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Final report

Find the forage-efficient cows and increase profitability

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Main applicant: Kjell Holtenius, SLU, kjell.holtenius@slu.se

Co-applicants : SLU, Maria Åkerlind, Växa Sverige, Erling Strandberg, SLU, Örjan Bergman,

Background

Dairy cows consume large amounts of concentrate, which makes a significant part of the total costs of milk production. Thus, the concept of *large amounts of forage, instead of concentrate, to forage-efficient* cows would be profitable for the dairy industry through positive impact on the key figure "milk income minus feed cost" provided that the cows consume enough forage to maintain a high milk production. Indeed, there is also a strong, long-term global incentive to allocate both soy and other protein feeds and even grain from cows to humans and monogastric animals and instead utilize ruminants' unique ability to convert forage to high-quality protein. One likely consequence of climate change is that forage production in Scandinavia will benefit from longer growing seasons and warmer climate while the conditions will be impaired in central and southern Europe. Therefore, the concept of *large amounts of forage to forage-efficient cows* is expected to be even more profitable and publically acceptable in the future.

The cows' ability to consume forage varies considerably. Many factors affect forage intake, such as age, live weight, stage of lactation, amount of concentrate and forage quality. However, these factors explain only part of the variation. There is also genetic variation in forage intake capacity.

New advances in genomics offer possibilities both to identify individuals in the herd with high forage intake capacity (FIC) and to estimate genomic breeding values for FIC. With knowledge of the genetic ability to consume forage for individual cows in the herd, it would be possible to tailor the diet to individual cows or groups of cows and thus get better economy in milk production. With genomic breeding values for FIC it would also be possible to select cows and bulls with superior FIC to become parents of the next generation, thus improving FIC in the breed. Tools that accurately estimate FIC are required in order to identify individuals in the herd with high FIC and to estimate genomic breeding values for FIC. Selection of cows based on feed intake has largely been hampered by lack of tools to estimate intake in individual cows outside research facilities, which dramatically limits the number of cows possible to measure. However, mid-infrared spectroscopy (MIRS) of milk opens for recording of many new phenotypes, including feed intake that can be used for breeding purposes. MIRS predictions have been shown to provide useful on energy intake (EI), but also energy balance (EB) and changes in body condition score (ΔBCS) and body weight change (ΔBW) in individual cows. In many commercial herds, individual intake of concentrate is registered. Thus, the energy contribution from forage may be estimated provided that total EI is estimated.

Overall objective and aims
The overall objective of the proposed project is to strengthen the profitability of the dairy industry by increasing the "milk income minus feed cost".

The specific aims have been changed relative the application:

- Use new genomic tools to identify cows that have a high forage intake capacity, which contributes to reduced concentrate needs combined with high yields and increased profitability.
- ~~Demonstrate the phenotypic variation in performance of cows with varying genetic FIC in commercial dairy herds.~~
- To use milk infrared spectroscopy to develop predictive equations for forage intake and other traits influencing productivity.
- *Added aim:* To study the performance of cows fed a low concentrate diet in early lactation and during a full lactation.

Material and Methods

Animals, Experimental Design and Housing

The project was performed at the Swedish Livestock Research Centre (Lövsta). This centre has almost 300 dairy cows of Swedish Holstein and Swedish red breed respectively.

Experiment 1A & 1B
Eighty-five cows were subjected to a low concentrate (**LC**) ration during their first six weeks of lactation in order to study individual variations in intake (experiment 1A). A subgroup of 13 cows on the LC diet was compared with 13 other cows were subjected to a high concentrate (**HC**) ration as a control (Experiment 1B). The cows entered the study during the first week after calving and stayed in the study until 40-42 days in milk (**DIM**). In total 100 cows were studied in Experiment 1.

Diets and feeding
The concentrate was pelleted and based on by-products of low human interest while the forage was a grass-clover silage fed ad libitum. Before calving, all cows were fed the experimental concentrate starting two weeks before expected calving. The concentrate ration increased with 0.5 kg/d until 3 kg/d was reached. When the cows entered the group of milking cows after calving the concentrate was gradually increased with 0.5 kg/d for both treatments, to 4.0 (primiparous) and 5.0 (multiparous) kg/d for LC cows and 14.0 (primiparous) and 15.0 (multiparous) kg/d for HC cows.

