Effect of Grazing and Fat Supplementation on Production and Reproduction of Holstein Cows*

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ABSTRACT

The objective of this trial was to investigate the effects of feeding a soybean oil refining by-product (SORB), made up mainly of sodium salts of long-chain fatty acids, on reproductive performance and productivity of 36 early lactation Holstein cows managed in a free-stall barn or on annual rye-ryegrass pasture. In this 2 × 2 factorial arrangement of treatments, cows consumed 0 or 0.5 kg/d of SORB as part of a total mixed ration for barn cows or as part of a grain supplement fed to cows on intensively, rotationally stocked pasture. Blood was sampled 3 times weekly and plasma was measured for progesterone to assess ovarian activity. Estrus activity was recorded using the HeatWatch estrus detection system. Although average 14-wk milk production (37.2 kg/d) was not different among treatments, barn cows had more persistent lactations than did grazing cows. Cows housed in the barn lost less body weight and returned to initial body weight sooner and had lower mean concentrations of plasma nonesterified fatty acids (464 vs. 261 mEq/L) than those managed on pasture. The milk fat of cows on pasture contained greater proportions of conjugated linoleic acid and linolenic acid but a corresponding 0.22 percentage unit decrease in milk fat concentration (3.39 vs. 3.16%). Cows managed on pasture had greater peak concentrations of plasma progesterone during the first estrous cycle. Cows managed on pasture and fed SORB had the greatest accumulation of plasma progesterone over the 14 wk of the study (SORB × housing interaction). These cows experienced the most mounts during their first estrus (9.3) and pregnancy rate was also greatest for this treatment (62.5%). Feeding SORB did not affect production of milk, fat, or protein. Loss of body condition

was less in cows fed SORB. Ruminal fluid concentration of propionate increased and ruminal pH decreased in cows fed SORB. A lower proportion of fatty acids less than 18 carbons in length was found in the milk fat of cows fed SORB, thus indicating lower *de novo* synthesis of fatty acids. Higher proportions of C18:2n-6 and conjugated C18:2 were found in the milk fat of cows fed SORB. Based on concentrations of plasma progesterone, cows fed SORB experienced their first ovulation earlier (26.7 vs. 42.4 d postpartum) than did cows not supplemented with SORB. Neither housing system nor SORB supplementation influenced detection of first estrus (50.5 d) or the mean length of each estrus period (447 min).

(**Key words:** grazing, soybean oil, fat, reproduction)

Abbreviation key: CLA = conjugated linoleic acid, FA = fatty acid, HW = HeatWatch, SORB = soybean oil refining byproduct.

INTRODUCTION

Adding supplemental dietary fat as whole cottonseeds (Harrison et al., 1995), tallow (Maiga et al., 1995), calcium salts of long-chain fatty acids (Sklan et al., 1989), and yellow grease (Cant et al., 1991) to the diets of dairy cows in early lactation has often increased milk production. In addition, fat added as calcium salts of long-chain fatty acids (Garcia-Bojalil et al., 1998) and tallow (Son et al., 1996) at 2 to 3% of dietary DM for dairy cows in early lactation has resulted in increased conception rates.

An oil by-product produced from the refining of soybeans for oil has received little research attention. Milk production was increased by 4.5 kg/d when this product (including lecithin) was fed to dairy cows at 0.9% of dietary DM (Shain et al., 1993). However milk production was not improved when various mixtures of the refining by-product (soybean oil soapstock and soy lecithin) were fed to dairy cows at 2.25% of dietary DM (Abel-Caines et al., 1998b). The concentration of linoleic acid in milk fat was increased by feeding a 1:1 mixture of soybean oil soapstock and soy lecithin compared with

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soybean oil (Abel-Caines et al., 1998b). This increased delivery of linoleic acid postruminally by the refining by-product might influence reproductive performance.

Pasture grazing is the most common practice for managing dairy cows worldwide. Although the practice diminished in the United States during the last 5 decades, new equipment and potential labor and economic benefits of intensive rotational stocking practices have generated renewed interest by US producers. In a study comparing the performance of pasture-based dairy cows offered supplemental grain to cows fed a TMR kept in free-stall housing, Fontaneli et al. (2005) reported that milk production was 19% lower in pasture-based cows. Kolver and Muller (1998) also reported decreases in milk production, DMI, and BW by unsupplemented grazing dairy cows vs. cows fed a TMR.

Housing management may play a role in the reproductive performance of dairy cows. In New Zealand, rotational stocking is the standard management system for dairy production. Compared with the United States, conception rate to first service is 2 times higher. In a comparison between the 2 locations, cows in New Zealand grazed perennial ryegrass and clover, whereas cows in the United States were fed a TMR (Bilby et al., 1998). Plasma progesterone clearance after ovariectomy and removal of a controlled intravaginal drug release device was less in grazing cows from New Zealand. Progesterone is a key hormone produced by the corpus luteum that helps maintain pregnancy.

The objectives of this trial were 1) to compare the effect of managing cows in an intensive rotational stocking system to free stall confinement and 2) to determine whether supplementation of a by-product of soybean oil refining would influence the productivity or reproductive performance of lactating Holstein cows.

MATERIALS AND METHODS

Cows, Design, and Treatments

The trial was conducted at the University of Florida, Dairy Research Unit (Hague, FL) between January and May. Immediately after calving, 36 Holstein multiparous cows were assigned randomly to 1 of 4 treatments arranged in a 2×2 factorial design. One main treatment factor was housing management system (free-stall housing vs. intensive rotational stocking of winter pastures). The second main treatment factor was type of supplement (without and with fat). The fat source used was a soybean oil refining by-product (**SORB**; Archer Daniels Midland Co., Chattanooga, TN) composed of approximately 65 to 70% sodium salts of long-chain fatty acids and 30% water having a pH of 8 to 9. Only a trace of lecithin was present. The oil was mixed with liquid molasses (Westway Trading Corp., Tomball, TX)

such that the SORB made up 30% of liquid volume (DM basis). Liquid molasses alone or molasses with SORB were mixed with the concentrate portion of the diet. The fatty acid (**FA**) profile of SORB was 15.4% palmitic acid, 4.6% stearic acid, 16.1% *cis*-9 oleic acid, 1.5% *cis*-10 oleic acid, 53.5% linoleic acid, 6.2% linolenic acid, and 2.7% other FA (Ralston Analytical Laboratories, Ralston Purina Co., St. Louis, MO). Cows remained on experimental treatments through 14 wk postpartum.

Pastures were seeded with a mixture of 'Grazemaster' rye (*Secale cereale* L.) and 'Big Daddy' annual ryegrass (*Lolium multiflorum* Lam.) between October 20 and 22. Pastures were irrigated to ensure establishment in the fall and during periods of drought in the spring. The initial fertilization on November 18 included N at a rate of 45 kg/ha and K at a rate of 37 kg/ha. Thereafter, 45 kg of N/ha was applied on December 28, February 3, March 3, April 3, and April 25. The seasonal total of N applied was 270 kg/ha. Soil tests indicated that no P fertilizer was needed. Pastures were 0.8 ha each.

