Factors Influencing Feed Efficiency in Dairy Cattle

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INTRODUCTION

Although feed efficiency has long been a parameter of major importance for beef, swine, and poultry operations; an emphasis in dairy cattle feeding has been relatively recent (Hutjens, 2005). Britt et al. (2003) reported that for 13 commercial dairy herds visited 34 times over 14 mo, feed efficiency (kg milk / kg dry matter intake [**DMI**]) averaged 1.4 and ranged from 1.1 to 1.7. Dyk (2009) reported that for 11 commercial dairy herds evaluated during 1 mo, feed efficiency (kg milk / kg DMI) averaged 1.6 ranging from 1.3 to 1.9. Cabrera (2009), using a milk price of $0.26/kg and a TMR cost of $0.22/kg DM, calculated that income over feed cost increased by about $5.00/cow/d as feed efficiency was increased from 1.1 to 1.9.

Clearly, feed efficiency is highly variable among commercial dairy herds and this variation can have a significant impact on economic performance. Linn et al. (2009) recently reviewed various factors that can influence feed efficiency in dairy herds; i.e. days in milk (**DIM**); body weight change, whether expressed on an actual, fat-corrected or energy-corrected milk basis; herd management; feed digestibility; heat stress; activity; etc. Addition of monensin sodium to the lactating cow diet increases feed efficiency through reduced feed intake (Ipharraguerre and Clark, 2003). The purpose of this paper is to review 4 factors regarding feed efficiency that we have recently researched: crossbreeding, reduced-starch diets, exogenous amylase, and essential oils.

CROSSBREEDING

There has been considerable recent interest by both researchers and dairy farmers in the crossbreeding of dairy cows (Weigel, 2007). Reasons for this interest include:

- Change to multiple component pricing of milk and desire by some processors to move to cheese-yield pricing of milk,
- Potential for improving herd fertility and health through heterosis or hybrid vigor effects of crossbreeding (Weigel, 2007), and
- An emphasis on improving feed efficiency (Hutjens, 2005).

Holstein (high milk volume) and Jersey (high milk solids content) breeds are established as the predominant breeds in the United States, and thus have been included in many of the early crossbreeding programs on dairy farms. The objective of our trial (Anderson et al., 2007) was to measure milk yield and components, feed efficiency, reproduction, health, and economic performance of paired pens of lactating Jersey plus Jersey-Holstein crossbred and Holstein cows over a year in a Wisconsin confinement dairy herd (Tauchen Harmony Valley, Bonduel, WI).

Cows were freestall housed with a center drive-thru feed alley and milked in a parlor. To initiate the trial a pen (**JX**) of approximately 140 cows was filled from the population of lactating Jersey and Holstein-Jersey crossbred cows. There were not enough lactating crossbred cows to fill the JX pen. Jersey cows were included in the JX pen, because maintaining under-stocked trial pens would have meant over-stocking the non-trial pens for a year, which was unacceptable to herd management. Another pen (**H**) of approximately 140 cows was filled from the population of lactating Holstein cows by pairing with JX cows to equalize parity and DIM of the pens. As cows were dried off from the pens, fresh H and JX cows were added to the pens to maintain similar parity and DIM composition of the pens throughout the trial. Both H and JX cows were co-mingled with other herd mates (both trial and non-trial cows) in a dry cow pen and a fresh cow pen from calving to 21 DIM before entering their respective trial pen. All cows were milked 3 times daily and fed a total mixed ration (**TMR**) once daily with frequent TMR push-up throughout the day. No cows in either pen were injected with bovine somatotropin. The same diet was fed to both pens, and the diet was formulated by the herd nutritionist.

