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Feeding, production, and efficiency of Holstein-Friesian, Jersey, and mixed-breed lactating dairy cows in commercial Danish herds

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ABSTRACT

The objective of this paper was to compare efficiency measures, milk production, and feed intake for lactating cows in commercial herds using different breeds and production and milking systems. To accomplish this, we used all feed evaluations made by the Danish extension service during the period November 2012 to April 2013 for 779 herds, of which 508 were Holstein-Friesian (HOL); 100 were Jersey (JER); and 171 herds were a mixture of these 2 breeds, other dairy breeds, and crossbreeds (OTH). The annually recorded, herd-average energy-corrected milk (ECM) yield was 8,716 kg (JER) and 9,606 kg (HOL); and average herd size was 197 cows (HOL) and 224 cows (JER). All cows were fed a total mixed or partial mixed ration supplemented with concentrate from feeding stations, housed in loose housing systems with a slatted floor, and milked in either a parlor milking unit or an automatic milking system. Energy efficiency was calculated as net energy efficiency defined as total energy demand as a percentage of energy intake and as residual feed intake defined as energy intake (net energy for lactation; NE_L) minus energy requirement. Production efficiency was expressed as kilograms of ECM per kilogram of dry matter intake (DMI), kilograms of ECM per 10 MJ of net energy intake (NE_L), kilograms of ECM per 100 kg of BW, and kilograms of DMI per 100 kg of BW. Environmental efficiency was expressed by the nitrogen efficiency calculated as N in milk and meat as a percentage of N in intake, and as enteric emission of methane expressed as kilograms of ECM per megajoule of CH_4. Mean milk yield for lactating cows was 30.4 kg of ECM in HOL and 3 kg less in JER, with OTH herds in between. Mean NE_L intake was 122 MJ in JER, increasing to 147 MJ in HOL, whereas ration energy density between breeds did not differ (6.4–6.5 MJ of NE_L per kg of DMI). The NE_L intake and DMI explained 56 and 47%, respectively, of variation in production (ECM) for HOL herds but only 44 and 27% for JER. Jersey had a higher efficiency than HOL and OTH, except in nitrogen efficiency, where no significant difference between breeds existed. Most of the efficiency measures were internally significantly correlated and in general highly positively correlated with milk production, whereas the correlation to DMI was less positive and for JER negative for net energy efficiency, kilograms of ECM per kilogram of DMI, and nitrogen efficiency. Only little of the variation in efficiency between herds could be explained by differences in nutrient or roughage content of DMI. This could be explained by the fact that data were collected from herds purchasing feed planning and evaluation from the extension service.
Key words: Jersey, Holstein, efficiency, commercial herd, environmental impact

INTRODUCTION

Dairy farming has a long tradition of recording milk yields as a major source of information for evaluating individual cows and the productivity of herds. Information about feed intake at herd, or even individual-cow, level will significantly increase the scope for evaluation and planning of the production, leading potentially to an increased economic profit and reduced environmental load from the production (Maltz et al., 2013). To do this in an optimal way, tools are needed that can estimate the outcome as part of the planning process and for methods than can evaluate the production results, including benchmarking figures.

Feed is the largest of the running costs in intensive, confined milk-production units, and more than two-thirds of that feed is used for the group of lactating cows. Although feed is a large expenditure, it is possible for the farmer to influence the cost by using different types and amounts of feed and by changing the energy content and nutrient concentration in the ration. Feeding level, ration, and nutrient composition and energy concentration are known to affect production efficiency as well as the excretion of nutrients and emission of

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greenhouse gasses from the herd (Aguerre et al., 2011) and farm (Rotz et al., 2010; Kristensen et al., 2011). Therefore, feed management is of great importance. Thus, Jonker et al. (2002) have shown that milk yield and N efficiency were increased when farms introduced weekly or monthly determination of roughage DM content compared with farms with less-frequent determination.

The Nordic feed evaluation system (**NorFor**) is a nonadditive, net-energy system (Volden, 2011) that also balances the protein supply according to the absorption of amino acids in the intestine and supply of protein to the rumen. The output from NorFor is the expected intake of individual feeds or TMR, defined by specific feeds, and the expected milk production in kilograms of ECM and live weight change per day according to stage of lactation. NorFor has been incorporated into the dairy management system developed in recent years in Denmark and adopted by dairy-farm advisors (DLBR, 2014). The dairy management system includes several tools with specific aims: NorFor-Plan for economic optimization of the daily feed ration and individual intake, and NorFor-Control for evaluating the actual feeding and production, including efficiency of production, energy, and nutrients at herd or group level.

Jersey is the second-most-common dairy breed in Denmark, making up 13% of the dairy stock in Denmark, whereas Holstein-Friesian is the most dominant breed at 70% of all dairy stock (RYK, 2013). Based on annual results from commercial dairy herds, Kristensen and Kjærgaard (2004) found a higher net energy efficiency (energy requirements/energy intake) for Jersey herds than for Holsteins, using the Scandinavian Feed Unit (**SFU**) system (Weisbjerg and Hvelplund, 1993) to calculate net energy intake from DMI, and a higher efficiency in herds managed organically rather than conventionally. Nitrogen efficiency is also higher for Jerseys than for Holsteins, but annual milk yield per cow and energy efficiency, rather than breed, are the main explanatory factors for this difference in N efficiency (Nielsen and Kristensen, 2001). In earlier studies, Jersey cows have been shown to have a higher intake capacity per kilogram of live weight than Holstein-Friesians (Oldenbroek, 1988), which was confirmed in a newer study with primiparous cows by Olson et al. (2010). This could be part of the reason why Prendiville et al. (2009) found that Jerseys have higher gross energy efficiency (milk solids/DMI) than Holsteins, despite a lower milk-solid production. Milk yield across systems and breeds has been increasing, from 7,900 kg of ECM in 2004 (Kristensen and Kjærgaard, 2004) to 9,500 kg in 2010 (RYK, 2013). The former results were based on data from an entire dairy herd over 1 yr and use of the SFU system. The treatment of breed effect, as affected by cow weight and feeding level, in the NorFor system differs from the SFU system. A comparison based on information from only the lactating cows might change the conclusions because DIM and parity have an effect on energy balance (Olson et al., 2010).