Three cows were assigned randomly to each pasture ($n = 18$) resulting in a stocking rate of 3.75 cows per ha. Three pasture replicates of each supplement treatment were established. Each pasture was subdivided into 29 paddocks and cows were moved to a new paddock daily, allowing for a 28-d rest period between grazing. Energized polywire fencing prevented cows from grazing the next day's allotment and from grazing previously grazed areas. Cows were provided water tubs that were moved each morning along with the cows. When air temperature exceeded 27°C, portable shade structures were placed in each paddock to provide 4.6 m² of shade per cow and were moved daily. Supplements were fed to each group of cows housed in individual pastures after each milking at a rate of 1 kg (as-fed) per 2.5 kg of milk produced per day. Averages of 3- or 4-d milk weights were reviewed twice weekly and the amount of supplement provided was adjusted accordingly. Fifty percent of this daily amount was fed after each milking according to treatment assignment. The ingredient (Table 1) and chemical composition (Table 2) of the diets are provided. Certain feedstuffs were selected as ingredients for the supplement (Table 1) that are known to have a slower rate of fermentation or that are fermented toward greater proportions of acetate rather than propionate such as citrus pulp, soyhulls, and dried distillers grains with solubles compared with ground corn to minimize the acid load within the rumen.

Cows assigned to the barn treatment ($n = 18$) were managed in an open-sided, free-stall barn bedded with sand and fed in 2 groups of 9. Diets were fed daily as TMR. The SORB made up 0 or 2.0% of dietary DM. The DM content of corn silage was measured weekly

Table 1. Ingredient composition of TMR fed to cows housed in a free-stall barn and the supplemental grain mixture fed to grazing cows that contained or did not contain soybean oil refining by-product (SORB).

Ingredient	TMR		Supplement	
	–SORB	+SORB	–SORB	+SORB
	(% of DM)			
Alfalfa hay	9.9	9.9	—	—
Corn silage	24.4	24.4	—	—
Corn, ground	18.3	16.8	30.6	28.7
Liquid molasses	3.9	—	7.8	—
Liquid molasses with SORB ¹	—	6.6	—	13.0
Soybean meal	13.7	13.9	—	1.1
Soybean hulls	—	—	22.5	20.9
Cottonseed hulls	5.1	5.1	—	—
Whole cottonseeds	3.3	3.2	8.4	7.6
Distillers grains with solubles	7.8	7.5	7.7	6.9
Citrus pulp	8.9	8.0	17.5	16.3
Mineral mix ²	4.7	4.7	3.3	3.3
Sodium bicarbonate	—	—	1.4	1.4
Trace mineralized salt ³	—	—	0.8	0.8

¹Soybean oil refining by-product was prepared as 30% of the molasses product (DM basis).

²Contained 12% Ca, 2.8% P, 2.9% Mg, 1.0% S, 1.6% K, 7.8% Na, 800 ppm of Zn, 320 ppm of Cu, 800 ppm of Fe, 800 ppm of Mn, 242,000 IU of vitamin A/kg, 35,200 IU of vitamin D/kg, and 880 IU of vitamin E/kg (DM basis).

³Contained a minimum of 40% Na, 55% Cl, 0.25% Mn, 0.2% Fe, 0.033% Cu, 0.007% I, 0.005% Zn, and 0.0025% Co (DM basis). Product was purchased from Flint River Mills, Inc., Bainbridge, GA.

to maintain the proper forage to grain ratio of the TMR. Refused TMR was weighed and recorded daily.

Experimental Procedures

Every 2 wk throughout the experimental period, pasture forage samples were collected before grazing at six 0.5-m² sites that represented average pregraze herbage

mass. The plants were clipped to a 2.5-cm stubble height using metal shears. Seven sampling dates were used to calculate pregraze herbage allowance. At the time of pregraze sampling, hand-plucked samples were taken by severing herbage at the height to which the previous paddock had been grazed at the end of the 24-h occupancy period. Herbage was collected at 20 to 30 locations per paddock, composited, dried in a forced air

Table 2. Chemical composition of TMR fed to cows housed in a free-stall barn, the supplemental grain mixture fed to grazing cows, and the rye-ryegrass pasture forage.

Composition	TMR		Supplement		Rye-ryegrass
	–SORB ¹	+SORB	–SORB	+SORB	
CP, % of DM	19.1	19.3	15.8	15.5	22.4
NDF, % of DM	31.2	29.5	29.0	25.5	54.7
ADF, % of DM	18.8	18.6	16.2	15.1	—
Ether extract, % of DM	3.97	5.68	4.49	8.58	—
NE _L , Mcal/kg of DM ²	1.63	1.70	1.71	1.86	1.54
Ca, % of DM	0.91	0.92	0.87	0.91	—
P, % of DM	0.40	0.41	0.38	0.40	—
Mg, % of DM	0.41	0.42	0.38	0.39	—
K, % of DM	1.40	1.43	1.17	1.43	—
Na, % of DM	0.43	0.45	1.15	1.22	—
S, % of DM	0.29	0.30	0.28	0.32	—
Cl, % of DM	0.46	0.46	0.89	0.95	—
Fe, mg/kg of DM	200	210	262	248	—
Zn, mg/kg of DM	102	113	149	202	—
Cu, mg/kg of DM	34	34	33	32	—
Mn, mg/kg of DM	92	107	83	84	—
% IVOMD ³	—	—	—	—	70.1

¹SORB = Soybean oil refining by-product.

²Estimated value as calculated using NE_L value for individual feeds from NRC (2001).

³IVOMD = In vitro organic matter digestibility.

oven at 55°C until dry, and ground to pass a 1-mm screen (Wiley mill, Arthur H. Thomas, Philadelphia, PA).

Hand-plucked forage samples were digested for N determination using a modification of the aluminum block digestion procedure of Gallaher et al. (1975). Ammonia in the digestate was determined by semiautomated colorimetry (Hambleton, 1977). In vitro organic matter digestion was performed by a modification of the 2-stage technique (Moore and Mott, 1974). Neutral detergent fiber of forage samples was determined using the procedure of Golding et al. (1985). The grain mixes, alfalfa hay, and corn silage used in the TMR were sampled weekly, frozen, dried in a forced-air oven at 55°C for 48 h, composited monthly, ground through a 1-mm screen, and analyzed for chemical concentration. For the feedstuffs other than pasture samples, CP was determined by a modification of the AOAC (1996) procedure in which a mixture of 96% Na₂SO₄ and 4% Cu₂SO₄ without mercury sulfide, or thiosulfate was added prior to ammonia distillation. Distilled ammonia was recovered in 4% boric acid solution. Feedstuff samples were analyzed for DM (105°C for 8 h), OM (512°C for 8 h), NDF (Goering and Van Soest, 1970) using heat stable α -amylase, ADF (AOAC, 1996), and ether extract (AOAC, 1996). Mineral composition was determined by Dairy One (Ithaca, NY).

On a weekly basis, cows were weighed and body condition scored (Wildman et al., 1982). Cows were milked daily at 0500 and 1700 h and milk weights recorded. Milk samples from consecutive a.m. and p.m. milkings were collected weekly. Samples were sent to Southeast Dairy Laboratory, Inc. (McDonough, GA) and analyzed for fat and protein concentrations according to approved procedures (AOAC, 1996) using near infrared spectroscopy (Bentley 2000, Bentley Instruments, Chaska, MN); MUN was determined by a modified Berthelot assay using a Chemspec 150 instrument (Bentley Instruments Inc., Chaska, MN) by Midsouth Dairy Records (Springfield, MO). Two consecutive milk samples were collected on April 19 and 26 for FA determination. Samples were stored at -20°C. Milk fat was extracted by the method of Chilliard et al. (1991). The extracted lipid was analyzed for FA by gas chromatography (Jenkins, 2000).