Milk yield measured daily on individual cows was used to determine weekly pen averages for milk yield. Milk samples from each pen were collected on the same day each week using an in-line drip sampler to determine weekly pen milk composition. Samples were analyzed for fat, true protein, lactose, other solids, and milk urea nitrogen. Weekly pen average

Table 1. Production data over the 51 wk of data collection.[1]

Item	Holstein Pen	Jersey/Holstein-Jersey Crossbred Pen
Milk		
kg/cow/d	37.2 ± 1.8	31.7 ± 1.9
Fat, %	3.65 ± 0.13	4.26 ± 0.20
TP, %	2.86 ± 0.09	3.05 ± 0.10
FCM, kg/cow/d	35.2 ± 1.7	33.0 ± 2.0
SCM, kg/cow/d	34.1 ± 1.4	31.8 ± 1.8
ECM, kg/cow/d	37.0 ± 1.6	34.5 ± 1.9
Cheese yield, kg/cow/d	3.7 ± 0.1	3.3 ± 0.1

[1]TP = True protein; FCM = Fat-corrected milk; SCM = Solids-corrected milk; ECM = Energy-corrected milk.

yields of 4 % fat-corrected milk (**FCM**), solids-corrected milk (**SCM**), and energy-corrected milk (**ECM**) were calculated. Weekly pen average cheese yields were calculated using a modified Van Slyke cheddar formula. Scale body weights were recorded for individual cows in the milking parlor return lane on 1 d/mo. Cows were body condition scored monthly. Amounts fed and refused were recorded daily for each pen by the feeder. The TMR was sampled monthly for TMR quality control assay. The monthly TMR DM content was used to calculate the average weekly DMI for the pens for that month. Average weekly pen feed efficiencies (FCM/DMI, SCM/DMI and ECM/DMI) were calculated.

Production data are presented in Table 1. Average milk yield was 5.5 kg/cow/d lower, while average milk fat and true protein percentages were 0.61 and 0.19 %-units, respectively, higher for JX than H. Average yields of FCM, SCM, and ECM were 2.2, 2.3, and 2.5 kg/cow/d, respectively, lower for JX than H. The average calculated cheese yield was 0.5 kg/cow/d lower, for JX than H. Intake and feed efficiency data are presented in Table 2. Average DMI was 2.2 kg/cow/d lower for JX than H, while DMI as a percent of body weight was higher for JX than H. The average body weights were 93 kg lower for JX than H, while average body condition scores were numerically similar for the 2 pens. All feed efficiency measures were numerically similar for the 2 pens. Heins et al. (2008) reported that feed efficiency was not different for JX compared to H during the first 150 d of first lactation.

REDUCED STARCH DIETS AND EXOGENOUS AMYLASE

The optimum starch content of diets for lactating dairy cows is not well defined, but 24 to 26 % starch (DM basis) has been suggested (Staples, 2007). Kaiser and Shaver (2006) and Bucholtz (2006), from surveys of high-producing commercial dairy herds in Wisconsin and Michigan, respectively, reported dietary starch concentrations ranging from 25 to 30 % (DM basis). High corn prices have heightened the interest in feeding reduced-starch diets. Improving corn starch utilization can reduce feed costs by reducing corn in diets or increase income by increasing milk production. Total tract digestibility of starch by dairy cows is highly variable ranging from 70 to 100 % (Firkins et al., 2001). Some exogenous enzymes are resistant to ruminal degradation (Hristov et al., 1998), and thus may offer potential for improving diet digestibility and animal performance. Klingerman et al. (2009) reported that exogenous amylase addition to a normal-starch diet (26 % of DM) increased milk yield by dairy cows. The objective of our trial (Gencoglu et al., 2010) was to determine DMI, total-tract digestibility, lactation performance, and feed efficiency responses in high-producing dairy cows to:

1) A reduced-starch versus a normal-starch diet formulated by partially replacing corn grain with soy hulls and
2) Addition of exogenous amylase to the reduced-starch diet.