The objective of this paper was to compare efficiency measures, milk production, and feed intake for lactating cows in commercial herds using different breeds and production and milking systems to supply dairy farmers and the extension service with updated information and benchmarking figures for feed intake, production, and efficiency in the dairy herd.

MATERIALS AND METHODS

Feeding plans and evaluation of feeding in dairy herds made by the extension service in Denmark are uploaded into a central database (DLBR, 2014), allowing the compilation of a large number of data representing dairy farming in Denmark. For the present work we used all feed evaluations recorded for the lactating cows in the period November 2012 to April 2013, which, after filtering, resulted in 1,389 recordings, representing 779 herds, or 25% of all herds with milk records in Denmark (RYK, 2013). Only the last recording for each herd was used to avoid replicates for farms. All herds were fed either a total mixed or partial mixed ration. The cows were housed in loose housing systems, typically cubicles with slatted floor, and milked in either a parlor milking unit or an automatic milking system (**AMS**). More detailed information about milking and housing was not available. In a milking parlor system, cows are typically milked twice a day, but some herds might have been milked 3 times, whereas the typical milking frequency in an AMS is 2.6 to 3.0 times a day (Bossen and Sigurdsson, 2013). Of the herds, 10% were organic certified, which includes use of organic-produced feed of which 60% of DMI has to be roughage.

Information on feed intake was based on daily consumption of concentrates at the feeding stations or AMS, calculated from the daily amounts (kg) of feedstuffs offered to the lactating cows (measured by scale at the mixer wagon), and corrected for leftovers. Dry matter and nutrient contents of each feed item were primarily based on feed analysis and second on standard table values (www.norfor.info). The expected feeding value of the ration, taking into account the actual DMI, was calculated by the Nordic feed evaluation system (NorFor) and expressed in megajoules of NE_L, whereas the feeding value of a single feed item was expressed in megajoules of $\mathbf{NE_{20}}$, based on the net energy content at a standard intake of 20 kg of DM. In addition, NorFor calculated nutrient content, protein value, fill value, and chewing time in the ration (Volden, 2011). Besides, we obtained information about daily herd milk production, and content of fat and protein, delivered to the dairy and corrected for on-farm use for calves, and so on. Energy-corrected milk was calculated as described by Sjaunja et al. (1990). The proportion of primi- and multiparous cows and average DIM were also available. Average live weight in kilograms and daily gain in grams per day at the day of feed registration for the group of lactation cows were also included in the data set. However, this information was based on standard live weight changes according to breed, parity, and DIM, with adjustments for slaughter weights for culled cows within herd (Volden, 2011).

The data were grouped into 3 breed categories based on the proportion of genes in the herd, with Holstein-Friesian (**HOL**) defined as herds with more than 85% Holstein genotype and similarly for Jersey (**JER**), whereas the remaining herds were grouped as other breeds (**OTH**). Average herd milk yield (kg of ECM) from the last year (1 October 2011 to 30 September 2012) of milk recording was added. This average milk yield per herd was based on all feeding days in the herd including dry cows.

The final data set consisted of 508 HOL, 100 JER, and 171 OTH herds. The annual, average milk yield recorded per herd was 8,716 kg of ECM for JER and 9,606 kg of ECM for HOL (Table 1). Average herd size in the 3 breeds ranged from 197 to 224 lactating cows, with 36 to 40% primiparous cows and an average of 190 to 196 DIM. The proportion of herds managed according to the organic principles ranged from 8% for JER to 13% for OTH, whereas the use of AMS ranged from 22% of JER to 30% of OTH herds.

Efficiency has been defined in several ways in the literature (Østergaard et al., 1990; Prendiville et al., 2009). For calculating energy efficiency we used net energy efficiency (**NELEFF**), defined as total energy requirement (milk, growth, reproduction, and maintenance) in percent of energy (NE_L) intake, and residual feed intake, defined as energy intake (NE_L) minus energy requirement. In addition, we calculated production-efficiency variables using only intake and milk, either as milk per kilogram of DMI (**ECMDMI**), defined as kilograms of ECM per kilogram of DMI, or as milk per 10 MJ of NE_L (**ECMNEL**). Production and intake were also measured in relation to live weight, as ECM per 100 kg of live weight, and as DMI per 100 kg (**DMIBW**). The environmental efficiency was described for nitrogen (N) as nitrogen efficiency (**NEFF**) calculated as N in milk and meat in percent of N intake, where N in milk was defined as milk protein/6.38 and N in meat was set to 26 g of N per kilogram of live-weight change (Poulsen and Kristensen, 1998), whereas N in feed was defined as CP/6.25. In addition we estimated the enteric emission of methane (CH_4) from the equation implemented in NorFor (Nielsen et al., 2013), where MJ of CH_4 = 1.23 × DMI (kg) − 0.145 × fatty acids (g/kg of DM) + 0.012 × NDF (g/kg of DM), and as efficiency in kilograms of ECM per megajoule of CH_4.

Each herd was considered as an experimental unit. Production and milking system in each herd was used to correct the average breed effect due to the unbalanced structure of the data set. Effects of breed (HOL, JER, and OTH), production system (organic and conventional), and milking system (parlor and AMS) and all 2-way interactions were tested using PROC GLM (SAS, 2009). Because the interaction was not significant ($P > 0.6$) between breed and production system or breed and milking system, the model was reduced to include only breed, production system, and milking system as independent variables. Results for effect of breed are reported in tables as least squares means and standard deviation (**SD**) within breed, and significance is declared if $P \leq 0.05$. Some of the significant results of systems are given in the text.

