Response of Lactating Dairy Cows to Diets Containing Wet Corn Gluten Feed or a Raw Soybean Hull-Corn Steep Liquor Pellet

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ABSTRACT

We evaluated effects of wet corn gluten feed (WCGF) and a novel product (SHSL) containing raw soybean hulls and corn steep liquor on performance and digestion in lactating dairy cows. In Experiment 1, 46 multiparous Holstein cows were assigned to control (C), WCGF (20% of diet DM), or SHSL (20% of diet DM). Diets were fed as a total mixed ration beginning after calving. The C diet contained (dry matter [DM] basis) 30% alfalfa hay, 15% corn silage, 32% corn, 9.3% whole cottonseed, 4.4% solvent soybean meal (SBM), and 3.3% expeller SBM. The WCGF replaced 10% alfalfa hay, 5% corn silage, and 5% corn grain, while expeller SBM replaced solvent SBM to maintain diet rumen undegradable protein. The SHSL replaced 10% alfalfa hay, 5% corn silage, 3% solvent SBM, and 2% corn. Dietary crude protein averaged 18.4%. Milk, energy-corrected milk (ECM), DM intake (DMI), and ECM/DMI were similar among diets during the first 13 wk of lactation. During wk 14 through 30 postpartum, WCGF and SHSL improved milk, ECM, milk component yield, and ECM/DMI. In Experiment 2, 6 cows were used to evaluate digestibility and rumen traits. Dry matter intake and total tract digestibilities of DM, fiber, and crude protein were not different among diets. Diets did not affect ruminal liquid dilution rate, pH, or concentrations of total volatile fatty acids or ammonia, but acetate:propionate was higher for C (3.38) than for WCGF (2.79) or SHSL (2.89). The WCGF and SHSL products can serve as alternative feedstuffs in diets fed to lactating dairy cattle.

(Key words: wet corn gluten feed, soybean hull, corn steep liquor, byproduct)

Abbreviation key: C = control, ECM = energy-corrected milk, ME = mature equivalent, SBM = soybean

meal, SHSL = soybean hull steep liquor pellet, WCGF = wet corn gluten feed.

INTRODUCTION

Dairy cattle are in a negative energy balance during the first weeks of lactation because they are unable to consume sufficient nutrients to offset the demands of the mammary gland (Bauman and Currie, 1980). Thus, mammary function during this period is supported by the mobilization of stored nutrients, primarily lipids with limited protein and carbohydrates, and nutrients supplied by the diet. Dietary nutrient supply is a function of nutrient density, DMI, and diet digestibility. Nutrient density of the diet is a formulation issue. Digestibility is primarily dependent on diet ingredients and rumen function. Dry matter intake is likely influenced by both ruminal and metabolic factors.

Diets for early postpartum cows should be formulated to meet the requirements of an adapting and changing ruminal microbial population and to supply nutrients, especially energy (Varga et al., 1998), to a highly metabolically active cow. The form of energy in the diet is important because rapidly fermented starch from concentrates increases ruminal acidity and can lead to decreased fiber digestion and development of subclinical or acute acidosis (Nocek, 1997). However, excess fibrous carbohydrates reduce the energy density of the diet and decrease productivity (Mertens, 1997).

By-product feedstuffs such as wet corn gluten feed (WCGF; VanBaale et al., 2001) and soybean hulls (MacGregor et al., 1976; Bernard and McNeill, 1991; Cunningham et al., 1993) have been successfully fed to lactating dairy cows and provide a highly digestible source of fibrous carbohydrates without increasing ruminal acidity. On a DM basis, WCGF contains 18 to 22% starch, 42% NDF, and a highly rumen degradable (65%) protein fraction (Firkins et al., 1984). Replacing a portion of alfalfa hay, corn silage, and corn grain with WCGF increased DMI, energy-corrected milk (ECM), and production efficiency (ECM/DMI; VanBaale et al., 2001).

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DeFrain et al. (2002a) developed a novel, pelleted product (**SHSL**) by combining raw soybean hulls, a digestible source of structural carbohydrates, with corn steep liquor, a source of carbohydrates, soluble protein, vitamins, and minerals, in a 3:1 ratio, respectively, on a DM basis. Incorporating SHSL in the diet at a level of 20% of the diet DM to replace a portion of alfalfa hay, corn silage, ground corn, and solvent soybean meal (**SBM**) improved ECM and protein yields without depressing milk fat yield (DeFrain et al., 2002a). Furthermore, in a subacute ruminal acidosis model, DeFrain et al. (2002b) observed that SHSL buffered the rumen similarly to alfalfa hay.

Studies that have evaluated production responses to WCGF or SHSL have been relatively short term and did not evaluate early or complete lactation responses. Therefore, the objectives of our experiments were 1) to evaluate the effect of WCGF and SHSL on the performance of lactating dairy cows during the entire lactation and 2) to evaluate the effect of WCGF and SHSL on diet digestibility and rumen traits.

MATERIALS AND METHODS

Use of the cows for both experiments was approved by the Kansas State University Institutional Animal Care and Use Committee.

Experiment 1

Beginning in October 2000, and ending in October 2001, 46 multiparous Holstein cows were used in a randomized incomplete block design, blocked by calving date, and assigned randomly to one of 3 dietary treatments. Dietary treatments (Table 1) were control (**C**), WCGF (20% of diet DM), and SHSL (20% of diet DM). Groups of 16, 16, and 14 cows were assigned to C, WCGF, and SHSL diets, respectively. Wet corn gluten feed replaced 10% alfalfa hay, 5% corn silage, and 5% ground corn grain, and expeller SBM (Soybest; Grain States Soya, West Point, NE) replaced solvent SBM to maintain dietary RUP. Soybean hull-steep liquor pellets (DeFrain et al., 2002a) replaced 10% alfalfa hay, 5% corn silage, 3% solvent SBM, and 2% ground corn grain in the diet. Diets were initiated at the first feeding postpartum and continued throughout lactation. Cows were housed and fed individually in a tie-stall facility for the first 13 wk and then moved to group pens (2 pens per treatment) in a free-stall facility for the remainder of the study. Each pen eventually contained 8 cows except one SHSL pen that had 6 cows. Cows were removed from the study as dictated by health incidences. The study was terminated when one of the 6 pens contained <4 cows. Lactation records were stan-

Table 1. Ingredient and nutrient composition of diets.