Thirty-six multiparous Holstein cows 51 ± 22 DIM and 643 ± 49 kg BW at trial initiation were randomly assigned to 1 of 3 treatments in a completely randomized design; a 3-wk covariate adjustment period with cows fed the normal-starch diet followed by a 12-wk treatment period with cows fed their assigned treatment diets. Diets contained 50 % forage comprised of 2/3rd corn silage and 1/3rd alfalfa silage (DM basis). Soy hulls partially replaced dry ground shelled corn to formulate the reduced starch diet. The normal-starch diet contained 31 % NDF, 27 % starch (DM basis), and did not contain exogenous amylase (**NS-**). The reduced-starch diets contained 37 % NDF, 21 % starch (DM basis), and were fed without (**RS-**) and with (**RS**+) exogenous amylase addition to the TMR. A liquid amylase formulation, Ronozyme RumiStar, provided by DSM Nutritional

Table 2. Intake and feed efficiency data over the 51 wk of data collection and body weight and condition score data over the 12 mo of data collection.[1]

Item	Holstein Pen	Jersey/Holstein-Jersey Crossbred Pen
DMI		
kg/cow/d	23.1 ± 1.0	20.9 ± 1.0
% of body weight	3.96 ± 0.21	4.26 ± 0.18
Feed efficiency		
FCM/DMI	1.53 ± 0.10	1.58 ± 0.12
SCM/DMI	1.48 ± 0.09	1.53 ± 0.11
ECM/DMI	1.61 ± 0.10	1.65 ± 0.12
Body weight, kg	587 ± 16	494 ± 12
Body condition score	2.90 ± 0.05	2.86 ± 0.06

[1]DMI = Dry matter intake; FCM = Fat-corrected milk; SCM = Solids-corrected milk; ECM = Energy-corrected milk.

Products (Basel, Switzerland) and Novozymes (Bagsvaerd, Denmark), was used for this study. Cows were fed individually the TMR twice daily in tie-stalls for 5 % refusal with DMI measured on individual cows throughout the 15-wk trial. Body weight and condition score were recorded weekly throughout the 15-wk trial. Milk yield was recorded daily on individual cows milked twice daily throughout the 15-wk trial. Milk samples were obtained from all cows weekly on the same 2 consecutive days from am and pm milkings throughout the 15-wk trial and analyzed for fat, true protein, lactose, and MUN concentrations. Actual milk and FCM, SCM, and ECM feed conversions were calculated by week using average daily yield and DMI data. Estimated diet energy concentrations were calculated by summing the Mcal of NE_L required for milk production, maintenance, and BW change (NRC, 2001) and then dividing the sum by DMI.

The DMI for cows fed RS- was 2.4 and 3.2 kg/d greater than for cows fed NS- ($P < 0.02$) and RS+ ($P < 0.01$), respectively. Milk yield was unaffected by treatment ($P > 0.10$), and averaged 50.4 kg/d. Fat-corrected milk yield was 2.9 kg/d greater ($P < 0.02$) for cows fed RS- than for cows fed NS-, and tended to be 2.0 kg/d greater ($P < 0.10$) for cows fed RS+ than for cows fed NS-. Similar treatment effects as those observed for FCM yield were observed for SCM, ECM, and milk fat yields. Treatment effects on covariate adjusted least squares means for BW, BW change, BCS, feed efficiency, and estimated diet energy concentrations are presented in Table 3. Body weight, BW change, and BCS were unaffected by treatment ($P > 0.10$). Feed efficiency (kg milk / kg DMI) was 12 % greater ($P < 0.01$) for cows fed RS+ than for cows fed RS-, and tended to be greater ($P < 0.06$) for cows fed NS- than for cows fed RS-. Fat-corrected milk feed efficiency (kg 3.5 % FCM / kg DMI) was 12 % greater ($P < 0.02$) for cows fed RS+ than for cows fed RS-, and tended to be 7 % greater ($P < 0.10$) for cows fed RS+ than for cows fed NS-. Similar treatment effects as those observed for FCM feed conversion were also observed for SCM and ECM feed efficiencies. Estimated diet energy content (Mcal NE_L / kg DM), calculated using energy-corrected milk, BW, BW change, and DMI data, was 12 % greater ($P < 0.02$) for cows fed RS+ than for cows fed RS- and tended to be 8 % greater ($P < 0.10$) for cows fed RS+ than for cows fed NS-.