Rumenocentesis was performed at approximately 70 DIM and 6 to 7 h after feeding. The pH was determined immediately upon collection. The ruminal fluid was acidified with 50% sulfuric acid to stop fermentation and then frozen at -20°C until time of analysis. Upon thawing, samples were centrifuged at 17,300 $\times g$ for 30 min, filtered with a high-protein affinity syringe-driven filter unit (Millex SLAA025LS), and run on a 4% carbowax 80/120 BDA column (Supelco Inc., Bellefonte, PA)

in a gas chromatograph (Autosystem XL, Perkin-Elmer Inc., Norwalk, CT).

At approximately the same time as the rumenocentesis was performed, a sample of urine (100 mL) was collected for analysis of creatinine and allantoin to estimate microbial protein synthesis in the rumen. Samples were immediately placed on ice for transport and frozen (-20°C) for analysis. Purine and allantoin analyses were completed as described by Vagnoni et al. (1997).

Blood was collected from the coccygeal vein or artery into vacuum tubes containing potassium oxalate and sodium fluoride (Becton Dickinson, East Rutherford, NJ) 3 times/wk from 1 to 98 d postpartum. Following collection, blood was stored in ice for transport, and centrifuged at 2619 $\times g$ for 30 min to separate plasma. Aliquots of plasma were frozen at -20°C. One blood sample a week was used for analysis of urea N, insulin, and NEFA. Blood urea nitrogen was determined using a Technicon Autoanalyzer (Technicon Instruments Corp., Chauncey, NY) using a modification of the method of Marsh et al. (1965) as described in Bran and Luebbe Industrial Method #339-01. A double antibody radioimmunoassay procedure, as described by Soeldner and Sloane (1965) and modified by Malven et al. (1987), was used for assay of insulin. Bound radioactivity in tubes was measured using a Packard auto gamma counter (model B-5005). Results were calculated using the log-logit curve fit for radioimmunoassay data processing procedure with 8.0000 as a correction multiplier to correct concentrations to nanograms per milliliter. Plasma concentrations of NEFA were measured (Wako NEFA C test kit, Wako Chemicals, Richmond, VA). Progesterone was measured by test kit (Diagnostic Products Corp., Los Angeles, CA). The assay is a radioimmunoassay with a sensitivity in cows of 0.1 ng/mL (Garbarino et al., 2004). A sample of 100 μ L was pipetted into antibody-coated assay tube and 1 mL of 125-I progesterone solution was added. All tubes were incubated at 37°C for 1 h in a water bath. Tubes were decanted and counted for 1 min using a gamma counter. Intra- and interassay coefficients of variation (9 and 8.5%, respectively) were calculated from a known luteal phase sample run with each assay.

Cows were fitted with estrus monitoring devices (HeatWatch, DDx Inc., Denver, CO) within 1 wk of being assigned to treatment. On approximately 35 d postpartum, cows were administered an intramuscular injection of PGF_{2 α} (25 mg of Lutalyse, Pharmacia-Upjohn Co., Kalamazoo, MI) to regress any existing corpora lutea and synchronize estrous activity. After a waiting period of 45 d postpartum, cows displaying estrus activity [as defined by HeatWatch (HW)] were inseminated by 1 of 2 technicians using the same lot of

semen from the same bull. Cows were defined as being in heat if they were mounted at least 3 times within 4 h. Cows observed in estrus by visual observation that were not detected by HW were also inseminated. Pregnancy was confirmed at 45 d postinsemination by rectal palpation.

Statistical Analyses

Milk composition, VFA proportions, microbial protein synthesis, luteal cycle lengths, ovulation intervals, and sexual behavior were analyzed by the GLM procedure of SAS (SAS Institute, 1996) using the following model:

$$Y_{ij} = \mu + \alpha_i + \beta_j + \varepsilon_{ij},$$

where Y_{ij} = dependent variable, μ = overall mean, α_i = housing management ($i = 1, 2$), β_j = SORB supplementation ($j = 1, 2$), and ε_{ij} = residual error.

Results are reported as least squares means and standard error. Significance was assigned at $P < 0.05$. Orthogonal contrasts were 1) effect of pasture vs. barn management, 2) effect of not feeding SORB or feeding SORB, and 3) interaction of management and SORB feeding.

Milk production, plasma NEFA, plasma insulin, plasma BUN, BW, BCS, and herbage allowance data were analyzed using repeated measures of the mixed procedure of SAS (SAS Institute, 1996). Main effects of treatment, sampling time, and treatment $\times$ sampling time interactions were tested with time, housing management, and fat supplementation treated as classification variables using Type III sums of squares. Cows were nested within treatment, treated as a random variable, and used to test for treatment effects. Time was a continuous variable. The SLICE command was used to test for differences between treatments at each week of measurement. The following model was used:

$$Y_{ijk} = \mu + \alpha_i + \beta_j + \gamma_k + \delta_l + \beta\gamma_{jk} + \beta\delta_{jl} + \gamma\delta_{kl} + \beta\gamma\delta_{jkl} + \varepsilon_{ijk}$$

where Y_{ijk} = dependent variable, μ = overall mean, α_i = cow ($i = 1, 2, \dots, 35$), β_j = housing management ($j = 1, 2$), γ_k = SORB supplementation ($k = 1, 2$), $\beta\gamma_{jk}$ = housing management by SORB supplementation interaction, δ_l = time ($l = 1, 2, \dots, 14$), $\beta\delta_{jl}$ = housing management by time interaction, $\gamma\delta_{kl}$ = SORB supplementation by time interaction, $\beta\gamma\delta_{jkl}$ = housing management by SORB supplementation by time interaction, and ε_{ijk} = residual error.

Plasma progesterone values at each sampling day were summed in a cumulative fashion from calving to

60 DIM. These values were modeled as a polynomial function of time that yielded regression equations for plotting over time. Data best fit a quadratic function. Test of interactions of treatment with linear and quadratic DIM were made. Differences in pregnancy rates between treatment groups were determined using the χ^2 procedure of SAS (SAS Institute, 1996). Results were reported as least squares means and standard error. Significance was assigned at $P < 0.05$.

RESULTS AND DISCUSSION

One cow left the trial early due to acute mastitis and was omitted from the data set. Over the course of the study, DM consumption of TMR averaged 23.0 and 25.0 kg/d by cows fed diets without and with SORB, respectively. The SORB-supplemented cows consumed on average 0.49 kg/d of SORB, which is similar to the 0.47 kg/d of SORB consumed by cows on pasture. Cows managed on pasture consumed 12.4 and 12.1 kg/d (DM basis) of concentrate supplement without and with SORB, respectively. Pregraze herbage mass averaged 1801 ± 245 kg/ha across the 7 measurement dates and did not differ across time of sampling or by treatment.

Milk Production and Milk Components

Mean milk production over the first 14 wk postpartum did not differ among treatments (Table 3), however the patterns of milk production over time did differ (Figure 1). Milk production was similar the first 7 wk postpartum but beginning in wk 8 of lactation, cows on pasture started a trend of lower milk production (week $\times$ housing interaction, $P = 0.02$). By the end of the trial (wk 14), cows on pasture produced 5.8 kg/d less milk than cows in the barn (a 15% decrease). Lower milk production by cows on pasture was due most likely to lower energy intake. Fontaneli et al. (2005) reported that cows managed on pasture with supplementation from 0 to 259 d postpartum produced 19% less milk than cows managed in a free-stall barn. In a trial conducted by Kolver and Muller (1998), early lactation cows were taken out of free-stall confinement and placed on pasture without supplementation for a 4-wk period. Pasture-managed cows produced 33% less milk than did cows managed in freestalls.