Measurements and Sample Collection
Individual forage intake was recorded automatically from forage troughs, as was daily concentrate intake fed from dispensers. Spot samples of faeces were collected at two different occasions per cow, three weeks apart, and at each occasion once daily on three consecutive days. Milk was sampled for composition analysis at afternoon milking and the following morning in lactation week 2, 4 and 6 for each cow. Milk was sampled once a day, twice weekly from all cows for progesterone analysis.
The cows were weighed automatically when passing a sort gate after milking, and mean daily body weight was recorded. Body condition scoring (**BCS**; scale 1-5) was done automatically with a 3-dimentional camera when cows were passing a sort gate after milking. Weekly mean BW and BCS was calculated from daily mean BW and BCS, respectively.
Blood was sampled in lactation week 2, 4, and 6.

Chemical Analysis and Calculations

All feed analyses were performed by the laboratory at the Department of Animal Nutrition and Management at the Swedish University of Agricultural Science (**SLU**), Uppsala, Sweden if nothing else is stated.
Energy balance (**EB**) and residual feed intake (**RFI**) were calculated as difference between net energy intake and net energy requirements:

$EB = NE_{intake} – (NE_{maintenance} + NE_{lactation})$

$RFI = (NE_{intake}) – (NE_{maintenance} + NE_{milk} - NE_{mobilisation} + NE_{deposition})$
with NE_{intake}, $NE_{maintenance}$, NE_{milk}, $NE_{mobilisation}$, and $NE_{deposition}$ calculated according to the NorFor system.

Total tract apparent dry matter digestibility (**DMD**) was calculated from estimated intake and excretion of DM from feed intake and faeces, as $(DM_{intake} - DM_{faeces}) /DM_{feed}$. The calculation was based on faecal samples taken once daily three days in a row with intake data from the three days of faecal sampling and the day before faecal sampling with acid insoluble ash as internal indigestible marker. Milk samples were analysed for composition of fat, fatty acids (**FA**), protein, and lactose using infrared Fourier transformation. The progesterone was measured for each animal and days from calving to commencement of luteal activity (**CLA**) with the limit for luteal activity set at a milk progesterone concentration of >5 ng/ml. Glucose, insulin, non-esterified fatty acids (NEFA) beta-hydroxybutyrate (BHB) and insulin-like growth factor 1 (IGF-1) by well-established methods.

Statistical Analyses
All statistical analyses were performed in SAS software (version 9.4, SAS Institute Inc., Cary, NC, USA). The treatment effects of feed and nutrient intake, milk yield and composition, BCS and BW variables, and blood plasma parameters were analysed using the PROC MIXED with lactation week as autoregressively repeated:
$Y_{ijklm} = \mu + C_i + P_j + B_k + L_l + W_m + BW_{km} + LW_{lm} + \varepsilon_{ijklm}$,
where Y_{ijklm} is the dependent variable, μ is the overall mean, C_i is the random effect of cow i, P_j is the effect of parity j, B_k is the effect of breed k, L_l is the effect of concentrate level l, W_m is the effect of lactation week m, BW_{km} is the breed × lactation week interaction effect of breed k and lactation week m, LW_{lm} is the concentrate level × lactation week interaction effect of concentrate level l and lactation week m, and the ε_{ijklm} is the random error. Primiparous cows formed one parity class and all multiparous cows (parity 2 or older) formed another. Treatment effects of weekly change of BCS and BW were analysed by PROC GLM with the model: $Y_{ijklm} = \mu + C_i + P_j + B_k + L_l + W_m + \varepsilon_{ijklm}$,
where Y_{ijklmn} is the dependent variable, μ is the overall mean, C_i is the random effect of cow i, P_j is the effect of parity j, B_k is the effect of breed k, L_l is the effect of concentrate level l, W_m is the effect of lactation week n, and the ε_{ijklmn} is the random error. Several models were tested to combine and account for interactions between variables. The models with lowest Akaike information criterion (AIC) were used. All residuals were tested for normality and log transformations were used for those that did not follow normal distribution. Values in the text and tables are presented as least square means calculated using the LSMEANS/PDIFF option. Statistical differences were determined following Tukey's adjustment declared at P ≤ 0.05. Pedigree and genomic profiles are available on all cows.