Feeding a reduced-starch diet, formulated by partially replacing corn grain with soy hulls, compared to a normal-starch diet without addition of exogenous amylase to either diet resulted in the following:

- Greater intakes of DM, OM, NDF, and CP but lower starch intake;
- Greater apparent total tract nutrient digestibilities; and
- Greater FCM, SCM, and ECM yields.

Addition of exogenous amylase to the reduced-starch diet resulted in the following:

- Lower DM and nutrient intakes;
- Greater apparent total tract nutrient digestibilities except for starch which was similar;
- Lower MUN; and
- Greater milk, FCM, SCM, and ECM feed efficiencies.

Greater conversion of feed to milk for dairy cows fed reduced-starch diets with inclusion of exogenous amylase may offer potential for improving economic performance depending on diet and additive costs.

Table 3. Effect of treatment on covariate adjusted least squares means for BW, BW change, body condition score, feed conversion, and estimated diet energy concentrations.[1]

Item	NS-	RS-	RS+	SEM[2]	NS- vs. RS-	NS- vs. RS+	RS- vs. RS+
					- - - - - - - - - - - -	*P* <	- - - - - - - - - - - - -
BW, kg[3]	692	701	699	4	NS[5]	NS	NS
BW Change, kg/d	0.40	0.47	0.41	0.08	NS	NS	NS
BCS[3]	2.2	2.2	2.1	0.1	NS	NS	NS
Feed Conversion[3]							
kg Milk/ kg DMI[4]	1.91	1.77	1.98	0.05	0.06	NS	0.01
kg 3.5 % FCM/ kg DMI	1.77	1.70	1.90	0.05	NS	0.10	0.02
kg SCM/ kg DMI[6]	1.65	1.56	1.75	0.04	NS	0.10	0.01
kg ECM/ kg DMI[7]	1.78	1.68	1.90	0.05	NS	0.10	0.01
Estimated Diet							
Energy Content, Mcal/ kg DM[8]	1.69	1.62	1.82	0.05	NS	0.10	0.02

[1]Treatments were normal-starch diet with no amylase added to TMR (NS-), reduced-starch diet with no amylase added to TMR (RS-), and reduced-starch diet with amylase added to TMR (RS+).
[2]Standard error of the mean.
[3]Wk effect ($P < 0.01$).
[4]Wk × treatment interaction ($P < 0.05$).
[5]Non significant.
[6]Solids corrected milk calculated according to NRC (2001) equations.
[7]Energy corrected milk calculated according to NRC (2001) equations.
[8]Calculated by summing the Mcal of NE_L required for milk production, maintenance, and BW change (NRC, 2001) and then dividing the sum by DMI.

ESSENTIAL OILS

Essential oils (**EO**) are volatile aromatic compounds with an oily appearance extracted from plants, and are secondary metabolites usually made up of terpenoids and phenylpropanoids (Calsamiglia et al., 2007). Plant EO exhibit a wide range of antimicrobial activities (Burt, 2004) and have gained interest as a possible natural replacement for antibiotic rumen fermentation modifiers due to the increase in public concern over antibiotic residues and resistance. Some of the more common EO compounds include (Calsamiglia et al., 2007): thymol (thyme and oregano), eugenol (clove), pinene (juniper), limonene (dill), cinnamaldehyde (cinnamon), capsaicin (hot peppers), terpinene (tea tree), allicin (garlic), and anethol (anise).

Calsamiglia et al. (2007) from an extensive review of the *in vitro*, *in situ* and continuous culture based literature concluded the following about the ruminal effects of EO:

1) Inhibition of deamination and methanogenesis resulting in lower ammonia-N, methane, and acetate and higher propionate and butyrate concentrations;
2) Variable responses depending on specific EO or combination of EO supplemented; and
3) Effects of some EO are pH and diet dependent.

