought feed
Bedding/energy/ water
Feed model
Dairy
Labour
Land
Market (Milk, calves, culled animals)
Fertiliser/ manure
Grass/silage
Grass yield model
ScotFarm

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