Experiment 2 (A & B)
Thirty-seven cows from the previous study were followed for a full, 305 days, lactation. Out of the 37 cows 10 were fed a HC diet and the remaining cows were fed a LC diet. Material and methods were largely similar with those in experiment 1 A & B and thus not described due limited space.

The genetic variation in forage intake capacity (FIC) was studied in cows from the Lövsta herd. We used data from 575 cows 1177 lactations to estimate genomic breeding values for this trait that can be used toselect cows according to their ability to perform well on high-forage production systems.

Results and discussion

Dairy cows can produce highly nutritive food products as milk but also meat from fibrous diets, which is not consumed directly by humans, such as grass and different by-products from food and fuel industry. Even so, high yielding dairy cows are in many places fed large quantities of cereal grain and pulses that just as well is consumed directly by humans. Given that high milk production is maintained if feeding dairy cows products of low human interest then the overall net production of food would increase and in turn help to reach the food security needed to support our growing human population. As part of the present project 26 primiparous and multiparous cows, Swedish Red and Holstein were followed in early lactation, between lactation weeks 2-6, and fed either a low (LC) or a high (HC) by-product-based concentrate ration in combination with highly digestible silage ad libitum. Multiparous cows were offered up to 5 kg concentrate on the LC diet and up to 15 kg concentrate on the HC diet, while primiparous cows were offered up to 4 kg concentrate on the LC diet and up to 14 kg concentrate on the HC diet. We found no differences in dry matter intake, energy corrected milk yield and energy balance between cows on LC and HC diets. Although, cows on HC diet had a higher dry matter intake per kg body weight along with a body weight gain compared with cows on LC diet. Additionally, we found that multiparous cows having a higher dry matter intake and energy corrected milk yield also had a higher dry matter intake per kg body weight which can contribute to the lower total tract apparent digestibility of multiparous cows compared with primiparous cows. Although, no difference in energy balance between parities multiparous cows lost more in body condition and had higher blood plasma concentrations of non-esterified fatty acids compared with primiparous cows. In conclusion, both multiparous and primiparous cows of breeds Swedish Red and Holstein seem to be able to adapt to low concentrate diets in early lactation and thereby having the potential to increase sustainability in dairy production.

In a follow up study, we wanted to investigate the performance of dairy cows fed a low concentrate diet during a complete 305 days lactation. In the present study, 37 multiparous Holstein and Swedish Red dairy cows were followed over an entire lactation. The cows got the same kind of concentrate and the allowances of concentrate in the LC and HC groups of cows in the same range as in the early lactation study Grass silage of high digestibility was offered ad libitum also in the present study. Over the entire lactation cows on the LC diet had lower dry matter intake and higher forage intake than cows on the HC diet (Table 1). Milk yield and energy balance were not influenced by concentrate level (Table 2 & 3). The energy balance result is supported by the fact that neither feed efficiency (as energy-corrected milk yield/dry matter intake or Residual feed intake, body weight change, body condition score change, plasma non-esterified fatty acids, glucose, β-hydroxybutyrate nor any fertility measurements were affected by diet (Table 2, 3 & 4). However, higher plasma concentrations of insulin-like growth factor-1 and insulin were observed among cows fed the HC diet (table 4). This study shows that cows perform virtually as good during a full lactation on a diet with a small amount of concentrate when highly digestible silage is available ad libitum. The results goes well in line with our results from the first study with cows in early lactation contributing to sustainable food production. Although, no difference in energy balance was observed between parities, multiparous cows lost more in body condition and had higher blood plasma concentrations of non-esterified fatty acids compared with primiparous cows (Data not shown). We have yet no plausible explanation to this finding. Never the less, multiparous and primiparous cows of Swedish Red and Holstein breeds seem to be able to adapt to low concentrate diets based on by-products and grass/clover silage in early lactation and thereby having the potential to increase sustainability in dairy production.