Table 1. Description of herds on commercial dairy farms grouped after breed, annual data

	Holstein-Friesian		Jersey		Other	
Item	Mean	SD	Mean	SD	Mean	SD
Herd size, no. of lactating cows	197	102	224	123	198	119
Production,[1] kg of ECM per year	9,606	978	8,716	1,084	9,158	1,201
Live weight, kg	602	30	414	22	584	50
Parity, % primiparous	39	6	36	7	40	6
DIM	197	20	191	21	193	20
Holstein-Friesian, % of cows	97	4	0		39	33
Jersey, % of cows	0		98	3	6	18
Other, % of cows	3	3	2	3	55	26
Organic farming, % of herds	10		8		13	
AMS,[2] % of herds	28		22		30	

[1]Production = herd average from milk recording.

[2]AMS = automatic milking system.

Table 2. Production and feed intake in the group of lactating cows in commercial herds of different breeds

	Holstein-Friesian		Jersey		Other	
Item	Mean	SD	Mean	SD	Mean	SD
Milk yield, kg of ECM	30.4[a]	3.2	27.4[c]	2.2	28.9[b]	3.2
Live weight gain, g	104[a]	68	75[b]	50	109[a]	71
Energy requirement, MJ of NE_L[1]	139[a]	11	119[c]	7	133[b]	12
Intake, MJ of NE_L	146[a]	11	122[c]	7	139[b]	11
Intake, kg of DM	22.6[a]	1.7	18.8[c]	1.2	21.6[b]	1.7

[a–c]Means with identical superscripts are not significantly ($P > 0.05$) different.

[1]NE_L = net energy for lactation calculated according to Volden (2011).

The relation between intake, production, and efficiency measurements was investigated by PROC CORR (SAS, 2009) to calculate partial correlation coefficients for each breed. Only results for HOL and JER are presented because OTH was very similar to HOL. In addition, the effect of production level (kg of ECM) on selected efficiency measurements was modeled using PROC GLM (SAS, 2009) within each breed with a model including intercept, a linear and second-power polynomial relation. The predicted efficiency at production levels within the range of average ±3 SD within breed is presented as benchmarking figures.

The relation between intake (NE_L or DMI) and production (ECM) were modeled using PROC GLM (SAS, 2009) with a model that included intercept, a linear and second-power polynomial relation. This was done for 2 subgroups of herds with either high or low efficiency (NELEFF or ECMDMI), defined as the top or bottom 25% of observations within breed, identified by PROC Univariate (SAS, 2009). The results of the subgroup modeling are presented in figures where the minimum–maximum axis values are set according to ±3 SD within breed calculated for the total number of observations within breed.

Evaluation of variation in efficiency measurements in relation to feeding was difficult because of a high degree of interrelation and correlation between the variables. To tackle the complex relations between the variables we used a principal-component analysis (**PCA**) by PROC PRINCOMP (SAS, 2009) to identify the correlation structure between the variables defining the feed ration. Based on the PCA plots of loadings from the 2 first principal components, one variable from each group of correlated variables was selected for use in a regression analysis by PROC GLM (SAS, 2009). First the model was run with breed included in the model, but because breed was nonsignificant, the final model only included the selected low correlated feed variables as independent variables. For each efficiency measures is the result of the model reported as the proportion of variation explained by each independent variable, calculated from type 3 mean square values for each independent variable and the total model explanation.

Table 3. Dietary characteristics of the total ration fed to lactating dairy cows in commercial herds of different breeds

	Holstein-Friesian		Jersey		Other	
Item	Mean	SD	Mean	SD	Mean	SD
Energy density, MJ of NE_L per kg of DM	6.45	0.18	6.49	0.22	6.44	0.19
OM, g/kg of DM	925	8	923	9	926	8
CP, g/kg of DM	163[b]	9	169[a]	11	163[b]	10
AAT,[1] g/kg of DM	111	9	112	10	111	10
PBV,[2] g/kg of DM	15[a]	8	13[b]	10	16[a]	9
Crude fat, g/kg of DM	44[b]	6	49[a]	18	44[b]	6
FA, g/kg of DM	29[b]	5	34[a]	15	29[b]	5
NDF, g/kg of DM	337[a]	23	318[b]	22	339[a]	22
Starch, g/kg of DM	165[b]	33	178[a]	34	166[b]	35
Sugar, g/kg of DM	60	22	60	29	58	27
Fill units,[3] per kg of DM	0.37	0.01	0.37	0.01	0.38	0.01
Chewing time, min/kg of DM	36[a]	3	32[b]	3	36[a]	4

[a,b]Means with identical superscripts are not significantly ($P > 0.05$) different.

[1]AAT = amino acids absorbed in the intestine estimated according to Volden (2011).

[2]PBV = protein balance in the rumen estimated according to Volden (2011).

[3]The cow has a capacity and the feedstuffs or diet have a fill, calculated in arbitrary units according to Volden (2011).

Table 4. Ingredients (% of DMI) and energy concentration of maize silage and grass silage in rations fed to lactating cows in commercial herds of different breeds

	Holstein-Friesian		Jersey		Other	
Breed	Mean	SD	Mean	SD	Mean	SD
Ingredient, % of DMI						
Cereals	7	6	8	8	7	7
Protein feed (soy and rape)	11[b]	8	13[a]	10	11[b]	9
Concentrate mix	13	10	14	12	13	10
By-product	4	5	5	6	5	6
Maize silage	31	11	32	13	32	13
Grass silage	31[a]	12	25[b]	13	29[a]	14
Other roughage	2	2	1	2	2	2
Mineral	1	2	2	2	1	1
Maize silage, MJ of NE_{20} per kg of DM[1]	6.20[b]	0.37	6.34[a]	0.39	6.24[b]	0.37
Grass silage, MJ of NE_{20} per kg of DM	6.04[a]	0.24	5.99[ab]	0.29	5.98[b]	0.30

[a,b]Means with identical superscripts are not significantly ($P > 0.05$) different.