Item	Diet ¹		
	Control	WCGF	SHSL
Ingredient	(% of DM)		
Alfalfa hay	30.00	20.04	20.12
Corn silage	15.00	10.02	10.06
Corn grain	32.05	27.03	30.17
Wet corn gluten feed	—	20.04	—
SHSL ¹	—	—	20.12
Whole cottonseed	9.30	9.30	9.34
Solvent soybean meal	4.39	—	1.40
Expeller soybean meal	3.30	7.71	3.32
Fish meal	1.30	1.31	1.31
Molasses	1.00	1.00	1.01
Dicalcium phosphate	0.88	0.59	0.18
Limestone	1.36	1.54	1.62
Sodium bicarbonate	0.75	0.75	0.67
Magnesium oxide	0.21	0.21	0.22
Trace-mineralized salt ²	0.32	0.32	0.32
Vitamin A, D, and E premix ³	0.13	0.13	0.13
Sodium selenite premix ⁴	0.01	0.01	0.01
Nutrient, Experiment 1			
DM, %	82.6	74.6	84.5
CP	18.4	18.2	18.5
RUP	7.1	7.4	7.5
ADF	18.2	16.7	20.3
NDF	26.6	29.2	29.2
NE _L ⁵ Mcal/kg	1.62	1.63	1.62
NFC ⁶	42.3	40.4	40.3
Ca	1.38	1.43	1.20
P	0.63	0.69	0.56
S	0.25	0.28	0.28
Nutrient, Experiment 2			
DM, %	82.8	79.7	82.1
CP	18.3	18.2	18.2
RUP	7.4	7.5	7.7
ADF	16.9	15.7	19.3
NDF	25.5	28.5	28.6
NE _L ⁵ Mcal/kg	1.64	1.66	1.64
NFC ⁶	44.8	41.8	41.9
Ca	1.26	1.25	1.36
P	0.61	0.61	0.56
S	0.20	0.24	0.27

¹WCGF = Wet corn gluten feed; SHSL = pellet containing 75% raw soybean hull and 25% corn steep liquor (DM basis).

²Composition: ≥95.5% NaCl, 0.24% Mn, 0.24% Fe, 0.05% Mg, 0.032% Cu, 0.032% Zn, 0.007% I, and 0.004% Co.

³Contributed 4912 IU vitamin A, 2358 IU vitamin D, and 24 IU vitamin E/kg of dietary DM.

⁴Provided 0.06 mg of Se/kg of dietary DM.

⁵Calculated according to NRC (2001).

⁶Nonfiber carbohydrate (NFC) = 100 - (% NDF + % CP + % ether extract + % ash).

standardized to 305d-2×-ME (305-d lactation, milked twice daily, mature equivalent). Cows fed C, WCGF, and SHSL averaged 248, 283, and 266 DIM, respectively, when the study was terminated.

Cows were injected with recombinant bST (Posilac; Monsanto, St. Louis, MO) at 14-d intervals beginning at 66 ± 6 d postpartum. Urine ketones were monitored daily (Ketostix Reagent Strips; Bayer Corporation, El-

khart, IN) for 14 d postpartum, and rectal temperature was measured daily for 7 d postpartum.

Diets were offered as a TMR twice daily (0600 and 1700 h) for ad libitum consumption. Samples of WCGF, SHSL, and corn silage were analyzed weekly for DM (105°C), and their inclusion in the TMR was adjusted accordingly. Orts were removed and weighed daily before the afternoon feeding, and the amount of TMR offered was adjusted to ensure 10% Orts. Individual feed intakes were recorded through 13 wk postpartum, and pen intakes were measured for the remainder of lactation. Samples of the TMR and Orts were collected weekly and composited by treatment of analysis of DM. Samples of feed ingredients were collected weekly and composited monthly for analyses by Northeast DHI Forage Testing Laboratory (Ithaca, NY). Crude protein was determined as Kjeldahl N (AOAC, 1997) $\times 6.25$. *Streptomyces griseus* enzymatic technique was used to measure protein degradability using the method of Roe and Sniffen (1990) for concentrates and the method of Colblentz et al. (1999) for forages. The ANKOM A200 (ANKOM Technology Corp., Fairport, NY) filter bag technique was used to measure NDF (ANKOM, 2003b) and ADF (ANKOM, 2003a). The nonfiber carbohydrate (NFC) fraction was calculated by difference (NFC = 100 - [% NDF + % CP + % ether extract + % ash]), (NRC, 2001); NDF was not corrected for N.

Cows were milked daily at 0530 and 1630 h, and individual milk weights were recorded. Milk samples (a.m.–p.m. composite) were obtained weekly for analyses of protein, fat, lactose, SCC, and urea N by the Heart of America DHI Laboratory, Manhattan, KS. Milk protein, fat, and lactose were determined by near infrared spectroscopy (Bentley 2000 Infrared Milk Analyzer; Bentley Instruments Inc., 1984), somatic cells were counted using a flow cytometer laser (Somacount 500; Bentley Instruments Inc., 1994), and urea N was determined using chemical methodology based on a modified Berthelot reaction (ChemSpec 150 Analyzer; Bentley Instruments Inc., 1998).

Body weight was measured on 2 consecutive d weekly, immediately after the p.m. milking, and the average used for analysis. Body condition was scored weekly on a scale of 1 to 5 (Wildman et al., 1982) using 0.25 increments.

Blood was collected 2 h after feeding from the coccygeal vein into evacuated tubes containing EDTA (Becton Dickinson, Franklin Lakes, NJ) on d 1, 7, 14, 21, 28, 60, 90, 120 $\pm$ 3, 150 $\pm$ 3, 180 $\pm$ 3, and 210 $\pm$ 3 postpartum. Blood samples were immediately placed on ice, transported to the laboratory, and centrifuged at 752 $\times g$ for 20 min. Plasma was harvested and frozen at -20°C until further analysis. Additional blood (~8 mL) was collected into evacuated tubes containing sodium hepa-

rin (Becton Dickinson) on d 1, 14, 60, and 90 postpartum, and plasma was analyzed for individual AA (Campbell et al., 1997). Stimulated midstream urine and fecal grab samples were obtained on d 1, 7, 14, 21, 28, 60, and 90 postpartum for determination of pH.

