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An analysis of the financial and environmental impacts of early maturing of heifers on Norwegian dairy farms

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Abstract

This paper explores a management practice that increases average daily weight gain (ADG) in dairy heifers from three months of age until confirmed pregnancy. The practice achieves early maturation of the animal as heifers under this management start lactation at 22 months of age compared to 26 months under common farm practices. This practice is an efficient rearing process for dairy farms and is considered more environment-friendly. It is associated with reduced emissions of GHG due to a reduced need for maintenance feeding, as well as a lower demand for recruitment animals. The management practice implies higher daily feed costs, but there are lesser days of feeding and lower costs of housing and labour. The objective of this study is to explore the financial and environmental impacts of the ADG management practice on Norwegian dairy farms.

To this end the study uses two separate models. A farm level optimising model, ScotFarm, is used to analyse the financial consequences of the ADG management practice. The model uses farm level data drawn from Farm Account Survey provided by the Norwegian Institute of Bioeconomy Research. These data contains information from 311 Norwegian dairy farms. The Norwegian feed requirement dataset, obtained from NorFor - the Nordic Feed Evaluation System, is used to determine the energy- and protein requirements for each of the animals on each farm. The model runs under a baseline scenario where all management practices are based on the farm survey and a management scenario where farms are allowed to implement ADG management practices. A second model, the Global Livestock Environmental Assessment Model (GLEAM), is used to conduct a life cycle analysis of GHG emissions. A counterfactual comparison of the model results under the management scenarios and the baseline scenario is conducted to analyse the impacts of the ADG management practice. The practice is new to Norwegian dairy farmers and is considered to have potential to improve financial and environmental status of farms. The results from this study will improve our understanding of the overall impacts of ADG management on farms. Accelerated heifer growth increased annual gross margin by 12.8-18.9% depending on farm size, and higher ADG gave slightly less GHG emissions.

Keywords: dairy heifer management, average daily gain, greenhouse gas emissions, net farm earnings, farm level modelling, life cycle analysis

Introduction

Norway constitutes the western and northern part of the Scandinavian Peninsula, and extends from approximately N 57°58' - N 71°10' longitude and E 4°53' - E 31°06' latitude. Around 8,800 dairy farm are present almost all over the country. This implies that the natural conditions for dairy farming is widely diverse, from large flat areas with large farms to steep mountain areas with smaller farms. Statistics from the Norwegian Dairy Herd Recording System (NDHRS), with 98.6% of all dairy herds participating, reveals that the average Norwegian dairy farm have 25.7 dairy cows that produces 8,147 kg ECM per year each (NDHRS 2015). The average age at first calving (AFC) is 25.9 months. Of around 200,000 dairy cows in Norway almost 94% are of the Norwegian Red breed, which is a dual-purpose (milk and meat) breed with excellent production, fertility and health traits (GENO 2017).

Rearing of replacement heifers represents a large part of the total costs in dairy farming. (Heinrichs (1996) in Mourits et al. 1997) estimated the cost of rearing dairy heifers to be between 15 and 20% of the total cost of milk production. The period before a heifer calves and starts lactating, she does not produce any income. It is therefore of interest to investigate the possibilities for accelerated heifer growth to reduce the unproductive life of the animal. Reduced rearing time to first calving is associated with lower rearing cost (Hoffman & Funk 1992; Mourits et al. 1997; Tozer 2000; Tozer & Heinrichs 2001) and lesser contribution from replacements to emissions of GHG, mainly due to a decreased demand for recruitment animals (Knapp et al. 2014). At the same time, there is no clear evidence that calving at an earlier age is detrimental to milk yield as long as the heifer reach a sufficient level of maturity before giving birth. Heifer growth strategies stands out as a management area to be addressed in the future as a step towards coping with increased efficiency and profitability demands.

A second point is that the Norwegian government expect all sectors, including the agricultural sector to contribute to cuts in national GHG emissions (Norwegian Government 2009). Estimations of Norwegian GHG emissions in 2015 were 53.9 million CO_2-equivalents (CO_2-e), and agriculture's share of this was 4.5 million CO_2-e, equal to 8.3% of the total emissions (SSB 2016). With that in mind, it becomes interesting to investigate alternative measures that are easily accessible at low costs. One such measure is accelerated growth in pre-bred heifers. This study aims to explore effects of changes in dairy heifer management on the farms annual gross margin (AGM), and to what extent management change affects GHG emissions from the dairy farm.