Interestingly there was no difference in milk yield between SR and Holstein cows over a complete lactation. Most published studies, including the first study in this project, show that Holstein cows have slightly higher milk production. Never the less Holstein cows consumed more feed (Table 1) and consequently they were less efficient (Table 2).

Table 1. Feed intake during lactation week 1-42 and apparent digestibility of DM (DMD) and organic matter (OMD) in early and mid-lactation, presented as least square mean with standard error of the mean (SEM) and P-value of multiparous dairy cows fed a daily ration of up to 6 kg of concentrate (6kgConc) or up to 12 kg of concentrate (12kgConc) and of breeds Holstein and Swedish Red (SR)

		Diets				Breeds			
Item	Obs.	6kgConc	12kgConc	SEM[1]	P-value	Holstein	SR	SEM	P-value
Number of cows[2]		27	10	-	-	13	24	-	-
Intake (kg DM/d)									
Total dry matter	1578	24.0	25.0	0.30	0.04	25.4	23.6	0.33	<0.01
Forage intake	1577	19.7	16.7	0.30	<0.01	19.2	17.3	0.33	<0.01
Conc. intake	1578	4.24	8.34	0.042	<0.01	6.23	6.35	0.046	0.08
Digestibility (%)									
DMD[3]	74	70.0	69.7	0.59	0.77	69.2	70.5	0.64	0.17

[3]Apparent total tract digestibility.

Table 2. Energy intake, energy balance (EB), residual feed intake (RFI), feed conversion and N efficiency, body condition score (BCS) and body weight (BW) and their weekly change, during lactation week 1-42 of multiparous dairy cows fed a daily ration of up to 6 kg of concentrate (6kgConc) or up to 12 kg of concentrate (12kgConc) and of breeds Holstein and Swedish Red (SR), presented as least square mean with standard error of the mean (SEM) and P-value

		Diets				Breeds			
Item	Obs.	6kgConc	12kgConc	SEM[1]	P-value	Holstein	SR	SEM	P-value
Number of cows[2]	-	27	10	-	-	13	24		-
Energy (MJ NE_L/d)									
NE_L	706	158	166	2.0	0.01	167	156	2.2	<0.01
EB	706	3.71	3.45	2.336	0.94	7.39	-0.23	2.547	0.05
RFI[3]	706	4.03	3.77	2.046	0.94	7.50	0.30	2.232	0.03
N-efficiency, g/kg (log10)	706	2.45	2.45	0.012	0.74	2.44	2.46	0.013	0.40
N-efficiency antilog[4]	-	284	280	-	-	277	288	-	-
Body weight and condition									
BCS change (BCS/week)	676	-0.002	-0.002	0.0016	0.95	-0.001	-0.003	0.0017	0.47
BW change (kg/week)	671	1.62	1.53	0.594	0.92	1.67	1.49	0.640	0.85

[3]Nitrogen efficiency = (milk protein yield / 6.38) / (CP intake / 6.25).

Table 3. Milk performance during lactation week 1-42 of multiparous dairy cows fed a daily ration of up to 6 kg of concentrate (6kgConc) or up to 12 kg of concentrate (12kgConc) and of breeds Holstein and Swedish Red (SR), presented as least square mean with standard error of the mean (SEM) and P-value

		Diets				Breeds			
Item	Obs.	6kgConc	12kgConc	SEM[1]	P-value	Holstein	SR	SEM	P-value
Number of cows[2]	-	27	10	-	-	13	24		-
Yield (kg/d)									
Milk	1591	32.1	33.4	0.88	0.35	33.2	32.2	0.96	0.46
ECM	707	33.9	36.3	0.94	0.13	35.3	34.9	1.03	0.81
Concentration (%)									
Fat	707	4.36	4.56	0.077	0.12	4.36	4.56	0.084	0.10
Protein	707	3.54	3.53	0.040	0.86	3.48	3.59	0.044	0.10
Lactose	707	4.72	4.74	0.027	0.70	4.77	4.69	0.030	0.07