Plasma was thawed and analyzed for albumin, NEFA, triglycerides, glucose, urea N, and total α -amino N. Plasma albumin concentrations were measured using Albumin Reagent procedure no. 631, Sigma Diagnostics, St. Louis, MO; plasma NEFA concentrations using a NEFA-C Kit, Wako Chemicals, Richmond, VA as modified by Eisemann et al. (1988); and plasma triglyceride concentrations with Infinity Triglycerides Reagent procedure no. 343, Sigma Diagnostics. Concentrations of glucose, urea, and total α -amino N were measured using a Technicon AutoAnalyzer III (Technicon Industrial Systems; Tarrytown, NY). Glucose concentrations were determined by a peroxidase indicator reaction with glucose oxidase (Technicon industrial method no. SE-4-0036FJ4). A diacetyl-monozime assay (Technicon industrial method no. 339-01) was used to measure urea, and total α -amino N was determined by a trinitrobenzenesulfonic acid assay (Technicon industrial method no. 512-77T).

Experiment 2

Four ruminally cannulated and 2 intact multiparous Holstein cows during late lactation (168 $\pm$ 7 DIM) were used in a replicated 3 $\times$ 3 Latin square to evaluate the effect of feeding WCGF and SHSL on diet digestibility and rumen traits. Experiment 2 was conducted in the months of June and July 2001. Cows were housed in a tie-stall facility. Periods were 14 d and included a 10-d adaptation and a 4-d collection period. Experimental diets were formulated as described in Experiment 1 (Table 1). Chemical composition of dietary ingredients are presented in Table 2. Diets were fed as a TMR twice daily (0700 and 1900 h) for ad libitum consumption. Orts were removed and weighed once daily and used to adjust feeding levels to ensure 10% Orts. Diet samples were collected and composited on d 10 to 12. Ten percent of the Orts from individual cows were collected and composited on d 11 to 13. Samples were dried at 55°C in a forced-air oven for 96 h, air-equilibrated, weighed to determine partial DM, and ground (No. 2 Wiley mill; Arthur H. Thomas Co., Philadelphia, PA) to pass a 1-mm screen. Samples of dietary components (alfalfa hay, concentrate, corn silage, SHSL, WCGF, and whole cottonseed) were collected, frozen (-20°C), composited by period, and analyzed by Northeast DHI Forage Testing Laboratory as for Experiment 1. Fecal grab samples were collected every 6 h and advanced by 2 h each day, beginning at 0700 h on d 11 and ending at 0500 h on

Table 2. Nutrient composition of dietary ingredients.

	Ingredient						
	Alfalfa hay	Corn silage	Whole cottonseed	Solvent soybean meal	Expeller soybean meal	Wet corn gluten feed	SHSL ¹
Experiment 1	((% of DM))						
CP	21.4	9.4	28.0	53.9	48.3	16.2	19.2
RUP	4.3	2.4	13.9	18.9	29.0	6.0	7.3
ADF	30.2	24.5	37.5	2.5	8.0	14.2	31.7
NDF	39.5	41.9	44.2	5.1	27.3	44.5	45.5
Ether extract	2.6	3.0	23.4	1.6	5.1	3.9	3.0
Ash	9.5	4.4	3.9	6.6	6.7	1.5	4.9
NFC ²	27.0	41.3	0.5	32.8	12.6	33.9	27.4
Ca	1.75	0.28	0.19	0.40	0.34	0.07	0.60
P	0.34	0.35	0.83	0.80	0.70	0.58	0.65
S	0.23	0.11	0.26	0.38	0.37	0.36	0.49
Experiment 2							
CP	22.3	9.0	27.3	53.9	48.3	16.5	19.3
RUP	4.7	2.7	15.3	18.9	29.0	4.8	7.1
ADF	28.0	22.1	35.6	2.5	8.0	14.4	31.0
NDF	36.6	37.3	45.6	5.1	27.3	45.0	47.7
Ether extract	2.9	3.2	22.8	1.6	5.1	3.8	3.2
Ash	10.7	5.1	3.8	6.6	6.7	1.5	5.2
NFC ²	27.5	45.4	0.5	32.8	22.8	33.2	24.6
Ca	1.98	0.30	0.21	0.40	0.34	0.05	0.64
P	0.33	0.38	0.93	0.80	0.70	0.53	0.60
S	0.23	0.12	0.32	0.38	0.37	0.39	0.58

¹SHSL = pellet containing 75% raw soybean hull and 25% corn steep liquor (DM basis).

²Nonfiber carbohydrate (NFC) = 100 - (% NDF + % CP + % ether extract + % ash).

d 14. Composited samples were dried in a 55°C forced-air oven for 120 h and then ground (No. 2 Wiley mill) to pass a 1-mm screen.

Cows were milked at 0630 and 1830 h daily, and individual milk weights were recorded. Milk samples (a.m.–p.m. composite) were obtained once each period for analyses of protein, fat, lactose, SCC, and urea N as described for Experiment 1.

Ruminal fermentation profiles were measured on d 11. Approximately 90 mL of rumen fluid were collected from 3 sites with a suction strainer (19 mm diameter; 15 mm mesh) just prior to feeding (0 h) and at 3, 6, 9, and 12 h thereafter. Rumen fluid pH was measured immediately after collection. Eight milliliters of strained rumen fluid were mixed with 2 mL of 25% (wt/vol) metaphosphoric acid and frozen at –20°C until analyzed for VFA, NH₃, and lactic acid concentrations. Samples for peptides and free AA analyses were placed on ice and transported to the laboratory where handling of samples and determination of peptide and free AA concentrations was according to Wessels et al. (1996).

Five grams of Co (as CoEDTA) in 200 mL of deionized water were pulse dosed into the rumens of cows prior to the a.m. feeding on d 11 to estimate liquid passage. Samples of rumen fluid were collected just prior to dosing (0 h) and 3, 6, 9, 12, and 24 h thereafter. Twenty milliliters of rumen fluid from each sampling time was frozen (–20°) for future analysis.

On d 14 at 0700 h, rumen contents were manually removed, weighed, mixed by hand, and sampled in triplicate. Ruminal digesta samples were dried in a forced-air oven for 168 h at 55°C. Following partial DM determination, samples were ground to pass a 1-mm screen.

Laboratory Analysis

Ground feed, orts, ruminal digesta, and fecal samples were dried in a convection oven (105°C for 16 h) for DM determination and then ashed at 450°C in a muffle oven for 8 h to determine ash content. Ground feed, orts, and fecal samples were analyzed for concentrations of acid detergent insoluble ash, which was used to predict fecal output and calculate digestibility coefficients (Cochran and Galyean, 1994). The ANKOM A200 (ANKOM Technology Corp., Fairport, NY) filter bag technique was used to determine NDF (ANKOM, 2003b) and ADF (ANKOM, 2003a). Nitrogen content was determined by combustion (Nitrogen Analyzer model FP-2000; Leco Corporation, St. Joseph, MI), and CP was calculated as N × 6.25. Starch concentrations were determined by enzymatically liberating glucose as described by Herrera-Saldana and Huber (1989) and measuring glucose concentration (Gochman and Schmitz, 1972).