Supplemental SORB had no effect on mean milk yield or pattern of milk yield in the present trial. Shain et al. (1993) fed a diet containing 0, 0.9, or 1.8% of soy lecithin:soapstock mixture (DM basis) to early lactation cows for 10 wk. Consumption of soy oil product was 0, 0.24, and 0.49 kg/d. Milk production was increased only by those cows fed the 0.24 kg/d of soy oil product. Milk production was unaffected when cows were fed soy leci-

Table 3. Effect of housing management (pasture grazing or barn freestalls) and supplemental fat (soybean oil refining by-product) on production and composition of milk, BW, BCS, and plasma components during the first 14 wk of lactation.

Measurement	Treatment				SE	<i>P</i> = ¹		
	Pasture		Barn			Fat	Mgt	Fat × Mgt
	– Fat	+ Fat	– Fat	+ Fat				
Milk yield, kg/d	36.4	35.7	38.2	38.5	1.4	0.93	0.25	0.80
Milk fat, %	3.27	3.05	3.42	3.36	0.08	0.12	*	0.39
Milk fat, kg/d	1.2	1.1	1.3	1.3	0.1	0.46	*	0.64
3.5% FCM, kg/d	34.7	32.9	37.6	37.3	2.1	0.63	†	0.73
Milk protein, %	2.88	2.91	2.90	3.05	0.06	0.15	0.18	0.29
Milk protein, kg/d	1.0	1.0	1.1	1.2	0.1	0.68	*	0.47
MUN, mg/100 mL	12.4	10.2	12.8	11.0	1.0	†	0.58	0.83
BW covariate-adjusted, kg	596	599	621	623	11	0.85	*	0.99
BCS, covariate-adjusted	2.97	3.14	3.00	3.23	0.11	†	0.57	0.76
NEFA, mEq/L	422	507	294	231	50	0.83	**	0.15
Insulin, ng/dL	0.47	0.47	0.61	0.59	0.06	0.93	*	0.84
Blood urea nitrogen, mg/dL	12.4	10.8	13.9	14.0	0.6	0.25	**	0.19

¹Mgt = Effect of managing in confinement or on pasture; Fat $\times$ Mgt = interaction of fat supplementation and management.

* $P \leq 0.05$; † $P \leq 0.10$.

thin:soap stock in 3 different ratios at 2.25% of dietary DM or soybean oil at 2.25% of dietary DM (Abel-Caines et al., 1998a).

Percentage milk fat was lower ($P = 0.02$) for cows managed on pasture, resulting in lower production of fat ($P = 0.04$) and a tendency for lower production of 3.5% FCM ($P = 0.09$) compared with cows managed in confinement (Table 3). Lower concentration of fat in milk of cows on pasture was likely due to a greater intake of linolenic acid leading to the formation of

greater amounts of *trans* isomers in the ruminal fluid, which are associated with reduced milk fat production (Griinari et al., 1998).

Supplemental SORB did not affect milk fat percentage or production. Likewise, feeding a soy lecithin:soap-stock mix at 0.9 and 1.8% of dietary DM did not affect milk fat concentration (Shain et al., 1993). In addition, milk fat concentration was not affected by feeding soybean oil at 1.5% of dietary DM (Abel-Caines et al., 1998a) or at 2.25% of dietary DM (Abel-Caines et al., 1998b). However, when soybean oil made up 3.0 and 4.5% of dietary DM, percentage of milk fat decreased (Abel-Caines et al., 1998a). Feeding these greater amounts of soybean oil (1.0 and 0.8 kg/d) may overwhelm the hydrogenation capacity of ruminal microorganisms, may affect VFA patterns, and cause the formation of greater amounts of those *trans*C18 fatty acids reported to be responsible for lowering milk fat concentration.

Milk protein percentage was unaffected by housing management or feeding of SORB (Table 3). There results are in agreement with those of Abel-Caines et al. (1998a,b) and Shain et al. (1993) who fed soybean oil or soybean soapstock. Although percentage of milk protein was not different between housing management groups, production of milk protein was lower ($P = 0.05$) for cows on pasture (1.00 vs. 1.15 kg/d; Table 3) because of numerically lower values for milk production and milk protein concentration. Lastly, concentrations of MUN were not affected by housing but cows not fed SORB tended to have greater MUN values (12.6 vs. 10.6 mg/100 mL).

Figure 1. Effect of housing management [pasture (solid line) vs. barn (dashed line)] and feeding soybean oil refining by-product (solid symbols = no SORB; open symbols = + SORB) on production of milk during the first 14 wk of lactation. A significant week $\times$ housing interaction ($P = 0.02$) was detected. Each symbol represents least squares means. Week of lactation number designated with + indicates a housing type difference detected at $P < 0.10$; weeks with * indicates difference detected at $P < 0.05$.

BW and BCS

Treatment groups began the trial with mean BCS of 3.4, 3.6, 3.5, and 3.4; at the end of 14 wk, groups ended with mean BCS of 2.6, 3.0, 2.8, and 3.1 (pasture, no SORB; pasture + SORB; barn, no SORB; and barn + SORB; respectively). Cows not fed SORB tended to have ($P = 0.09$) lower body condition than cows fed SORB (2.98 vs. 3.25; Table 3). Because all cows began the trial at similar BCS, the effects of SORB were to minimize the loss of body condition during the first 14 wk postpartum. The change in BCS units per week was unaffected by treatment (mean of -0.048 units/wk). Shain et al. (1993) reported no difference in mean BCS among early lactation cows fed diets containing 0, 0.9, and 1.8% of a soy lecithin:soapstock mix for 10 wk. In agreement, Abel-Caines et al. (1998a) reported no change in BCS of cows fed a diet of 4.5% compared with 1.5 or 0% soybean oil.

By chance, the BW at calving of cows fed SORB was greater ($P = 0.004$) than that of cows not fed SORB (698 vs. 614 kg). Therefore, BW at calving was used as a covariate for analysis of treatment effects on BW change postpartum. Although the BCS of treatment groups at calving were not different, it too was used as a covariate for analyzing BCS changes postpartum. Postpartum loss of BW was less and recovery of lost BW was achieved by cows fed a TMR and housed in a free-stall barn compared with grain-supplemented cows grazing rye-ryegrass pastures (week $\times$ housing interaction, $P = 0.025$; Figure 2A). Similarly, Fontaneli et al. (2005) reported that cows managed on pasture lost greater BW after 5 wk postpartum than cows managed in a free-stall barn. This differential loss of BW was not due to greater loss of condition (Figure 3A). However, this differential pattern might be explained if the rise in DMI over time postpartum by cows fed a TMR was greater than that of grazing cows. Eventually this differential DMI resulted in a separation in BCS at wk 14 (Figure 3A). Loss of body condition was greater by cows not fed SORB (BCS decrease from 3.6 at calving to 2.7) compared with those fed SORB (BCS decrease from 3.5 at calving to 3.0; week $\times$ SORB interaction, $P = 0.049$; Figure 3B); however, BW change was similar between the 2 groups of cows (Figure 2B). This apparent discrepancy between BW and BCS changes might be explained as follows. Similar BW changes postpartum would occur if DMI were similar between the 2 groups so that gut fill was similar. Under conditions of similar DMI, the greater energy density of the SORB diet (Table 2) allowed a greater intake of energy, which allowed the diet to support a greater proportion of the milk produced compared with cows not fed SORB. The latter cows had to rely to a greater degree on body reserves

Figure 2. A) The postpartum patterns of BW by lactating cows housed on pastures of rye-ryegrass (solid line) or in a free-stall barn (dashed line). A significant week $\times$ housing interaction ($P = 0.025$) was detected. Each symbol represents least squares means. Week of lactation number designated with + indicates a housing type difference detected at $P < 0.10$; weeks with * indicates difference detected at $P < 0.05$. B) Postpartum patterns of BW by lactating cows fed without (closed symbols) or with (open symbols) soybean oil refining by-product (SORB) were not different (week $\times$ SORB interaction, $P = 0.949$).

for milk production and hence, lost more body condition (Figure 3B). Shain et al. (1993) reported an increase in mean BW but no difference in mean BCS of lactating dairy cows fed diets containing 0.9 or 1.8% soy lecithin:soapstock compared with controls.