Table 4. Blood plasma concentrations of glucose, insulin, non-esterified fatty acids (NEFA), β-hydroxybutyrate (BHB) and insulin-like growth factor 1 (IGF-1) during lactation week 2, 4, 6 and 20 of multiparous dairy cows fed a daily ration of up to 6 kg of (6kgConc) or up to 12 kg of concentrate (12kgConc) and of breeds Holstein and Swedish Red (SR),

		Diets				Breeds			
Item	Obs.	6kgConc	12kgConc	SEM[1]	P-value	Holstein	SR	SEM	P-value
Number of cows[2]	-	27	10	-	-	13	24	-	-
Glucose, mmol/L	144	2.98	3.03	0.073	0.65	3.05	2.96	0.079	0.44
Insulin (log10)	144	-1.04	-0.76	0.059	0.01	-0.78	-1.02	0.064	0.02
Insulin antilog, µg/L	-	0.09	0.17	-	-	0.17	0.10	-	-
NEFA (log10)	142	-0.54	-0.57	0.027	0.46	-0.62	-0.49	0.029	<0.01
NEFA antilog, mmol/L	-	0.29	0.27	-	-	0.24	0.33	-	-
BHB (log10)	144	-0.01	-0.036	0.0265	0.54	-0.05	0.00	0.029	0.20
BHB antilog, mmol/L	-	0.98	0.92	-	-	0.89	1.01	-	-
IGF-1 (log10)	144	1.84	1.94	0.027	0.03	1.92	1.86	0.030	0.16
IGF-1 antilog, ng/ml	-	69.0	86.7	-	-	83.1	72.0		-

[2]The number of animals were unbalanced due to a parallel genetic study on the low concentrate cows.

Table 5. Fertility data for multiparous dairy cows fed a daily ration of up to 6 kg of concentrate (6kgConc) or up to 12 kg of concentrate (12kgConc) and of breeds Holstein and Swedish Red (SR). Binominal fertility data (progesterone (P4) profiles, early CLA) presented as distributions with percentage within diet in parentheses and p-value

		Diets				Breeds			
Item	Obs.	6kgConc	12kgConc	SEM[1]	P-value	Holstein	SR	SEM	P-value
Number of cows[2]	-	27	10	-	-	13	24	-	-
Normal P4 profile[5]	-	17 (63%)	4 (40%)	-	0.15	6 (46%)	15 (63%)	-	0.22
Disturbed P4 profile	-	10 (37%)	6 (60%)	-	-	7 (54%)	9 (38%)	-	-
Early CLA[6]	-	8 (30%)	3 (30%)	-	0.87	7 (54%)	4 (17%)	-	0.03

[3]Milk progesterone above 5 ng/mL.
[4]Milk progesterone below 5 ng/mL after first CLA.
[5]Classification of normal and disturbed progesterone profiles according to Petersson et al., 2006.
[6]Early CLA = commencement of luteal activity before 23 DIM

As hypothesised, there was a marked variation in FIC between individual cows. We divided 27 cows offered the LC diet for a complete lactation into four categories according to their RFI and capacity to consume forage (silage) relative their metabolic body weight (FIC). Cows with a low forage consumption and high RFI, upper left quartile, were heavy, hade a relatively low milk production and, most important, had a low profitability in terms of milk income minus feed cost. Interestingly, there was no difference in dry matter digestibility between the four categories of cows. Taken together the results indicate that the cows differed in capacity to consume forage relative their size and in their metabolism post absorption. Heavier cows were generally less efficient. There was no effect of breed or body condition on any of these factors (Data not shown).