Rumen fluid collected for VFA, NH₃, and lactic acid analyses was thawed and centrifuged at 30,000 × g at 4°C for 20 min. Concentrations of VFA were measured

by gas chromatography (model 5890; Hewlett-Packard) as described by Vazant and Cochran (1994), ammonia was determined following the protocol of Broderick and Kang (1980), and lactic acid was measured using the procedure of Barker and Summerson (1941). Only 4 of 60 samples contained >1 mM lactate, so data for ruminal lactate are not presented. Ruminal Co concentrations were determined by atomic absorption spectrophotometry, and liquid dilution rate was calculated by regressing the natural logarithm of the Co concentration on time. Whole rumen contents were analyzed for acid detergent insoluble ash, and solid passage rate was calculated as intake of acid detergent insoluble ash (g/h) divided by ruminal acid detergent insoluble ash content (g).

Statistical Analysis

Results from Experiment 1 were analyzed as repeated measures (SAS, Inst. Inc., Cary, NC) using the MIXED procedure (Littell et al., 1996). Previous lactation mature milk equivalent was included as a covariate. Individual cows served as the experimental unit during the first 13 wk postpartum, and pen was the experimental unit for data recorded thereafter. The AR (1) error structure was used for all data analyzed except the plasma metabolites for which the sp(pow) error structure was used due to unequal number of days between sampling periods. Treatment means were determined with the LSMEANS option and were separated using pairwise *t*-tests among all means when the *F*-test was significant. Experiment 2 was analyzed as a replicated 3×3 Latin square design using the MIXED procedure (SAS Inst. Inc., Cary, NC). Treatment means were evaluated as in Experiment 1.

RESULTS AND DISCUSSION

Experiment 1

General observations. The ingredient and chemical compositions of experimental diets are reported in Table 1. Nutrient composition of individual feed ingredients is presented in Table 2. The chemical composition of WCGF can vary with source because of the amount and type of steep liquor added to the bran. The steep liquor included in WCGF and for manufacturing SHSL in Experiments 1 and 2 was a mixture from starch extraction and ethanol production facilities (Minnesota Corn Processors, LLC, Columbus, NE). Diets were formulated to be isonitrogenous (18.4% CP, DM basis) and to contain similar amounts of RUP, NE_L, calcium, phosphorus, and sulfur. Diet RUP contents were slightly lower for the C diet, but it was in excess for all diets (NRC, 2001). Dietary forage NDF (% of diet DM)

was 18, 12, and 12% for C, WCGF, and SHSL diets, respectively. Total NDF was 29.2% of diet DM in the WCGF and SHSL diets compared with 26.6% in the C diet, which follows the general recommendation that total dietary NDF should be increased when high NDF byproduct feedstuffs are substituted for a portion of the forage. Dietary NFC decreased as NDF increased, but NE_L (NRC, 2001) remained constant. Diets were formulated to contain 1% calcium and 0.5% phosphorus (DM basis) using standard ingredient values.

Several health issues are problematic in fresh cows and were of particular interest in our study because of the decrease in forage NDF when WCGF or SHSL was included in the diet. Disease incidences did not differ across diets ($P > 0.35$), and cows that were diagnosed with disorders were treated and remained in the study. The number of cows that experienced subclinical milk fever, subclinical ketosis (urine acetoacetic acid concentration >80 mg/dL), and displaced abomasal disorder was 1, 4, and 3 of 16 C cows; 1, 2, and 1 of 16 WCGF cows; and 3, 2, and 4 of 14 SHSL cows, respectively.

Cows fed the C diet entered positive energy balance (estimated from NRC, 2001) by 8 wk, whereas cows fed WCGF or SHSL diets reached positive energy balance by 7 wk. Cows fed WCGF or SHSL attained higher peak milk yield (49.3 and 48.8 kg, respectively) than cows fed the C diet (45.4 kg) and peaked later in lactation (d 75 and 73, respectively) than cows fed the C diet (d 39). Furthermore, cows fed the WCGF or SHSL diets had higher peak DMI that peaked later in lactation (29.1 kg, d 71; 29.8 kg, d 73; respectively) than cows fed the C diet (27.8 kg, d 62).

Cow performance (wk 1 to 13). Production responses to dietary treatment of wk 1 through 13 are reported in Table 3. Total DMI was numerically greater for cows fed the WCGF and SHSL diets compared with cows fed the C diet, and intake as a percentage of BW was greater ($P < 0.01$) for cows fed the WCGF and SHSL diets than for cows fed the C diet. VanBaale et al. (2001) reported an increase in DMI when primiparous and multiparous cows were fed WCGF. Gunderson et al. (1988) and Armentano and Dentine (1988) did not observe a difference in DMI when WCGF partially replaced concentrate in diets fed to lactating cows. Staples et al. (1984) and Macleod et al. (1985) reported a decrease in DMI when WCGF was included; however, their diets were higher in moisture than diets used in this study. Several have reported that inclusion of soybean hulls did not impact DMI (Bernard and McNeill, 1991; Firkins and Eastridge, 1992; Sarwar et al., 1992; Cunningham et al., 1993). DeFrain et al. (2002b) fed diets similar to the C diet and SHSL diet in our study to midlactation cows and did not observe a difference in DMI. Evaluation of daily DMI (data not

Table 3. Lactational performance of cows from 1 to 13 wk postpartum (Experiment 1).