[1]NE_{20} = net energy at 20 kg of DMI calculated according to Volden (2011).

RESULTS

Mean milk yield at the day of feed registration for lactating cows was 30.4 kg of ECM for HOL and 3.0 kg less in JER, with OTH herds in between (Table 2). The organic herds produced 1.8 kg of ECM less than the conventional, and the AMS herds produced 0.8 kg of ECM more than the herds milked in parlor (data not shown), without any significant interaction with breed.

The calculated energy requirement ranged from 119 MJ of NE_L in JER, of which 71% was for milk production, to 139 MJ in HOL, where 66% was for milk production. Mean NE_L intake was 122 MJ in JER, increasing to 146 MJ in HOL, whereas no difference in ration energy density between breeds existed, which varied from 6.4 to 6.5 MJ of NE_L per kilogram of DMI (Table 3). The level of CP, fatty acids, and starch was higher in JER than in HOL and OTH, whereas supply of protein to the rumen and content of NDF were lower in JER than in HOL and OTH, as also was the chewing time.

The proportion of roughage (maize silage, grass silage, and other roughages) was high in all herds, with an average of 58% of DMI for JER and more than 63% in the 2 other groups (Table 4), with a SD between herds of only 6 to 8 percentage units (data not shown). Grouping according to production system showed a higher proportion of roughage in the organic herds (68% of DMI) than in the conventional herds (62%; data not shown). Overall, roughage was close to being 50–50 grass–maize silage, with grass silage based on ryegrass–clover mixtures. Maize silage was more dominant in JER than in the 2 other groups, and the energy concentration of the maize silage was slightly higher for JER herds, which resulted in an average roughage energy concentration of 6.19 versus 6.08 MJ of NE_{20} per kilogram of DM for JER and HOL herds, respectively.

The efficiency expressed by the 8 different variables in the breed groups showed that JER in most cases had a higher efficiency than HOL and OTH, except for NEFF with no significant difference between groups

Table 5. Efficiency measures for energy, production, and environmental load in the group of lactating cows in commercial herds of different breeds

	Holstein-Friesian		Jersey		Other	
Item[1]	Mean	SD	Mean	SD	Mean	SD
Energy						
NELEFF, %	95.6[b]	4.7	97.8[a]	4.4	95.8[b]	4.8
Residual feed intake, MJ of NE_L	6.4[a]	6.9	2.8[b]	5.4	6.0[a]	6.6
Production						
ECMNEL, kg of ECM per 10 MJ of NE_L	2.09[b]	0.15	2.25[a]	0.13	2.07[b]	0.16
ECMDMI, kg of ECM per kg of DMI	1.35[b]	0.11	1.46[a]	0.10	1.34[b]	0.12
ECMBW, kg of ECM per 100 kg of LW	5.06[b]	0.55	6.65[a]	0.63	4.97[b]	0.66
DMIBW, kg of DM per 100 kg of LW	3.76[b]	0.30	4.56[a]	0.36	3.72[b]	0.32
Environment						
N efficiency, %	27.5	2.3	27.3	2.5	27.4	2.4
ECMCH4, kg of ECM per MJ of CH_4	1.12[b]	0.10	1.26[a]	0.18	1.11[b]	0.11

[a,b]Means with identical superscripts are not significantly ($P > 0.05$) different.

[1]NELEFF = total energy requirement in percent of NE_L intake; LW = live weight.

Table 6. Correlation coefficients of efficiency measures, milk yield, and intake from the group of lactating cows in commercial herds[1]

No.	Measure[2]	1	2	3	4	5	6	7	8	9	10
1	NELEFF		−0.99	0.77	0.71	0.24	−0.34	0.64	0.33	0.40	−0.30
2	RFI	−0.99		−0.76	−0.71	−0.72	0.36	−0.64	−0.32	−0.37	0.33
3	ECMNEL	0.78	−0.76		0.88	0.69	NS	0.68	0.47	0.70	NS
4	ECMDMI	0.73	−0.71	0.94		0.59	NS	0.67	0.32	0.64	−0.31
5	ECMBW	0.33	−0.27	0.72	0.69		0.69	0.31	0.26	0.84	0.38
6	DMIBW	−0.28	0.33	NS	NS	0.69		−0.22	NS	0.45	0.75
7	NEFF	0.65	−0.63	0.71	0.71	0.50	NS		0.21	0.39	−0.25
8	ECMCH4	0.70	−0.68	0.89	0.97	0.66	NS	0.65		0.31	NS
9	ECM	0.40	−0.33	0.70	0.72	0.90	0.52	0.52	0.70		0.52
10	DMI	0.21	0.28	NS	NS	0.54	0.80	NS	0.28	0.66	

[1]Above diagonal = Jersey, below diagonal = Holstein-Friesian.

[2]NELEFF = total energy requirement in percent of NE_L intake; RFI = residual feed intake; ECMNEL = kilograms of ECM per 10 MJ of NE_L; ECMDMI = kilograms of ECM per kilogram of DMI; ECMBW = kilograms of ECM per 100 kg of live weight; DMIBW = kilograms of DM per 100 kg of live weight; NEFF = N efficiency; ECMCH4 = kilograms of ECM per megajoule of CH_4.

(Table 5). Most of the efficiency variables were internally significantly correlated (Table 6). The 2 energy-efficiency variables, NELEFF and residual feed intake, were highly correlated, indicating that only one of them is needed for evaluations at herd level. Of the efficiency variables, the 3 based on ECM were significantly positively correlated, whereas DMIBW seemed disconnected with low or no significant relation to the other variables for both HOL and JER. In general, only minor differences across breeds existed, with kilograms of ECM per megajoule of CH_4 as an exception, showing lower correlations for JER than HOL.