Ruminal Microbial N, VFA, and pH

Production of microbial N in the rumen did not differ (mean of 326 g/d) across management systems and fat supplementation treatments (Table 4). This supports the lack of effect of treatments on milk protein concentration. Jenkins and Fotouhi (1990) fed diets of 0% lipid, 5.2% soybean lecithin, and 2.4% corn oil (DM basis) to Hampshire wethers and measured flow of microbial N from the rumen. Adding fat to the diet did not change microbial N flow to the duodenum but did affect positively efficiency of microbial CP synthesis and lowered ruminal ammonia concentration. Although ammonia concentration in the rumen was not measured in the current study, a tendency for lower MUN values for

Figure 3. A) Postpartum patterns of BCS by lactating cows housed on pastures of rye-ryegrass (solid line) or in a free-stall barn (dashed line). A week $\times$ housing interaction was not detected ($P = 0.787$). B) Postpartum patterns of BCS by lactating cows fed without (closed symbols) or with (open symbols) soybean oil refining by-product (SORB) were different (week $\times$ SORB interaction, $P = 0.049$). Week of lactation number designated with + indicates that SORB treatments differed as detected at $P < 0.10$; weeks with * indicates difference detected at $P < 0.05$. Each symbol represents least squares means.

cows fed SORB (Table 3) support this influence of fat in the rumen.

The housing system in the current study had little effect on individual or total ruminal VFA concentrations (Table 4). Ruminal concentrations of individual VFA but not total VFA were changed by SORB supplementation. Total VFA concentration in ruminal fluid was not affected in nonlactating cows fed soybean oil until the oil reached 8% of dietary DM in the study of Bateman and Jenkins (1998). Supplementation with SORB resulted in a decreased acetate concentration and increased propionate concentration. This effect was seen primarily in cows housed in the barn (fat $\times$ housing interaction, $P = 0.04$). A linear shift in the same directions for acetate and propionate concentrations in cows fed increasing amounts of soybean oil was reported by Bateman and Jenkins (1998). The ratio also decreased for cows fed a mixture of soy lecithin and soapstock at 0.9 and 1.8% of dietary DM (Shain et al., 1993). Cows fed SORB also had lower concentrations of isobutyrate, methyl butyrate, and valerate than cows not receiving

SORB. Isobutyrate, methyl butyrate, and valerate are growth factors for many cellulolytic organisms, and other species use them for long-chain FA synthesis or occasionally for amino acid synthesis (Van Soest, 1994). The reduced concentration of isobutyrate, methyl butyrate, and valerate as growth factors in the rumen fluid of SORB-supplemented cows may result in a reduction in the population of acetate-producing cellulolytic bacteria.

Ruminal fluid pH was not different between the cows managed in the 2 systems. Although "slug feeding" of concentrates might be expected to create a more acidic ruminal environment, Reis and Combs (2000) reported no effect on mean or pattern of ruminal fluid pH by supplementation with ground, dry-shelled corn at 0, 5, or 10 kg/d offered in 2 separate feedings daily, suggesting that grazing cows can produce copious amounts of saliva through extensive chewing to buffer the acids produced by grain supplementation. Cows not fed supplemental SORB had a tendency toward a less acidic ruminal pH than did cows fed supplemental SORB (6.23 vs. 5.99; Table 4). Similarly, ruminal pH declined when soybean oil increased from 0 to 4% of dietary DM (Bateman and Jenkins, 1998). Abel-Caines et al. (1998a) reported a tendency toward a lower ruminal pH of cows fed 4 or 6% lipid from nonenzymatically browned soybeans. However, Abel-Caines et al. (1998b) reported no effect on ruminal pH because of feeding soybean oil or 3 mixtures of soy lecithin and soapstock. Lower pH and decreased molar acetate proportions in ruminal fluid may indicate a decline in the populations of acetate-producing cellulolytic bacteria in this study.

Milk Fatty Acids

The FA profiles of milk fat were affected by both supplemental SORB and housing system (Table 5). The lower concentrations of C6 through C16 (38.0 vs. 47.4% of total FA) and the higher concentrations of C18 FA (except C18:3) in milk fat of cows supplemented with SORB likely represents a greater de novo synthesis of milk fat by control cows compared with the incorporation of preformed C18 FA into the milk fat of cows fed SORB. In a similar fashion, cows managed on pasture had reduced ($P < 0.05$) concentrations of C6 to C16 FA (38.9 vs. 46.5% of total FA) in milk fat. Concentrations of C18:0, C18:1, and C18:3 were increased in cow's milk fat on pasture. Kelly et al. (1998) also reported a lower concentration of C6 to C16 FA and a higher concentration of C18:1 and C18:3 FA for grazing compared with TMR-fed cows. Information on the FA profile of milk fat from cows fed different forages is sparse (Chilliard et al., 2001). In their review, C6 to C12 FA were in lower concentrations and C18:0 and C18:1 were in greater

Table 4. Effect of housing management (pasture grazing or barn freestalls) and supplemental fat (soybean oil refining by-product) on ruminal volatile fatty acid concentration, pH, and microbial N production.

Measurement	Treatment				SE	<i>P</i> = ¹		
	Pasture		Barn			Fat	Mgt	Fat × Mgt
	– Fat	+ Fat	– Fat	+ Fat				
	n = 8	n = 5	n = 8	n = 5				
Acetate, molar %	65.19	65.16	66.16	61.90	0.94	*	0.49	*
Propionate, molar %	20.06	21.06	19.6	24.94	1.01	**	0.11	*
Isobutyrate, molar %	0.94	0.58	0.79	0.60	0.11	*	0.59	0.48
Butyrate, molar %	11.79	11.56	11.34	10.28	0.67	0.35	0.21	0.54
Methyl butyrate, molar %	0.66	0.32	0.90	0.68	0.13	*	*	0.64
Valerate, molar %	0.36	0.26	0.33	0.20	0.06	†	0.42	0.85
Isovalerate, molar %	1.36	1.28	1.24	1.58	0.20	0.52	0.67	0.30
Acetate: propionate	3.28	3.12	3.46	2.50	0.18	**	0.24	*
Total VFA, mmol/L	n = 6 122.42	n = 4 121.35	n = 6 97.78	n = 5 121.66	10.74	0.30	0.27	0.26
pH	6.07	6.02	6.40	5.96	0.12	†	0.39	0.30
Microbial N production, ² g/d	n = 8 322	n = 7 332	n = 9 373	n = 8 278	43	0.26	0.30	0.26

¹Mgt = Effect of managing in confinement or on pasture; Fat $\times$ Mgt = interaction of feeding fat and management.

²Production of microbial nitrogen as estimated by allantoin and creatinine analyses of spot samples of urine.

† $P < 0.10$; * $P < 0.05$; ** $P < 0.01$.

Table 5. Effect of housing management (pasture grazing or barn freestalls) and supplemental fat (soybean oil refining by-product) on milk fatty acid profile (% of total fatty acids).