Materials & methods

The methodology used in this study consists of two simulation models, an optimising farm level economic model and a GHG-emissions simulator. The first part of the study uses Norwegian farm level data as input to a modified version of ScotFarm, which is a farm level economic model. The model simulates a nine-year perspective, and the objective function aims to maximise farm gross margin. The tails of the modelled period (year 1-2 and 7-9) was deleted from the output since they tends to influence on the results. Results are therefore an average of year three to six. The second part of the study determines the emission intensity of herd level GHG for the same set of Norwegian dairy farm types under a baseline scenario, and under two alternative scenarios with different levels of pre-breeding ADG in replacement heifers.

Three model herds were defined using the PROC CLUSTER procedure in SAS version 9.4 (SAS Institute Inc., Cary, NC) on a dataset provided by the Norwegian Institute of Bioeconomy Research containing both financial and physical data on 311 Norwegian dairy farms. The farms was clustered by information on grassland, number of animals, total milk produced and variable costs per animal, as these variables were thought to be the most important parameters differentiating the farm groups. The analysis resulted in a small (S, n=107), medium (M, n=148) and a large (L, N=56) size model farm, and main characteristics are shown in Table 1. Some key production figures were taken from the NDHRS. Data on fertiliser use and manure management was retrieved from a report, "Use of inorganic and organic fertilisers in agriculture", given by Statistics Norway (SSB 2015). Grass yield data was calculated, based on a Norwegian grass growth simulator (VIPS 2017), using available weather- and location data from Ås, Norway (N 59°39'37.6", E 10°46'53.0") for the years 2012 and 2013. The model predicted kg grass yield per 1/10 ha. A feed analysis dataset from 2012-2013 for silages in the Oslofjord area was used to calculate dry matter and energy- and protein content of the grass silage. Grass silage production costs were set equal to 0.303 NOK per MJ (incl. subsidies). This gave a production cost per hectare of 8,426 NOK.

ScotFarm is a profit optimising financial model developed at Scotland's Rural College (SRUC) that is based on a farm level dynamic linear programming model described in detail in Shrestha (2004). Modified versions of ScotFarm has been used in several farm level studies of farm profitability under changing management and political impact in different places in Europe (Glenk et al. 2017; Shrestha 2015). The model assumes that all farmers are profit oriented and maximise farm income within a set of limiting farm resources. Dairy is the only production system in this modified model, and the system is constrained by available land, labour, feed and stock replacement, as well as the milk quota for each farm. Total available land is fixed, but farms are allowed to buy feeds, animal replacements and hire labour if required. The gross margin is comprised of accumulated revenues from milk and meat sales plus farm subsidies, minus costs incurred for inputs under these activities.

Land was used only for grass production as either grass silage or pasture, which is a mixture of timothy, meadow fescue and clover. Heifer replacement rate in Norway is high, and is set equal to that in the official statistics (0.44) from the NDHRS (2015). The animals are replaced by the farms own replacement stock, or by externally bought replacements. Energy- and protein requirements for growing heifers, bulls and dairy cows were obtained from NorFor (Volden 2011), and available feeds were grass pasture, grass silage, and concentrate.

The GHG-emission simulator used was the Global Livestock Environmental Assessment Model (GLEAM), developed by the Food and Agriculture Organisation (FAO) of the United Nations. GLEAM is a life-cycle analysis (LCA) model, which simulates processes within livestock production systems in order to estimate their environmental impact (EI). GLEAM consists of five modules; namely the herd module, the manure module, the feed module, the system module and the allocation module. For a more detailed explanation, see MacLeod et al. (2013). The model primarily focuses on the quantification of GHG emissions and includes emissions from pre-farm emissions originating from the manufacture of input, via on-farm emissions during crop/grass and animal production, to post-farm emissions arising from processing and transportation of products to the retailer. Emissions arising after delivery to the retailer are not included. The three major GHG in agriculture, methane (CH_4), nitrous oxide (N_2O) and carbon dioxide (CO_2) are included in the model, while less important gases have been omitted. The only ScotFarm output used in this model is the distribution of feedstuffs in each cohorts feed ration, listed in Table 4. Other input data collected were from sources like SSB (2015) (manure management) and NDHRS (2015) (all animal and herd management records).