Item	Diet ¹			SEM	<i>P</i> ²
	Control	WCGF	SHSL		
DMI, kg/d	23.4	24.9	24.4	0.79	0.28
DMI, % of BW	3.61 ^a	3.79 ^b	3.88 ^b	0.091	0.0002
Milk, kg/d	41.2	44.9	43.9	1.59	0.24
ECM, ³ kg/d	43.2	45.3	44.1	1.60	0.53
ECM/DMI	1.96	1.86	1.85	0.058	0.22
Milk fat, %	4.00 ^a	3.68 ^b	3.75 ^b	0.075	0.0005
Milk fat, kg/d	1.61	1.63	1.59	0.060	0.77
Milk CP, %	2.99	2.99	3.00	0.040	0.92
Milk CP, kg/d	1.22	1.32	1.29	0.049	0.28
CP efficiency, ⁴ %	29.8	29.7	28.9	0.65	0.52
Milk lactose, %	4.87 ^b	4.99 ^a	4.91 ^b	0.030	0.0009
Milk urea N, mg/dL	14.7	14.7	14.8	0.36	0.95
SCC, ×1000	665	209	531	224	0.17
Initial BW, kg	718	717	694	62.9	0.63
BW change, kg	-69	-79	-85	15.4	0.80
Initial BCS	3.04	3.13	3.03	0.096	0.69
BCS change	-0.35	-0.31	-0.24	0.12	0.80
Urine pH	8.29	8.26	8.27	0.033	0.71
Fecal pH	6.44	6.43	6.46	0.045	0.88

^{a,b}Means not bearing common superscript differ ($P < 0.05$).

¹WCGF = Wet corn gluten feed; SHSL = pellet containing 75% raw soybean hull and 25% corn steep liquor (DM basis).

²Significance of *F*-test.

³ECM = Energy-corrected milk.

⁴CP output in milk (kg/d)/CP intake (kg/d).

shown) indicated that our cows adjusted to all diets similarly and that ruminal acidosis was not problematic.

Cows fed WCGF or SHSL produced 9 and 6.5% more milk, respectively, than cows fed the C diet, but these increases were not statistically different, likely because of the number of cows used and the contribution of tissue mobilization to mammary function. Wet corn gluten feed (VanBaale et al., 2001) and SHSL (DeFrain et al., 2002a) have been reported to improve milk yield by cows fed diets similar to those used in our study, but their cows were in midlactation. The numerical increase in ECM ($[0.327 \times \text{milk}] + [\text{fat kg} \times 12.95] + [\text{protein kg} \times 7.2]$; Orth, 1992) across diets was less than that observed for actual milk yield because fat concentration was lower in milk from cows consuming WCGF or SHSL. The decrease in milk fat percentage was significant, but not sufficient to decrease milk fat yield below the C diet and, thus, can be attributed to dilution. Wet corn gluten feed has been reported to increase milk fat percentage (Staples et al., 1984) when it replaced concentrate in the diet, likely because of an increase in dietary NDF at the expense of NFC. VanBaale et al. (2001) fed diets similar to ours and reported no differences in fat concentration in milk from primiparous cows; however, milk fat percentage, but not yield, was depressed in milk from multiparous cows

during midlactation when WCGF was included in the diet.

The influence of soybean hulls on milk fat is influenced by the amount of forage in the diet (Weidner and Grant, 1994). Diets containing 25% soybean hulls and 20% alfalfa hay (DM basis) improved milk fat and protein yields over diets without alfalfa hay (Weidner and Grant, 1994). The ability of diets to maintain milk fat has been used as an indicator of effective fiber content (Allen and Grant, 2000). Diets in our study with WCGF or SHSL contained 20% alfalfa hay (DM basis) and a forage NDF of 12.1% of DM, lowered milk fat percentage, but maintained fat yield. Milk protein percentage and yield were similar across treatments, but the WCGF diet increased lactose percentage over the C and SHSL diets. VanBaale et al. (2001) also observed an increase in lactose percentage in milk when cows were fed WCGF. Milk protein yield increased with feeding of WCGF in the study of VanBaale et al. (2001) because of an increase in milk production, but Staples et al. (1984) observed a decrease in milk and protein yield when cows were fed WCGF, likely a reflection of depressed DMI. We observed that milk urea N concentrations and CP efficiencies (CP output in milk/dietary CP intake) did not differ across diets.

The amount of milk produced per unit of DM consumed is often used as an indication of the efficiency

Figure 1. Effect of diets on production efficiency (SEM = 0.10). ECM = Energy-corrected milk, WCGF = wet corn gluten feed, and SHSL = pellet containing 75% raw soybean hull and 25% corn steep liquor (DM basis).

by which cows use various diets. The use of this measure when evaluating diets with early lactation cows can be misleading because of the contribution of mobilized tissue to mammary gland function. In our study, production efficiency (ECM/DMI) was similar across treatments when the mean efficiencies for wk 1 through 13 were compared, but a diet by week interaction ($P = 0.03$) was detected (Figure 1). Cows fed the C diet were more ($P < 0.01$) efficient during the first 2 wk postpartum than were cows fed the WCGF diet, they tended ($P = 0.06$) to be more efficient during the first week than cows fed the SHSL diet, and they were more efficient ($P < 0.01$) than cows receiving the SHSL diet during the second week. Cows fed the SHSL diet tended ($P = 0.07$) to be more efficient than cows receiving the WCGF diet during the first week. Because production efficiencies of cows fed the 3 diets were similar for wk 3 through 13 of lactation, it is likely that the higher efficiencies during the second week postpartum for cows fed the C diet were supported by greater tissue mobilization by those cows compared with cows fed the WCGF or SHSL diets. Plasma NEFA concentrations were highest on d 1 for cows fed the C diet and tended ($P < 0.05$) to be higher on d 7 for cows fed the C diet and the SHSL diet relative to those fed the WCGF diet (Figure 2).

Changes in BW and BCS during the first 13 wk were similar across diets and fail to support the hypothesis that cows fed the C diet were more efficient during wk 1 and 2 because they mobilized more body fat. However, subtle changes in BW may be masked by rumen fill and the subjective nature of BCS.

Urine and fecal pH (Table 3) were similar among dietary treatments. Urine pH was used to evaluate dif-

Figure 2. Effect of diets on plasma NEFA concentration (SEM = 32). WCGF = Wet corn gluten feed and SHSL = pellet containing 75% raw soybean hull and 25% corn steep liquor (DM basis).

ferences in dietary cation-anion balance. Fecal pH was used as a gross measure of shifts in site of digestion by diets.

Plasma constituents (wk 1 to 13). Plasma glucose, total α -amino N, triglycerides, albumin, and NEFA were similar among dietary treatments during wk 1 to 13 (Table 4). No differences were observed for plasma urea N or essential, nonessential, and total AA (Tables 4 and 5), demonstrating that protein efficiencies and balance of RUP and RDP for diets containing WCGF and SHSL were similar to the C diet as expected because of diet formulation. VanBaale et al. (2001) reported that the inclusion of WCGF at 20% of dietary DM did not affect plasma total α -amino N, but observed higher ($P < 0.05$) plasma urea in cows fed WCGF. DeFraen (2002a) reported that SHSL increased ($P < 0.05$) plasma total α -amino N but not total essential, nonessential, and total AA. Dietary treatments did not affect individual α -amino acids, except for phenylalanine, which was lower ($P < 0.01$) in plasma from cows fed the SHSL diet compared with cows fed the C diet.