Fatty acid	Pasture		Barn		SE	$P = ^1$		
	– Fat	+ Fat	– Fat	+ Fat		Fat	Mgt	Fat $\times$ Mgt
4:0	2.60	2.60	2.70	2.56	0.07	0.32	0.61	0.36
6:0	1.94	1.49	2.18	1.87	0.09	*	*	0.49
8:0	1.00	0.67	1.23	0.97	0.06	*	*	0.59
10:0	2.28	1.40	2.99	2.26	0.06	*	*	0.67
11:0	0.08	0.03	0.12	0.10	0.02	†	*	0.42
12:0	2.41	1.56	3.30	2.47	0.17	*	*	0.93
14:0	8.94	6.08	10.60	8.75	0.36	*	*	0.18
14:1	0.91	0.68	1.04	0.83	0.05	*	*	0.89
15:0	0.85	0.71	0.91	0.83	0.03	*	*	0.38
16:0	25.57	21.14	28.50	24.07	0.71	*	*	0.99
16:1	0.84	0.97	1.04	1.43	0.34	0.35	0.45	0.70
17:0	0.62	0.57	0.49	0.50	0.02	0.37	*	0.17
18:0	16.29	16.81	12.20	14.98	0.54	*	*	*
18:1 <i>cis</i> -9	20.57	26.83	19.41	21.53	0.71	*	*	*
18:1 <i>trans</i>	3.87	5.23	2.72	4.50	0.18	*	*	0.27
18:2	3.65	4.07	4.27	4.62	0.17	*	*	0.83
18 <i>cis</i> -9, <i>trans</i> -11	0.67	0.98	0.60	0.80	0.05	*	*	0.38
18 <i>trans</i> -9, <i>trans</i> -11	0.04	0.08	0.01	0.04	0.01	*	*	0.77
18:3	0.79	0.84	0.65	0.59	0.07	0.94	*	0.49
19:0	0.28	0.47	0.19	0.27	0.04	*	*	0.13
20:0	0.21	0.23	0.17	0.21	0.01	*	*	0.49
22:0	0.10	0.07	0.13	0.13	0.01	0.17	*	0.18
22:1	0.17	0.12	0.21	0.21	0.01	†	*	†

¹Mgt = Effect of managing in free-stall housing or on pasture; Fat $\times$ Mgt = interaction of feeding fat and management.

† $P < 0.10$; * $P < 0.05$.

concentrations in milk fat from cows fed grass silage and concentrates compared with cows fed corn silage and concentrates. This agrees with the results of the current study. Pasture grasses growing under temperate conditions usually contain from 55 to 65% C18:3 (Chilliard et al., 2001). The C18:3 concentration of milk fat in the current study was greater from pasture-based cows compared with barn-based cows; nevertheless, the values for C18:3 were all <1%.

Cows not supplemented with SORB had lower ($P < 0.05$) concentrations of *trans* C18:1 (3.29 vs. 4.86%) in their milk fat (Table 5). This increase in *trans* C18:1 due to the feeding of SORB is supported by the work of Bateman and Jenkins (1998). Nonlactating cows fed diets of increasing concentrations of soybean oil (0, 2, 4, 6, and 8% of dietary DM) had increasing concentrations of *trans* C18:1 in their ruminal fluid, going from 0.55 to 4.07 mg/g of ruminal DM (a 7-fold increase). In a study summarizing 17 studies and 27 individual treatments, Griinari et al. (1998) reported that as the percentage of *trans* C18:1 increased in milk fat, milk fat percentage decreased ($R^2 = 0.54$). An increase in *trans* C18:1 as seen in the current study may be a result of the incomplete biohydrogenation of C18:2 as a result of the effect of PUFA on ruminal microbial metabolism.

The milk fat of cows on pasture had greater proportions ($P < 0.05$) of the 2 conjugated linoleic acid (CLA) isomers detected (*cis*-9,*trans*-11 C18:2 and *trans*-9,*trans*-11 C18:2; Table 5). Likewise, CLA concentrations increased in milk fat from dairy cows mainly grazing ryegrass and white clover without supplement compared with cows kept in freestalls and fed a TMR containing whole cottonseed (Kelly et al., 1998). The ruminal biohydrogenation of C18:3, the major FA in pasture grass, does not include the CLA isomers as intermediates but does include *trans*-11 C18:1 (Harfoot and Hazelwood, 1997). When the *trans*-11 C18:1 FA is taken up by the mammary gland, it can be desaturated to *cis*-9,*trans*-11 C18:2 by Δ^9 -desaturase. Supplementation with SORB increased ($P < 0.05$) total CLA by 0.29 g/100 g of fat (a 44% increase). This change may have occurred because of the incomplete biohydrogenation of C18:2 supplied by SORB.

NEFA, Insulin, and BUN

Mean concentration of plasma NEFA was greater ($P < 0.001$) for cows on pasture than for those in freestalls (464.5 vs. 262.5 mEq/L; Table 3). Weekly treatment differences exceeded 200 mEq/L from wk 2 to 7 postpartum (Figure 4). Increased NEFA concentrations reflect a dietary energy deficiency that the cow attempts to rectify by mobilizing adipose reserves. Even though milk production during these early weeks of lactation

Figure 4. Effect of housing management [pasture (solid line) vs. barn (dashed line)] on plasma concentration of NEFA during the first 14 wk of lactation. A significant week $\times$ housing interaction ($P < 0.01$) was detected. Treatments differed at wk 2 through 10. Each symbol represents least squares means.

were similar between pasture and barn-housed cows (Figure 1), cows kept on pasture were not consuming amounts of energy needed to support milk production compared with cows fed a TMR. When the milk production curves of pastured cows began decreasing about wk 9 (Figure 1), NEFA concentrations of pastured cows began approaching those of cows in freestalls (housing $\times$ time interaction, $P < 0.01$) suggesting that energy intake at about that time was more nearly sufficient to support milk production.

Although SORB supplementation had no effect on NEFA concentrations in the current study, most studies have reported that fat supplementation increased concentrations of plasma NEFA (Grummer and Carroll, 1991). This response, however, is not always reported. Chilliard and Ottou (1995) infused rapeseed oil duodenally and monitored blood NEFA, insulin, and glucose concentrations. They reported no effect of rapeseed oil on blood NEFA concentrations but noted that work performed in vitro showed that high concentrations of rapeseed would elicit a lipolytic response.

Cows on pasture had lower ($P < 0.05$) mean concentrations of plasma insulin than cows in confinement (0.47 vs. 0.60 ng/100 mL; Table 3). Although not measured, this finding most likely reflects lower circulating concentrations of glucose in pasture-based cows. Grazing cows had lower concentrations of plasma glucose compared with cows fed TMR in freestalls for several weeks after calving (Fontaneli et al., 2005). Through the first 8 wk of lactation in the current study, weekly concentrations of pastured cows remained below 0.45 ng/100 mL, at which point concentrations began to increase for the remainder of the study. A decrease in milk production around wk 8 (Figure 1) accompanied by an increase in DMI would likely result in an improved energy state (greater plasma glucose concentrations), that may be

Table 6. Effect of housing management (pasture grazing or barn freestalls) and supplemental fat (soybean oil refining by-product) on estrous cycle measurements.