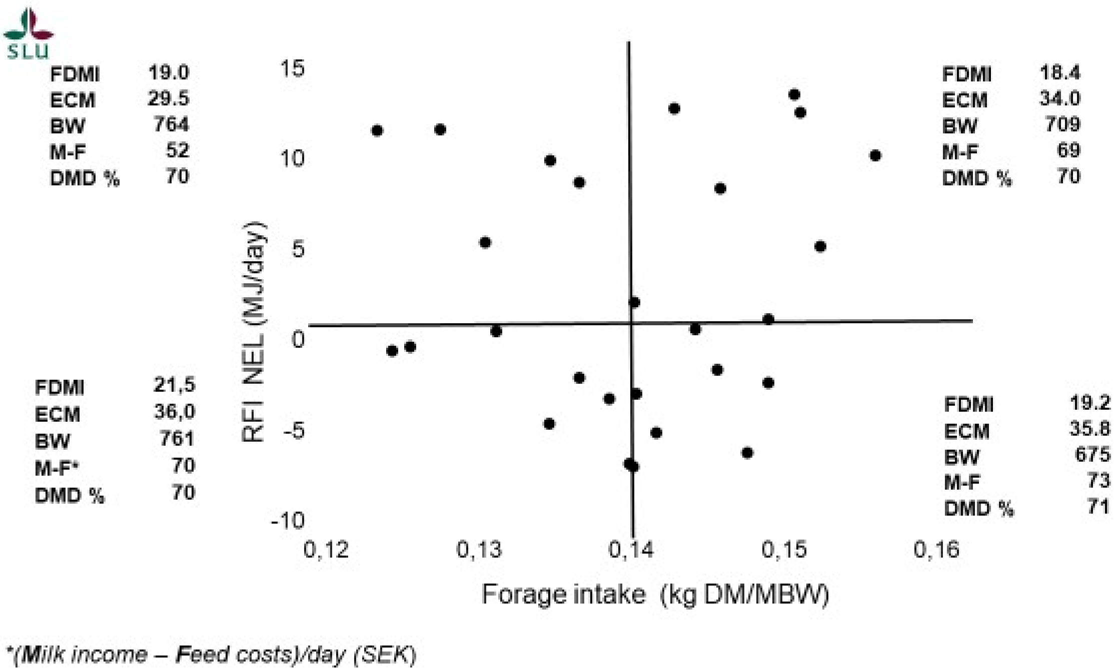

Figure 1. Forage intake, kg DM/day (DMI), milk yield (kg ECM/day), body weight (Kg) milk income –

feed costs (SEK/day) and Dry matter digestibility (%) in 27 primiparous and multiparous cows. Data are presented as least square means of 305 days lactation. The horizontal axis diverts the 50 % cows with the lowest RFI from those with the highest RFI. (note that low RFI is beneficial). The vertical line diverts the 50 % cows with the lowest forage intake in relation to the metabolic body weight from those with the highest intake. Effect of quartile was tested with procedure GLM. We observed significant quartile effects ($p<0.01$) for all parameters except dry matter digestibility. Neiter breed or parity effects were observed $p>0.2$).

One specific aim of this study was investigate the potential milk infrared spectroscopy to develop predictive equations for forage intake and other traits influencing productivity. Previously published studies indicate that mid infra-red spectra based on milk samples showed moderate relationships between dry matter intake (ref). In the present study we used a regression model based on the concentration of milk fatty acid (FA) C18:1 cis 9 in milk and energy corrected milk yield estimate intake of metabolizable energy (ME) (Figure 2). We tested several models including other milk FA, body weight, breed and parity to estimate ME. However, the improvements of the estimates were marginal and the regression equations got more complex. The FA C18:1 cis released from the adipose tissue during negative energy balance and reflects energy balance of dairy cows (Ref). We tested the equation presented in figure 1 in another data set (Experiment 2) and it explained 75 % of the variation in intake of cows in negative energy balance in that study.