The efficiency variables were, in general, highly positively correlated to milk production, whereas the correlation to DMI was less positive and for JER negative for NELEFF, ECMDMI, and NEFF. The effect of variation in yield (ECM) on efficiency measurements was modeled for the NELEFF, ECMNEL, ECMDMI, and NEFF for HOL and JER (Table 7). The models explained from 15 to 62% of the variation in efficiency, with increasing goodness of fit from NELEFF and NEFF to ECMDMI and ECMNEL. Only for ECMNEL and ECMDMI was the second-power polynomial significant, with a reduced effect on efficiency with increasing milk yield.

The NE_L intake and DMI, based on a model including intercept and a linear relation (because the second-power polynomial was nonsignificant), explained 56 and 47%, respectively, of variation in production (ECM) between HOL herds but only 44 and 27% in JER herds. The marginal effect of 1 MJ of NE_L was 0.22 kg of ECM in HOL and 0.20 kg in JER, compared with the 0.32 kg of ECM per MJ of NE_L as standard in NorFor (Volden, 2011), leading to a marginal net energy ef-

Table 7. Benchmarking figures for 4 efficiency measures[1] from the group of lactating cows in commercial herds at different levels of milk yield within breed

ECM[2]	NELEFF	ECMNEL	ECMDMI	NEFF
Holstein				
20.8	90.1	1.73	1.08	23.9
24	91.9	1.87	1.18	25.1
27.2	93.8	1.99	1.27	26.3
30.4	**95.6**	**2.11**	**1.35**	**27.5**
33.6	97.5	2.20	1.43	28.7
36.8	99.3	2.29	1.49	29.9
40	101.2	2.36	1.55	31.1
Jersey				
20.8	92.4	1.87	1.20	24.3
23.0	94.1	2.04	1.32	25.3
25.2	95.9	2.17	1.42	26.3
27.4	**97.7**	**2.28**	**1.50**	**27.3**
29.6	99.5	2.36	1.56	28.3
31.8	101.2	2.40	1.59	29.3
34.0	103.0	2.42	1.61	30.3

[1]NELEFF = total energy requirement in percent of NE_L intake; ECMNEL = kilograms of ECM per 10 MJ of NE_L; ECMDMI = kilograms of ECM per kilogram of DMI; NEFF, % = N efficiency.

[2]Average yields ±3 times SD within breed are shown (kg/d of ECM per lactating cow). Bold indicates average yield.

ficiency of 68% in HOL and 64% in JER by increasing net energy intake. Figures 1 and 2 give model estimates for HOL and JER calculated for the low- and high-efficiency herd groups, based on NELEFF when NEL is the model output (a) and on ECMDMI when DMI is the model input (b). The effect of efficiency group on production level is clear, and the higher marginal effect in the high-efficiency group increased the difference in production at high level of intake.

The effect of nutrient content and ration formulation on efficiency measures was investigated by first reducing the number of variables by a PCA followed by a traditional ANOVA. Four groups of variables were identified based on the PCA plot, where variables represented in one group are higher correlated than variables from other groups. Four variables were selected to be used in the ANOVA:

1. Roughage (% of DMI),
2. Fiber (NDF; g of NDF per kg of DMI),
3. Protein (g of CP per kg of DMI), and
4. Starch (g of starch per kg of DMI).

The variation expressed by the variables explained from 4% (NELEFF) to 30% (NEFF) of the variation in the different efficiency measurements (Figure 3). For production efficiency, the model explained 7% of variation in DMIBW, increasing to 27% of the total variation in ECMDMI, where the proportion of roughage had a negative effect and the protein content of the ration a