Preliminary results

Herd structure did not differ within farms between different heifer rearing strategies in the optimising model. This is probably because the model runs on a one-year basis. The difference between the highest and lowest ADG equals eight months difference in AFC, hence all variation is inside a 12-month interval. Although herd structure did not differ within farms, there was an increasing difference between model input and output values regarding the number of recruitment heifers needed between farm sizes. On average, the decrease in recruitment heifers were 1.7 for S farms, and 5.7 and 10.5 for M and L farms, respectively. The number of dairy cows were almost as the initiating numbers. Just a small decrease by 0.6 dairy cows for both the M and L farms. This suggests that M and L farms probably have more recruitment animals than what is economically optimal. Total DM feed consumption among the various scenarios are presented in Table 3, and proportions of available feedstuffs used for each alternative are listed in Table 4. Table 5 contains the total feed costs per animal for each cohort.

Annual gross margin (AGM) for the baseline scenario (pre-bred ADG 779 g/d, AFC 26 months) was NOK 655,456, NOK 1,061,435 and NOK 1,734,894 for the S, M and L farms respectively (1NOK = 0.1117€, average exchange rate 2015). Increasing pre-bred ADG to 877 g/d (resulting in an AFC of 22 months) gave an increase in AGM of 12.8, 15.8 and 18.9% for the S, M and L farms respectively, compared to the baseline scenario. Lowering pre-bred ADG to 692 g/d (resulting in an AFC of 30 months) decreased AGM by 10.6, 13.1 and 15.5% for the S, M and L farms, compared to the baseline scenario. See Table 2 for further details. All of the three farm sizes utilized their milk quota to a full extent.

Calculations of GHG emissions from GLEAM revealed only minor benefits of altering the management system. Table 6 compiles the estimated GHG emissions (CO_2-e) per kg animal protein and per kg milk for the baseline scenario (BL, AFC26), compared with the two alternative scenarios (AFC22 and AFC30) for the S, M and L farms. Total emissions from each farm scenario is included in the table. Emissions per kg animal protein for the BL scenario were 34.29 for the L farm. It was 35.63 kg for the M farm and 37.81 kg for the S farm. Accelerated heifer ADG resulted in a decreased environmental impact (EI) of 1.4%, meaning the AFC22 scenario level at 98.6% of the BL scenario emissions. The ADG30 scenario ended up at 102.1% of BL emissions. Expressed as emissions per kg ECM the BL scenario spanned from 1.190 to

1.312 kg CO_2-e from the L to the S farm. The M farm had an EI of 1.236 kg per kg ECM. Given the assumptions in the model, accelerated heifer ADG slightly reduced emissions of GHG.

Discussion

This assessment of financial and environmental impact regarding the different heifer management scenarios includes some assumptions that have to be discussed. One such assumption is that milk yield is the same for all three scenarios within farm size. Some previous studies have found that rapid heifer growth had a negative impact on milk yield (Sejrsen & Purup 1997; Van Amburgh et al. 1998), whereas others (Capuco et al. 1995; Waldo et al. 1998) found no such effect. Silva et al. (2002) used data from two studies to investigate factors associated with milk production. They found that even if heifers receiving a high-energy diet before puberty produce less milk during first lactation, prepubertal BW gain had no value as a predictor of milk yield. Within treatment, fast growing heifers produced as much milk as heifers growing slower. The authors suggests this implies that rapid BW gain per se is not the cause of reduced first lactation milk yield, but that BCS at breeding is a rather more probable cause. This is somehow in line with the later findings of Hultgren et al. (2011), who claimed that thin cows had higher and fat cows lower lifetime milk revenues. Neither did they find any relationship between prepubertal growth and milk revenues, but their study showed increasing lifetime net milk revenues with lower AFC, at least down to 22 months of age. Gardner et al. (1977) found (with the exception of one animal that had to be bred eight times before conception) no effect of effect of prepubertal growth rate on reproductive performance. Van Amburgh et al. (1998) reached the same conclusion. This implies that the assumptions about AFC and milk yield, reproductive performance and longevity in the model can be justified.