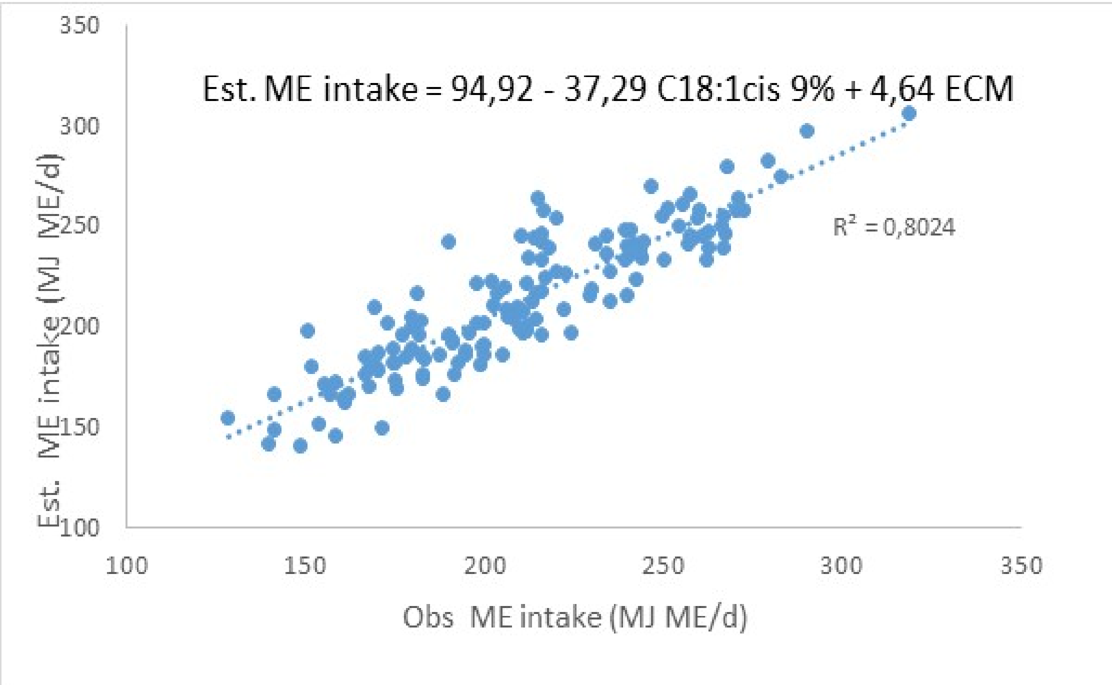

Figure 2. Linear regression analysis of daily intake of metabolisable energy. Data from 100 dairy cows in early lactation with negative energy balance (142 observations).

One objective of the project was to estimate the genetic variation and heritability in forage intake FIC. We had forage and concentrate intake information from 575 cows (356 SRB and 219 Holstein, HOL) from 1177 lactations between August 2013 and October 2018. Apart from studying total dry matter intake (DMI) and DMI from forage (DMI_{For}), we also constructed a trait called energy-corrected milk produced on forage (ECM_{For}). From the ECM produced, we deducted the ECM that could be expected to be produced from the concentrate intake (after the usage of energy for maintenance was deducted). The reasoning is that the ECM that is left is assumed to have been produced on forage. In herds with recording of concentrate intake of cows this could be used as an alternative trait to measuring forage intake.

Assuming that the traits are genetically the same in all lactations and lactation stages, heritabilities for

DMI_{For} was 0.14 and 0.23 for SRB and HOL, respectively. Corresponding values for ECM_{For} were 0.09 and 0.16. This is the heritability for one weekly observation of ECM and intake, with several weeks of observation the accuracy of an estimated breeding value (EBV) would become much higher. For the lowest heritability with 5 weeks of intake data, the accuracy of the breeding value would become 0.58, which corresponds to a heritability of 0.33 for a single measurement. For the highest heritability (0.23) and 10 weeks of intake data, the accuracy would be 0.77. These observations could either be used to estimate traditional pedigree-based EBVs or for use in a reference population to estimate genomic EBVs.

We also divided the lactation in stages and heritability was generally higher in the first two months for SRB but in months 3-4 for HOL. The heritability for first lactation was also higher than for later lactations, about 0.15 for DMI_{For} and about 0.24 for ECM_{For}, for both breeds.