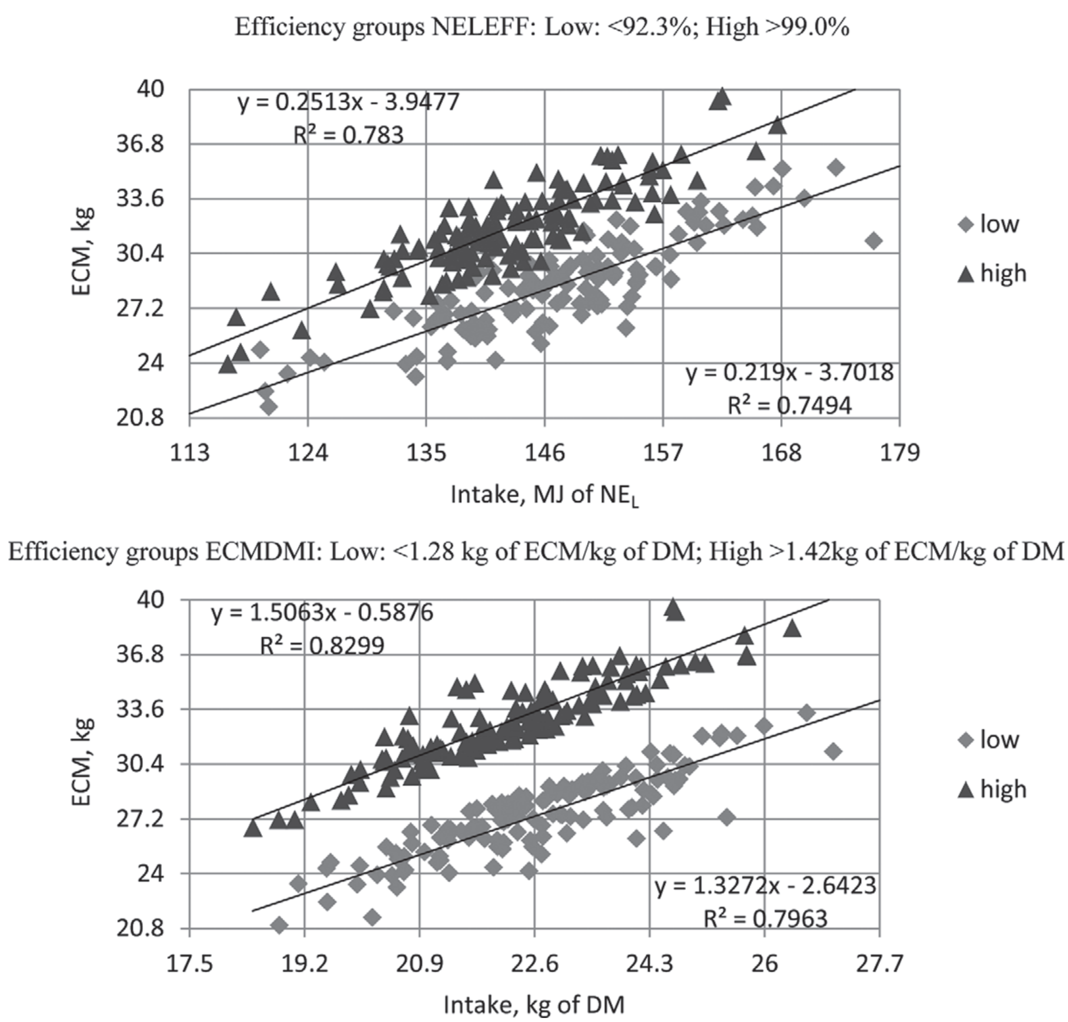

Figure 1. Intake (a: net energy; b: DM) and production of milk, kilograms of ECM, in high- and low-efficiency groups of lactating Holstein cows. Average ±3 SD for intake and production illustrated by gridlines. NELEFF = total energy requirement in percent of NE_L intake; ECMDMI = kilograms of ECM per kilogram of DMI.

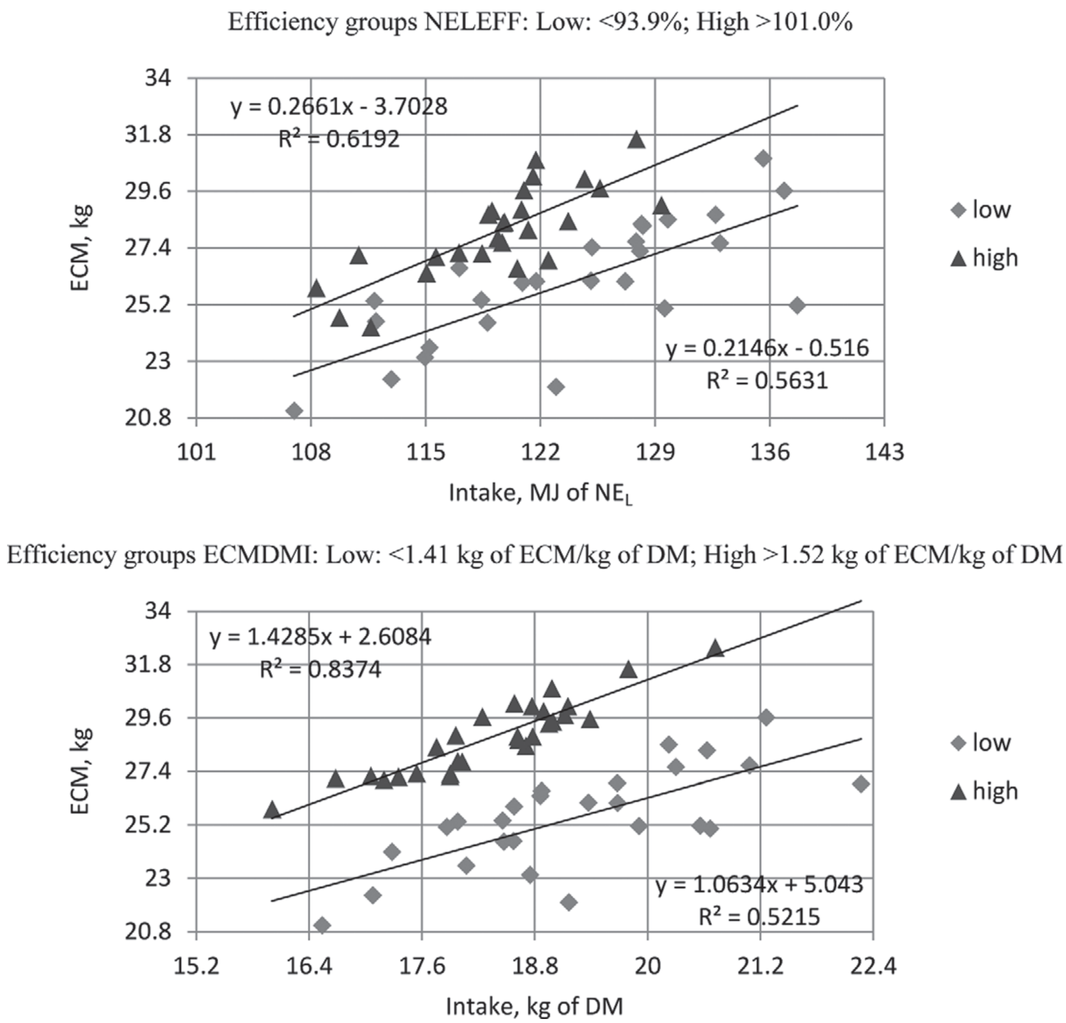

Figure 2. Intake (a: net energy; b: DM) and production of milk, kilograms of ECM, in high- and low-efficiency groups of lactating Jersey cows. Average ±3 SD for intake and production illustrated by gridlines. NELEFF = total energy requirement in percent of NE_L intake; ECMDMI = kilograms of ECM per kilogram of DMI.

positive effect on ECMDMI. Environmental efficiency, NEFF, was strongly influenced by CP content.

DISCUSSION

The paper is based on observational data from commercial herds. The main limitation in extracting causal relationships is because feed is not randomly allocated, independently of the production and efficiency variables. Detailed and more biological analysis of the relation between input and output is therefore not possible, but some ideas will be stressed based on literature and knowledge about herd management to explain the results.