Cow performance (wk 14 to 30). Our justification for a complete lactation study was based on the premise that cow response to diets in the immediate postpartum period (first 60 d) is confounded by nutritional support from tissue mobilization, metabolic instability, and metabolic adaptations by the mammary gland. Thus, responses to diets following peaks in milk production and DMI should provide a more accurate representation of nutrient delivery by experimental diets. Furthermore, if an experimental diet failed to meet the lactational demands of the cow as fat mobilization declines, performance would be impaired. The response of cows to experimental diets during wk 14 to 30 is reported in

Table 4. Plasma constituents from 1 to 13 wk postpartum (Experiment 1).¹

Plasma	Diet ²			SEM	<i>P</i> ³
	Control	WCGF	SHSL		
Glucose, mg/dL	61.2	60.9	60.5	0.83	0.82
Total α -amino N, mM	2.38	2.41	2.46	0.041	0.35
Urea N, mg/dL	13.7	13.7	14.4	0.45	0.49
Triglycerides, mg/dL	9.16	9.59	9.12	0.25	0.23
Albumin, g/dL	3.75	3.74	3.78	0.072	0.93
NEFA, μ M	392	342	361	32.1	0.42

¹Days sampled = 1, 7, 14, 21, 28, 60, 90 d postpartum.²WCGF = Wet corn gluten feed; SHSL = pellet containing 75% raw soybean hull and 25% corn steep liquor (DM basis).³Significance of *F*-test.

Table 6. All cows consumed similar amounts of total DM (kg/d and % of BW), but cows fed the WCGF or SHSL diets produced more ($P < 0.01$) milk and ECM with a lower ($P < 0.05$) fat concentration compared with cows fed the C diet. Milk protein concentration was slightly reduced by the 2 byproducts, and this effect was significant for SHSL ($P < 0.05$). However, yields of milk fat and CP were increased ($P < 0.01$) by both WCGF and SHSL. Increased protein yields observed for cows

fed WCGF and SHSL and similar levels of DMI across treatments resulted in greater ($P < 0.01$) CP efficiency for cows fed WCGF and SHSL. Compared with the C diet, milk lactose percentage and yield were greater ($P < 0.01$) for cows fed the WCGF or SHSL diets. VanBaale et al. (2001) and DeFrain et al. (2002a) also observed increased milk CP and lactose yields when WCGF and SHSL, respectively, were fed at 20% of dietary DM, but they did not report an increase in milk fat yield. In

Table 5. Plasma amino acid concentrations from 1 to 13 wk postpartum (Experiment 1).¹

Amino acid	Diet ²			SEM	<i>P</i> ³
	Control	WCGF	SHSL		
Essential	(μ M)				
Lys	88.9	83.0	83.1	3.8	0.44
His	65.9	69.0	60.8	2.6	0.09
Arg	87.2	84.6	79.5	3.5	0.30
Thr	102	106	102	4.2	0.69
Val	292	280	272	13.7	0.42
Met	26.6	28.9	27.5	1.0	0.29
Ile	138	131	131	6.2	0.44
Leu	198	192	180	8.4	0.20
Phe	58.4 ^a	55.1 ^{ab}	52.7 ^b	1.2	0.01
Trp	36.9	36.5	35.5	1.6	0.83
Total	1094	1065	1024	36.5	0.29
Nonessential					
Asp	17.7	18.1	18.1	0.6	0.89
Ser	96	107	98	3.9	0.12
Glu	124	126	121	4.9	0.74
Gly	348	367	374	14.3	0.34
Ala	209	228	238	8.9	0.07
Asn	41.1	44.5	39.8	1.8	0.18
Gln	188	199	175	8.6	0.11
Tyr	65.1	63.4	60.3	2.6	0.37
Cit	94	110	95	6.4	0.12
Orn	49.9	49.1	44.0	2.6	0.23
Tau	34.9	36.4	34.2	1.7	0.68
Total	1267	1349	1298	30.0	0.12
Total	2362	2414	2322	57.5	0.44

^{a,b}Means not bearing common superscript differ ($P < 0.05$).¹Days sampled = 1, 14, 60, 90 d postpartum.²WCGF = Wet corn gluten feed; SHSL = pellet containing 75% raw soybean hull and 25% corn steep liquor (DM basis).³Significance of *F*-test.

Table 6. Lactational performance of cows from 14 to 30 wk postpartum (Experiment 1).

Item	Diet ¹			SEM	<i>P</i> ²
	Control	WCGF	SHSL		
DMI, kg/d	26.6	25.6	27.4	0.92	0.56
DMI, % of BW	4.42	4.26	4.42	0.14	0.31
Milk, kg/d	35.1 ^b	39.7 ^a	42.1 ^a	0.87	0.003
ECM, ³ kg/d	36.3 ^b	39.9 ^a	40.9 ^a	0.57	0.0003
ECM/DMI	1.37 ^b	1.56 ^a	1.49 ^a	0.037	0.014
Milk fat, %	3.74 ^a	3.55 ^c	3.35 ^b	0.063	0.003
Milk fat, kg/d	1.31 ^b	1.41 ^a	1.40 ^a	0.023	0.009
Milk CP, %	3.12 ^a	3.04 ^{ab}	3.00 ^b	0.025	0.02
Milk CP, kg/d	1.09 ^b	1.21 ^a	1.26 ^a	0.02	0.0001
CP efficiency, ⁴ %	22.4 ^b	25.9 ^a	24.8 ^a	0.66	0.02
Milk lactose, %	4.83 ^b	4.93 ^a	4.92 ^a	0.015	0.0003
Milk urea N, mg/dL	14.5	14.8	14.9	0.28	0.56
SCC, ×1000	392	585	524	210	0.77
Initial BW, kg	622	649	600	35.3	0.63
BW change, kg	-22	-21	-1	15.5	0.72
Initial BCS	2.71	2.95	2.82	0.14	0.48
BCS change	0.08	0.11	-0.06	0.04	0.28

^{a,b,c}Means not bearing common superscript differ ($P < 0.05$).

¹WCGF = Wet corn gluten feed; SHSL = pellet containing 75% raw soybean hull and 25% corn steep liquor (DM basis).

²Significance of *F*-test.