It was not possible to get predicted forage intake based on MIRS as proxy phenotypes of cows from the commercial herds. Therefore, we were limited to the genotyped cows from our own herd only, which amounted to only 173 cows. In order to include also information from all cows with forage intake data (575 cows), but without genotype information, we started to implement a new statistical method called single-step GBLUP. In this method, the genomic relationship matrix (based on marker information) and the traditional pedigree-based relationship matrix are combined, so that information from relatives without genotypes can be used to estimate effects of markers. Analyses are still ongoing, but we have good results from applying the method to another dairy cattle dataset, using fertility traits.

One objective of the project was use a genome-wide association approach to search for genome regions that are important for forage intake. However, we underestimated the complexity of this approach and we have not been able, within the available time-frame, to perform this objective. As a consequence we did not have the genetic tools to perform the planned demonstration study.

In conclusion

The overall objective of the proposed project was to strengthen the profitability of the dairy industry by increasing the "milk income minus feed cost". The results of the present project showed a significant phenotypic variation in milk income minus feed costs that was not related to feed offered, parity or breed. The quartile of cows with the lowest value for milk income minus feed cost was characterized by high RFI, low forage intake capacity, high body weight and low milk production. However, the less efficient cows were not inferior when comes to dry matter digestibility.

Furthermore, it was possible to markedly reduce the proportion of concentrate in the diet without significant negative consequences for milk production. Health and fertility traits were apparently not affected by the concentrate level in the diet.

One objective of the project was to estimate the genetic variation and heritability in forage intake capacity. A trait called energy-corrected milk produced on forage was also constructed. Several weeks (for instance 5-10 weeks) of concentrate and ECM yield observations could be used to estimate traditional pedigree-based breeding values or for use in a reference population to estimate genomic breeding values with quite high accuracy.

We have constructed regression equations that reasonably well predicted intake of metabolizable energy and energy balance of cows in early lactation based on data from milk mid infrared analyses and ECM yield. These equations can potentially be used in all commercial dairy herds enrolled to the official Swedish milk recording scheme to estimate feed- and forage intake in early lactation. However, the equations s be verified in larger data sets.

Dissemination of results of the project

Scientific publications:

- Karlsson, J., Lindberg, M., Åkerlind, M. & Holtenius, K. 2020. Feed intake, milk yield, and metabolic status of early lactation Holstein and Swedish Red dairy cows of different parities fed grass-clover silage and two levels of by-product-based concentrate. (manuscript to be submitted)

- Karlsson, J.*, Lindberg, M., Åkerlind, M. & Holtenius, K. 2020. Whole lactation feed intake, milk yield, and energy balance of Holstein and Swedish Red dairy cows fed grass-clover silage and two levels of by-product-based concentrate. (Under review, *Journal of Dairy Science*)
- PhD thesis: Johanna Karlsson Nailing date 20 04 03. Milk production from grass and by-products - for improved sustainability of dairy production. The thesis work was partly supported by the current project.
- Furthermore, data from the project has generated > 10 proceedings and abstracts presented orally or as posters at international conferences.

Oral presentations in Swedish

- Beräkna kons grovfoderintag från en mjölkanalys. Kronqvist, C och Karlsson J. Vallkonferens 2017. . (oral presentation and written report)
- Hitta de fodereffektiva korna och öka lönsamheten Holtenius K & Karlsson J. 2020. Vallkonferens 2020. (oral presentation and written report)
- Mjölkproduktion med stora ensilagegivor över en hel laktation Karlsson J., Lindberg, M. & Holtenius K. 2020. Vallfoderkonferens 2020. (oral presentation and written report).
- Presentation: SRB-föreningen vårmöte 2020. ”Hitta de fodereffektiva korna och öka lönsamheten” (Kjell Holtenius)

Other publications:

- Artikel i Lantmannen 2020 om projektet ”Hitta de fodereffektiva korna och öka lönsamheten”

Student work

- Masters arbete, SLU Effect of feeding low concentrate diets to dairy cows Adriana Palomaris 2016
- Internship: Impact of nutrition on dairy cow productivity Part “Forage-efficient cow research” Emelie Laur, Institut Universitaire de Technologie de Toulouse, FRANCE