Measurement	Treatment				SE	$P = ^1$		
	Pasture		Barn			Fat	Mgt	Fat $\times$ Mgt
	– Fat	+ Fat	– Fat	+ Fat				
First estrous cycle	n = 9	n = 8	n = 9	n = 9				
Ovulation, DIM	42.8	21.5	42.2	32.6	7.9	†	0.51	0.47
Ovulation interval, d	19.6	23.9	21.9	18.6	1.0	0.52	0.83	0.11
Peak progesterone, ng/mL	7.2	6.8	5.5	4.6	1.0	0.47	*	0.77
Second estrous cycle	n = 7	n = 8	n = 7	n = 8				
Ovulation, DIM	50.7	42.6	53.3	43.4	5.3	†	0.76	0.87
Ovulation interval, d	20.7	22.8	21.2	21.3	1.7	0.52	0.75	0.56
Peak progesterone, ng/mL	8.0	5.8	7.1	6.4	1.1	0.24	0.91	0.51
Third estrous cycle	n = 6	n = 7	n = 5	n = 8				
Ovulation, DIM	67.0	61.3	63.6	65.0	3.6	0.57	0.97	0.35
Ovulation interval, d	21.0	27.3	18.8	22.7	2.2	*	0.15	0.59
Peak progesterone, ng/mL	9.1	6.2	7.4	6.9	1.2	0.21	0.71	0.37

¹Mgt = Effect of managing in confinement or on pasture; Fat $\times$ Mgt = interaction of fat supplementation and management.

* $P \leq 0.05$; † $P \leq 0.10$.

reflected by the increased insulin concentrations beyond wk 8. Low blood insulin enhances lipolysis in the adipose tissue of the lactating dairy cow. Low blood insulin appeared to coincide with high blood NEFA concentrations in cows on pasture. Fat supplementation had no effect on plasma insulin concentrations. Data reviewed in 17 studies by Staples et al. (1998) revealed that fat effects on insulin concentration are inconclusive with much of the data reporting no effect.

Supplemental SORB had no effect on mean concentration of BUN, although mean BUN did differ between pasture and barn-housed cows (11.6 vs. 13.9 mg/dL; Table 3). The greatest differences occurred during wk 2 to 5 at which time the BUN values for pastured cows were ≤ 10 mg/dL (housing $\times$ week interaction, $P = 0.01$). Expected low intakes of DM during that time likely resulted in insufficient intake of protein and thus, low BUN values.

Effect of Housing Management and SORB Supplementation on Reproduction Estrous Cycles

Based upon concentrations of plasma progesterone >1 ng/mL in 2 consecutive samples, all cows initiated an estrous cycle before 98 DIM (range: 13 to 91 d). Five of 35 cows (2 from pasture without SORB, 2 from barn without SORB, and 1 from barn plus SORB) started their first ovulatory cycle at ≥ 80 DIM. The first and second ovulation cycles tended to begin later for cows not fed SORB (42.5 vs. 27.0 d and 52.0 vs. 43.0 d, respectively; Table 6). An earlier return to ovulation postpartum has been correlated to a less negative nadir of energy status (Canfield and Butler, 1991). Because

plasma concentrations of NEFA, insulin, or glucose were not affected by feeding SORB, mean energy status was likely similar between cows not fed or fed SORB. In fact, cows fed SORB tended to lose more BW postpartum (Table 3) suggesting that they were in a more negative energy state. Beam and Butler (1997) also reported that dairy cows fed a diet containing a mixture of tallow and yellow grease at 1.9% of dietary DM had fewer days to first ovulation compared with cows fed diets of 0 or 3.8% fat-mixture (21.4 vs. 45.3 and 37.4 d, respectively). As in the current study, their reported response occurred without any change in plasma concentrations of plasma NEFA, insulin, or glucose. Greater peak concentrations of estradiol during the first follicular wave in their study may have contributed to the earlier return to estrus by the cows fed the diet of intermediate fat concentration.

Ovulation interval was unaffected by management and SORB supplementation in the first 2 estrous cycles. In the third cycle, cows not supplemented with SORB had a shorter ovulation interval (19.9 d) than did cows fed SORB (25.0 d; Table 6). Ovulation interval was associated closely with luteal phase ($P = 0.0001$). Perhaps the extended ovulation interval of cows fed SORB in the third estrous cycle was due to an extended life span of the corpus luteum rather than to an extended follicular phase. Williams (1989) induced ovulation at d 21 to 26 postpartum in crossbred beef cows fed supplemental whole cottonseed (0 and 30% of dietary DM). Cows supplemented with whole cottonseed had greater concentrations of plasma progesterone at 5 to 8 d post-ovulation and the life span of the corpus luteum was increased.

Figure 5. Effect of housing management [pasture (solid line) vs. barn (dashed line)] and feeding soybean oil refining by-product (solid symbols = no SORB; open symbols = + SORB) on accumulated concentration of plasma progesterone during the first 60 DIM. A significant quadratic DIM $\times$ treatment interaction ($P = 0.01$) was detected.

Type of housing management system had no effect on the number of days to first, second, or third ovulation. During the first ovulatory cycle, cows managed on pasture had a greater peak concentration of plasma progesterone than cows managed in the barn (7.0 vs. 5.0 ng/mL, $P = 0.05$). A greater increase in concentration of plasma progesterone during the cycle of conception has been associated with greater conception rates (Butler et al., 1996). This trend was not observed for the second or third cycles.

Feeding SORB did not influence peak concentration of progesterone during any of the 3 estrous cycles (Table 6). However, accumulated values of plasma progesterone through 60 d postpartum (time when first cow became pregnant) increased at a faster rate for cows managed on pasture and fed SORB compared with that of cows on the other treatments (quadratic DIM by treatment interaction, $P = 0.01$; Figure 5). This more rapid increase in progesterone was accompanied by greater loss of BW (Table 3) indicating that the progesterone response was not due to an improved energy state brought about by SORB supplementation. Rather, it suggests that dietary fatty acids may be responsible for improvement in circulating progesterone. In a recent review, Staples et al. (1998) cited several papers that reported an increase in concentration of plasma progesterone by cows fed supplemental fat. The integrated effects of earlier ovulation in association with a numerically greater peak progesterone concentration and longer interovulatory intervals of cows on pasture and fed SORB contributed to the greater progesterone accumulation during the 60-d postpartum period.

Estrus Detection Using HeatWatch and Insemination

Estrus activity was analyzed using all cows ($n = 35$) and secondly, using only cows detected by HW as in standing heat ($n = 26$). In the model using all cows, cows that were not detected in estrus by HW were assigned 98 d as their first detected estrus date. Occurrence of first estrus ranged from a mean of 61 to 72 DIM and did not differ among treatments (Table 7). When including only those cows detected in estrus by HW, mean occurrence of first estrus ranged from 49 to 58 DIM and was similar among treatments (Table 7). The mean length of the first estrus was 4.4 h and was unaffected by treatment (Table 7). The number of mounts during the first estrus was greater ($P = 0.05$) for cows on pasture (7.7 vs. 4.8). This might be expected because of better footing on soil compared with that on concrete. The greatest mounting activity took place on pasture by cows fed SORB and the least by cows housed in the barn and fed SORB (housing $\times$ fat interaction, $P = 0.07$). This interaction was also apparent when all estrus events were included ($P = 0.04$). In a large Wisconsin study, Scott et al. (1995) reported that cows fed calcium salts of palm oil showed more standing estruses (71.4 vs. 69.5%) and required less exogenous $\text{PGF}_{2\alpha}$ to induce first estrus than cows not fed supplemental fat. The total number of estrus events, and average length (mean = 447 min; range of 7 to 780 min) were not affected by treatment (Table 7). Dransfield et al. (1998) analyzed data from 17 herds and 2661 AI records that used the HW detection equipment. Standing events during estrus averaged ($\pm$ SD) 8.5 ± 6.6 per cow, and duration of estrus averaged 7.1 ± 5.4 h. Cows in the current study showed somewhat less intense and less prolonged estrus.