³ECM = Energy-corrected milk.

⁴CP output in milk (kg/d)/CP intake (kg/d).

agreement with others (VanBaale et al., 2001; DeFrain et al. 2002a), cows fed the WCGF or SHSL diets were more efficient ($P < 0.05$) than cows fed the C diet. VanBaale et al. (2001) fed WCGF and attributed the increase in ECM to increased DMI as well as increased production efficiency in multiparous cows. Cows in their study (VanBaale et al., 2001) were between 60 and 145 DIM when the diets were introduced and were fed a common diet (similar to our control diet) prior to the study. VanBaale et al. (2001) observed an increase in DMI and production efficiency of ECM when WCGF was added to diets, whereas cows fed WCGF in our study consumed the same amount of DM as cows fed the C diet but used it more efficiently. VanBaale et al. (2001) suggested that the improvement in efficiency was due to improved digestibility of diets containing WCGF. In our study (see Experiment 2), WCGF did not alter total tract digestibility, which implies that other factors are responsible for the observed improvement in production efficiency. The improved efficiency could be due to an increase in ruminal propionate (Experiment 2) and/or enhanced ruminal digestion. In our study, cows fed the C diet reached peak milk at 39 DIM compared with 75 and 73 DIM for cows fed WCGF or SHSL, respectively. Furthermore, when comparing ECM production between the 2 wk prior to the first rbST injection with the 4 wk postinjection, cows fed the C diet produced less ECM milk after injection (45.4 vs. 42.8 kg). Cows fed WCGF produced the same amount of ECM (46.8 kg) prior to and following rbST injection,

and cows fed SHSL experienced only a small decrease in ECM production (44.5 vs. 43.8 kg). Cows fed the C diet were less efficient ($P < 0.05$) than cows fed the other 2 diets during 14 to 30 wk. This lower efficiency during wk 14 to 30 was due to a lower milk yield, not DMI. These results may indicate that cows fed the C diet used more nutrients to replenish tissue stores and less for milk yield than cows fed WCGF and SHSL. Observed BW and BCS changes do not support this concept, but they may not be sufficiently precise to detect subtle changes.

Plasma constituents (wk 14 to 30). No differences were observed in plasma glucose, total α -amino N, urea N, triglycerides, and NEFA concentrations during wk 14 to 30 (Table 7). Plasma albumin concentrations were greater ($P < 0.05$) in cows fed the WCGF and SHSL diets, and a diet $\times$ day interaction was observed for plasma albumin concentrations. Plasma albumin was less ($P < 0.05$) in cows fed the C diet than in cows fed the WCGF diet on d 120, 150, and 210 and lower than in cows fed the SHSL diet on d 120.

Cow performance (305d-2 $\times$ -ME). For cows fed the WCGF or SHSL diet, 305d-2 $\times$ -ME milk, ECM, milk fat yield, and milk CP yields were numerically greater than for cows fed the C diet, but differences were not statistically significant because of the small number of experimental units (Table 8). The numerically higher 305d-2 $\times$ -ME production responses for cows fed the WCGF or SHSL diets reflect the numerically higher yields of milk from cows fed those diets for the first 13 wk postpartum

Table 7. Plasma constituents at 14 to 30 wk postpartum (Experiment 1).¹

Plasma	Diet ²			SEM	<i>P</i> ³
	Control	WCGF	SHSL		
Glucose, mg/dL	69.7	69.1	71.1	0.96	0.49
Total α -amino N, mM	2.17	2.20	2.50	0.12	0.35
Urea N, ⁵ mg/dL	15.8	15.5	15.6	0.58	0.94
Triglycerides, mg/dL	9.2	9.7	11.3	0.69	0.32
Albumin, g/dL	2.96 ^b	3.22 ^a	3.29 ^a	0.059	0.04
NEFA, μ M	109	125	138	13.3	0.39

^{a,b}Means not bearing common superscript differ ($P < 0.05$).

¹Days sampled = 120, 150, 180, and 210 d postpartum.

²WCGF = Wet corn gluten feed; SHSL = pellet containing 75% raw soybean hull and 25% corn steep liquor (DM basis).

³Significance of *F*-test.

and statistically greater yield observed for wk 14 to 30 postpartum.

Experiment 2

General observations. Ingredient and chemical composition of experimental diets are reported in Table 1. The difference in diet analyses between Experiment 1 and Experiment 2 can be attributed to seasonality. Dietary CP levels and calculated energy density (Mcal/kg NE_L) for the C, WCGF, and SHSL diets were 18.7 and 1.64, 18.7 and 1.66, and 18.7 and 1.64, respectively. Nutrient compositions of individual feed ingredients are reported in Table 2. Cows in Experiment 2 consumed considerably less DM and produced less milk than those in Experiment 1, and there were no differences in milk production or efficiency (Table 9). Differences in DMI and milk yield between cows in Experiment 1 and 2 were attributed to stage of lactation and seasonal affects (Experiment 2 was conducted during June and July 2001).

Diet digestibility. Apparent total tract digestibilities of DM, OM, CP, NDF, ADF, and starch were similar for all diets (Table 9). Fellner and Belyea (1991) also did not observe differences in total tract digestibilities

of DM, NDF, ADF, starch, and N when WCGF was included at 20% of dietary DM as a partial replacement for corn silage, chopped alfalfa hay, and concentrate in diets fed to nonlactating dairy cows. Allen and Grant (2000) demonstrated that replacing a portion of alfalfa silage with WCGF and alfalfa hay such that WCGF was included at 24.4% of dietary DM resulted in similar apparent extent of ruminal NDF digestion as the control diet. In contrast, Staples et al. (1984) observed a linear increase ($P < 0.05$) in apparent digestibility of NDF, hemicellulose, and ether extract when corn grain in diets fed to dairy cattle was replaced with WCGF at 0, 20, 30, and 40% of dietary DM.

Our study is the only one that has evaluated total tract digestibility of diets containing SHSL, but the literature does contain information regarding the effect of soybean hulls, a major component of the SHSL pellet, on digestibility. Cunningham et al. (1993) reported that when soybean hulls replaced high moisture corn at 12.5 and 25% of dietary DM, total tract digestibilities of DM and OM were not affected, but ruminal NDF and ADF digestion were higher when soybean hulls replaced corn silage and alfalfa hay at 12.5 and 25% of dietary DM. Total tract digestibilities of ADF and NDF in soybean hull diets also were higher than for the C diet. Sarwar

Table 8. Standardized 305d-2 $\times$ -ME (mature equivalent) production (Experiment 1).