Comparing DM feed use for the replacements in Table 3 we find that daily DM intake is on average around 7.3-7.6 kg/day from weaning to calving. This was a bit surprising, because one could expect that a lower ADG lead to a lower DM intake per day. If we, on the other hand, have a look at the distribution between concentrate and roughage in Table 4, we see that the proportion of concentrate declines with decreasing ADG. Thus, the high ADG scenario has a more energy dense (and expensive) daily feed ration even though the accumulative feed costs are lower, as shown by Mourits et al. (1997) and Tozer (2000), amongst others.

Moving from AFC30 to AFC22 reveals a potential increase in AGM of around 25-40% depending on farm size. One weakness in the model is the use of fixed values for both costs and revenues. Feed cost, for example, can fluctuate largely from one year to another. Feed, as an example, constitutes the major part of variable costs in milk production and this is of course an uncertainty in the model. It has to be mentioned that one should always do on-farm calculations to ensure each farms own resources are utilized in the best possible way.

A benchmark of GHG emissions of bovine milk production systems in 38 countries by Hagemann et al. (2011) quantifies emission levels to be from 80 to 307 kg CO_2-e/100 kg ECM. Most typical farms had emissions ranging from 100-150 kg CO_2-e/100 kg ECM and estimates of emissions from our study are in the middle of this range. Heifer rearing management had some effect on GHG emission. A change from AFC30 to AFC22 gave an estimated reduction of GHG emissions between 5-16 tons (just above 3%) of CO_2-e subject to farm size (S to L size) (Table 6). The effect of moving from AFC 30 to BL is greater than that of moving from BL to AFC22. One management measure that would contribute further to reduced emissions is to reduce the heifer replacement rate. According to Knapp et al. (2014), a reduction in culling rate from 40 to 30 % in a BL scenario reduce the replacement contribution to whole-herd enteric CH_4 from 31.6 to 25.7 %. A simultaneous decrease in AFC to 22 months will bring this further down to 22.7 %. However, reducing the replacement rate will decrease the amount of beef coming from the dairy industry, which again would require an increase in specialized beef animals to maintain the same national supply. Specialized beef production shows to give higher GHG per kg of meat than meat from dual-purpose dairy systems (Zehetmeier et al. 2012).

Conclusion

This study gives an example of the financial benefit of accelerated heifer growth. Given the present national average AFC of almost 26 months, there is a potential for many dairy farmers to increase their heifer growth rate. Reaching a sufficient level of maturity at calving at 22 months of age reveals a potential increase in AGM of around 12-19% (depending on farm size) compared to calving at 26 months of age. Heifer rearing management had some effect on GHG emissions, and a change from AFC30 to AFC22 gave an estimated reduction of between 5-16 tons (just above 3%) of CO_2-e subject to farm size. Although the effect is small, the vast majority of farms adapting to this strategy are expected to reduce their GHG emissions.

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Table 1: Main characteristics of the modelled small (S), medium (M) and large (L) farm[1].

Variable	S	M	L	Unit
Number of cows	15.0	26.9	47.6	Cow years (feeding days/365)
Grassland, incl. rough grazing	31.3	43.5	66.4	ha
Milk sold	6717	7491	8054	Kg head^{-1} year^{-1}
Milk price	5.36	5.32	5.33	NOK l^{-1}
Cow weight	600	600	600	Kg head^{-1}
Fertility rate	0.95	0.95	0.95	
Calving period	All year	All year	All year	
Calving interval	12	12	12	Month
Age at first calving	26	26	26	Month
Replacement rate	0.44	0.44	0.44	
Cull price (cow)	12,375	12,375	12,375	NOK head^{-1}
Carcass value bulls	14,945	14,945	14,945	NOK head^{-1}

[1] System is year round calving, pasture available during May - September, winter housing with grass silage feed, feed supplemented with concentrate. Pasture for males not allowed. Male calves were breed for meat and slaughtered at 18 mo. of age with a carcass weight of 305 kg.

Table 2: Annual gross margin (AGM) measured in NOK[1] for the baseline (BL) scenario and the two alternative scenarios for the S, M and L farms.