The study herds had slightly lower annual milk yields—289, 133, and 173 kg of ECM per cow for HOL, JER, and OTH, respectively—than the Danish average, whereas herd size in the study was higher than the Danish average of 155, 171, and 177 cows for HOL, JER, and OTH, respectively (RYK, 2013). Herd structure was comparable to the national average with 39% primiparous cows. The proportion of organic farms was identical to the national average of 10%, whereas AMS milking systems was slightly more common in the study herds at 28% of herds compared with 22% for Denmark generally.

Intake and Production

Intake of DM and energy was 20% higher in HOL than JER in this study, and milk production was 11% higher, which agrees with the findings of Bossen et al. (2009) across different feeding strategies; Olson et al. (2010), who used first-lactation cows; and Olden-

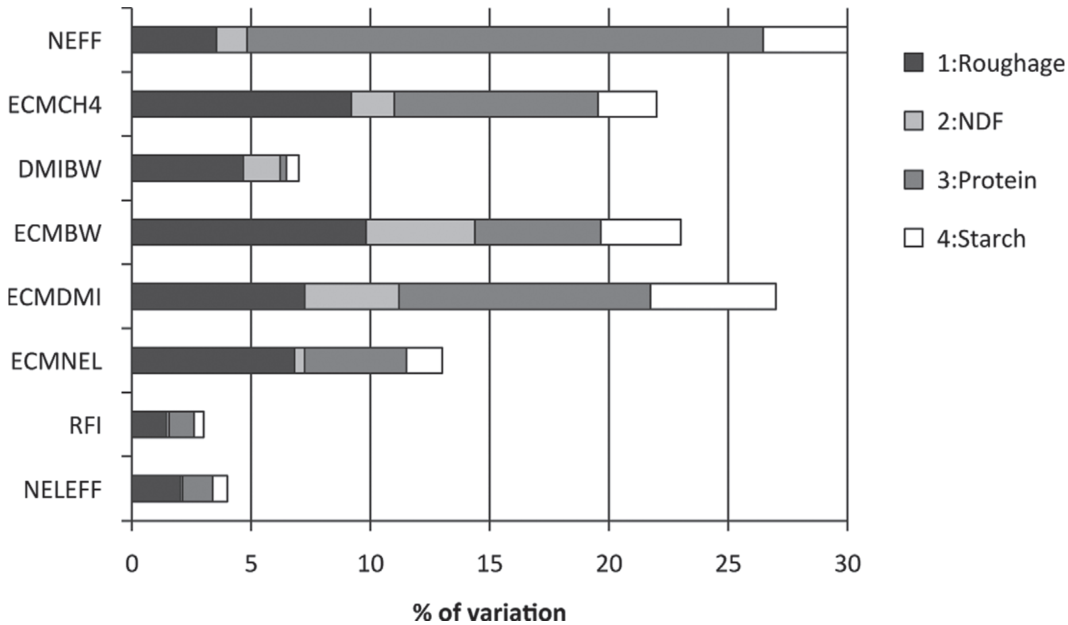

Figure 3. Percentage of variation in 8 efficiency measures in commercial herds explained by 4 variables related to feeding. Roughage = proportion of DMI from roughage; NDF = grams per kilogram of DMI; Protein = CP, grams per kilogram of DMI; Starch: grams per kilogram of DMI; NELEFF: total energy requirement in percent of NE_L intake; RFI: residual feed intake; ECMNEL: kilograms of ECM per 10 MJ of NE_L; ECMDMI: kilograms of ECM per kilogram of DMI; ECMBW: kilograms of ECM per 100 kg of live weight; DMIBW: kilograms of DM per 100 kg of live weight; ECMCH4: kilograms of ECM per megajoule of CH_4; NEFF: N efficiency.

broek (1988), who used cows in their first 3 lactations. Friggens et al. (2007) found a similar effect of breed on intake at a slightly lower absolute level of intake, whereas Prendiville et al. (2009), in a study that was almost entirely pasture based and with lower-yielding cows, found a 15% lower DMI in JER compared with HOL and an 8% lower milk yield. The smaller effect might be a result of some restriction in feed allowance during grazing, compared with the ad libitum feeding with TMR in this study and in the study by Friggens et al. (2007).

The variation between herds in nutrient content and energy concentration was much lower than in experimental treatments in the literature. In our study the SD for CP was 9 to 11 g/kg of DM in the 3 breeds, whereas Phuong et al. (2013) in a meta-analysis of energy and nitrogen efficiency achieved an SD for 306 diets of 20 g/kg of DM but the same mean of 170 g of CP in DM as in this study. The low variation in our study is because the data represent good farming practice, using feed formulations made by the farmer in consultation with NorFor, where default constraints in nutrient content are defined (Volden, 2011). These values can be exceeded either on purpose during the planning process or as a result of the actual feeding situation, leading to observations of some contents falling outside the default values, but still with low variation between farms. Using farm data from farms with less focus on the parameter in question would probably have increased the variation, as illustrated by Jonker et al. (2002), where the SD for N intake before intervention was almost double that calculated after intervention across 372 farms with focus on N efficiency. Also Godden et al. (2001) found larger variation in milk production, DMI, and nutrient content across 45 farms with less-intensive feed planning than in our study.

Efficiency

Ideally, estimates of efficiency should include all outputs and inputs relevant for the purpose of the specific efficiency variable but should also respect the practical limitations to getting reliable data. In this case, data were based on routinely sampled data from commercial herds with the original aim of collecting information at herd level for feeding management.

Energy Efficiency. In our study energy efficiency (NELEFF) was defined as net energy (NE_L) compared with the estimated net energy in DMI, where NE_L included a reduced efficiency with increased level of intake (Volden, 2011), which might reduce the estimated net energy intake compared with other, more traditional, net energy systems. The use of NE_L takes into account all deviations in energy losses from gross energy to net energy as calculated in the NorFor system; therefore, NELEFF in theory should be 100%. Variation between cows in energy requirement to meet specific demands and different utilization efficiency of net energy for the production of milk will introduce variation in NELEFF, as shown by André et al. (2010) for the response of individual cows to additional concentrates. The efficiency achieved was 97.8% in JER and significantly less at 95.6% in HOL. The higher efficiency in JER was also found by Kristensen and Kjærgaard (2004) in herd studies and by Bossen and Weisbjerg (2009) under experimental conditions, but no other comparable results can be found in literature.