305-2 $\times$ -ME ¹	Diet ²			SEM	<i>P</i> ³
	Control	WCGF	SHSL		
Milk, kg	10,750	11,584	11,865	606	0.49
ECM, ⁴ kg	10,986	11,708	11,885	634	0.60
Milk fat, kg	410	414	419	32	0.98
Milk CP, kg	325	355	358	15	0.34

¹305-2 $\times$ -ME = 305-d, twice daily milking, mature equivalent.

²WCGF = Wet corn gluten feed; SHSL = pellet containing 75% raw soybean hull and 25% corn steep liquor (DM basis).

³Significance of *F*-test.

⁴ECM = Energy-corrected milk.

Table 9. Intake, milk production, and apparent total tract digestibilities (Experiment 2).

Item	Diet ¹			SEM	P ²
	Control	WCGF	SHSL		
DMI, kg/d	16.4	18.0	17.2	2.7	0.23
ECM, ³ kg/d	21.0	25.0	23.1	4.6	0.30
ECM/DMI	1.33	1.36	1.35	0.13	0.98
Digestibility, %					
DM	71.3	71.3	72.2	2.1	0.90
OM	73.2	73.0	73.4	2.0	0.98
CP	72.2	72.9	73.9	2.1	0.77
NDF	62.6	63.7	62.8	2.7	0.93
ADF	57.9	57.6	60.0	3.6	0.81
Starch	89.6	91.4	87.8	2.2	0.14

¹WCGF = Wet corn gluten feed; SHSL = pellet containing 75% raw soybean hull and 25% corn steep liquor (DM basis).

²Significance of *F*-test.

³ECM = Energy-corrected milk.

et al. (1991) observed that heifers receiving soybean hulls as a partial replacement for forage NDF (chopped alfalfa hay and corn silage) had lower ruminal NDF digestibility but greater hindgut disappearance and total tract digestibility of NDF than those fed a control diet. Because we only measured total tract digestibilities, we are unable to determine the influence of diet on site of digestion.

Rumen measurements. Allen (1997) suggested that ruminal pH is an acceptable and accurate indicator of the effectiveness of fiber. Average ruminal pH did not differ among diets (Table 10), indicating that the partial

replacement of corn silage and alfalfa hay with WCGF and SHSL had little effect on the effective fiber of the diet. In agreement with these findings, DeFraen et al. (2002b) reported that SHSL addition to diets did not influence cow response to an acidosis challenge.

Similar concentrations of ruminal NH₃, free AA, and peptide N (Table 10) indicated that protein degradation and carbohydrate fermentation were not greatly different among diets. Because the protein of WCGF and corn steep liquor is highly degradable (Firkins et al., 1984; Patterson et al., 2001), diets in our study were formulated to use the highly degradable protein of these

Table 10. Ruminal fermentation, fill, and passage (Experiment 2).

Ruminal	Diet ¹			SEM	P ²
	Control	WCGF	SHSL		
pH	6.22	6.20	6.22	0.14	0.93
NH ₃ , mM	8.83	8.83	9.04	1.2	0.86
Free AA, mM	1.80	2.48	1.72	0.5	0.22
Peptide N, mM	3.79	4.70	4.58	2.3	0.92
Total VFA, mM	104.6	97.6	98.8	8.1	0.49
VFA, mol/100 mol					
Acetate (A)	66.1 ^a	63.4 ^b	64.1 ^b	0.83	0.009
Propionate (P)	19.5 ^b	22.9 ^a	22.6 ^a	1.33	0.05
Butyrate	10.6	10.2	9.7	0.58	0.59
Isobutyrate	1.10	1.07	1.09	0.11	0.87
Isovalerate	1.38	1.23	1.24	0.11	0.09
Valerate	1.30	1.23	1.19	0.06	0.17
A:P, mol/mol	3.38 ^a	2.79 ^b	2.89 ^b	0.21	0.03
Fill, kg					
Total	70.6	78.5	71.8	4.3	0.28
DM	9.1	10.1	9.8	0.9	0.58
OM	8.0	9.0	8.6	0.9	0.41
Liquid	61.6	68.2	62.1	3.5	0.31
Passage rate, %/h					
Solid	9.4	8.2	8.2	2.2	0.94
Liquid	13.2	12.7	13.1	1.5	0.88

^{a,b}Means not bearing common superscript differ (*P* < 0.05).

¹WCGF = Wet corn gluten feed; SHSL = pellet containing 75% raw soybean hull and 25% corn steep liquor (DM basis).

²Significance of *F*-test.

byproducts while including adequate dietary RUP and NFC to allow for efficient fermentation.

Total VFA concentrations did not differ among diets, but the WCGF and SHSL diets had lower ($P < 0.05$) proportions of acetate and greater ($P < 0.05$) proportions of propionate (Table 10), likely because of the lower amounts of alfalfa hay in these diets. Ruminal lactate (data not shown) was essentially nonexistent. The ratio of acetate to propionate, often associated with milk fat depression (Woodford et al., 1986), was less ($P < 0.05$) in cows fed WCGF and SHSL, and this might have contributed to lower milk fat concentrations in Experiment 1. The decrease in the ratio of acetate to propionate also might have been a factor influencing increased milk production in Experiment 1. By increasing propionate production, loss of energy through methane production would be decreased, resulting in increased metabolizable energy of the WCGF and SHSL diets (Fahey and Berger, 1993). Furthermore, propionic acid is the primary precursor for lactose synthesis. No differences were observed in proportions of butyrate, isobutyrate, isovalerate, and valerate (Table 10). Ruminal fill (total, DM, OM, and liquid) and solid and liquid passage rates (%/h) were similar across treatments (Table 10).

CONCLUSIONS

Inclusion of WCGF and SHSL at 20% of dietary DM as a partial replacement for alfalfa hay, corn silage, corn grain, and SBM in diets fed to lactating dairy cattle supported performance during early lactation and improved performance during mid and late lactation. Additionally, inclusion of WCGF or SHSL maintained milk fat yields and ruminal pH, thereby demonstrating that WCGF and SHSL can serve as sources of effective fiber when fed at 20% of dietary DM. Improved performance attributed to WCGF and SHSL is due to factors other than improved total tract digestibility of the diets. These results indicate that WCGF and SHSL can serve as alternative feedstuffs in diets fed to lactating dairy cattle, but elevated dietary phosphorus could be an environmental concern under certain situations.

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