Day of ovulation was estimated using concentrations of plasma progesterone. Efficiency of detection of ovulation across all DIM by HW was 42.7% (47/110; Table 7). Kyle et al. (1992) observed estrus behavior in 52 Holstein cows in early lactation and compared estrus behavior to blood progesterone concentrations. Forty-seven percent of cows in their first 3 cycles were detected in heat by visual observation. The first ovulation postpartum often is not accompanied by a standing heat if it occurs in the first few weeks postpartum. Of the 18 cows that had their first ovulation within the first 28 DIM, estrus was not detected via HW. In fact, the first ovulation postpartum was detected by HW in only 5 cows. If ovulations occurring before 45 DIM were eliminated from the data set, the efficiency of estrus detection by HW increased to 55.4% (36/65). Using χ^2 analysis, a greater proportion of all ovulations (62.5%; Table 7) were accompanied by detected estrus for barn

Table 7. Effect of housing management (pasture grazing or barn freestalls) and supplemental fat (soybean oil refining by-product) on estrus activity as measured using Heat Watch¹ during the first 14 wk of lactation.

Measurement	Treatment				SE	<i>P</i> = ²		
	Pasture		Barn			Fat	Mgt	Fat × Mgt
	– Fat	+ Fat	– Fat	+ Fat				
All cows (n = 35)	n = 9	n = 8	n = 9	n = 9				
Occurrence of first estrus, DIM ³	71.8	63.0	60.7	67.4	9.4	0.92	0.73	0.42
Total estruses per cow	1.1	1.3	1.5	1.4	0.4	0.92	0.37	0.67
Only cows recording estrus activity via HeatWatch								
First estrus	n = 5	n = 6	n = 9	n = 6				
DIM	50.8	51.3	58.3	49.3	8.5	0.62	0.75	0.58
Length, min	258	273	273	262	93.5	0.98	0.99	0.90
Intensity, number of mounts	5.8	9.3	5.5	3.8	1.1	0.52	*	†
All estrus events								
Total number of events per cow	1.7	1.7	1.7	2.5	0.26	0.36	0.31	0.36
Mean length, min	560	443	397	389	277	0.69	0.49	0.73
Mean number of mounts/event	5.9	8.8	7.4	5.6	1.0	0.62	0.44	*
Efficiency of estrus detection by HeatWatch ⁴								
All estruses recorded	35.7	37.0	62.5	38.7				
per ovulation detected, %	(10/28)	(10/27)	(15/24)	(12/31)				
Estruses recorded	42.1	61.5	80.0	44.4				
after 45 DIM per ovulation detected, %	(8/19)	(8/13)	(12/15)	(8/18)				

¹HeatWatch estrus detection system, DDx Inc., Denver, CO.²Mgt = Effect of managing in confinement or on pasture; Fat × Mgt = interaction of fat supplementation and management.³Cows not detected in estrus by HW were assigned a first estrus day of 98.⁴Ovulation estimated using plasma progesterone concentrations.**P* ≤ 0.05; †*P* ≤ 0.10.

cows without SORB supplementation (SORB × housing interaction, *P* = 0.03). This same pattern for an interaction continued if only estruses occurring after 45 DIM were considered (Table 7). Use of HW for estrus detection proved to be a useful tool but complications arose when cows were crowded into pens before milking, which gave rise to false recordings of estrus. Certain cows had excessive activity during periods of elevated progesterone concentrations in the luteal phase of the estrous cycle. In addition, 6 cows had regular estrous cycles but were never detected in standing heat. For example, the cow in Figure 6A had 4 ovulatory events. Her estrus, as recorded by HW, was detected in association with the last 3 ovulations. In contrast, the cow in Figure 6B had 5 postovulatory events and estrus was not detected either visually or by HW for any of the ovulations. This scenario of no estrus expression during reoccurring ovulatory periods occurred in both the pasture (n = 4) and the barn (n = 2) groups, and emphasizes the importance of timed insemination programs that are not dependent upon heat detection to improve reproductive efficiency.

The breeding data for these cows are included here even though the number of cows used in this study was too small to have much confidence in the pregnancy responses to treatment. Nine cows were not bred during the study because no computer or visual record was

made of animal estrus. Distribution was 4 on pasture without SORB, 2 on pasture + SORB, 0 on barn without SORB, and 3 on barn + SORB treatments. However, all of these cows ovulated based upon plasma progesterone values. In addition, 2 cows were bred (barn, no SORB treatment) that had no chance of conception based upon plasma progesterone values. Only 24 cows were inseminated with a biological chance of conception. Nine of the 24 inseminated cows became pregnant. Pregnancy rates as a percentage of cows inseminated were 40% (2/5), 83.3% (5/6), 28.6% (2/7), and 0% (0/6) for cows on the treatments pasture without SORB, pasture + SORB, barn without SORB, and barn + SORB, respectively. Pregnancy rate of cows on pasture was greater (*P* = 0.03) than cows housed in the barn [63.6 (7/11) vs. 15.4% (2/13)]. Of the fatty acids in rye-ryegrass, the one in greatest proportion is linolenic acid. Some linolenic acid escaped microbial hydrogenation as evidenced by increased milk concentration of linolenic acid. Mattos et al. (2003) showed that linolenic acid suppressed PGF_{2α}, which would be supportive of embryo survival. In contrast, Dransfield et al. (1998) reported no differences in conception rate between grazing cows and barn-housed cows in 14 herds analyzed. Five grazing dairies had an average conception rate of 48.0%, and 9 dairies that managed cows in freestalls had a conception rate of 45.7%. Pastured cows fed SORB had

Figure 6. Concentrations of plasma progesterone in A) a cycling cow that expressed estrus, and B) a cycling cow that failed to express estrus as monitored by HeatWatch.

the greatest pregnancy rate which resulted in an interaction between SORB supplementation and housing management ($P < 0.05$) because no cows from the barn + SORB group became pregnant. Cows in this group recorded a greater number of mounts in their first estrus suggesting greater estradiol production. Fat supplementation has improved pregnancy rates of lactating dairy cows previously (Staples et al., 1998).

Services per conception (defined as number of inseminations to obtain a pregnancy) were similar across treatments, ranging from 1.1 to 1.6. The present study only monitored cows through the first 98 d postpartum; thus, services per conception were low because cows only had 1.7 estrous cycles on average after 45 DIM. The period following the voluntary waiting period to inseminate (45 of 98 d) occurred for almost half of the experimental period.

CONCLUSIONS

Daily milk production was unaffected by the type of housing system in the early weeks of lactation; however, cows managed on pasture produced less milk between 8 and 14 wk postpartum. Cows on pasture lost more BW and had greater concentrations of plasma NEFA and lower concentrations of plasma insulin compared with cows housed in the barn. Thus, cows on pasture had to rely to a greater degree on body reserves to support their milk production. Fat concentration was reduced in milk from pasture-based cows and contained greater concentrations of long-chain FA (C18 to C20 including CLA and *trans* C18:1) with the exception of linoleic acid, which was lower.

Feeding SORB did not affect production of milk, fat, or protein although the loss of body condition was less for cows fed SORB. The FA profile of milk fat shifted to FA of the long-chain type including the *cis* and *trans* forms of linoleic acid but not linolenic acid.

Cows managed on pasture had greater peak concentrations of plasma progesterone in their first estrous cycle. Acknowledging that the number of cow observations per treatment were limited, the feeding of SORB resulted in an earlier return to first estrus after calving, better accumulation of plasma progesterone over DIM, and improved conception rates in spite of greater loss of BW for grazing cows but not cows managed in a free-stall barn. This may have been due to greater estradiol concentration suggested by greater mounting activity in this group of cows. Feeding SORB appeared to be of greater reproductive benefit to cows in a greater energy deficit.

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