Farm size		AFC22	BL	AFC30
S	AGM	739,133	655,456	585,820
	Deviation from BL	83,656	0	-69,636
	Deviation (%) from BL	12.8	0	-10.6
M	AGM	1,229,393	1,061,435	922,733
	Deviation from BL	167,958	0	-138,702
	deviation (%) from BL	15.8	0	-13.1
L	AGM	2,062,978	1,734,894	1,466,028
	Deviation from BL	328,084	0	-268,866
	Deviation (%) from BL	18.9	0	-15.5

[1] 1NOK = 0.1117€, average exchange rate 2015)

Table 3: Change in dry matter feed use in different cohorts between the baseline scenario (AFC26) and the two alternative scenarios (AFC22, AFC30). Bulls bred for beef are the same for all alternatives and sums up to 3619 kg DM in total.

Farm size	Cohort	AFC22	BL	AFC30
S	Replacement animals[1]	4454 (83.8)	5313 (100)	6399 (120.4)
	Dairy animals[2]	6390 (96.1)	6646 (100)	6504 (97.8)
M	Replacement animals	4467 (84.1)	5313 (100)	6403 (120.5)
	Dairy animals	6390 (96.2)	6646 (100)	6501 (97.8)
L	Replacement animals	4630 (87.1)	5313 (100)	6402 (120.5)
	Dairy animals	6390 (96.1)	6646 (100)	6501 (97.8)

[1] Amount of feed given as kg total DM feed per replacement animal (post weaning until freshening).

[2] total DM feed per dairy cow per year.

Table 4: Proportion (%) of fresh grass (fg), grass silage (gsil) and concentrate (conc) at each of the three heifer management strategies for different cohorts on the three farm sizes.

Cohort	Farm-size	AFC 22			BL			AFC30		
		fg	gsil	conc	fg	gsil	conc	fg	gsil	conc
Replacement	S	32.1	47.2	20.7	22.8	60.9	16.3	25.2	62.0	12.9
	M	32.3	47.0	20.7	—‖—	—‖—	—‖—	—‖—	—‖—	—‖—
	L	30.1	47.8	22.1	—‖—	—‖—	—‖—	—‖—	—‖—	—‖—
Dairy	S, M, L	31.2	41.0	27.8	38.3	34.8	26.9	34.6	36.0	29.4
Bulls	S, M, L	0	50.0	50.0	0	50.0	50.0	0	50.0	50.0

Table 5: Average total feed cost for replacements[1], dairy cows[2] and bulls[3] in Norwegian kroner (NOK[4]) and percent of baseline (BL) and alternative (AFC22, AFC30) scenarios.

Cohort	Farm-size	AFC22	BL	AFC30
Replacement	S, M, L	9,865	11,323	13,082
% of BL		87.1	100.0	115.5
Dairy	S, M, L	14,892	14,162	15,257
% of BL		105.2	100.0	107.7
Bulls	S, M, L	10,883	10,883	10,883
% of BL		100.0	100.0	100.0

[1] Post weaning until freshening

[2] Per lactation incl. dry period

[3] post weaning until slaughter

[4] 1NOK = 0.1117€, average exchange rate 2015)

Table 6: Estimation of GHG emissions expressed as kg CO_2-equivalents per kg animal protein and per kg milk for the baseline (BL) scenario and the two alternative scenarios for the S, M and L farm, as well as total GHG emissions. Deviation from BL given as absolute and relative value.

Farm size		Small			Medium			Large	
Scenario	AFC22	BL	AFC30	AFC22	BL	AFC30	AFC22	BL	AFC30
Emission per kg animal protein	37.283	37.809	38.633	35.171	35.634	36.391	33.900	34.290	35.008
Deviation from BL, kg	-0.526	0.00	0.824	-0.463	0.00	0.757	-0.390	0.00	0.718
Relative to BL	0.986	1.00	1.022	0.987	1.00	1.021	0.989	1.00	1.021
Emission per kg milk	1.294	1.312	1.341	1.220	1.236	1.263	1.176	1.190	1.215
Deviation from BL, kg	-0.018	0.00	0.029	-0.016	0.00	0.026	-0.014	0.00	0.025
Relative to BL	0.986	1.00	1.022	0.987	1.00	1.021	0.989	1.00	1.021