While experiments have been done to evaluate the effect of EO in lactating dairy cows, trials using transition cows and (or) early lactation cows are lacking in the literature. The objective of our experiment (Tassoul and Shaver, 2009) was to determine the effect of a specific mixture of plant EO on DMI, milk yield and composition, and feed efficiency when fed to periparturient and early lactation dairy cows.

Forty multiparous Holstein cows were used in a completely randomized design. Cows received an EO mixture (CRINA®, DSM Nutritional Products Inc., Parsippany, NJ) targeted for 1.2 g/cow/d through 62 g/cow/day of premix or a control (**C**) carrier premix (62 g/cow/day) without EO. The CRINA® EO was a defined and patented blend of natural and natural-identical essential oil compounds that included thymol, eugenol, vanillin, and limonene on an organic carrier (McIntosh et al., 2003). Cows were individually fed a TMR, which included either the C or EO premix, once daily in tie stalls for 10 % refusal. The TMR amounts fed and refused were recorded daily. Cows were started on treatments 3 wk before expected calving date and continued for 15 wk after calving. The prepartum TMR contained 70 % forage comprised of 70 % corn silage, 15 % alfalfa silage, and 15 % wheat straw (DM basis). The lactation TMR contained 50 % forage comprised of 60 % corn silage, 33 % alfalfa silage, and 7 % alfalfa hay (DM basis). Prepartum and lactation TMR were formulated to contain 12 and 17 % CP (DM basis), respectively, and to meet or exceed NRC (2001) mineral and vitamin guidelines. Body weights and condition scores were recorded weekly on all cows throughout the trial at the same time on the same day each week. Individual cow milk yields were recorded daily. Milk samples were collected from all cows on 2 consecutive milkings on the same day each week and analyzed for fat, true protein, lactose, and MUN concentrations.

Table 4. Effect of supplemental dietary essential oils on least squares means for DMI and performance of periparturient and early lactation cows[1].

	Control	EO	SEM[2]	*P* <
DMI				
kg/d				
Prepartum[3]	13.8	13.1	0.4	NS[4]
Lactation[3]	24.5	22.7	0.6	0.04
% BW				
Prepartum	1.85	1.77	0.11	NS
Lactation	3.67	3.47	0.07	0.07
Milk Yield, kg/d	48.2	48.1	1.1	NS
4 % FCM, kg/d	43.9	44.0	1.2	NS
Milk Fat, %	3.48	3.46	0.10	NS
kg/d	1.65	1.64	0.09	NS
Milk Protein, %	3.10	2.95	0.05	0.03
kg/d	1.46	1.41	0.06	NS
MUN, mg/dl	12.9	13.4	0.3	NS
Feed Efficiency				
kg Milk/ kg DMI	1.99	2.15	0.06	0.08
kg FCM/ kg DMI	1.83	1.98	0.06	0.07
BCS				
Prepartum	3.9	3.8	0.1	NS
Lactation	3.4	3.3	0.1	NS
BW, kg				
Prepartum	734	745	16	NS
Lactation	672	658	16	NS
EB, Mcal/d[5]	-1.1	-3.6	0.9	0.06

[1]TMR supplemented with a specific mixture of plant essential oils (CRINA®, DSM Nutritional Products Inc., Parsippany, NJ) targeted for 1.2 g/cow/d through 62 g/cow/day of premix (EO) or a control (C) carrier premix (62 g/cow/day) without the essential oils mixture.
[2]Standard error of the mean.
[3]Treatments were initiated 3 wk prior to the expected calving date and continued through 15 wk of lactation.
[4]Not significant (P > 0.10).
[5]Energy Balance=(DMI*Diet NE_L)–((0.08 x $BW^{0.75}$)+(Milk Yield x NE_L)) (NRC, 2001).