Only little (8%) of the variation in NELEFF could be explained by differences in feeding or by the production level (16%). Kristensen and Kjærgaard (2004) found 3 areas with significant effect on the variation in herd net efficiency based on the SFU system. The 2 most significant were nutrient content in the ration, which explained 9%, and production level, which explained 24% of the variation. The lower effect of production level in this study is probably because NorFor includes part of the effect of increased intake on NE_L, which the SFU system does not. The third area was health, which could explain 6% of the variation. The potential effect of health status on NELEFF is supported by Bareille et al. (2003), who found that mastitis, retained placenta, and leg injuries have a relatively larger deflating effect on production than intake, leading to reduced efficiency, whereas other diseases such as ketosis and milk fever have a positive effect on efficiency because intake is more affected than production.

Production Efficiency. In our study production efficiency was based on different combinations of DMI, NE_L intake, live weight, and ECM milk production. As argued by Østergaard et al. (1990) and Hall (2013), kilograms of milk per kilogram of DMI is the simplest version of efficiency, but adjusting for fat and protein content is at a minimum necessary to achieve more general figures across breeds. Even ECM needs to be specified because the correction can be made to different standards; in the formula from www.drms.org, the correction for fat and protein to ECM is 3.5 and 3.2%, respectively, leading to an 8 to 9% higher production in "kg of ECM" than when using the formula from Sjaunja et al. (1990).

Intake in this study was kilograms of DM offered based on weight, with a correction for refusals based on a subjective measurement. If only "offered amount" is used, it might increase DMI by 2 to 5%, even when intake is from commercial herds.

Jerseys produced 8% more milk than HOL, when calculated as milk per kilogram of DMI or per megajoule of intake, and 31% more when calculated per kilogram of live weight. Intake per kilogram of live weight was 21% higher in JER compared with HOL and OTH. The additional intake per kilogram of live weight was higher than that found by Friggens et al. (2007) and Olson et al. (2010) based on cows of same relative weight as in this study (JER 69% of HOL), and it was much higher than the 7% higher intake found by Prendiville et al. (2009) when taking into account the 74% relative weight of JER to HOL. The relatively higher intake was primarily a result of a higher intake in JER (4.56 kg of DM per 100 kg of live weight) compared with 3.63 to 4.20 kg in the 3 studies cited above. This also means that the milk production per kilogram of intake from JER compared with HOL in this study was less than the 11 to 21% increase in JER relative to HOL found in the 3 other studies. Compared at same level of production, it can be estimated from Table 7 that the advantage to JER compared with HOL (in terms of ECMDMI) increases from 11% additional milk per kilogram of DMI at 20.8 kg of ECM daily to 17% when production is the average of JER (27.4 kg of ECM) and decreases at higher production levels.

Increasing the proportion of roughage in the ration had a negative effect on all production-efficiency measures, as also found by Phuong et al. (2013) for energy efficiency. Aguerre et al. (2011) found a linear decrease in milk yield with increased proportion of roughage but an increase in ECM per kilogram of DMI when roughage increased from 47 to 54% of DMI, followed by a reduction when forage was increased to 68% of DMI. With proportions of roughage in our study being 58 and 64% of total DMI in JER and HOL, respectively, this may explain the reduced production efficiency.

The NDF content of the ration was positively related to ECMDMI and negatively to DMIBW. This could be a direct effect of intake being regulated by the physical capacity, with low energy concentration reducing the passage rate in the rumen.

Environmental Efficiency

Nitrogen efficiency was lower than that found by Aguerre et al. (2011) for HOL in early lactation and slightly lower than that in the study by Jonker et al. (2002) based on data from lactating cows, but it was higher than the results from 76 commercial herds found by Arriaga et al. (2009) and from Danish herds (Nielsen and Kristensen, 2001) during the indoor period, based on all cows in the herd. The effect of milk production on NEFF is consistent with others (Nielsen and Kristensen, 2001; Jonker et al., 2002; Arriaga et al., 2009), although the model only explained 16% of the variation between herds. Also the use of TMR, as in this study, has been found to have a positive effect on NEFF (Arriaga et al., 2009), whereas they could not find an effect of frequent ration formulation during the year compared with none or less-frequent feed formulation.

The variation in NEFF between herds was low (CV <10%), but the feed-ration variables explained 30% of the total variation, with, not surprisingly, CP intake being the most important, followed by proportion of roughage, which had a negative effect on NEFF.

We expressed efficiency in relation to CH_4 as megajoules of CH_4 per kilogram of ECM with efficiency of 1.12 in HOL and 1.26 MJ of CH_4 per kilogram of ECM in JER. The level in HOL was identical to that found by Aguerre et al. (2011), which had a similar proportion of roughage of total DMI. The higher efficiency in JER was the result of the higher ECMDMI and higher fatty acid contents in the ration, as the estimated emission of CH_4 was related to DMI and fat content. In general, kilograms of ECM per megajoule of CH_4 fell when reducing the proportion of roughage as a consequence of the negative correlation between proportion of roughage and DMIBW.

CONCLUSIONS

Estimation of efficiencies relating to energy, production, and environment, based on commercial herd data, can be an important aid in daily herd management. A strong positive correlation between the evaluated efficiency measures and between production and efficiency in general indicates that it is possible to increase productivity while decreasing the environmental load from dairy farming. Only a minor part of the variation in efficiency between herds could be explained by differences in the nutrient or roughage contents of DMI. This might be because data are based on herds participating in intensive feed planning and feed control. Holstein cows have a higher production and intake but lower efficiency than Jersey, when compared at the average production level of the commercial herds.

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