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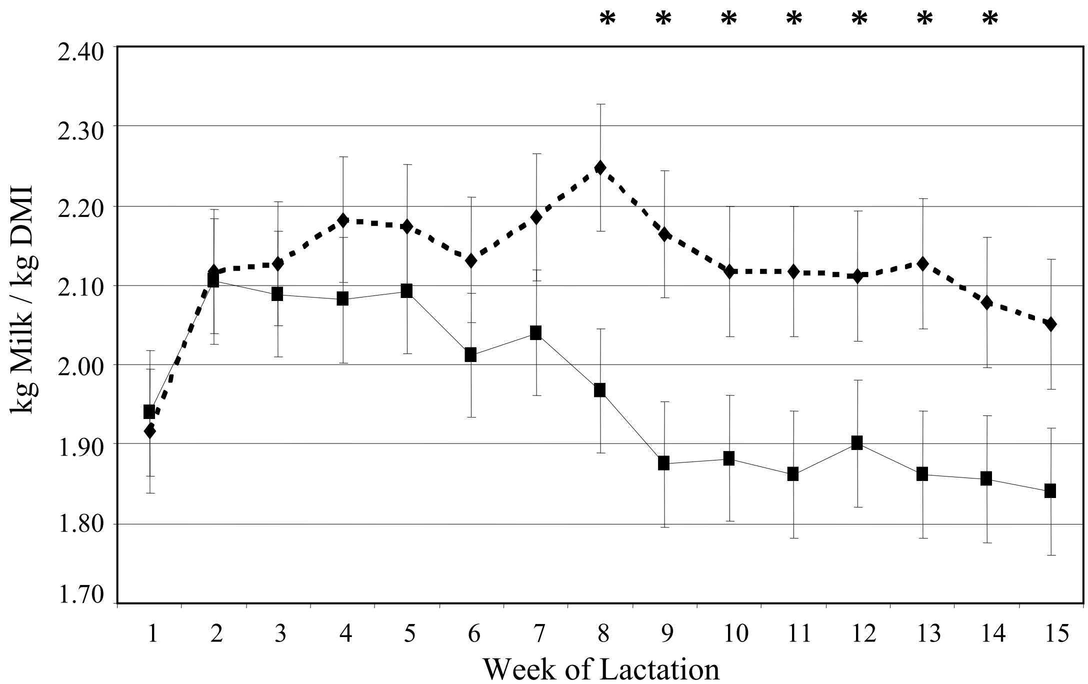

Figure 1. Weekly feed efficiency (kg Milk/kg DMI) least squares means for cows fed control (C; ■) and essential oils (EO; ♦) supplemented TMR. * = P < 0.05.

Presented in Table 4 are results for DMI and performance of periparturient and early lactation cows. Dry matter intake of prepartum cows was unaffected by treatment and lactation DMI was lower ($P < 0.05$) for EO (22.7 kg/d) than C (24.5 kg/d). Milk yield averaged 48 kg/d and was unaffected by treatment. We observed trends ($P < 0.10$) for increased average milk (2.15 vs. 1.99) and FCM feed efficiencies (1.98 vs. 1.83) and decreased average EB (-3.6 vs. -1.1 Mcal/d) for EO. Body weight and BCS measurements were unaffected by treatment. Feed efficiency responses by week are presented in Figure 1; differences ($P < 0.05$) were observed during wk 8-14.

There was no benefit to the dietary supplementation of EO for prepartum cows. The dietary supplementation of EO in early lactation cows decreased DMI 1.8 kg/d on average; while milk yield was maintained similar to the control at 48 kg/d. For diets costing $0.20/kg DM, 1.8 kg/d lesser DMI would reduce feed cost $0.36/cow/d. Further dairy cattle research is needed regarding potential interactions between basal diet, stage of lactation and dietary EO supplementation (specifically EO dose and composition), and mode of action of EO.

CONCLUSIONS

Feed efficiency appears to be highly variable among commercial dairy herds and this variation can have a significant impact on economic performance, especially with high feed ingredient prices. Numerous factors have been reported to influence feed efficiency of dairy herds. We found that feeding a reduced-starch diet, exogenous amylase addition to a reduced-starch diet, and EO also influenced feed efficiency in dairy cows. More research on these factors is warranted. We did not find improved feed efficiency for Holstein-Jersey crossbred cows compared to Holstein cows in agreement with another recent study in the literature.

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